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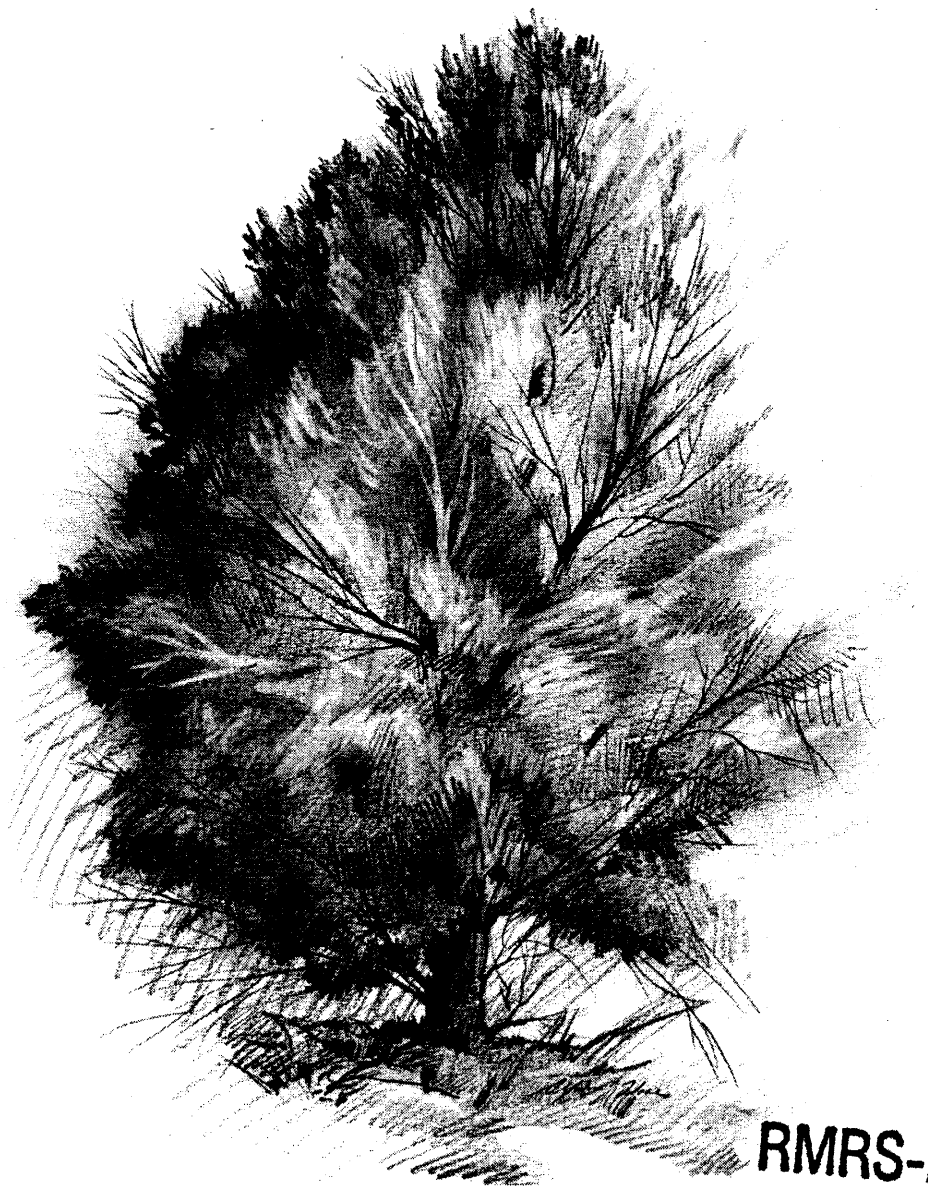

Sustaining and Restoring a Diverse Ecosystem

Abstract

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A symposium held September 15–18, 1997, in Provo, UT, and Sanpete County, UT, provided information on the ecology, management, resource values, and restoration of pinyon-juniper communities in the Interior Western United States. The conference was hosted by the USDA Forest Service, Rocky Mountain Research Station and the Utah Division of Wildlife Resources in cooperation with personnel from other agencies and organizations. Oral and poster presentations were given by scientists, land managers, and educators. Also included was a field tour to observe distribution and areas of occurrence of various woodland types. Mechanical chaining and seeding demonstrations exhibited operational procedures, removal of competition, and creation of multiple seedbeds. Comparisons of older treatments where introduced species were planted were made with more recent restoration plantings designed to restore native understory herbs and shrubs. The field tour also emphasized identification and characterization of successional or transition stages resulting in thresholds in vegetative composition that influence management practices.

This conference focused on four topics. First was identifying the principal pinyon-juniper community associations, defining areas of distribution, and characterizing climatic, biotic, edaphic, and human influences upon community structure. Second were several discussions of resources associated with pinyon-juniper communities. Topic three focused on methodologies and practices available to restore disturbed pinyon-juniper woodlands to natural assemblages of native species. The fourth topic examined the implications of management practices upon community distribution, species composition, and presence of introduced species. Management to sustain diverse pinyon-juniper communities is an important issue. In addition, management of disturbed sites is equally important as weeds continue to invade and spread, fire frequency and damages are increasing, and continued alteration of plant communities limits management options.

Keywords: restoration, range resources, succession, cheatgrass, native seed, watershed, wildlife, soil

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Proceedings: Ecology and Management of Pinyon-Juniper Communities Within the Interior West

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Introduction

Symposium on Pinyon and Juniper Ecology, Restoration, and Management: Introduction

Stephen B. Monsen
Richard Stevens

Pinyon and juniper woodlands provide human, wildlife, soil, water, and other ecologically important resources. These woodlands are an integral part of the landscape of large geographical regions of the Interior Western United States. Conditions and diversity of this type are critical. Managing pinyon and juniper woodlands to sustain tree and understory associations becomes more practical as the ecology of this type is better understood. For example, knowing how to manipulate management practices could help in modifying successional changes on a landscape basis.

To help reach the goal of increased knowledge, a multiagency-supported symposium brought Federal, State, and local government officials, university researchers, private companies, and private individuals together for 4 days in the autumn of 1997 at Brigham Young University, Provo, UT. This resulting proceedings is a step toward accumulating knowledge, and perhaps will foster cooperation and partnerships among the large array of private and public entities interested in the vast Interior Western ecosystem.

In this introduction we highlight some of the themes and critical issues that arose during the symposium, noting some of the management options.

The Western Setting

Within the Interior West, different species of pinyon and juniper occur with diverse shrubs and herbs forming distinct associations. The total area occupied by pinyon and juniper woodlands is not precisely mapped and described because various associations exist with different assembly of species, highly variable tree densities, and age classes, making the task of mapping difficult. In addition, climatic and biotic factors influence changes in plant composition, creating both expansion and decline of common woodlands.

Recent studies have better defined the interaction between environment and vegetative changes in pinyon and juniper woodlands and non-tree species than have previously existed. For example, changes are evident in the paleoecological records, and multiple stages of plant succession have been identified and can be used to predict general changes in landscape ecology. More recent studies show us the influence of disturbances on the long-term patterns of change and the potential recovery of specific plant associations.

Of particular concern is the presence and effect of thresholds on successional development of these woodlands. Although other plant communities may also express stages or thresholds as changes occur, once particular thresholds are reached within a pinyon and juniper woodland, subsequent changes are set and are not likely altered. Factors affecting these changes may include topography, soils, climate, history of use, fires, and tree presence. Influences operate over extended periods, affecting large regions and landscapes. Highly variable plant communities currently exist due to different stages of plant succession and to the recent expansion of both pinyon and juniper.

Understanding the structure and composition of pinyon and juniper woodlands is essential in identifying thresholds and their influence on returning communities to earlier status through management or active restoration. Selection of sites for improvement can be based on a better understanding of the ecological status and potential for natural recovery. Woodlands that support a sufficient array of understory species and can recover by elimination of tree competition can be better defined and treated. Sites that may require seeding to restore understory herbs and shrubs or may be subject to weed invasion can also be better identified.

Management Issues

Many pinyon and juniper communities within the West, like many other plant associations, have been subjected to intensive livestock grazing. This impact, along with recent changes in fire regimes and localized tree harvesting, has contributed to changes in tree presence, age structure, density, and particularly to the composition of understory species. Loss of habitat, diminished watershed conditions, and the recent increase of weeds have created serious management problems. In addition, increases in wildfire frequency caused by the presence of annual weeds, and increases in the frequency of devastating wildfires within overgrown stands of trees, are a more recent problem associated with disturbed woodland conditions. The decline and loss of understory species coupled with an increase in tree overstory ultimately results in a loss of species richness and likely conversion to a dominance of undesirable weeds. Recent appearance of more troublesome and persistent perennial weeds within pinyon and juniper communities creates additional need to retain native understory species.

These issues have been a concern to land managers for a long time. Various interagency steering committees and organizations (including this symposium) have addressed

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these and other issues. Ecology of pinyon and juniper communities was the first topic addressed in this conference. Although considerable information is lacking, a much better understanding of the distribution, community composition, and patterns of change, particularly of disturbed woodlands, is now available. Descriptions of stages and patterns of community degradation are better identified and understood. Factors influencing annual weed invasion and resulting conversion of woodlands to annual grasslands coupled with increasing fire frequency is also much better documented. Areas and sites that have degraded with diminished amounts of understory species and are likely to revert to weeds can now be better identified and treated.

Management Alternatives

Artificial restoration of pinyon and juniper woodlands has received considerable attention. Practices that included removal of existing trees to reduce competition have often been criticized as unnecessary, site destructive, and not ecologically sound. However, examination of existing information does not support these assumptions. Restoration or enhancement of any disturbed community including shrubland associations, upland herb communities, or weed-infested sites requires reduction of existing competition, creation of suitable seedbeds, and actual seeding. In most situations, elimination of competition is accomplished by mechanical tillage or application of selective herbicides. Plowing, disking, or related tillage treatments are the most common means of mechanical treatment. These procedures reduce competition and aid in creation of required seedbeds. Such practices can seriously disturb soils and tend to eliminate most existing vegetation.

Chaining and cabling practices were selectively tested and adapted to treat woodlands as minimal impacts occur to soils and understory species. Chaining has proven to be the most versatile practice available to selectively reduce trees, prepare diverse seedbeds, and facilitate planting mixtures of seed. Percent of trees removed and percent and depth of soil surface that is tilled can be easily regulated by modifying operational procedures. Chaining coupled with aerial seeding of select species that require minimal seedbed preparation has proven universally successful within this community type. Including the use of tractor-mounted seed dribblers to plant seeds that benefit from being more deeply incorporated in the soil has provided the necessary method required to seed most species. These techniques provide the means to successfully restore most species native of the pinyon and juniper woodlands by seeding.

Significant progress has been achieved in developing native seeds in sufficient amounts required to restore diverse communities. Seeds are now available from commercial companies are adapted ecotypes of many native species that can be used on a variety of sites. This has resulted in a slow but steady transition from rehabilitation plantings involving the use of introduced species to more complete restoration plantings using site-adapted native species. A much greater array of native species is currently available to restore pinyon and juniper communities than any other vegetative type that exists in the West. If properly planned, restoration of native communities through artificial seedings can be achieved on large projects. Regulations are in place to assure native seed of site-adapted ecotypes and species are harvested, produced, and marketed.

Older plantings in pinyon and juniper communities demonstrate that altering tree encroachment and restoration of diverse communities is attainable and can be ecologically maintained. Restoring communities to improve watershed stability, improve wildlife habitat, and prevent weed encroachment is feasible and ecologically attainable. Seeding introduced species, principally perennial grasses, to protect disturbances and prevent further site degradation can be successful, but can interfere with natural recovery processes.

We hope future conferences and partnerships will continue our knowledge sharing, always keeping in mind that sustaining and restoring pinyon and juniper woodlands will play a major role in achieving and maintaining a diverse ecosystem in the Interior Western United States.

Ecology

Ecology and Management of Pinyon-Juniper Communities Within the Interior West: Overview of the "Ecological Session" of the Symposium

W. A. Laycock

Abstract—Categories of papers in the "Ecological Session" were history and ecological change, distribution, classification, ecology and physiology, succession and diversity, and disease. Substantial changes have taken place in pinyon-juniper woodlands over the past 150 years. Coinciding with and following early extensive localized harvesting, these woodlands have been dramatically expanding and thickening. Several authors predicted future large, severe fires. Ecological research reported included seed dispersal and banks, seedling establishment, and ecophysiological relations of pinyon and juniper. One model presented illustrated the process of increases in tree density and cover and corresponding decreases in understory. This model would explain most of the processes and results reported in the other papers.

I discuss the plenary and poster papers in the "Ecological Session" in six broad and somewhat uneven categories, with considerable interrelations among them: (1) History and Ecological Change, (2) Distribution, (3) Classification, (4) Ecology and Physiology, (5) Succession and Diversity, and (6) Disease. I analyze strengths, weaknesses, and gaps in coverage of the ecology of the pinyon-juniper type in this symposium. Except where noted, all author references here refer to papers in this section of these proceedings, and the reader is encouraged to study the entirety of each paper.

History and Ecological Change

Trends since Pleistocene

Tausch outlined the landscape position held by juniper and pinyon in the Great Basin from the Pleistocene to the present. He emphasized that climatic change influences the key ecological processes that drive vegetation change. Vegetation types such as pinyon-juniper have shifted hundreds of miles north and south and also up and down in elevation during glacial cycles.

The fact that substantial changes have taken place in the pinyon-juniper woodlands in the past 150 years is one of the reasons for this symposium. According to Tausch, this period was characterized by: (1) a warming climate following the Little Ice Age, (2) the period of the heaviest use by European livestock, and (3) a decrease in wildfire frequency. These factors, in combination, enabled trees (juniper and pinyon) to establish in and then dominate new communities, expand to both higher and lower elevations, and, more recently, dramatically thicken in tree densities and canopies of both existing and new stands.

Harvesting After Settlement

Young and Svejcar summarized the history of tree harvesting in the pinyon-juniper woodlands in the late 19th century—harvesting that mainly provided energy for mining, industries, and domestic purposes. All over the Great Basin, use of pinyon and juniper wood for home heating and cooking was widespread until use of fossil fuels became common after World War II.

In the 1860's, the existing pinyon or juniper trees in the vicinity of large mining operations in Nevada and California were quickly exhausted. The demand for charcoal was so great that deforestation became a severe problem. In Nevada, Young and Svejcar estimated that 4,000 to 5,000 acres of woodland had to be cut annually to supply the Eureka District. By 1874, the mountain slopes around Eureka were denuded of accessible pinyon and juniper for 20 miles, and the average hauling distance from charcoal pit to smelter was estimated to be 35 miles. This 70 mile diameter cutting circle covered about 2.5 million acres of which 0.6 million acres may have been pinyon-juniper woodlands.

On a much smaller scale, Creque and others examined vegetation patterns and change in the past 120 years in the Upper Tintic Valley in Utah. Although their study could not define presettlement conditions, massive harvesting of pinyon-juniper also took place for early mining, domestic, and agricultural activities. Domestic fuelwood consumption from 1870-1900 was estimated to be as much as 74,000 cords. Total woodland harvest in the Tintic Valley from 1870 through 1900 may have been as high as 86,000 ha, with 74,000 cords cut for domestic fuelwood. All of these figures represent the maximum possible wood removed and not all are well documented.

The early period of widespread tree harvesting was followed by a the significant regionwide woodland expansion in the recent past (Creque and others). West stated that current conditions are far from the presettlement situation when much more savanna and less woodland and forest existed in the area where relatively dense pinyon-juniper stands now exist.

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Role of Fire in Pinyon-Juniper Systems

Gruell studied fire history based on fire-scarred trees in three areas showing a history of repeated fires. Presettlement fire intervals ranged from a mean of 8 years in the Walker River area of Nevada, 13 years at the Hart Mountain and Sheldon Refuges in Oregon, to 50 to 100 years in the Great Basin National Park in Nevada. In the past, fires occurred more frequently on deeper soils which produced an abundance of fine fuels. Less frequent fires were found on shallow soils and rocky sites which produced less fine fuel.

Gruell concluded that presettlement fires were common in the pinyon-juniper woodlands of the Great Basin. This fire regime was dramatically altered after settlement because of fire suppression and of heavy grazing, which removed fine fuels. This has resulted in increased density and crown cover of pinyon-juniper along with a more recent buildup of ground fuels. This has resulted in a shift from more frequent, low intensity, small fires, to less frequent but larger, high intensity fires. Gruell contended that "considering the extent of the fuel buildup, severe fires in the Great Basin will continue and perhaps become more frequent." West also stated that "The future holds increased probability of crown-fires, invasion by introduced annuals and short-lived perennials, and then repeated burning and permanent site degradation unless seeding of desirable understory takes place expeditiously." Tausch predicted the same future scenario.

Distribution

Area Covered by Pinyon-Juniper

Estimates of total area covered by pinyon and juniper varied considerably in the papers in the symposium. Some, but not all, of the discrepancies are because of differences in area considered.

Author	Acres	Area Considered
West	75 million	SW U.S. and Mexico
Nowak and others	74 million	Not specified
Weber and others	99-124 million	SW U.S.
Horman & Anderson	60 million	Nevada, Utah, Colo. New Mexico, Arizona
O'Brien & Woudenberg	45.3 million	Intermountain West
Bunting and others	42 million	NW Great Basin & S. Columbia Basin

Mitchell and Roberts probably reported the most accurate figures, based on satellite imagery. They estimated that pinyon-juniper covered 55.6 million acres in the entire Western United States.

Altitudinal Distribution

Drought and frost during the growing season limits distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on the sides of mountains. In western Utah, Harper and Davis found that elevation of pinyon-juniper sites on granite averaged 1,926 m while those on sandstone averaged 1,341 m. Lei reported pinyon-juniper woodland occupied the area from approximately 1,250 to 2,6000 m in elevation in southern Nevada. West stated that pinyons are less tolerant of drought and early spring frosts than junipers and usually dominate the middle elevations while juniper tend to dominate both the higher and lower elevations of the woodland belt.

Nowak and others reported that juniper has greater drought tolerance and that pinyon is more responsive to increased water and nitrogen. Lei studied the environmental variables of a pinyon-juniper woodland along an elevational gradient in a canyon in southern Nevada. Four primary species groups were identified with increasing elevation: blackbrush, big sagebrush, singleaf pinyon, and ponderosa pine. Species distribution was associated with elevation, soil moisture, air temperature, percent bare soil and rock cover, and soil depth.

In contrast to these reported results and published elsewhere, West and others reported that in the western part of the pinyon-juniper range, pine dominates or is the only tree in the upper elevations of these woodlands. (West N. E., Tausch, R. J. and Tueller, P. T. 1998. A management-oriented classification of pinyon-juniper woodlands of the Great Basin. Gen. Tech. Rep. RMRS-GTR-12. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.)

Classification

Tausch stated that "The understory is central to understanding the ecology and ecosystem function of a site." Within the Great Basin, pinyon-juniper woodlands represent multiple communities and ecosystems that are better identified by the understory species. This complexity is increased and often obscured by successional stages of each community. West stated that juniper-pinyon savannas and woodlands have understories that are floristically and structurally more variable than the overstory. Generally, the understory is compositionally similar to that of adjacent grasslands, shrub steppes, chaparral, and forests.

Classification Systems

Winward reported that, because of the complex geology and terrain, past climatic fluctuations and human disturbances, past attempts at classification of pinyon-juniper communities have only been marginally successful. He proposed the following step-down (hierarchical) classification:

Geographic Units (as homogeneous as possible)
Series-Level based on dominant tree species
Associations based on a dominant understory shrub species
Sub-Associations based on prominent herbaceous species

West and others (cited earlier in this paper) published a hierarchical approach to classification of pinyon and juniper woodlands that appears similar to, but perhaps more comprehensive than, the one presented in the proceedings by Winward.

Rust used a similar system to classify pinyon-juniper woodlands on 12 research natural areas in southeastern Idaho. He identified four series: singleleaf pinyon, Rocky Mountain juniper, Utah juniper, and curl-leaf mountain-mahogany. Within these series he described 23 plant associations based on differences in understory species.

Forest Inventory

About 40 percent of the 45.3 million acres of the pinyon-juniper and juniper woodlands in the Intermountain West occur in Nevada and Utah (O'Brien and Woudenberg). Net volume of wood was estimated at more than 10 billion cubic feet or about 137.5 million cords. About 53 percent of the woodland stands in Utah and 67 percent in Nevada were estimated to be between 40 and 120 years old. Only 20 percent of stands in Utah and 9 percent in Nevada are more than 200 years old.

Ecology and Physiology

Seed Dispersal of Pinyon and Juniper

Chambers and others studied seed dispersal and seedling establishment of pinyon and juniper species. Birds disperse pinyon seeds a distance of several meters to 5 km. Some birds and rodents make caches of pinyon seeds, which are important sources of new tree seedlings. Many mammals consume and disperse juniper seeds including rodents, rabbits, predators, deer, and livestock. All pass some seeds intact, which can enhance germination.

Chambers and others found that pinyons have relatively short-lived seeds that form only temporary seed banks. Junipers have a rather continuous seed bank because of long-lived seeds with gemination being delayed by impermeable seed coats, immature or dormant embryos, or germination inhibitors. Pinyon seedlings often require a nurse plant to survive, while juniper seedlings survive in open spaces almost as well as under the canopy of shrubs or trees. Areas under shrubs and trees often have higher concentrations of nutrients and organic matter and higher infiltration rates, making microenvironmental conditions favorable for many conifers. Ecotones between woodlands and adjacent shrublands or grasslands often provide favorable microhabitats for seedling establishment. Over time, and without periodic fires, this process would help to explain the expansion of the boundaries of pinyon-juniper woodlands in many areas.

Seed Banks of Non-Tree Species

Poulsen and others studied the soil seed bank of all species in pinyon-juniper sites in central Utah ranging from closed stands with minimal understory to open stands with excellent understory communities. As tree cover increased, the numbers of understory species and seeds in the soil seed bank decreased. The composition shifted from perennial grasses and shrubs in the moderately depleted and nondepleted understories to annuals and perennial forbs in the depleted understory.

Ecophysiological Patterns of Pinyon and Juniper

Nowak and others examined the ecophysiological patterns of pinyon and juniper and found that these trees generally are conservative in their acquisition and use of resources. Maximum assimilation and conductance rates and tolerance to severe water stress are considerably less for pinyon and juniper than for sagebrush. These conservative ecophysiological traits of pinyon and juniper do not, in themselves, provide for success but may benefit the conifer species by enhancing establishment and growth under nurse plants. The relatively low nutrient content per unit of foliage may allow the conifers to produce more foliage biomass per unit of ground area than sagebrush. These traits coupled with greater longevity allow the conifers to establish under nurse plants and then grow and ultimately outsize and outlive the shrub competitors.

Succession and Diversity

Relation of Tree Density to Species Diversity

The development of mature pinyon and especially juniper woodlands has often resulted in decreases in the herbaceous and shrub understory components. Bunting and others studied the effects on species richness caused by thickening of Western juniper stands and encroachment onto deeper soils in the northwestern portion of the Great Basin. Development of Western juniper woodland vegetation resulted in reductions of shrub and herbaceous plant cover and species richness. Many perennial herbaceous species were associated primarily with early to mid-seral communities and not found in the late seral communities dominated by trees. Maximum landscape species richness and species diversity would occur when all structural and seral stages are represented within a watershed. This emphasizes the need to reintroduce or include smaller scale disturbances, such as fire, as a process in landscape dynamics.

In northeastern Utah, Huber and others also found that both alpha and beta diversity were highest in seral communities where pinyon and juniper canopy cover did not exceed 20 percent. In woodland communities where canopy exceeded 30 percent, both understory cover and diversity were severely depressed.

Overstory/Understory Relationships

Miller and others presented a model of the conversion of shrub steppe to juniper woodlands in the absence of fire in eastern Oregon and northeastern California. Perennial forb/grassland and shrub steppe communities are fire driven systems. During the early stages of tree establishment, the transition is reversible, mainly by fire. Shrubs begin to die as the woodlands approach mid development, which decreases the probability of a fire intense enough to kill the large juniper trees. By the mid to late stages of this transition, a threshold is crossed where reversal to a shrub steppe community is unlikely (See figure 2 in Miller and others).

Crossing the mid to late development threshold often is characterized by a loss of native herbaceous species, possibility of dominance by alien annuals, the potential loss of surface soil, and the loss of habitat for many wildlife species, which are abundant in the shrub-steppe communities. Tausch discussed other thresholds important to the understanding of woodland dynamics. The relationships illustrated in the Miller and others' model help explain the results of many of the papers in this session. The model also would be quite helpful in evaluating potential resource problems, determining wildlife habitat values, and setting realistic goals and time frames for management. Svejcar, in the "Management Implementation Session," also suggested that state-and-transition models be developed for pinyon-juniper systems.

Horman and Anderson studied the effects of removal of juniper tree canopy and litter on the understory in Utah. In undisturbed woodlands, cover, understory plant abundance, and seedling emergence were quite low but were higher in the under the tree canopy than in the interspaces. Canopy removal decreased plant abundance and seedling emergence in the canopy zone but had no effect in the interspace. Litter removal had no significant effect on perennial species. This study was conducted only for 3 years, possibly too short a time for the effects of canopy removal to become evident. More likely, this site had crossed the threshold referred to by Miller and others, and the understory had lost the ability to respond to the canopy removal.

Naillon and others studied the relation of understory species frequency between canopy and interspaces between trees at different tree densities. As tree density increased, associated herbaceous cover and species diversity decreased. Sandberg bluegrass had higher frequency values under tree canopy than in the interspace at low tree densities. No difference occurred at high tree densities. At all tree densities, cheatgrass frequency values were higher under the canopy than in the interspaces.

Alien Annual Species in the Understory

Goodrich and Gale studied frequency of cheatgrass (*Bromus tectorum*) on two relic sites within a pinyon-juniper belt in northern Utah. The sites were protected by cliffs and steep slopes and probably had little or no historic livestock use. One area had burned about 80 years ago and the other had an open stand of trees even though it had not burned in the past 150 years. Cheatgrass was by far the dominant understory species on both sites. Its abundance indicates a capacity to drive plant community dynamics both after fire and in areas that had not recently burned, and even in areas where human and domestic livestock activities have been low. They concluded that the concept of potential natural communities based on only native species is seriously challenged by the dynamics of cheatgrass. Refusing to recognize cheatgrass within the site potential will not reduce its presence nor its potential to dominate a community. Tausch reported that the dominance of cheatgrass represents a recognizable threshold in pinyon-juniper woodlands.

Svejcar, in the "Management Implications Session," also discussed the invasion of cheatgrass and other weeds in disturbed areas. If a good cover of perennial species exists before disturbance, cheatgrass and other weeds often are not a problem. If considerable annuals are present, they likely will dominate the site after a disturbance, and seeding of adapted species may be required (Tausch). A state-and-transition model, including situations with presence and absence of cheatgrass and other annuals, would help managers make more informed decisions.

Jones and others studied drought tolerance of small burnet (*Sanguisorba minor*) and six cultivars of alfalfa (*Medicago sativa*), two nonnative species that might be suitable for planting on specific sites. Small burnet was more drought tolerant than alfalfa.

Changes Over Time in Mature Stands

While large changes have occurred in areas where trees have invaded or thickened, re-surveys of mature pinyon-juniper stands reported in this session showed little change, at least over relatively short periods. Austin found little change over 23 years (1974 through 1997) in trees, shrubs, grasses, or forbs in a mature pinyon-juniper community in northeastern Utah. In a relict area in Grand Canyon National Park, Brian and others found only slight changes in a mature pinyon-juniper woodland over 38 years (1958 through 1996).

Disease

Only two papers dealt with diseases of pinyon and juniper. Weber and others reported that a number of pathogens occur on *Pinus edulis* and *Juniperus osteosperma*. The most frequent pathogens on junipers are rust fungi. Mistletoe is more common on pinyon than juniper but occurs on both species. Mold/mildew diseases, wood rot, needle blight, shoot dieback and needle cast are common in juniper.

In southern Nevada, Lei found that taller Utah juniper trees were more likely to be infected by parasitic mistletoe than shorter trees. Mistletoe significantly reduced leaf water potentials, vigor, viability, and reproductive success of the host tree.

Discussion

Substantial changes have taken place in pinyon-juniper systems over the past 150 years. Tausch provided the historical basis for the Ecological Session by pointing out that this period was characterized by a warming climate, heavy livestock grazing, and a decrease in fire frequency. After the early exploitation of these woodlands for wood, these factors enabled pinyon and juniper to establish and then dominate new communities as well as thicken in existing stands. Young and Svejcar summarized the heavy tree harvesting for industrial and domestic purposes since 1900 before the current expansion and stand thickening.

Gruell provided evidence of pre- and postsettlement fire history for three areas. This type of research needs to be repeated all over the Great Basin and other areas where pinyon-juniper woodlands now exist. Gruell, West, and Tausch indicated that large severe fires covering large areas in the future will be the result of crown closure or fuel buildup.

The greatest lack of agreement among authors concerned the total area covered by pinyon-juniper woodlands. Figures presented ranged from 45 million to 120 million acres. The 55.6 million acre figure of Mitchell and Roberts probably was the most accurate because it was developed from satellite imagery.

Tausch stated that the understory is key to the understanding of the ecology and ecosystem function in pinyon-juniper woodlands. The hierarchical classification systems of Winward, Rust , and West and others (cited previously) start with some large geographic unit, then to the dominant tree species, and only then to the dominant shrub and herbaceous species. If the understory is, indeed, the key to understanding pinyon-juniper systems, then classification systems need to recognize that fact in a more positive manner.

Ecological and physiological research reported in this symposium that should lead to a better understanding of how pinyon-juniper woodlands function included seed dispersal and seedling establishment mechanisms of pinyon and juniper, understory seed banks, ecophysiological mechanisms of pinyon and juniper species, and species diversity at different seral stages. The papers by Miller and others and Tausch probably provided the most useful synthesis of the processes involved in the conversion of shrub steppe to juniper woodland. Miller and others suggested a model showing increase in tree density and corresponding understory changes. If a system crosses a threshold of tree cover and density, the process cannot be reversed, and the site becomes a woodland. This model explains the results of a great many papers in this session and should be read by anyone interested in the ecology or management of pinyon-juniper. Svejcar, in the "Management Implications Session," recommended that one or more state-and-transition models be developed for pinyon-juniper systems. The model proposed by Miller and others along with the thresholds defined by Tausch, could be developed into a state-and-transition model.

The Goodrich and Gale paper also is quite important to the understanding of the ecology of pinyon-juniper woodlands as well and many other ecosystems. They found that an alien species, cheatgrass, was the dominant species on two pinyon-juniper stands in Utah that had little or no historic disturbance by livestock or humans and 80 to 150 years since the last fire. They pointed out that a prevalent concept in management is that preservation of native plant communities will prevent or eliminate cheatgrass (and perhaps other alien annuals). This is not consistent with reality in many situations. If a woodland with an understory dominated by cheatgrass burns, the site then is dominated by cheatgrass and other annuals. Because such sites may re-burn every 3 to 5 years (West and others), they often are permanently converted from a woodland to an alien grassland. Thus, the domination of cheatgrass is a recognizable and important threshold in these woodlands (Tausch).

Similar management concepts, such as those that permit seeding of only native species in severely disturbed pinyon-juniper stands, likewise may be questionable. Site adapted native species are not available in sufficient amounts to adequately restore extensive disturbances. To prevent erosion and keep alien annuals from invading, adapted, drought-tolerant introduced species often will be required to stabilize disturbances until suitable native species become available. In this situation, it seems ecologically undesirable and economically unwise to insist that only native species be seeded. This is especially true if rather large areas have to be seeded to prevent erosion or cheatgrass invasion following extensive wildfires, and if the large sums of money required to purchase expensive native seed are not available.

Historic Pinyon and Juniper Woodland Development

Robin J. Tausch

Abstract—Climate change influences the ecological processes driving regional vegetation change. With the paleoecological and geomorphological perspective of Holocene history, it is apparent that each vegetation change interacting with the environment sets the conditions for the next vegetation change. Because of interactions between vegetation change and environment, particularly for non-tree species, pinyon-juniper woodlands of the Great Basin represent multiple communities and ecosystems. Multiple successional stages occur in repetitive, but constantly changing, mosaics across the landscape. Tree expansion over the last 150 years has set up the conditions for the possible decline in woodland area from large fires over the next 150 years. To manage these woodlands, better definitions of what is woodland versus other communities are needed that account for their long-term patterns of change and interacting cycles of disturbance and succession.

To understand the dynamics of Great Basin woodlands, knowledge of their development is necessary. At the core of current and historic woodland development is climate. Through the control of energy and water, climate is the most important factor in the occurrence and distribution of ecosystems and communities (Bailey and others 1994). Land form is the major modifier of climate. Climate change and its topographic modifications influence key ecological processes, driving both local and regional vegetation changes (Betancourt and others 1993; Woolfenden 1996). These changes cascade up and down between scales of space and time. History shows us that about the only thing we can predict about climate is that it will change. It is when and how it will change, and how communities will respond, that we largely do not know.

The combination of available paleobotanical proxy data from woodrat midden and pollen records from the late Pleistocene through the Holocene reveals that individualistic species responses to climate change have driven considerable vegetation change (Betancourt 1996; Betancourt and others 1990; Nowak and others 1994a; Tausch and others 1993; VanDevender and Spaulding 1979; Woolfenden 1996). These records are the most detailed for the last 4,000 to 5,000 years (Wigand and others 1995). Past environmental changes can also equal or exceed the importance of the current environmental conditions in determining the growth, development, and competitive and successional dynamics of current communities (Millar 1996, Woolfenden 1996). Each change in the vegetation, in turn, sets up the community conditions that interact with the next environmental change to set the direction and magnitude of the next vegetation change. Without an understanding of the history of past change, it is not fully possible to adequately explain current woodland patterns or ongoing changes. This is particularly true for the last 5,000 years and involves a shift in our perception of time to scales more appropriate to how Great Basin ecosystems function because functions change as an ecosystems respond to changing climate (Millar 1997, Tausch 1996).

With climate it is often the effects of its variability, and particularly its extremes, not the means, that have the most influence on community changes (Betancourt and others 1993). The types, frequencies of occurrence, outcomes of extreme events, and how vegetation responds vary with location across the Great Basin. Biological and ecological changes resulting from climatic variation have been studied primarily at the organismic and community level, and more rarely, at the ecosystem or regional scale (Betancourt and others 1993). Better understanding of historical climatic and community changes, and present ecosystem influences, at regional scales is central to successful ecosystem management.

On geologic time scales, most of the Great Basin is a region or zone of transition between northern coniferous forests and southern deserts that has shifted hundreds miles north and south during each glacial cycle. As community composition has continually changed, both between and within glacial cycles, these changes were modified by the topography of the region. There have been major shifts through time in the trees' location, their abundance, and their relative contribution to communities.

Historical Changes

Historical woodland development through the Holocene can be divided into 10 time periods. These periods have been based primarily on information provided by Wigand and others (1995) from the analysis of pollen data. I have modified the number and timing for these periods based on additional information from geomorphic studies of the Columbia River system (Chatters and Hoover 1992); from Betancourt and others (1993), from west and central Nevada woodrat midden (Tausch and Nowak 1998) and geomorphic and community studies (Chambers and others 1998), and from studies in the Sierra Nevada Mountains (Millar 1996, Woolfenden 1996).

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Pleistocene: More Than 11,500 Years BP

Semiarid woodlands were about 1,000 m lower in elevation and 500 to 600 km further south at the last glacial maximum about 18,000 years BP (Spaulding 1985; VanDevender and Spaulding 1979; Wells 1983; Wigand and others 1995; Woolfenden 1996). Woodlands during the Pleistocene were largely limber pine, bristlecone pine, and whitebark pine, and were largely open with the understory communities dominating the cover. The dense pinyon-juniper woodlands present today were mostly absent from the Great Basin until after about 10,000 years BP (Thompson 1990; Woolfenden 1996). Both western and Utah juniper were present in the Pleistocene but were apparently scattered around lower elevation areas of the Great Basin protected by topographically modified climate (Nowak and others 1994a; Thompson and others 1986; Wigand and others 1995). Pinyon was restricted to the valley floors and mountain slopes at the southern edge of the Great Basin (Nowak and others 1994b; Thompson 1990; Woolfenden 1996). Toward the end of this period, pluvial lake levels were dropping and many genera of large herbivores were becoming extinct (Betancourt and others 1993).

Early Holocene: 11,500 to 8,000 Years BP

The climatic conditions of the early Holocene were very different than in the previous 100,000 years of the Pleistocene. Climate during the Holocene, however, has also never been constant long enough for any strong interspecies relationships to develop. In southern Nevada, pinyon-juniper woodlands replaced limber pine at intermediate elevations as temperatures warmed (Thompson 1990; Wells 1983; Wigand and others 1995). This time period also saw the beginnings of the northward movement of pinyon into the Great Basin and expansion of juniper out of its more northerly refugia (Nowak and others 1994a,b; Woolfenden 1996). During this early Holocene period, pinyon was apparently a minor component of the juniper dominated woodlands (Spaulding 1985; Thompson 1990; Wigand and others 1995). The ability of both tree genera to dominate a site increased in the Holocene, especially in the absence of disturbance such as fire. The species composition of all communities continued to change over this period of the Holocene (Nowak and others 1994a,b).

Mid-Holocene: 8,000 to 5,500 Years BP

This was the warmest part of the Holocene. In the mid-Holocene the woodlands and upper tree lines were 300 to 500 m higher in elevation than today (Jennings and Elliot-Fisk 1993; Wigand and others 1995; Woolfenden 1996). Lake Tahoe was also 10 to 15 m below its geologic rim. Trunks of trees that established along the lower shoreline during this period, and were then drowned when the lake level rose, still exist in the Lake (Furgurson and Mobley 1992; Lindstrom 1990). Many desert shrub species in the Great Basin increased in abundance (Mehringer and Wigand 1990; Tausch and Nowak 1998; Wigand 1987; Wigand and others 1995). Some expansion in the range of the woodlands also occurred.

Early Late Holocene: 5,500 to 4,500 Years BP

A gradual but erratic increase in precipitation occurred following the mid-Holocene (Chatters and Hoover 1992; Davis 1982; Mehringer 1987; Wigand 1987), and there was additional migration of both juniper and pinyon northward into the Great Basin. This period also had the first evidence of western juniper in northeastern California and eastern Oregon (Mehringer and Wigand 1990; Miller and Wigand 1994; Wigand and others 1995). The range in woodland distribution continued to slowly increase during this time period.

Neoglacial: 4,500 to 2,500 Years BP

The Neoglacial period was much cooler and wetter than the mid-Holocene (Davis 1982; Grayson 1993; Wigand 1987; Woolfenden 1996). Western juniper expansion continued into the northernmost Great Basin (Wigand 1987), and this expansion accelerated in the middle of the period. Much of the remainder of the pinyon and juniper range expansion in Nevada and Utah occurred during this period and was accompanied by a reduction in desert shrub vegetation. Pinyon abundance increased relative to that of juniper (Thompson and Kautz 1983). The increase in range for the trees was largely at mid and low elevations (Mehringer and Wigand 1990). Woodland extent and density at mid to low elevations was possibly equal to that present today (Kinney 1996; Wigand and others 1995, Wigand 1998). Large increases in grass are associated with evidence of periodically occurring fire. Upper tree line lowered in elevation in the White Mountains (LaMarche 1973), in the Sierra Nevada Mountains (Scuderi 1987), and in the Canadian Rockies (Luckman 1990). The Great Salt Lake Desert apparently flooded during the latter part of the period (Mehringer 1977; Thompson and Kautz 1983), and Mono Lake reached its highest level since the early Holocene (Stine 1990).

Post-Neoglacial Drought: 2,500 to 1,300 Years BP

Following the Neoglacial there was a significant drop in precipitation, but temperatures apparently remained relatively cool (Chatters and Hoover 1992). Coinciding with this severe drought was a region wide decrease in woodland density and extent and increasing dominance of desert shrub vegetation that was dominated by Chenopods, particularly greasewood (Wigand and others 1995). Juniper declined less than pinyon (Thompson and Kautz 1983). Major geomorphic changes from floodplain construction and rapid alluvial fan development occurred to the north (Chatters and Hoover 1992). Similar alluvial fan building and aggradation of valley floors, along with reductions in plant diversity, occurred in central Nevada during this period (Chambers and others 1998).

Medieval Warm Period: 1,300 to 800 Years BP

This period had warmer temperatures (Grove and Switsur 1994) and an increase in precipitation from the previous period, but also saw a shift in precipitation with a greater proportion coming in late spring and early summer (Davis 1994; Leavitt 1994). Winter conditions may have also been milder (Wigand and others 1995), reducing snowpack and lake and stream levels (Born 1972; Stine 1994; Woolfenden 1996). These climate changes resulted in an increase in grass abundance (Wigand and Nowak 1992), and the presence of buffalo (Agenbroad 1978; Butler 1978; Schroedl 1973). About 1,000 years BP, there was a brief juniper woodland expansion in the north and the maximum dominance of pinyon was centered about 1,200 years BP (Wigand and others 1995). The Fremont Indian Culture, with its corn-based agriculture, occurred in many areas of the eastern Great Basin at this time.

800 to 550 Years BP

This is an unnamed dry period that is reflected in tree ring studies (Holmes and others 1986; Woolfenden 1996), and the reduction of lake levels (Stine 1990). It was also accompanied by cool temperatures and again had a decline in tree dominance (Wigand 1987; Wigand and Rose 1990), an increase in desert shrubs, and an increase in fire in some locations (Wigand and others 1995). Some of the previous extent in woodland distribution was also lost. The Fremont Indian Culture disappeared from the Great Basin during this time period.

Little Ice Age: 550 to 150 Years BP

The Little Ice Age was a cooler and initially wetter period during which glacial advances, possibly the largest of the Holocene, occurred (Naftz and others 1996; Woolfenden 1996). Upper tree lines were the lowest of the last 7,000 years in the Sierra Nevada and growing season temperatures were low until about 1850 (Stine 1996) A gradual increase in dominance and range of the woodlands began following the decline that occurred following the Neoglacial (Mehringer and Wigand 1990). This increase included western juniper in the north and primarily pinyon in the rest of the Great Basin (Nowak and others 1994a,b). This expansion in range, although not so much in density, was well underway when the first Europeans arrived (Wigand and others 1995).

We have some idea of the plant communities of the last 400 to 500 years of the Little Ice Age because it is the vegetation that was in the Great Basin when the first European explorers crossed through it. For climatic periods prior to the Little Ice Age, we have much less information on Great Basin communities, but they were different (Woolfenden 1996). Species presence information from middens (Tausch and Nowak 1998) tell us that during the Little Ice Age, the species composition of many Great Basin riparian communities was at least as diverse, particularly in herbaceous species, as in any other wetter period of the Holocene. These Little Ice Age communities were also different than what is present at the same locations today. Even though the Little Ice Age represents our best understanding of past vegetation, major gaps in knowledge are still present.

Despite a similar extent in woodland distribution, tree dominance patterns within that range were very different during the Little Ice Age compared to what is present today. Many sources of evidence, including relict woodlands, tree age-class ratios, fire scars, and historic documents (Gruell, this proceedings) indicate that particularly during the drier (Woolfenden 1996) part of the Little Ice Age woodlands were more open with the trees either found in savannas or confined to scattered fire-protected sites (Wigand and others 1995).

Throughout the Little Ice Age, the vegetation of the Great Basin has been represented by a matrix of nontree-dominated communities with pockets of woodlands and individual trees scattered through it. This appears to have been a dynamic equilibrium maintained by many factors including a cold, somewhat dry climate (Woolfenden 1996) and a higher fire frequency. These high fire frequencies did not occur everywhere. Maybe as much as one-fourth of the present woodlands fire return intervals may have been in centuries, rather than decades.

Overall, the geographic range of woodland trees during the Little Ice Age was close to what now exists, but the abundance within those areas was less. Interestingly, this is a pattern that is typically seen during the early stages of invasion by a new species. The advance does not occur as a solid front but first occurs as pockets or small populations establishing in scattered locations across the landscape. The scattered advance is then followed by a filling-in of the intervening spaces and eventual dominance of the area. The processes of this last step is what has been occurring in the woodlands since the end of the Little Ice Age.

Recent: 150 Years BP to the Present

The beginning of this period coincides with several important changes in the environment that occurred simultaneously. The most important of these changes were (1) cessation of the hunting, gathering, and burning by populations of indigenous people that had occurred during the Little Ice Age (Creque 1996), (2) a change in climate with rising temperatures (Ghil and Vautgard 1991; Woolfenden 1996), (3) the period of heaviest livestock use of the region following European settlement with its effects on plant competition and fire potential, (4) a decrease in wildfire frequency along with increasing wildfire suppression efforts in the latter part of the period (Bunting 1994), (5) increasing atmospheric CO_2 levels that are changing community competitive interactions (Farquhar 1997) and favoring the dominance of large woody perennials (Polley and others 1996), and (6) an increasing availability of nitrogen from air pollution.

Whatever the combination of factors were that had maintained the Little Ice Age prevalence of a scattered distribution of trees, they changed with the mid nineteenth century end of the Little Ice Age. With those changes, the ability of the trees to successfully establish into and dominate many new communities increased. Movement of woodlands into higher elevations, as well as to lower elevations, has accompanied these recent changes (Blackburn and Tueller 1970;

Miller and Rose 1995; Tausch and others 1981; West 1984; Wigand and others 1995). Dense, tree-dominated woodlands are now possibly as much as three times as common as at the end of the Little Ice Age (Tausch and others 1981).

Key to this expansion is the ability of the tree species to establish into many new communities (Chambers and others, this proceedings). They clearly have effective methods of seed dispersal that results in a sufficient number ending up in sites suitable for germination. Once germinated, many of the tree seedlings become established into the invaded communities and successfully compete with, and eventually dominate, the other plant species present (Nowak and others, this proceedings). With their longevity topping 500 years, the last ice advance ended only a few score generations ago for both pinyon and juniper (Betancourt and others 1993). This implies that the increased establishment rate is not a new adaptation by the trees, but the result of recent environmental changes.

For the last several thousand years, woodlands throughout the southwest have also been significantly affected by direct human manipulation (Denevan 1992; Kohler 1992) and the role of humans in past woodland dynamics must be considered (Betancourt and others 1993). The major differences between prehistoric management, and management occurring following European settlement, have been important contributors to the recent changes in the distribution, structure, and composition of the woodlands.

Current Situation

Knowledge of woodland history helps in understanding the woodlands of today in many ways. About half of the plant taxa present today in the Great Basin are found scattered through the woodrat midden and pollen paleorecord of the last 30,000 plus years (Thompson 1990; Nowak and others 1994a,b). All the associations of plant species with each other, and with the communities represented, have changed considerably and continuously. This is also true over the last 4,000 to 6,000 years and has included the distribution and density of both pinyon and juniper. These changes have occurred too frequently for clear links between soils and vegetation to form on a regional basis in Great Basin pinyon-juniper woodlands (West and others 1998).

Recent management activities have been largely based on a view that woodlands are the matrix, and imbedded within it are all the species assemblages found in the understory. This is a view based on what has been visible over only the last half to three-quarters of a century. With the full perspective of Holocene history, plant species found in the understory of today's woodlands, and in the majority of locations, have generally existed in a variety of shrub and grass-dominated communities for far longer periods of time than they have in tree-dominated communities. Because tree-dominated woodlands have been much more temporary or transitory, it is the nontree-dominated communities that are the matrix within which are imbedded pockets of woodlands of various successional stages.

Despite the similarity in appearance, pinyon-juniper woodlands of the Great Basin do not represent a single natural geographic division or natural land type. Both pinyon and juniper have large ecological amplitudes. Species of both genera can be found growing with other species ranging from Joshua trees at the lower elevations to limber pine and bristlecone pine at the upper elevations. Because pinyon-juniper woodlands of the Great Basin represent such a large area, they are an assemblage of many ecosystems at more regional and local levels that are dominated by one or more of the woodland tree species.

Many of the individual shrub taxa present in Great Basin communities can also have wide ecological amplitudes (West and others 1978; West 1984; West and others 1998). Although not as large as those for the trees, their range of occurrence still must be considered as reflecting real differences in broad-scale environments across the region that could be important for management. The same is true for many dominant perennial grasses. If the trees were not present, the Great Basin area now covered by woodlands would be an array of many different communities. This is consistent with the size of the region, the range of environmental conditions, and the species diversity present over the Great Basin.

One contribution to our lack of recognition of the shrub-grass communities in tree-dominated areas probably comes from a community interpretation where disturbance is something abnormal and external to, or separate from, the community. Although they are suppressed by the dominance of the trees, these communities are still largely there. All the environmental differences their presence represents are still important. The understory is central to the understanding of the ecology and ecosystem function of a site. This is probably why there are no species clearly identified with tree-dominated pinyon-juniper woodlands as can occur in many more mesic forest types. All other species present in the woodlands were also part of the sagebrush-grass dominated communities that preceded the trees. The trees can be a component of many communities, but history shows their dominance only represents one possible stage in the successional cycles of those communities. Thus, for most areas, and appropriate time scales, dominance by trees has been transitory.

The location in the basin, the topography, the soils, and the climate that dictates the differences between these communities still influence how the sites respond to changes, even when tree-dominated. The outcome of management activities, the affects of introduced exotics, and the types and successional patterns following fire are generally independent of the appearance of similarity in the structure in the tree layer. Understory community differences are more indicative of finer scale environmental controls and carry more information on how a specific site will respond if the trees are removed by some disturbance.

Additional community variation occurs because individual mountain ranges in the Great Basin are not independent. Their relative sizes and, in particular, their orientations to each other significantly affect each other's environment as they interact with storm system development and movement. These interactions between mountain ranges also affect how climate and vegetation change with position on a mountain. The environment and vegetation found at a specific location on one mountain can vary depending on the size, shape, and orientation of adjacent mountains. Interactions between altitude and physiographic position can also modify the effects of both latitudinal and longitudinal zonation. Because of the general north-south orientation, some very long ranges can encompass a considerable range of environments.

The same abiotic component may have a different influence in one species mix than in another, and in one location than in another, both between and within mountain ranges. Changes in the surrounding landscape can drive changes at the site level even if that site has seen minimal change. All interact through time to affect and drive future community changes. The level of influence that topography, soils, and environment have on ecosystems in the Great Basin varies with latitude and with altitude in complex interactions.

Within the context of the entire Great Basin, these variations are present as repetitive mosaics across the landscape. This complexity can be both increased and obscured by the many successional stages of each community. For example, long-term, self-reproducing woodland climax states have not existed except in very localized, specialized situations. They have been the exception. Functioning woodland and non woodland ecosystems and their respective successional stages have been connected on a landscape basis at multiple levels in complex heterogenous ways. Much of this variation is now being concealed by tree dominance. In the future, this complexity of communities and their interconnections will not be exact repeats of what occurred in the past (presettlement or Little Ice Age) , particularly because of ongoing climate change, the introduction of exotic annuals, and the increasing atmospheric CO_2. Attempts by management to restore those communities will usually not be successful (Millar 1997, Tausch 1996). How large an area is, its position on the landscape, the larger context of the associated communities in the surrounding the area, the presence of introduced species, and the potential interactions with those systems all need to be considered. Because no system exists in isolation, how a particular system responds to management is determined in many ways by its relationships with those systems that surround it.

Future Trends

The next step is to look ahead to what past trends and present conditions mean for future trends. There are direct implications in the history of long-term, ongoing changes in the successional processes of sites dominated by pinyon and juniper that are important for management. Most of what has been written about successional changes in pinyon-juniper dominated areas has the stated, or more often unstated, assumption that all sites where trees become established will end up tree-dominated and then stay that way. However, this assumes a stable climate and it ignores long-term historic fire patterns which have not been constant, but very different for different for past time periods preceding the Little Ice Age. These patterns can be expected to change again into the future as the Little Ice Age is left further behind. For example, as growth and successional patterns in the woodlands have changed over the last several decades, their susceptibility to fire, and the types of fire that occur, has changed. Evidence is now accumulating that the recent tree expansion and the successional changes involved are setting up the conditions for a new set of changes driven by large, stand-replacing crown fires that will take place over the next 150 plus years (Gruell, this proceedings; Tausch, this proceedings).

With the expansion of the woodlands, and an increased density and crown size of pinyon and juniper, distances between individual tree crowns have been decreasing. The result has been a steady increase in the evenness of crown fuels across larger and larger areas, particularly on more productive sites formerly dominated by sagebrush-grass communities. From the increase in crown fuels comes a steadily increasing risk of large crown fires that can rapidly cover those large areas. Such fires appear to be increasing in frequency, as well as size, as more and more woodland area matures to this condition and the contiguous areas involved become larger (Gruell this proceedings). Under the right conditions, many thousands of acres of mature woodland can now burn in a day.

In the woodland areas that were savannas during the Little Ice Age, the older trees, particularly juniper, have sometimes been observed to have several fire scars (Gruell, this proceedings). With the tree density increases of the last century, many of these former savanna sites often have an ingrowth of a high density of increasingly larger, younger trees, usually pinyon. Heat levels and flame lengths now being generated by these denser tree stands, particularly in areas with deeper soils, permit fire to carry up through many of the more open woodlands on the steeper adjacent slopes. These are some of the locations where fires often did not go when fire return intervals were more frequent. After more than a century of no fire, when fires do occur in these areas, they generally leave no surviving trees. This is the outcome from the greatly increased fire intensity that follows over a century of climate change, settlement impact, and tree expansion in the presence of a reduced fire frequency.

A large part of the historic establishment appears to have taken place in areas with deeper, more productive soils . These are sites in canyon bottoms and swales, and on alluvial fans where the available evidence appears to indicate that during the Little Ice Age, tree establishment and growth never got very far before they were removed by fire. Now, however, as a result of successful tree establishment, large areas of deeper soils are becoming dominated by trees. As a result, there are probably more acres of woodland, and a greater proportion of the total woodland area, now at risk for crown fire than at any time since the Neoglacial, and possibly longer. The amount of area in this condition is also steadily increasing.

The worst-case outcome of these changing community and associated fire patterns is that larger and larger areas of woodland could potentially cease to exist as more of the woodland area in the Great Basin becomes at risk and then burns. Currently, the area of woodland reaching tree dominance each year exceeds the amount burned. This may not long be the case, and the next 150 years could eventually see the area of the Great Basin that is dominated by woodlands decline. They will, in turn, be replaced by new shrub-perennial grass-dominated communities, or in the worse case, exotic annual-dominated communities.

Local topography, soils, associated species, environmental conditions, and disturbance types and frequencies can likely cause major changes in the way sites respond to a disturbance such as fire. Even on the more fire-protected types of areas, the relative proportions of various seral stages can be much different than what was present during the higher fire return frequencies that existed during the Little Ice Age. Control of reestablishment patterns after fire can be dependent on the composition of the understory community present prior to the fire. Clearly pre-identification of these areas by the understory communities and their different functional relationships will be necessary for determining proper management actions following fire.

Because of the extensive area of the Great Basin now dominated by trees, only on a small portion will it be possible to take management action to alter these trends. In the majority of the existing and future tree-dominated areas, it will be necessary to develop management strategies to deal with the results that follow these large fires. In burned areas where native shrub and perennial grass-dominated communities return following fires, the return of the woodlands is possible. Where the woodlands are being replaced following fire by communities dominated by exotic annuals, the return of the woodland could take several centuries or longer.

Despite the changes, there are areas that have been in the past, that are, and that are likely to remain in the future, generally immune to fire. These sites result in stands of trees that are more open or scattered and have a more sparse understory, and generally support a preponderance of the existing old-growth woodlands (Miller and others, this proceedings). In these stands, successional processes are often an internal patch dynamics type of regeneration.

The balance between tree and non tree-dominated communities has always been dynamic. Each has always been present and each has always had an important ecosystem role. Heavy dominance by one or the other, but particularly a monoculture of the trees, seems to have always been an unstable situation. We are only beginning to recognize the full complexity of the large array of communities that comprise Great Basin woodlands. Relatively little is known about the basics of that complexity, the range of future changes in woodland ecology, or of the range of possible management options that are likely in the future as conditions continue to change.

Composition changes, community type changes, and changes in species locations were dynamic throughout the Holocene. The pattern of woodland distribution and successional stage has never been random, but differed with the size, intensity, and frequency of fire interacting with differences in environment, topography, and soils. The higher fire frequencies of the past were also not uniform over time or across the landscape (Woolfenden 1996). But despite these continual disturbance and composition changes, a general pattern of a mosaic of variously interconnected communities and successional stages across the landscape appears to have remained. This is a dynamic state that Great Basin ecosystems appear to often develop, and which our management activities have often disrupted or simplified (Tausch, this proceedings). When this disruption or simplification of large areas of Great Basin ecosystems occurs, be it upland or riparian, unintended changes and consequences often result. When large-scale increases in community homogeneity happen, ecosystem function appears to be restricted or limited by the loss of the multiple interconnections between, and a reduction in, the range of communities and successional stages that are present. Usually, these unintended changes from ecosystem simplification, and the larger areas potentially affected by any disturbance, appear to be detrimental to long-term management goals.

Ecosystems occur at multiple levels of integration and nestedness. To be effective management must also occur at multiple levels of nested geographic scales. It requires awareness of landscape-scale non equilibrium dynamics (Betancourt and others 1993; Sprugel 1991; Tausch and others 1993) where both slow localized successional and large disturbance-related episodic changes in community composition and dynamics are present. Because ecosystems are spatially arranged and vertically nested, with complex relationships among the hierarchies, we need to provide a synthesis of information based on the interrelationships across each area or region of a landscape. In acquiring this information, it must be remembered that ecosystem boundaries are more open in the Great Basin than almost anywhere else (Bailey and others 1994).

To be successful, management in these woodlands needs to be on a landscape to regional scale that considers the heterogeneous, non equilibrium mix of disturbance and recovery situations they include. Central to this management of such heterogenous mixing of communities in the Great Basin will be a clarification of the definition of what is woodland what is not, where woodland is dominant and will remain so, and where it either is not or will not remain dominant. Such a revised definition needs to include the range of disturbance types and disturbance frequencies and how they change between communities and over time as environmental conditions change. It will be necessary, for example, to identify areas where the more frequent fires did or did not go in the past. To do this it will be necessary to identify the environment (particularly climate), topography, and community characteristics that have controlled the past fire patterns and frequencies. Some objective way of resolving definitions of woodland versus other communities that is dynamic and accounts for longer term patterns and cycles of disturbance needs to be found. Finally, because many aspects of future climate and plant community compositions and dynamics will be both new and unknown (Millar 1997, Tausch 1996), successful management can only occur by adequately monitoring the changes and responding accordingly.

References

Agenbroad, L. D. 1978. Buffalo jump complexes in Owyhee County, Idaho. Plains Anthropologist. 23: 313-221.

Bailey, R. G.; Avers, P. E.; King, T.; McNab, W. H. eds. 1994. Ecoregions and subregions of the United States. Map (scale 1:7,500,000). Washington, DC: U. S. Department of Agriculture, Forest Service.

Betancourt, J. L. 1996. Long- and short-term climate influences on southwestern shrublands. In: Barrow, J. R.; McArthur, E. D.; Sosebee, R. E.; Tausch, R. J., comps. 1996. Proceedings: shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 5-9.

Betancourt, J. L.; VanDevender, T.; Martin, P. S. 1990. Packrat middens: the last 40,000 years of biotic change. Tucson, AZ: University of Arizona Press.

Betancourt, J. L.; Pierson, E. A.; Rylander, K. A.; Fairchild-Parks, J. A.; Dean, J. S. 1993. Influence of history and climate on New Mexico piñon-juniper woodlands. In: Aldon, E. F.; Shaw, D. W., coords. 1993. Proceedings, managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30; Santa Fe, NM. Gen. Tech. Rep. RM-GTR-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 42-62.

Blackburn, J. W.; Tueller, P. T. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology. 51: 841-848.

Born, S. M. 1972. Late Quaternary history, deltaic sedimentation, and mudlump formation at Pyramid Lake, Nevada. Reno, University of Nevada, Desert Research Institute, 97p.

Bunting, S. C. 1994. Effects of fire on juniper woodland ecosystems in the Great Basin. In: Monsen, S. B.; Kitchen, S. G., comps. Proceedings: ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 53-55.

Butler, R. R. 1978. Bison hunting in the Desert West before 1800: the paleoecological potential and the archaeological reality. Plains Anthropologist. 23: 106-112.

Chambers, J. C.; Farleigh, K; Tausch, R. J.; Miller, J. R.; Germanoski, D.; Martin, D.; Nowak, C. 1998. Understanding long- and short-term changes in vegetation and geomorphic processes: the key to riparian restoration? In: Potts, D. F. ed. Proceedings of AWRA speciality conference, rangeland management and water resources. Herndon, Virginia: American Water Resources Association, TPS-98-1: 101-110.

Chaters, J. C.; Hoover, K. A. 1992. Response of the Columbia River fluvial system to Holocene climate change. Quaternary Research. 37: 42-59.

Creque, J. A. 1996. An ecological history of Tintic Valley (Juab Count), Utah. Logan, UT: Utah State University, Ph.D. Dissertation.

Davis, O. D. 1982. Bits and pieces: the last 35,000 years in the Lahontan area. SAA Paper Number 2. Society American Archeology: 53-75.

Davis, O.K. 1994. The Correlation of summer precipitation in the southwestern U.S.A. with isotopic records of solar activity during the Medieval warm period. Climate Change. 26: 271-287.

Denevan, W. M. 1992. The pristine myth: the landscape of the Americas in 1492. Annuals Association American Geographers. 82: 367-385.

Farquhar, G. D. 1997. Carbon dioxide and vegetation. Science. 278: 1411.

Furgurson, E. B.; Mobley, G. F. 1992. Lake Tahoe: playing for high stakes. National Geographic. 181: 112-132.

Ghil, M.; Vautgard, R. 1991. Interdecadal oscillations and the warming trend in global temperature time series. Nature. 350: 324-327.

Grayson, D. 1993. The deserts past: a natural prehistory of the Great Basin. Washington, D. C.: Smithsonian Institution.

Grove, J. M.; Switsur, R. 1994. Glacial geological evidence for the Medieval warm period. Climatic Change. 26: 143-169.

Holmes, R. L.; Adams, R. K.; Fritts, H. C. 1986. Tree-ring chronologies of Western North America: California, eastern Oregon and northern Great Basin and procedures used in the chronology development work including users manuals for computer programs COFECHA and ARSTAN. Tucson AZ: Chronology Series VI. 182 p.

Jennings, S. A.; Elliot-Fisk, D. L. 1993. Packrat midden evidence of late Quaternary vegetation change in the White Mountains, California-Nevada. Quaternary Science. 39: 214-221.

Kinney, W. C. 1996. Conditions of rangelands before 1905. In: Sierra Nevada ecosystem project: final report to congress, Vol. II, chap. 3. Davis, CA: University of California, Centers for Water and Wildland Resources: 31-45.

Kohler, T. A. 1992. Prehistoric human impact on the environment in the upland North American Southwest. Population and Environment. 13: 255-268.

LaMarche, V. C., Jr. 1973. Holocene climatic variations inferred from treeline fluctuations in the White Mountains, California. Quaternary Research. 3: 632-660.

Leavitt, S. W. 1994. Major wet interval in White Mountains Medieval Warm Period evidenced in $\delta^{13}C$ of bristlecone pine tree rings. Climate Change. 26: 299-307.

Lindström, S. 1990. Submerged tree stumps as indicators of mid-Holocene aridity in the Lake Tahoe Basin. Journal of California and Great Basin anthropology. 12: 146-157.

Luckman, B. H. 1990. Mountain areas and global change: a view form the Canadian Rockies. Mountain Research and Development. 10: 183-195.

Mehringer, P. J. 1977. Great Basin late Quaternary environments and chronology. In: Fowler, D., ed. Models and Great Basin prehistory: a symposium. Desert Research Institute Publications in Social Sciences no. 12: 113-167.

Mehringer, P. J. 1987. Late Holocene environments on the northern periphery of the Great Basin. Final Report. Portland, OR: U.S. Department of the Interior, Bureau of Land Management.
Mehringer, P. J.; Wigand, P. E. 1990. Comparison of late Holocene environments form woodrat middens and pollen. In: Betancourt, J. L.; VanDevender, T. R.; Martin, P. S. eds. Packrat middens: the last 40,000 years of biotic change. University of Arizona Press: 294-325.

Millar, C. I. 1996. Tertiary vegetation history. In: Sierra Nevada ecosystem project: final report to congress, Vol. II, chap. 5. Davis, CA: University of California, Centers for Water and Wildland Resources: 71-109.

Millar, C. I. 1997. Comments on historical variation and desired condition as tools for terrestrial landscape analysis. In: Sommarstrom, S. ed. What is watershed stability? Proceedings of the Sixth Biennial Watershed Management Conference. 23-25 October 1996, Lake Tahoe, California/Nevada. University of California Water Resources Center Report No. 92: 105-131.

Miller, R. F.; Rose, J. A. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. Great Basin Naturalist. 55: 37-45.

Miller, R. F.; Wigand, P. E. 1994. Holocene changes in semiarid pinyon-juniper woodlands. Biosicence. 44: 465-474.

Naftz, D. L.; Klusman, R. W.; Michel, R. L.; Schuster, P. F.; Reddy, M. M.; Taylor, H. E.; Yanosky, T. M.; McConnaughey, E. A. 1996. Little Ice Age evidence from a south-central North American ice core, U.S.A. Arctic and Alpine Research. 28: 35-41.

Nowak, C. L.; Nowak, R. S.; Tausch, R. J.; Wigand, P. E. 1994a. Tree and shrub dynamics in northwestern Great Basin woodland and shrub steppe during the late-Pleistocene and Holocene. American Journal of Botany. 81: 265-277.

Nowak, C. L.; Nowak, R. S.; Tausch, R. J.; and Wigand, P. E. 1994b. A 30,000 year record of vegetation dynamics at a semi-arid locale in the Great Basin. Journal of Vegetation Science. 5:579-590.

Polley, H. W.; Johnson, H. B.; Mayeux, H. S.; Tischler, C. R. 1996. Impacts of rising CO_2 concentration on water use efficiency of woody grassland invaders. In: Barrow, J. R.; McArthur, E. D.; Sosebee, R. E.; Tausch, R. J., comps. 1996. Proceedings: shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 189-194.

Schroedl, G. F. 1973. The archeological occurrence of bison in the Southern Plateau. Washington State University, Lobo, Anthropology. Report of Investigation 51. Pullman, WA:

Scuderi, L. A. 1987. Late Holocene upper timberline variation in the southern Sierra Nevada. Nature. 325: 242-244.

Spaulding, W. G. 1985. Vegetation and climates of the last 45,000 years in the vicinity of the Nevada Test Site, south-central Nevada. Professional Paper 1329. U. S. Department of the Interior, Geological Survey.

Sprugel, D. G. 1991. Disturbance, equilibrium, and environmental variability: What is 'natural' vegetation in a changing environment? Biological Conservation. 58: 1-18.

Stine, S. 1990. Late Holocene fluctuations of Mono Lake, eastern California. Palaeogeography, Palaeoclimatology, Palaeoecology. 78: 333-381.

Stine, S. 1994. Extreme and persistent drought in California and Patagonia during Medieval time. Nature. 369: 546-549.

Stine, S. 1996. Climate, 1650-1850. In: Sierra Nevada ecosystem project: final report to congress, Vol. II, chap. 2. Davis, CA: University of California, Centers for Water and Wildland Resources: 25-30.

Tausch, R. J. 1996. Past changes, present and future impacts, and the assessment of community or ecosystem condition. In: Barrow, J. R., McArthur, E. D.; Sosebee, R. E.; Tausch, R. J. Proceedings: shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 97-101.

Tausch, R. J.; Nowak C. S. 1998. Late Holocene ecology of Great Basin ecosystems. Unpublished draft supplied by the authors.

Tausch, R. J.; West, N. E.; Nabi, A. A. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34: 259-264.

Tausch, R. J.; Wigand, P. E.; Burkhardt, J. W. 1993. Viewpoint: plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the Quaternary? Journal of Range Management. 46: 439-447.

Thompson, R. S. 1990. Late Quaternary vegetation and climate in the Great Basin. In: Betancourt, J. L.; VanDevender, T.; Martin, P. S. eds. Packrat middens: the last 40,000 years of biotic change. Tucson, AZ: University of Arizona Press: 200-239.

Thompson, R. S.; Benson, L. V.; Hattori, E. M. 1986. A revised chronology for the last Pleistocene Lake cycle in the central Lahontan Basin. Quaternary Research. 25: 1-10.

Thompson, R. S.; Kautz, R. R. 1983. Chapter 7. Paleobotany of Gatecliff Shelter: Pollen analysis. In: Thomas, D. H. ed. The archaeology of Monitor Valley: 2. Gatecliff Shelter. Anthropological Papers of the American Museum of Natural History. Vol. 59: 136-157.

VanDevender, T. R.; Spaulding, W. G. 1979. Development and climate in the southwestern United States. Science. 204: 701-710.

Wells, P. K. 1983. Paleobiogeography of montane islands in the Great Basin since the last glaciopluvial. Ecological Monographs. 53: 341-382.

West, N. E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. In: Developing strategies for rangeland management. National Research Council/National Academy of Sciences. Boulder, CO: Westview Press: 1301-1332.

West, N. E.; Tausch, R. J.; Rea, K. H.; Tueller, P. T. 1978. Phytogeographical variation within pinyon-juniper woodlands of the Great Basin. In: Harper, K. T.; Reveal, J. L. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs. 2: 119-136.

West, N. E.; Tausch, R. J.; Tueller, P. T. 1998. A management-oriented classification of pinyon-juniper woodlands of the Great Basin. Gen Tech Rep. RMRS-GTR-12. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Wigand, P. E. 1987. Diamond Pond, Harney County, Oregon: vegetation history and water table in the eastern Oregon desert. Great Basin Naturalist. 47: 427-458.

Wigand, P.E. 1998. [Personal communication]. February 1998, Reno, NV: Desert Research Institute, University of Nevada, Reno.

Wigand, P. E.; Nowak, C. L. 1992. Dynamics of northwest Nevada communities during the last 30,000 years. In: Hall, C. A.; Doyle-Jones, V.; Widawski, B., eds. The history of water: eastern Sierra Nevada, Owens valley, White-Inyo Mountains. White Mountain Research Station Symposium Volume 4: 40-62.

Wigand, P. E.; Rose, M. R. 1990. Calibration of high frequency pollen sequences and tree-ring records. Proceedings of the International highlevel radioactive waste management conference and exposition, April 1990, Las Vegas, NV.

Wigand, P. E.; Hemphill, M. L.; Sharpe, S.; Patra, S. 1995. Great Basin semi-arid woodland dynamics during the late Quaternary. In: Waugh, W. J. ed. Proceedings: climate change in the four corners and adjacent regions: implications for environmental restoration and land-use planning: 1994 September 12-14; Mesa State College, Grand Junction, Co. Grand Junction, CO: U.S. Department of Energy: 51-70.

Woolfenden, W. B. 1996. Quaternary vegetation history. In: Sierra Nevada ecosystem project: final report to congress, Vol. II, chap. 4. Davis, CA: University of California, Centers for Water and Wildland Resources: 47-70.

Distribution, Composition, and Classification of Current Juniper-Pinyon Woodlands and Savannas Across Western North America

Neil E. West

Abstract—Pinyon-juniper woodlands involve vegetation dominated by about seven species of *Pinus* and 17 species of *Juniperus* scattered over more than 75 million acres of the Southwestern United States and Mexico. The junipers are more widespread latitudinally, longitudinally, and elevationally than the pinyons. The understory is much more diverse and reflects largely local climatic patterns. Grasslands and shrub steppes have successionally preceded pinyon-juniper savanna to woodland on sites with gentle slopes and fine soil textures. Excessive livestock grazing and direct fire control are the major factors which have led to present tree dominance. Tree dominance can be regarded as a sign of ecosystem degradation on sites formerly occupied by native herbs and shrubs. On many sites, trees will be eventually replaced by introduced herbs following fire storms unless proactive management is undertaken.

Tausch (this volume) has outlined how pinyon-juniper woodlands came to be. My task is to outline where these woodlands and savannas are presently found and how they currently vary in tree dominance and understory composition across the western half of the North American midsection. I will conclude with suggestions of how this information can be applied in land management.

Longitudinal and Latitudinal Patterns of Tree Dominance

I am considering here all lands with semiarid climates west of 103° W. long. in North America currently occupied by at least one drought-tolerant juniper (section *Sabina*) and/or one drought-tolerant pine (subsection *Cembroides* = the Pinyons). According to Küchler (1970), this amounts to about 75 million acres in the United States (Fig. 1) and an unknown additional area within Mexico. Juniper-Pinyon woodlands and savannas as a whole are a very coarse category, only useful when comparing nationally or regionally to other coarse (internally heterogeneous) categories such as yellow pine forests or sagebrush steppe.

The most obvious way to begin finer subdivision of these lands is to consider what the dominant trees are. Table 1 indicates the distribution of the major tree species in juniper-pinyon savannas and woodlands across western North America. Junipers are much more widespread than pinyons. The furthest north that self-sown pinyon occurs is in extreme southern Idaho. Thus, juniper only woodlands and savannas occur north of there. Pure pinyon woodlands, dominated by *Pinus monophylla*, exist only in extreme western Nevada and adjacent California where summer precipitation is minimal. From about 38° N lat. southward, pinyons, junipers, and oaks (*Quercus* spp.) become intimately intermingled (West 1998).

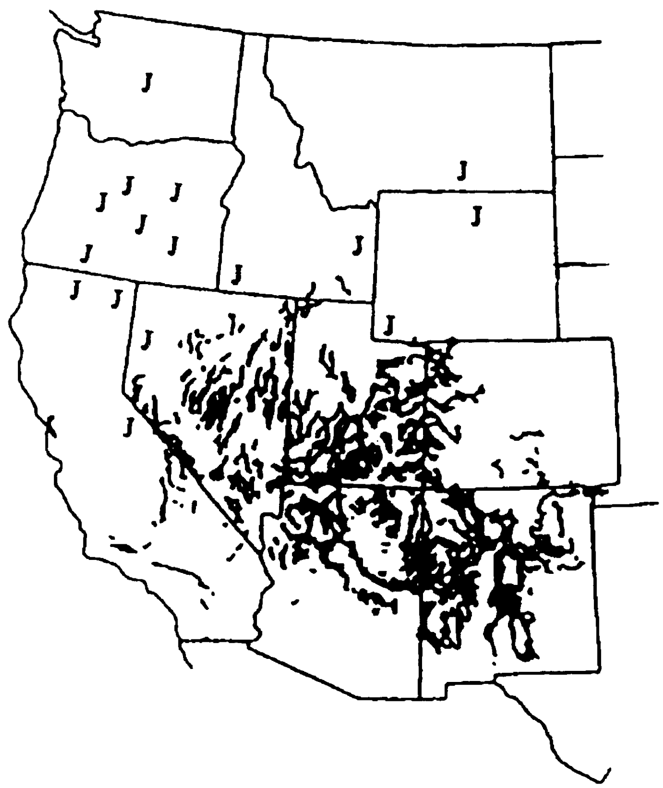

Figure 1—Geographic distribution of juniper-pinyon woodlands in the Western United States (according to Küchler 1970) with J's indicating pure stands of *Juniperus occidentalis* in the Pacific Northwest and *J. scopulorum* in the Northern Rocky Mountains and Great Plains.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Table 1—Distribution of principal tree species in juniper-pinyon savannas in various sections of western North America. Nomenclature follows Flora of North America Editorial Committee 1993.

Area	Pines	Junipers	Others
British Columbia and Alberta		*Juniperus scopulorum*	
Interior Pacific Northwest (Oregon, Washington, Idaho)		*J. occidentalis*	
Northern Rocky Mountains and adjacent Plains (Montana, Wyoming)		*J. scopulorum* *J. osteosperma*	
Eastern and Central Great Plains		*J. virginiana*	
Great Basin	*Pinus monophylla*	*J. osteosperma*	
Colorado Plateau	*P. edulis*	*J. osteosperma*	
Southern Great Plains and Edwards Plateau		*J. ashei* *J. pinchotii*	
Mogollon Rim	*P. edulis*	*J. monosperma* *J. deppeana*	*Cupressus arizonica*
Baja California Norte (Sierra Juarez)	*P. quadrifolia*	*J. californica*	
Sierra Madre Occidental	*P. cembroides*	*J. coahulensis*	*Quercus* spp.
Big Bend-Trans Pecos	*P. cembroides*	*J. deppeana* *J. flaccida*	*Quercus* spp.
Sierra Madre Oriental	*P. cembroides*	*J. coahulensis* *J. flaccida* *J. monosperma*	*Quercus* spp.
Serranias Meridionales del Altiplano Potosino	*P. ayachuite* *P. cembroides* *P. joharinis*	*J. flaccida*	*Quercus* spp.
Sierra Madre del Sur	*P. teocote*		
Sierra Madre de Chiapas		*J. comitana* *J. gamboana* *J. monticola*	

Elevational Patterns of Tree Dominance

Elevational segregation is usual in regions where both pinyons and junipers occur. Pinyons, being less tolerant of drought and cold than junipers, usually dominate in the middle elevations where both occur. Junipers tend to dominate both the higher and lower elevations of the woodland belt of Intermountain mountain ranges.

Within a given region, the density of woodland, both historically and currently, is strongly related to topoedaphic gradients. The trees persisted throughout past centuries on steeper, rockier, and thus less burned sites. Less steep sites, especially those with finer textured soils are where savannas, grasslands, and shrub steppes have occurred in the past. Various densities of younger trees now occur on such sites, largely because of new fire and grazing regimes recently imposed by Euroamericans. Understanding these dynamic relationships is a key to managing the current situations. For instance, Creque and others (this volume) describe the vegetational and environmental changes in semiarid portions of upper Tintic Valley, Utah. They delineated ecological sites based on soils, topography, and vegetational history. These stratifications can then focus local managerial actions to where it is most justified and responsive.

Patterns in Understory

Juniper-pinyon savannas and woodlands have understories that are both floristically and structurally more variable than the overstory. Generally the understory is compositionally similar to that of adjacent grasslands, shrub steppes, chaparral and forests (West and others 1975; West and Young 1998). For instance, in the western juniper woodlands and savannas of the Pacific Northwest, the understory is mostly a mixture of sagebrushes (Section *Tridentatae* of *Artemisia*) and cool season bunchgrasses. The relatively wet winters and dry summers there favor plants that can either complete their growth before midsummer, like the cool season grasses, or utilize deep soil moisture, as do the trees and shrubs (Flanagan and others 1992).

South and east of the Pacific Northwest, the portion of warm season bunch and sod grasses increases and the amount of shrubs declines as the fraction of total annual precipitation received during the summer increases. Juniper and pinyon stands of New Mexico, Texas, and northern Mexico thus have more half-shrubs (suffrutescents), such as *Senecio longilobus*, *Gutierrezia* spp., *Brickellia* spp., *Haplopappus* spp., and *Salvia* spp. and succulents, such as various cacti and monocots (for example, *Agave* spp., *Nolina* spp., *Yucca* spp., *Dasylirion* spp.) than true shrubs. Warm season, C_4 grasses which dominate are from the nearby semidesert grasslands or southern mixed and shortgrass prairies, including species of *Aristida*, *Digitaria*, *Eragrostis*, *Bouteloua*, *Hilaria*, *Sporobolus*, *Muhlenbergia*, *Schizachyrium*, *Botriochloa*, *Lycurus*, *Piptochaetum*, and *Leptochloa*, where not excessively grazed (Moir 1979; Pieper 1992).

Forbs associated with juniper-pinyon savanna or woodlands also display distinctive geographic distributions. Understory forbs in juniper stands of the Pacific Northwest and Great Basin are derivatives of the tree-dominated Arctotertiary Geoflora (Axelrod 1976). Principal genera are *Lupinus*, *Penstemon*, *Castelleja*, *Balsamorhiza*, *Allium*, etc. On the Colorado Plateau and south and east of that region, forbs associated with juniper and pinyons are mostly derivatives of the Madro-tertiary Geoflora (Axelrod 1958), a heat-tolerant group of plants. Example genera are *Croton*, *Euphorbia*, *Ipomea*, *Solanum*, *Polygala*, and herbaceous *Salvia* (Pieper 1992; Romero Manzanares and others 1998). Abundance of annuals varies greatly from year to year (Treshow and Allan 1979) making them of little value as indicators of other than near term climatic influences.

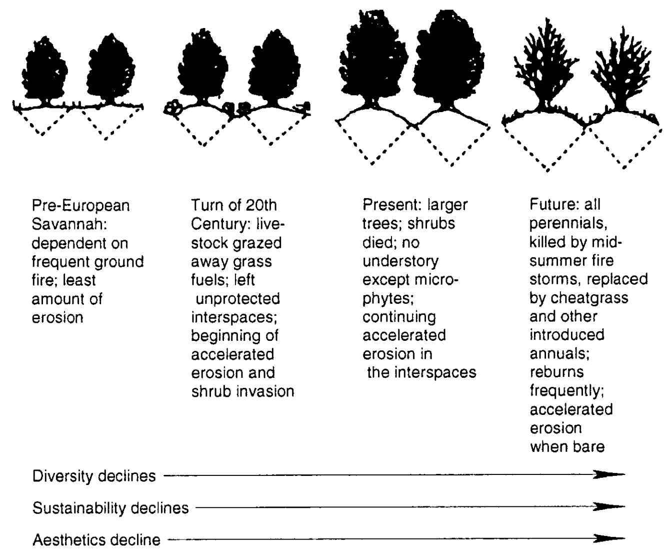

Figure 2—Depiction of how juniper-pinyon woodland structure changes through successional time (earlier to left, later to right). Broken lines are outer limits of tree roots.

Vegetation Dynamics

The foregoing "snapshot" of how we currently find juniper-pinyon dominated vegetation is incomplete without considering the dynamics of the vegetation on several scales in time and space. Tausch (this volume) covered the "deep" past. Focus on the more recent and local can be found in Gruell, Young, and Harper (this volume). Rather than repeating their stories, all I will offer here is the fact that the current conditions are far from the pre-Euroamerican situation when much more savanna (grassland or shrub mosaic with scattered trees) and less woodland (trees are the dominant matrix) and forest (where numerous tree crowns touch) existed.

The local plant community structure where junipers and pinyons are involved shows at least two phases (Fig. 2); a tree-centered phase where microclimates and soils are controlled by the trees; and a non-tree dominated open interspace where some mixture of shrubs, grasses, and forbs prevail. Everett and others (1983) add a third phase, the drip-line. As trees have become the matrix, many attributes of these ecosystems, such as the hydrologic and fire regimes, native animal and microbial communities have been altered as well (West 1998). Full expression of tree dominance, because it leads to diminished understory, has a negative influence on floristic and faunistic richness (West 1998). Long periods of exclusion of livestock grazing do little to aid recovery of the understory. Increased elk, feral horses, and jackrabbits can keep the diminished understory in check (Yorks and others 1994).

Whether these trends toward tree dominance are degradational or aggradational is a much disputed topic. One's conclusions on this issue determines whether proactive or custodial management is to be favored. While conservation biologists (for example, Belsky 1996) favor hands-off management of these woodlands, many others, myself included, regard the changes on most ecological sites as degradational (West 1998), and thus meriting proactive management.

Numerous forces have independent influences on tree or interspace-dominated phases of juniper-pinyon savannas and woodlands (Table 2). Causes of vegetational change are, however, rarely singular or simple. Synergistic interactions are the norm. The major compound effect is how livestock reduced the fine continuous fuel when savannas prevailed and along with both direct and indirect reductions in fire, allowing the trees to increase. Trees now control most sites and accelerated erosion prevails where slope and surface soil texture allow (Davenport and others1997).

Management Implications

The future holds increased probability of crown-fires, invasion by introduced annuals and short-lived perennials, and then repeated burning and permanent site degradation unless seeding of desirable understory takes place expeditiously. Different portions of the vast juniper-pinyon type have and will change differently. Each ecological site presents different potential in response to both passive and active management. Winward (this volume) tells you how we can recognize these differences and use them for guiding management activities.

Table 2—Summary of forces changing the balance between trees and perennial grasses in pinyon-juniper woodlands. P = pinyons, J = junipers, + means that the growth form increases when the given variable increases, – means that the growth form decreases when the given variable increases.

Forces	Trees	Grasses
Climate		
cool, wet (P)	+	–
warm, dry (J)	–	+
increasing CO_2 in atmosphere	+	–
Grazing		
Extinct browsers	–	+
Livestock	+	–
Elk	+	
Feral horses	+	
Saw flies	–	+
Fire	–	+
Tree harvest	–	
Animals		
Jays and nutcrackers (P)	+	–
Chipmunks and ground squirrels (P)	+	–
Thrushes (J)	+	–
Rabbits and hares (J)	+	–
Livestock	+	–
Parasites	–	+
Pathogens	–	+

References

Axelrod, Daniel. 1958. Evolution of the Madro-tertiary Geoflora. Botanical Review 24:433-509.

Axelrod, Daniel I. 1976. History of the coniferous forests, California and Nevada. Berkeley, CA. University of California Publications in Botany 70.

Belsky, A. J. 1996. Western juniper expansion: Is it a threat to arid northwestern ecosystems? Journal of Range Management 27: 91-96.

Davenport, D. W.; Breshears, D. D.; Wilcox, B. P.; Allen, C. D. 1998. Viewpoint: Sustainability of pinyon-juniper ecosystems: A unifying perspective of soil erosion thresholds. Journal of Range Management 51: 231-240.

Everett, R. L.; Sharrow, S. H.; Meeuwig, R. O. 1983. Pinyon-juniper woodland understory distribution patterns and species associations. Bull. Torrey Bot. Club 110: 454-463.

Flanagan, L. B.; Ehleringer, J. R.; Marshall, J. D. 1992. Differential uptake of summer precipitation among co-occurring trees and shrubs in a pinyon-juniper woodland. Plant Cell and Environment 15: 831-836.

Flora North America Editorial Committee. 1993. Flora of North America, Vol. 2, Pteridophytes and Gymnosperms. New York, Oxford University Press.

Küchler, Arthur W. 1970. Potential natural vegetation map (map at scale of 1:7,000,000) In: The national atlas of the U.S.A. pp. 90-91. Washington, D. C., Government Printing Office.

Moir, W. H. 1979. Soil vegetation patterns in the central Peloncillo Mountains, New Mexico. American Midland Naturalist 102 (2): 317-331.

Pieper, R. D. 1992. Species composition of woodland communities in the Southwest. In: Ffolliott, P. F.; Gottfried, G. J.; Bennett, D. A.; Hernandez, V. M.; Ortega-Rubio, A.; Hamre, R. H. tech. coords. Proceedings-Symposium on ecology and management of oak and associated woodlands: Perspectives in the southwestern U.S. and northern Mexico. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station Gen. Tech. Rep. RM-218.

Romero Manzares, A.; Garcia Moya, E.; Oyama Nakagawa, K.; Passini, M.-F. 1998. Los inventarios floristicos y la inerciaresiliencia en los pinonares meridinonales de San Luis Potosi. Boletin Sociedad de Mexico (in press).

Treshow, M.; Allan, J. 1979. Annual variations in the dynamics of a woodland plant community. Environmental Conservation 6: 231-236.

West, N. E.; Rea, K. H.; Tausch, R. J. 1975. Basic synecological relationships in juniper-pinyon woodlands. pp. 41-53 In: Gifford, G. F.; Busby, F. E. eds. The pinyon-juniper ecosystem. A symposium. Utah Agriculture Experiment Station, Logan, UT.

West, N. E. 1998. Juniper-pinyon savannas and woodlands of western North America In: Anderson, Roger C.; Baskin, Jerry C. eds. Vegetation of Savannas and Barrens of North America. New York: Cambridge University Press (in press).

West, N. E.; Young, J. A. 1998. Vegetation of intermountain valleys and lower mountain slopes In: Barbour, M. A.; Billings, W. D. eds. North American Terrestrial Vegetation. Second Edition. New York: Cambridge University Press.

Yorks, T. P.; West, N. E.; Capels, K. M. 1994. Changes in pinyon-juniper woodlands in western Pine Valley between 1933-1989. Journal of Range Management 47: 359-364.

Historical and Modern Roles of Fire in Pinyon-Juniper

George E. Gruell

Abstract—Fire history investigations were carried out in three widely separated Great Basin pinyon-juniper woodlands in east-central Nevada, southeastern Oregon and northwestern Nevada, and western Nevada. Study results suggested frequent fires on deep soils that produced an abundance of fine fuels and infrequent fires on shallow soils and rocky sites where fuels were sparse. Decades of intensive livestock grazing and successful fire suppression in pinyon-juniper woodlands have resulted in a shift from low intensity fires to high intensity fires. This shift has been the result of large increases in woody fuels and introduction of exotic grasses. Considering the extent of fuel buildup, severe wildfires in the Great Basin will continue and perhaps become more frequent.

Charred wood and tree stems bearing fire scars indicate that historically fire influenced succession in pinyon-juniper woodlands. Researchers investigating pinyon-juniper ecology have noted the importance of fire as a historic disturbance agent (Arnold and others 1964; Humphrey and Mehrhoff 1958; Miller and Rose 1995; West 1988;). Past fires can be dated by study of fire scars on tree rings. However, in contrast to mixed conifer forests where fire-scarred ponderosa pine (*Pinus ponderosa*) or Jeffrey pine (*P. jeffreyi*) are common; the relatively low number of fire scars in pinyon-juniper woodlands and their restriction to sites that did not readily burn, limits our ability to accurately determine fire history (Gruell 1997a). The few fire history studies carried out in pinyon-juniper woodlands show variations in fire frequency. Young and Evans (1981) concluded that between 1600 and 1850, there were periods of up to 90 years that western juniper (*Juniperus occidentalis*) growing on low sagebrush (*Artemisia arbuscula*) sites of northeastern California showed no evidence of fire scars. Burkhardt and Tisdale (1976) reported average fire intervals of less than 20 years in climax western juniper on the Owyhee Plateau of southwestern Oregon. Chappel (1997) reports a mean fire interval of 50 years for four pinyon-juniper sites on Monroe Mountain south of Richfield, Utah and she considered this to be a conservative estimate of the fire interval.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Study Areas and Methods

Between 1990 and 1997, I investigated fire frequency in pinyon-juniper woodlands at three widely separated localities of the Great Basin. They included Great Basin National Park in east-central Nevada, Hart Mountain-Sheldon Refuge complex in southeastern Oregon and northwestern Nevada, and the Walker River Watershed Project area in western Nevada. Fire-scarred pinyon (*P. monophylla*), Utah juniper (*J. osteosperma*) and western juniper were cut with a chainsaw following careful search of study areas. Surfaces of cross-sections were later sanded smooth and annual rings were counted under magnification to determine the approximate year of scarring. This procedure did not include dendrochronological cross-dating as described by Stokes and Smiley (1968). The fortuitous presence of ponderosa or Jeffrey pine provided a unique opportunity to collect more definitive data in each of the study areas. Ponderosa and Jeffrey pine are excellent recorders of fire since they are long-lived, fire resistant, have clear annual growth rings, and occupy sites that were fire susceptible.

Great Basin National Park

This study entailed removal of fire scars from 23 pinyon and three juniper in four locations representative of variations in pinyon-juniper woodlands in Great Basin National Park (GBNP), a 30,840 ha (77,100 acre) portion of the South Snake Range in east-central Nevada (Gruell and others 1994). Increment coring of 73 pinyon was also carried out to determine the approximate ages of post-fire regeneration.

Intact fire scars were found on or near 16 of 20 macroplots that had previously been established for purposes of classifying Potential Native Plant Communities (Eddleman and Jaindl 1994). Although singleleaf pinyon, Utah juniper, and curlleaf mountain-mahogany (*Cercocarpus ledifolius*) all showed scarring, pinyon yielded the best scar samples. The probability of locating sound fire scars was low because: (1) a majority of trees in the study area were too young to bear scars of pre-1900 fires, (2) most trees old enough to bear fire scars were growing in the protection of boulders or on sites where fuels were sparse (areas unlikely to burn), and (3) some fire scars had been destroyed by carpenter ant excavations.

Hart Mountain and Sheldon Refuges

The historic influence of fire on plant succession, plant communities, and wildlife habitat was studied during 1994-95 at Hart Mountain National Antelope Refuge (HMNAR), Oregon and Sheldon National Wildlife Refuge (SNWR), Nevada (Gruell 1995). These refuges are situated in the volcanic plateau region of the Great Basin. Vegetation composition in this shrub steppe community is dominated by mountain big sagebrush (*A. tridentata* subsp. *vaseyana*). Western juniper covers less than 4 percent of the area. Field studies included aging of curlleaf mountain-mahogany and western juniper, collection of fire scars from trees, and repeat photography.

The opportunity to evaluate historic fire frequency on HMNAR and SNWR was severely limited by the scarcity of trees that survived and recorded past fires by scarring. Analysis of 36 multiple scarred aspen provided no definitive information on fire return intervals. Only nine trees were old enough to have recorded fire before 1880. Of these, two were scarred. Six trees were scarred in the 1890's, apparently by causes other than fire.

Insight on the frequency of historic fires was made possible by the presence of scarred ponderosa pine in a 12 ha (30 acre) stand growing in association with western juniper at Blue Sky on the lower east slope of Hart Mountain. No other ponderosa pine occur on the refuges excepting scattered individuals at high elevations at HMNAR and several trees in an isolated stand growing on bare mineral soil at SNWR. The Blue Sky stand is almost entirely composed of second-growth (Simonson 1975) that regenerated following cutting of nearly all trees in 1866-67 by the U.S. Cavalry for construction material and fuel at Fort Warner (Shaver and others 1905). A few large pines were not cut, including a "catfaced" tree with multiple scar wounds. A cross-section was removed from this tree and from a stump that contained multiple fire scars.

Walker River Watershed Project Area

This study was conducted in the Walker River Watershed Project (WRWP), an area encompassing 157,100 ha (392,750 acres) inclusive of the east slope of the Sweetwater Mountains, the Pine Grove Hills, and the west slope of the Bodie Hills (Gruell 1997b). Pinyon dominates the landscape. Scattered juniper is intermixed with pinyon, being primarily found on south slopes and dry sites at lower elevations.

A collection of fire scars from 22 pinyon and Jeffrey pine was made during June-July 1997 in the Little Frying Pan and Desert Creek drainages of the Sweetwater Mountains, Nye Canyon and a nameless canyon on the northeast side of Bald Mountain in the Pine Grove Hills, and the Masonic Gulch area in the Bodie Hills. Random searches were made until three or more trees bearing fire scars were located. The size of the search area varied according to fire scar availability. Few fire-scarred pinyons were found in areas where the trees were young (less than 130 years of age). Those bearing fire scars were widely distributed on fire resistant sites. Except for two trees in isolated stands in the Pine Grove and Bodie Hills, fire-scarred Jeffrey pine were confined to the Little Frying Pan drainage where scattered stands grew on sites susceptible to fire. Trees with well-developed scars were sampled by removing a cross-section from each with a chain saw. Between four and nine samples were collected from each area.

Emphasis was placed in the Little Frying Pan area because the Jeffrey pine intermixed with pinyon and juniper exhibited a high complement of fire scars. Although Jeffrey pine grows in association with pinyon-juniper on the lower east slope of the Sierra Nevada, they are not normally present in Great Basin woodlands. Six fire-scarred Jeffrey pine (four live trees and two stumps) and three pinyon were sampled. Although the cambial ring year of the stumps was unknown, historical accounts (Kerston 1964; Paher 1970) suggest these trees were cut in the 1860's. An 1868 cutting date was assigned to the stumps after synchronizing their most recent fire scars with those on nearby live trees (Arno and Sneck 1977).

A master fire chronology was developed for the Little Frying Pan area according to the geographical position of sample trees. Questionable fire years were adjusted with those considered to be the most probable years of scarring (Arno and Sneck 1977). The probability of false rings, missing rings, and the deteriorated state of counting surfaces reduced the accuracy of ring counts on portions of some samples.

Thus, the fire history statistics are considered reasonably accurate, but no exact. A master fire chronology was not prepared for the Desert Creek, Bald Mountain and Masonic areas because of the minimal number of fire scars on the samples collected.

Three historical photographs taken during the period 1899-1906 were rephotographed in the Bodie Hills and the east slope of the Sweetwater Mountains. These scenes aided interpretations of plant succession by providing visual evidence of composition and structure during early stages of EuroAmerican settlement (Gruell 1997b).

Results

Great Basin National Park

Data and field observations demonstrated that fire played a major ecological role in pinyon-juniper woodlands of GBNP over the past several hundred years. Insight into fire frequency in the 1800's and 1700's within four macroplot complexes was provided by fire scar samples. These data showed a complex and variable fire history that largely took place before 1860. Pooling of 35 datable fire scars revealed that 3 percent of the fires occurred in the 1900's, 76 percent in the 1800's, and 21 percent in the 1700's or earlier. Pre-1900 fire frequencies varied considerably depending on aspect, topography, and ignition source. Apparently fires occurred at close intervals on north-facing slopes, in canyon bottoms, and in other localities where fine fuels were sufficient to carry fire. Quantitative evidence suggested that north-facing slopes in the Snake Creek and Strawberry Creek drainages burned on the order of 15-20 years (Gruell and others 1994). This figure may be conservative considering the low number of scars in the sample.

Close fire intervals were apparently the product of lightning and Indian ignitions. Indians intentionally set fire to vegetation for a variety of reasons including production of grass seed and other food plants, stimulation of willow (*Salix* spp.) shoots used in basket-making, immobilizing crickets and grasshoppers, driving jackrabbits (*Lepus* spp.), clearing campsites, and signaling between bands (Cooper 1961; Gruell 1985; Lewis 1985; Moore 1972; Stewart 1963).

Intentional or escaped fires could have spread from the valley or canyon bottoms to adjacent slopes wherever fuel continuity allowed.

Contrastingly, on rocky landscapes containing localized patches of flammable fuels, it appeared that fires of any appreciable size occurred infrequently. The limited fire scar evidence suggests that fire return intervals were 50 to 100 years or longer. These areas included the drier south-facing slopes and some west-facing slopes on the west and south end of the Snake Range. Under extreme conditions, fire apparently spotted into available fuels, thereby creating a mosaic of burned and unburned landscape.

By design, fire scar sampling was confined to pinyon and juniper trees at previously established macroplots which did not support ponderosa pine. Ponderosa pine was present, however, in some localities at higher elevations where they are associated with pinyon and juniper. Because of ponderosa pine's proclivity to scar, a sample was taken from a stump at about 2,500 m (8,200 ft) on the Lehman Creek Scenic Highway west of Baker, Nevada. This tree had been scarred 8 times in a 124-year period for a mean fire return interval of 18 years. The longest interval was 29 years, while the shortest was 8 years. The locality in which the stump was located had burned periodically as evidenced by charred wood and multiple fire-scarred trees and stumps. These data are consistent with the fire-scarred pinyon, which suggest vegetation occupying deep soils on GBNP burned frequently before settlement by EuroAmericans.

Fire has not been a significant factor in the Snake Range since EuroAmerican settlement. As recalled by Wayne Gonder, a local rancher, the largest fire in the South Snake Range in modern times took place between 1908-1910 covering an area of 80-120 ha (200-300 acres). U.S. Department of Agriculture, Forest Service fire reports during the 29 year period between 1959-1988, show an average of less than 3 fires a year (total 83) suppressed in the Snake Range. Nearly all fires were less than 1 ha, excepting three that were between 4 and 24 ha (10 and 60 acres). Lightning ignited nearly 90 percent of all fires. Although significant fires have not occurred in this century, these woodlands have the potential to fuel high intensity fires during periods of hot temperatures and strong winds.

Hart Mountain and Sheldon Refuges

Collectively, samples cut for purposes of aging included 48 mountain-mahogany, 43 western juniper and six ponderosa pine. Thirty-eight mahoganies at HMNAR averaged 81 years old and ranged between 54 and 109 years. This suggested that current stands were composed mainly of trees that established after 1880. Ten cross-sections removed from varying diameter mahogany growing on deep soils on Badger Mountain (SNWR), showed an average age of 89 years (range 55-137). A previous study that included aging of mahogany on Badger Mountain suggested that tree age ranged from 30-145 years (Tiedemann and Furniss 1985).

Collectively, 94 percent of the juniper associated with mountain big sagebrush were of post-1900 origin. These trees averaged 82 years old (range 59-110). Junipers associated with low sagebrush exhibited a greater average age (143 years) and greater variance in age (range 63-289 years) compared to juniper associated with mountain big sagebrush. These data suggest that fuels on the more productive big sagebrush sites supported a fire regime that burned more often than that in low sagebrush where fuels were light and discontinuous. Hence, tree encroachment of big sagebrush communities was inhibited, while on low sagebrush sites that burned infrequently and at low intensity, trees were able to persist.

Analysis of the scar data from Blue Sky showed that the two sample trees had recorded a total of 9 fires within an area of less than 20 ha (50 acres) during the 101-year period 1760-1861. This suggested a composite mean fire-return interval of 13 years (Arno and Sneck 1977). Fire intervals ranged from 3 to 32 years. This record appears conservative considering the limited number of old pine (greater than 200 years of age) that had potential to record fire before EuroAmerican settlement. It was also likely that the two trees sampled did not unerringly record every fire because of variations in fuel loading. Furthermore, the cross-section from the scarred stump did not contain a complete record of the original fire scars due to rot.

The short mean fire interval indicated by the Blue-Sky data suggested grass dominance on deep soils. Recent prescribed fires in the vicinity of Blue Sky demonstrate the potential for dominance of a grass sere following fire in the shrub steppe. Abundant grass fuels would have been receptive to recurrent burning upon being ignited by lightning or Indians. Further evidence of frequent fires in the shrub steppe is indicated by the expansion of woody vegetation since the late 1800's. There is almost a complete absence of snags, stumps, and charred wood within existing stands of pine, juniper, and mahogany growing on deep soils. Had woody vegetation comprised significant cover historically, residual material would be very apparent in these tree stands today. Substantial increases of juniper and mahogany on HMNAR and SNWR was also documented by retake of five historical photographs (Gruell 1995).

Modern wildfire was not a significant disturbance factor on SNWR until 1988 when 840 ha (2,100 acres) burned on Bald Mountain. Between 1945 and 1967, 9 of 10 fires suppressed burned less than 1 acre. One fire in sagebrush reached 40 ha (100 acres). During this era heavy utilization of fine fuels by livestock had essentially removed the potential of fires to spread. Fire occurrence at HMNAR has followed the same trend except that three fires ranging in size from 2,400 ha (6,000 acres) to 6,400 ha (16,000 acres) (the later being an escaped prescribed fire) occurred between 1954 and 1985. A decline in livestock grazing, followed by recent removal of livestock from both refuges has increased the potential for large wildfires. Despite a major suppression effort, 3,000 ha (7,500 acres) of sagebrush and mountain-mahogany burned on Badger Mountain in 1994.

Walker River Watershed Project

The samples from the six Jeffrey pine and three pinyon pine in the Little Frying Pan area produced a 208-year master fire chronology dating from 1687 to 1895. A total of 51 fire scars formed on the nine trees during this period. At least 27 different fire years are represented. Sample trees recorded from 1 to 5 fire scars during each of these 27 fire years. This suggests that fires burned somewhere within the less than 40 ha (100 acre) study area every 8 years. Fire scars on five of the six Jeffrey pine samples suggested extensive burning in 1857. Extensive burning is also indicated in 1864, 1844, 1801, and 1785 when three trees were scarred in each of these years. Fires were particularly frequent during the 1840's, 1850's, and 1860's when 17 of the 51 scars formed.

Fire scarred pinyons in the Little Frying Pan area verified fire occurrence, but were not a reliable indicator of fire frequency. The three pinyon sampled had been scarred one time ea~h, while the six Jeffrey pine carried between 3 and 12 fire scars each (total 48). This marked contrast in fire frequency reflects major differences in fuel loading on sites occupied by pinyon compared to those occupied by Jeffrey pine. The fire scarred pinyons were able to persist in microsites where fuels were sparse, and as a result they seldom were exposed to lethal heat. In contrast the Jeffrey pine grew on productive microsites that supported fine fuels of sufficient volume to carry fire. Moreover, pinyon needle litter is not as combustible as the long-needle litter of Jeffrey pine.

Ten of the 14 pinyon collected in the four sample areas were over 300 years of age, while three exceeded 400 years. Excepting one, these trees recorded only one fire each; this demonstrates an extremely low susceptibility to scarring. A low susceptibility to scarring was also indicated by the length of time since the last fire (range 82-248 years).

The repeat of three photographs taken between 1899-1906 indicated substantial increases in the density of pinyon-juniper in the Walker River Watershed Project (Gruell 1997b). However, they are not considered representative of pre-European settlement conditions. As suggested by the fire history data, the absence of fire for 2 to 4 decades or longer had probably allowed an increase in tree cover by the turn of the century when the original photos were taken.

Pre-settlement fire intervals averaging only 8 years in the less than 40 ha (100 acre) Little Frying Pan study area provide strong evidence that low intensity spreading fires ignited by lighting and Indians were a common occurrence within the WRWP prior to EuroAmerican settlement. The high frequency and apparent low intensity of these fires suggested that they were fueled by abundant perennial grass, the remnants of which are present today. Sites capable of producing contiguous surface fuels, including north slopes, canyon bottoms, and gentle topography were particularly susceptible to frequent fire. The relatively young age of trees and low incidence of charred wood (fragments), the presence of which required burning of heavy fuels, provide further evidence of frequent low intensity fires on these sites. Tree establishment would have been inhibited since trees less than 50 years old are very susceptible to being killed by fire (Young and Evans 1981). Infertile shallow soils and rocky sites seldom burned since they did not produce sufficient fuel to allow fire spread. Thus, the prevailing presettlement fire regime maintained a savanna-like landscape composed of groups and single trees interspersed by large openings with grass being the primary ground cover.

Judging from the presence of down tree trunks, localized stand replacement fires apparently occurred during extreme conditions. These fires appear to have been uncommon, however, because concentrations of down tree trunks are lacking in these woodlands. Fire scar records indicate that pinyon-juniper woodlands of the WRWP were fire maintained until the beginning of EuroAmerican settlement. Soon afterwards fire became infrequent, probably due to removal of light fuels by livestock, and later by aggressive fire suppression.

By the 1930's, fire suppression strategy placed emphasis on aggressive attack of all fires. Since 1960, 266 wildfires have been suppressed in the Walker River Watershed Project area. Ninety percent of these fires have been held under one-quarter acre. Only five of these have been over 40 ha (100 acres). The largest, 360 ha (900 acres), occurred in 1996.

Modern Fire in the Great Basin

USDA Forest Service, Intermountain Region fire reports covering Nevada, Utah, southern Idaho and western Wyoming show an apparent trend. During the 58 year period 1930-1978 there were two years when 40,000 ha (100,000 acres) or more burned in the Intermountain Region. In contrast, in 9 of the past 18 years 100,000 or more acres burn in the Intermountain Region. In 1988 and again in 1994 over 200,000 ha (500,000 acres) burned. Although these data reflect a wide range of fuel types, they show a significant increase in the occurrence of wildfire in the Intermountain Region over the past 76 years.

Fire reports at the Boise Interagency Fire Center, show that many Intermountain Region wildfires have occurred in pinyon-juniper woodlands. In the 15 year period 1970-1985 suppression action was taken on 1,744 of these fires. Twenty-eight reached 40 ha (100 acres) or more. The largest of these was 14,000 ha (35,000 acres). The fire report record for the 1986-96 fire seasons is incomplete. This was a period of many high intensity wildfires. In 1995 and 1996 alone, 24 fires reached or exceeded 40 ha (100 acres). Some of these were between 2,000 ha (5,000 acres) and 6,400 ha (16,000 acres). Fire reports covering suppression actions in a larger area of pinyon-juniper woodlands administered by USDI Bureau of Land Management (BLM) were not available. Wildfire occurrence on BLM lands has paralleled that on lands administered by the Forest Service. Over 100,000 ha (250,000 acres) burned in western Utah in 1996. A majority of these lands are administered by the BLM and include considerable acreage in pinyon and juniper.

Management Implications

The results of fire history studies summarized in this paper suggest that in the presettlement era, fires were common in pinyon-juniper woodlands of the Great Basin. Fire frequency varied greatly because of marked differences in fuel continuity. Fire scar evidence suggests that fire was frequent on soils that supported sufficient fuels to allow fire spread. It was infrequent and did not readily spread on thin soils or rocky sites where fuels were sparse or absent. Considering these variables, it appears that fire burned in irregular patterns, producing a mosaic of burned and unburned landscape. This fire regime was severely altered by EuroAmericans. Many decades of heavy livestock grazing and fire suppression in the Great Basin allowed an enormous increase in density and crown cover of pinyon-juniper (Christensen and Johnson 1964; Cottam and Stewart 1940; Eddleman and Jaindl 1994; Tausch and others 1981; West 1984). Buildup of woody fuels and increase in fine fuels coincident with marked reductions in livestock grazing has resulted in a shift from low intensity fires to high intensity fires. Considering the enormity of fuel buildup, it is evident that high intensity wildfires will continue and perhaps increase. This presents a major resource management challenge.

Fire has played a major role in the ecology of pinyon-juniper woodlands. The challenge facing society is one of deciding whether to treat fire as an essential disturbance agent or as a destructive force that should be suppressed. The ultimate outcome will be decided on the reliability of information that reaches the public. It is likely that a knowledgeable public would support a program that emphasizes fuel reduction by harvesting excess trees and application of prescribed fire in priority areas. Considering long-term costs and resource values, it is abundantly evident that this would be highly beneficial to future generations, both environmentally and economically.

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References

Arno, S. F.; Sneck K. M. 1977. A method for determining fire history in coniferous forests in the Mountain West. Gen. Tech. Rep. INT-42. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 28 p.

Arnold, J. R.; Jameson, D. A; Reid E. H. 1964. The pinyon-juniper of Arizona: effects of grazing, fire, and tree control. United States Department of Agriculture Project Resource Report 84. 28 p.

Burkhardt, J. W.; Tisdale, E. W. 1976. Causes of juniper invasion in southwestern Idaho. Ecology. 57: 472-484.

Chappell, L. 1997. A fire history study conducted on the Monroe Mountain demonstration area. U.S. Department of Agriculture, Forest Service, Fishlake National Forest , Richfield District, and U.S. Department of Interior, Bureau of Land Management, Richfield, Utah. 24 p.

Christensen, E. M.; Johnson H. B. 1964. Presettlement vegetation and vegetation change in three valleys in central Utah. Provo, UT: Brigham Young University Science Bulletin, Biology Series. Vol. 4, No. 4. 16 p.

Cooper, C. F. 1961. The ecology of fire. Scientific American. 204: 150-156.

Cottam, W. P.; Stewart G. 1940. Plant succession as a result of grazing and of meadow desiccation by erosion since settlement in 1862. Journal of Forestry. 38: 613-626.

Eddleman, L. E.; Jaindl R. 1994. Great Basin National Park vegetation analysis. U.S. Department of Interior, National Park Service, Technical Report NPS/PNROSU/NRTR-94/02, Seattle, Washington. 110 p.

Gruell, G. E. 1985. Indian fires in the interior West: a widespread influence. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W. technical coordinators. Proceedings—symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 68-74.

Gruell, G. E. 1995. Historic role of fire on Hart Mountain National Antelope Refuge, Oregon, and Sheldon National Wildlife Refuge, Nevada. A report submitted to U.S. Department of Interior Fish and Wildlife Service, Lakeview, Oregon. 58 p.

Gruell, G. E. 1997a. Influence of fire on Great Basin wildlife habitats. 1996 Transactions of the Western Section of the Wildlife Society. 32: 55-61.

Gruell, G. E. 1997b. Historical role of fire in pinyon-juniper woodlands. Walker River Watershed Project: A report submitted to U.S. Department of Agriculture, Forest Service, Humboldt-Toiyabe National Forest, Bridgeport Ranger District, Bridgeport, California. 20 p.

Gruell, G. E.; Eddleman, L. E.; Jaindl, R. 1994. Fire history of the pinyon-juniper woodlands of Great Basin National Park. U.S. Department of Interior, National Park Service, Technical Report. NPS/PNROSU/NRTR-94/01, Seattle, WA. 27 p.

Humphrey, R. R.; Mehrhoff L. A. 1958. Vegetation changes of a southern Arizona grassland range. Ecology 34: 720-726.

Kersten, E. W. 1964. The early settlement of Aurora, Nevada, and nearby mining camps. Annuals, Association of American Geographers. 54: 490-507.

Lewis, H. T. 1985. Why Indians burned: specific versus general reasons. In: Lotan, J. E.; Kilgore, B. M.; Fischer, W. C.; Mutch, R. W. technical Coordinators. Proceedings—symposium and workshop on wilderness fire; 1983 November 15-18; Missoula, MT. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 75-80.

Miller, R. F.; Rose J. A. 1995. Historic expansion of (*Juniperus occidentalis*) (western juniper) in southeastern Oregon. Great Basin Naturalist. 55: 37-45.

Moore, C. T. 1972. Man and fire in the central North American grasslands 1835-1890. Ph. D. thesis documentary in historical geography. University of California, Los Angeles. 133 p.

Paher, S. W. 1970. Nevada ghost towns and mining camps. Howell-North Books. Berkeley, California. 492 p.

Shaver, F. A.; Rose, A.P.; Rose, R. F; Adams, A. E. 1905. History of central Oregon: Spokane, WA. Western History Publishing Company.

Simonson, T. W. 1975. Hart Mountain timber examination. Unpublished memorandum from U.S. Department of Agriculture, Forest Service, Fremont National Forest to U.S. Department of Interior, Fish and Wildlife Service, Sheldon-Hart Mountain Refuge Complex, Lakeview, Oregon.

Stewart, O. C. 1963. Barriers to understanding the influence of use of fire by aborigines on vegetation. In: Proceedings 2nd Tall Timbers Fire Ecology Conference, March 1963: Tall Timbers Research Station, Tallahassee, FL: 117-126.

Stokes, M. A.; Smiley T. L. 1968. An introduction to tree ring dating. Chicago, IL. The University of Chicago Press. 73 p.

Tausch, R, J.; West N. E.; Nabi A. A. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34: 259-264.

Tiedemann, A. R.; Furniss M. M. 1985. Soil and litter response to looper defoliation of curlleaf mountain-mahogany. Forest Science. 32: 382-388.

West, N. E. 1984. Successional patterns and productivity of pinyon-juniper ecosystems. In: Developing strategies for range management. Boulder, CO., Westview Press: 1301-1332.

West, N. E. 1988. Intermountain deserts, shrub steppes, and woodlands. In: Barbour, M. B.; Billings, W. D. ed., North American terrestrial vegetation. Cambridge, MA, Cambridge University Press: 209-230.

Young, J. A.; Evans A. E. 1981. Demography and fire history of a western juniper stand. Journal of Range Management. 34: 501-505.

Seed Dispersal and Seedling Establishment of Piñon and Juniper Species within the Piñon-Juniper Woodland

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Abstract—Understanding the prehistoric and historic dynamics of piñon-juniper woodland requires knowledge of the seed dispersal mechanisms and seedling establishment requirements of the tree species. Here, the types and effectiveness of the different seed dispersers and the environmental requirements for seedling establishment are compared and contrasted for the various piñon and juniper species within the woodlands. The importance of long-distance vs. short-distance dispersal and the roles of ecotones and disturbance in woodland dynamics are discussed. Recommendations for future research are given.

The distribution of piñon and juniper species within the woodlands has undergone dramatic changes in both prehistoric and historic times. Since the end of the Wisconsin Ice Age 12,000 years ago, some species have moved upward in elevation as much as 1,000 to 1,500 m and northwards as much as 6° latitude. For example, singleleaf piñon (*P. monophylla*) has migrated from the warm deserts of southern Arizona and New Mexico and northern Mexico northwards through the Great Basin as far as southern Idaho. Colorado piñon (*P. edulis*) has migrated over most of the Colorado Plateau and southern Rockies (Betancourt 1987). Recent expansions of the woodlands appear to be influenced by human activities. Prior to settlement of the West in the early 1800's, fires burned through much of the woodlands as often as every 50 to 100 years, resulting in a mosaic of early seral grasses, mid-seral shrublands, and late seral woodlands (West and Van Pelt 1987). However, overgrazing by livestock and a severe reduction in fire frequency has resulted in an increase in relatively unpalatable and fire-intolerant shrub and tree species throughout the woodland (West and Van Pelt 1987; Miller and others 1994). Trees are expanding into adjacent grasslands and shrublands throughout their range (Johnsen 1962; Tausch and others 1981; Miller and Rose 1995), and tree density is increasing within existing stands (Tausch and others 1981).

Information on seed and seedling ecology of the tree species is essential for understanding both the long- and short-term dynamics of piñon-juniper woodlands. Despite the fact that seed dispersal and seedling establishment processes are critical determinants of both the prehistoric migration and historic expansion of the woodlands, relatively little research has focused on this area. Here, we provide an overview of the state of our knowledge of seed dispersal and seedling establishment of piñon and juniper species within the woodlands. We then discuss the importance of long-distance versus short-distance dispersal and the roles of ecotones and disturbance in woodland expansion. Finally, we suggest areas for future research.

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Seed Dispersal Processes

To understand plant dispersal processes, information on both the types and behaviors of the seed dispersers and the effectiveness of dispersal for plant establishment is necessary. Disperser effectiveness has been defined as "the contribution a disperser makes to the future reproduction of a plant" population (Schupp 1993). Effectiveness has a quantitative component (the number of seeds dispersed) and a qualitative component (the likelihood that a dispersed seed will survive to produce a new plant in the population). Here, we examine the information on both the types and behaviors of the animals that disperse piñon and juniper and the effectiveness of those dispersers.

Seed dispersal of both piñon and juniper is probably much more complex than the literature to date indicates. We have the best information on seed dispersal of piñon pines by birds. Piñon pines are dispersed by several species of corvids (jays and nutcrackers) that store seeds in shallow caches in the soil (Vander Wall and Balda 1981; Vander Wall 1990). Piñon pine cones and seeds are well adapted for dispersal by birds. The seeds are large and nutritious (Botkin and Shires 1948), and the cones are weakly constructed so that the seeds can be easily extracted by corvids with long pointed beaks, such as Clark's nutcracker (*Nucifraga columbiana*) and piñon jays (*Gymnorhinus cyanocephalus*). Seeds are enclosed in deep pockets and held by thin flanges so that they do not fall readily from the cones. Unlike many conifers, cones are primarily pointed to the side and upward, which not only retards seed loss, but increases the visibility and availability of the seeds to avian dispersers.

Birds typically disperse seeds from several meters to 5 km (Vander Wall and Balda 1981). Differences in dispersal distances exist among different bird species with the more solitary scrub jays (*Aphelocoma coerulescens*) seldom dispersing seeds more than 1 km, the gregarious piñon jays carrying seeds slightly farther, and Clark's nutcrackers carrying seeds as far as 22 km. While jays typically place one seed in each cache site, nutcrackers cache from one to 10 seeds with a mean of about four seeds per cache. The total number of seeds cached can be phenomenal. Individual Clark's nutcrackers scatter hoard between 22,000 to 33,000 Colorado piñon seeds (Vander Wall and Balda 1977) or 17,900 singleleaf piñon seeds (Vander Wall 1988) in a good seed crop year. Ligon (1978) estimated that a flock of 250 piñon jays could cache about 4.5 million Colorado piñon seeds over 5 months.

Seed caching by corvids has important consequences for the fates of piñon pine seeds. It can be quantitatively effective for piñon pine as large numbers of seeds are cached and, especially in large seed crop years, many are left unrecovered to germinate and possibly establish. Some aspects of bird dispersal are qualitatively effective while others are not. Piñons almost always require burial for establishment, and birds bury the seeds 2 to 4 cm in the soil (Vander Wall, personal observation). However, piñons also have a fairly strict nurse plant and shading requirement, and birds tend to place most seeds in interspace environments, not in more favorable microhabitats under trees or shrubs (Vander Wall, personal observation).

The importance of seed caching of piñon pine by rodents has been largely ignored and probably vastly underestimated. Most rodents, unlike the corvids, forage for seeds on the ground after the seeds have fallen from the tree. In the Pine Nut Range of Nevada, deer mice (*Peromyscus maniculatus)*, piñon mice (*Peromyscus truei*), Great Basin pocket mice (*Perognathus parvus*), and Panamint kangaroo rats (*Dipodomys panamintinus*) all scatter hoard singleleaf piñon seeds (Vander Wall 1997). Of 1,000 labeled seeds placed under five source trees, 69 percent were taken by rodents and 24 percent were scatter hoarded 5 to 30 mm deep. Rodents placed 36 percent of these scattered caches under shrubs, 39 percent in the open and the rest (25 percent) at the edge of shrub canopies. At other locations chipmunks, such as cliff chipmunk (*Tamias dorsalis*) and Panamint chipmunk (*T. panamintinus*), are probably important dispersers of piñon seeds. Rodents are qualitatively effective seed dispersers in that they bury the seeds and place most of them (about 60 percent) under or adjacent to shrubs. However, many of the seeds that are harvested are placed in larders where they have little or no chance of establishment (Vander Wall 1990). From a quantitative perspective, they may be less important because, except in heavy seed crop years, most seeds do not fall to the ground before they are harvested by birds.

Relatively little is known about dispersal of juniper species within the woodland. In general, most species of juniper have been assumed to be bird dispersed. Unlike bird dispersal of piñon in which the seeds are scatter hoarded, bird dispersal of junipers is by frugivory in which the seeds are ingested and passed through the gut track. Many bird species are involved in juniper dispersal. At least 12 species of birds feed on fruits and potentially disperse seeds of western juniper (*J. occidentalis*) (Maser and Gashwiler 1978), 13 species are known to disperse Ashe juniper (*J. ashei*) (Chavez-Ramirez and Slack 1994), and 52 species have been observed feeding on eastern red-cedar (*J. virginiana*) (Van Dersal 1938). Of the wide diversity of bird species involved, the most important for juniper dispersal are probably members of the highly frugivorous subfamily Turdinae (Muscicapidae) such as bluebirds (*Sialia mexicana* and *S. currucoides*), Townsend's solitaire (*Myadestes townsendi*), and American robin (*Turdus migratorius*), and two members of the family Bombycillidae, the waxwings *Bombycilla garrulus* and *B. cedrorum* (Gabrielson and Jewett 1940; Salomonson 1978; Holthuijzen and Sharik 1985; Chavez-Ramirez and Slack 1994). The rounded and more or less fleshy cones of junipers are well suited for frugivorous dispersal, especially by birds (Salomonson and Balda 1977; Salomonson 1978).

Fruits are conspicuously colored blue or reddish and are easily accessible on the outer layers of the foliage. The fleshy portion of a one-seed juniper (*J. monosperma*) cone has an energy content of 1.32 kJ making it a reasonably rich energy source. Also, the thick hard seed coat allows seeds to pass undamaged through the guts of most birds and mammals. Dispersal distances and patterns vary depending on the bird species and the juniper species (Holthuijzen and Sharik 1985; Chavez-Ramirez and Slack 1994). The effectiveness of birds as dispersal agents varies among species of junipers. For species such as western juniper, birds appear to disperse the majority of the seeds and, thus, are quantitatively important. Bird dispersal is often qualitatively effective as most birds deposit seeds primarily in more favorable under shrub or tree microhabitats and only occasionally carry seeds to open microsites. Also, seeds tend to be deposited singly or in small groups and, thus, may be less likely to die from density-dependent seed predation or competition (Chavez-Ramirez and Slack 1993; Schupp 1993). However, some bird species, such as cedar waxwings, travel in flocks and use the same perches repeatedly resulting in high seed densities under single trees. Another limitation of bird dispersal is that seeds are deposited on the soil surface and are dependent on other mechanisms of burial.

Mammals, considered to be unimportant dispersers of juniper seeds in the past, may be quite important for certain juniper species. Mammals that consume and disperse juniper seeds include woodrats (*Neotoma* spp.), Virginia opossum (*Didelphis virginiana*), Nuttalls cottontail (*Sylvilagus nuttallii*), desert cottontail (*S. auduboni*), black-tailed jackrabbit (*Lepus californicus*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), gray fox (*Urocyon cinereoargenteus*), black bear (*Ursus americanus*), ringtail (*Bassariscus astutus*), racoon (*Procyon lotor*), mule deer (*Odocoileus hemionus*), white-tailed deer (*O. virginianus*), and assorted livestock (Miller 1921; Parker 1945; Martin and others 1951; Johnsen 1962; Maser and Gashwiler 1978; Salomonson 1978; Chavez-Ramirez and Slack 1993; Willson 1993; Schupp and others 1997a, b). All species pass at least some seeds intact and, in some cases, seed germination is increased (Miller 1921; Johnsen 1962; Schupp and others 1997a).

Mammals may be quantitatively more important for some species of juniper than others. Western juniper is dispersed by several different bird species, but coyotes appear to be one of the few important mammalian dispersers (Schupp and others 1997b). In contrast, Utah juniper (*J. osteosperma*) appears to be dispersed primarily by cottontail rabbits and jackrabbits, and less so by birds (Schupp and others 1996; 1997a). This would seem to indicate that for the fleshier, moister species of junipers, coyotes and, perhaps in some species, foxes are the major mammalian dispersers. These are also the species fed on mostly by birds. In contrast, the woodier, drier juniper species may be dispersed largely by rabbits. In general, mammalian endozoochorous dispersal may not be effective for plant establishment. Seeds are deposited on the soil surface, often in high densities, and usually in the open and not in more favorable shaded environments. One advantage of mammalian seed dispersal is that passage through the gut track can be relatively slow resulting in long transport distances.

As for piñon pines, the role of scatter hoarding rodents in the dispersal of juniper has probably been greatly underestimated. Rodents commonly cache tree seeds (Vander Wall 1990; 1997), and clumps of juniper seedlings have been observed emerging from caches in the spring (Vander Wall 1990; Schupp unpublished data). In west-central Utah, a minimum of 16 to 33 percent of all natural Utah juniper recruits less than or equal to 2.0 m tall emerged from rodent caches. To quantify the role of rodents in the dispersal of Utah juniper, 500 labeled seeds were placed under four different source trees in the Pine Nut Range, Nevada, and seed fates were monitored (Vander Wall unpublished data). Slightly less than half of the seeds were taken (41 percent) and of those 27 percent were found in caches. Although a relatively low percentage of seeds were cached, the study was conducted in mid-summer when other, possibly more desirable shrub and forb seeds were available.

In general, the low preference for juniper seeds may result in low recovery of cached juniper seeds and, thus, a high potential for seed germination and establishment. Also, many juniper seeds are available under the trees on a year-around basis potentially resulting in more caching activity than this single study indicates. As described for piñon pine, seed caching by rodents may be highly effective in that many of the seeds are placed in favorable environments and have a high potential for establishment.

Seedling Establishment Processes

Both the seed characteristics and the types of microhabitats in which seeds are placed are important in determining seed fates after dispersal. In general, piñon pines have short-lived seeds with little innate dormancy (Meewig and Bassett 1983). Thus, they form only a temporary seed bank with most seeds germinating the spring following dispersal. Density of seeds in the seed bank is highly dependent on the current year's cone crop. Piñon pines exhibit regionwide synchrony in cone production with singleleaf piñon masting every 2 to 3 years and Colorado piñon every 5 to 7 years (Tueller and Clark 1975). The potential for a large temporary seed bank is high during mast years, especially since many seeds probably remain unrecovered by animals. During nonmast years, the seed bank is probably quite sparse. For piñon, germination and establishment are most likely when favorable growing season conditions follow a mast year.

In contrast to piñon pines, junipers often have long-lived seeds. Tests of stored juniper seeds showed that 45-year old Utah juniper still had 17 percent germination, 21-year-old one-seed juniper had 54 percent germination, and 9-year-old alligator juniper (*J. deppeana*) had 16 percent germination (Johnsen 1959). The long-lived seeds are often highly dormant with germination being delayed by impermeable seed coats, immature embryos, embryo dormancy, or the presence of inhibitors (Fisher and others 1987). Consequently, junipers have highly persistent seed banks with germination of a single seed cohort extending over many years.

Although seed production is highly variable among both individuals and years, junipers exhibit less pronounced masting than piñon. The result is a more or less continuous input of seeds into the seed bank. For juniper, germination and establishment can occur whenever favorable environmental conditions exist.

A common assumption concerning the establishment of piñon and juniper is that they require a nurse plant for establishment. However, there is little establishment data that directly follows the fates of piñon or juniper seedlings. Most establishment studies have examined the locations of seedlings in communities with varying tree and shrub cover without considering the pattern or effectiveness of dispersal or the requirements for establishment. Usually, higher numbers of piñon and juniper seedlings are found under shrubs or adult trees than in interspace environments (Johnsen 1962; Burkhardt and Tisdale 1976; Everett and others 1986a.; Eddleman 1987; Callaway and others 1996). In fully stocked stands of one-seed juniper, singleleaf piñon, and western juniper, higher number of seedlings occur under trees than in interspace environments (Johnsen 1962; Everett and others 1986a; Miller and Rose 1995). However, in areas where western juniper is expanding into sagebrush communities, higher numbers of seedlings occur under sagebrush (52 to 65 percent) than under trees (17 to 31 percent).

A more detailed examination reveals large differences in the nurse plant requirement both among and within species. Piñon seedlings rarely establish in interspaces or open environments (Everett and others 1986a; Callaway and others 1996). This is well illustrated by the total lack of first-year survival of singleleaf piñon seedlings in interspace microhabitats in the Pine Nut Range, Nevada (Chambers unpublished data). In contrast, juniper seedlings are capable of establishing in these environments under the proper conditions. First-year survival of Utah juniper seedlings in the Pine Nut Range in interspace microhabitats was less than in undertree sites, but was as high or higher than in under sagebrush sites (Chambers unpublished data). In Tintic Valley, Utah, emergence of Utah juniper seedlings differed among open, shrub, and tree microhabitats and also among years (Schupp and Gomez, unpublished data). The undershrub microhabitat had the highest emergence in one year, the lowest in a second, and was intermediate in two other years. Survival differed for only one emergence year, being least under shrubs and highest under trees. In expanding western juniper populations, 18 to 47 percent of established seedlings occurred in interspaces (Burkhardt and Tisdale 1976; Miller and Rose 1995). For Utah juniper on stabilized Lake Bonneville sand dunes in Utah, most of the few natural seedlings occurred in interspaces (Schupp unpublished data). Also, in the Southwestern grasslands and shrublands, juniper seedlings readily establish in open environments (Johnsen 1962; Salomonsen 1978). Differences between piñon and juniper in the nurse plant requirement may be related to their physiological characteristics.

Juniper species have greater drought tolerance and a higher capacity to obtain water resources for interspace microhabitats and shallow soils (Nowak and others, proceedings). This may enable seedlings to establish in unshaded interspaces with higher soil temperatures.

Higher establishment of juniper in open or interspace environments in the southwestern portion of the woodlands may be due to differences in precipitation patterns. While much of the Great Basin and more northern areas receive most precipitation during winter, the southwestern grasslands and shrublands receive moderate winter precipitation and monsoonal summer rains. Summer precipitation in the Southwest may offset the beneficial microenvironmental effects of nurse plants for seedling establishment in the Great Basin and more northern areas.

In those ecosystems with little summer rainfall, undertree and shrub microhabitats appear to provide favorable conditions for establishment of both piñon and juniper. Many environmental characteristics under trees and shrubs are more favorable for seedling establishment than those in interspaces. Shrubs and trees in arid or savanna ecosystems have been described as "islands of fertility." The microhabitats under both shrubs and trees often have higher concentrations of limiting nutrients, higher organic matter and total nitrogen, lower bulk densities, higher infiltration and soil water holding capacities, and higher rates of nutrient cycling (Everett and others 1986b; Doescher and others 1987; Klopatek 1987). They are also characterized by lower irradiance and soil temperatures (Stark 1994) — microenvironmental conditions favorable for many conifers. Although these areas receive less effective precipitation than interspace areas, they experience higher relative humidity and delayed dry down relative to open areas and grasslands (Johnsen 1962; Vetaas 1992; Stark 1994).

Although nurse plants facilitate seedling establishment, they also compete for available resources. Lowered seedling growth rates may be a tradeoff for favorable microenvironmental conditions beneath nurse plants. Piñon and juniper seedlings exhibit higher seedling survival under artificial shading (Meagher 1943), but seedlings in full sun have higher growth rates than those beneath shrubs (Burkhardt and Tisdale 1976; Miller and Rose 1995; Callaway and others 1996). Favorable water relations may also increase seedling survival underneath adult trees or nurse plants. Seedlings of western juniper have tighter stomatal control over water use than adult trees and are more responsive to environmental changes (Miller and others 1992). Singleleaf piñon seedlings associated with sagebrush exhibit reduced stomatal conductance as the summer progresses, while sagebrush water use continues to increase reaching levels up to five times greater (per unit leaf area) than associated piñon (Drivas and Everett 1988).

The effects of competition from grasses and other herbaceous vegetation on piñon and juniper seedling establishment are not clear because of the lack of experimental data. It appears that competition from annual forbs and grasses can reduce the seedling survival of Utah juniper and singleleaf piñon during the first year after emergence (Chambers, personal observation). Also, competition from established grasses reduces the initial establishment of one-seed juniper (Salomonson 1978). However, once seedlings are established (that is, greater than 1 or 2 years old) competition appears to have little effect on subsequent survival. In western Oregon, western juniper seedlings were capable of establishing into the community regardless of grass cover or range condition (Miller and others 1994)

Short-Distance Versus Long-Distance Dispersal

Highly effective seed dispersal and seedling establishment processes have been key elements in both the long-distance migration and local expansion of piñon and juniper species within the woodlands. Recently, it has been suggested that local population growth, short-distance dispersal, and long-distance migration are all interdependent (Clark and others 1998). Although rapid migration is driven by occasional, long-distance dispersal events, the likelihood of such long-distance events occurring increases with seed availability at the existing front. The greater the local population growth and the greater the seed production, the higher the probability that some seeds will be dispersed long distances. Thus, it is important to consider both the local component of seed dispersal that is responsible for local population growth and expansion, and the long-distance component of seed dispersal that is responsible for species migration.

In piñon and juniper, different classes of dispersers are responsible for local versus long-distance dispersal. In piñon, relatively short-range dispersal is accomplished largely by rodents, scrub jays, Mexican jays, and piñon jays that often or always cache seeds within a few hundred meters of the source tree (Vander Wall and Balda 1981; Vander Wall 1997). Unrecovered caches produce new recruits, resulting in population growth and local range expansion. Relatively long-range dispersal is achieved by birds that often carry seeds long distances to new habitats. These birds include nutcrackers, piñon jays, and Steller's jays. Seed dispersal out of the piñon-juniper woodland introduces the species to habitats that may or may not be suitable for establishment. If suitable, the cached seeds can establish a founding colony from which a new stand may eventually arise.

The two extreme spatial scales of dispersal are not as obvious for juniper as for piñon. Depending on the juniper species, local dispersal within stands leading to seedling recruitment is probably due to birds, lagomorphs, and scatter hoarding rodents. Most birds have short gut-retention times and, thus, dispersal is probably within or near the woodland. Birds frequently fly only short distances to perches where they sit and process fruit before returning to the same tree or moving to a nearby fruit source (Schupp 1993). Although rodents and lagomorphs are capable of moving seeds hundreds of meters, they probably cache or deposit most seeds within or near the woodland (Schupp and others 1997b). Long-distance dispersal of junipers is likely by birds and large frugivorous mammals. Although most seed dispersal by birds is probably local, some seeds are potentially dispersed longer distances by flocks of robins, bluebirds, and waxwings, which are widely ranging in fall and winter (Gabrielson and Jewett 1940). Large frugivorous mammals are likely candidates for long-distance dispersal because they have long gut-retention times and can travel long distances over diverse terrain (Willson 1993; Clark and others 1998).

Role of Ecotones

Ecotones between woodlands and adjacent shrublands and grasslands frequently provide favorable microhabitats for seedling establishment and are often particularly active zones of seed dispersal. Because shrubs provide favorable establishment microhabitats, expansion into shrublands along ecotones or transitional areas is common. Most juniper and piñon seedlings occur under shrubs and, as trees mature, they over-top the shrubs and the shrubs die. In southwestern grasslands, grasses may inhibit initial seedling establishment, but once established seedlings experience little competition. In contrast, in fully stocked stands most seedlings establish under adult trees forming "seedling banks" with little chance of maturing unless the adult tree is removed or dies.

Ecotones are often used by animal dispersers that occur exclusively in one area or the other as well as by those that occur in both areas. Following fire in piñon and juniper woodlands in Nevada, ecotonal areas had the highest rodent species diversity (richness), were actively used by frugivorous mammals, and had the highest bird use (Mason 1981). Even rodent species such as piñon mice that depend on the presence of trees and species such as Great Basin pocket mice and chipmunks (such as, *Tamias* spp.) that prefer some tree or shrub cover use ecotones once vegetation has established. Species such as deer mice that prefer more open habitats occur in both the woodlands and ecotonal areas. Frugivorous mammals frequently forage 100s of meters out of the woodland, and lagomorphs are known to deposit seeds in grasslands up to 1.6 km from the nearest woodland (Schupp and others 1997b). Important avian dispersers of piñon, such as the corvids, depend on the woodlands, but utilize the ecotonal areas (Mason 1981). Because avian dispersers of juniper, such as the Turdinae and waxwings, are more likely to use larger trees or snags as perches, they may be more important for dispersal within the woodlands or after disturbances that leave some trees in place.

Importance of Disturbance

In piñon-juniper woodlands, as in other ecosystems, characteristics of the disturbance and life history attributes of the species determine establishment probabilities of seeds and seedlings. Most tree seedlings are killed by fire, but seeds of both piñon and juniper, especially those that are cached, have a reasonable probability of survival depending on cache microhabitat. Undershrub and tree microhabitats often experience higher soil temperatures than interspace areas, especially if the entire shrub or tree and the duff burn (Wells and others 1979) and would be expected to exhibit the highest seed mortality after fires.

Mechanical disturbances such as chaining have a much different effect on seed and seedling fates than fires. Tree seedlings frequently survive mechanical disturbances, and because a significant "seedling bank" can exist under mature trees, they can be released from competition after overstory removal. Seeds that have already arrived on the soil surface are left in place, although redistribution or burial may occur due to the equipment. Establishment probabilities depend on the characteristics of the microhabitats after treatment. If downed trees and understory shrubs are left in place, more shaded microhabitats and nurse plants for seedling establishment will be available. If trees are piled and burned and understory shrubs are removed, fewer desirable microhabitats for seedling establishment will remain.

Disturbances that remove both trees and understory shrubs in piñon-juniper woodlands have a relatively greater effect on the establishment of piñon than juniper. Because piñons have short-lived seeds and a nurse plant requirement, piñon seeds and seedlings that survive the disturbance have a minimal chance of survival. In contrast, because junipers have long-lived seeds and less strict nurse plant requirements, their seeds and seedlings have a higher probability of establishment. Also, piñon seedlings appear to be less tolerant of competition from grasses and other herbaceous vegetation than juniper seedlings (Burkhardt and Tisdale 1976; Miller and Rose 1994). Consequently, initial establishment of juniper seedlings is frequently higher than that of piñon seedlings following disturbance in the singleleaf piñon-western juniper woodland (Tausch and others 1981) and probably other woodland types.

Future Research

Several areas relating to the seed dispersal and seedling establishment of piñon and juniper require additional research if we are to understand the dynamics of the woodlands. We need more information on: (1) types and behaviors of rodent dispersers of piñon and of all dispersers of juniper; (2) effectiveness of different types of animal dispersers for seedling establishment; (3) environmental requirements for seedling establishment; and (4) the differences in seed dispersal and seedling establishment among species and regions. Ecotones appear to be particularly promising for increasing our understanding of ecosystem disturbance and woodland dynamics.

References

Betancourt, J. L. 1987. Paleoecology of pinyon-juniper woodlands: summary. In: Everett, R. L.,ed. Proceedings—Pinyon juniper conference; Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 129-139.

Botkin, C. W.; Shires, L. B. 1948. The composition and value of piñon nuts. Exp. Sta. Bull. 344. Las Cruces, NM: New Mexico State University: 3-14.

Burkhardt, J. W.; Tisdale, E.W. 1976. Causes of juniper invasion in southwestern Idaho. Ecology. 76: 472-484.

Callaway, R. M.; DeLucia, E. H.; Moore, D.; Nowak, R.; Schlesinger, W. H. 1996. Competition and facilitation: contrasting effects of *Artemisia tridentata* on desert vs. montane pines. Ecology. 77:2130-2141.

Chambers, J. C.; Schupp, E. W.; Vander Wall, S. B. 1998. Seed and seeding ecology of piñon and juniper species in the pygmy woodlands of Western North America. Botanical Review (in press).

Chavez-Ramirez, F.; Slack, R. D. 1993. Carnivore fruit use and seed dispersal of two selected plant species of the Edwards Plateau, Texas. Southwestern Naturalist. 38: 141-145.

Chavez-Ramirez, F.; Slack, R. D. 1994. Effects of avian foraging and post-foraging behavior on seed dispersal patterns of Ashe juniper. Oikos. 71: 40-46.

Clark, J. S.; Fastie, C.; Hurtt, G.; Jackson, S. T.; Johnson, C.; King, G.; Lewis, M.; Lynch, J.; Pacala, S.; Prentice, C.; Schupp, E. W.; Webb, T. III.; Wyckoff, P. 1998. Dispersal theory offers solutions to Reid's paradox of rapid plant migration. BioScience. 48: 13-24.

Doescher, P. S.; Eddleman, L. E.; Vaitkus, M. R. 1987. Evaluation of soil nutrients, pH, and organic matter in rangelands dominated by western juniper. Northwest Science 61: 97-102.

Drivas, E. P.; Everett, R. L. 1988. Water relations characteristics of single leaf pinyon seedlings and sagebrush nurse plants. Forest Ecology and Management. 23:27-37.

Eddleman, L. E. 1987. Establishment and stand development of western juniper in central Oregon. In: Everett, R. L., ed. Proceedings—Pinyon juniper conference; Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 255-259.

Everett, R. S.; Koniak, S.; Budy, J. D. 1986a. Pinyon seedling distribution among soil surface microsites. Res. Paper INT-363. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Everett, R. S.; Sharrow, S. H.; and Thran, D. 1986b. Soil nutrient distribution under and adjacent to single leaf pinyon crowns. Soil Science Society of America Journal. 50: 788-792.

Fisher, J. T.; Fancher, G. A.; Neumann, R. W. 1987. Germination and field establishment of juniper in the Southwest. In: Everett, R. L., ed. Proceedings—Pinyon juniper conference; Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 293-299.

Gabrielson, I. N.; Jewett, S. G. 1940. Birds of Oregon. Corvallis, OR: Oregon State University.

Holthuijzen, A. M.; Sharik, T. L. 1985. The avian seed dispersal system of eastern red cedar (*Juniperus virginiana*). Canadian Journal of Botany. 63: 1508-1515.

Johnsen, T. N. 1959. Longevity of stored juniper seeds. Ecology. 40:487-488.

Johnsen, T. N. 1962. One-seed juniper invasion of northern Arizona grasslands. Ecological Monographs. 32:187-207.

Klopatek, J. M. 1987. Nutrient patterns and succession in pinyon-juniper ecosystems of northern Arizona. In: Everett, R. L., ed. Proceedings—Pinyon juniper conference; Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 391-396.

Ligon, J. D. 1978. Reproductive interdependence of piñon jays and piñon pines. Ecological Monographs. 48: 111-126.

Mason, R. B.1981. Response of birds and rodents to controlled burning in pinyon-juniper woodlands. M.S. Thesis. University of Nevada, Reno.

Martin, A. C.; Zim, H. S.; Nelson, A. L. 1951. American wildlife and plants. New York, NY: McGraw-Hill.

Maser, C.; Gashwiler, J. S. 1978. Interrelationships of wildlife and western juniper. In: Proceedings of the western juniper ecology and management workshop. Gen. Tech. Rep. PNW-4. Portland, OR: U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station: 37-82.

Meagher, G. S. 1943. Reaction of pinyon and juniper seedlings to artificial shade and supplemental watering. Journal of Forestry. 41: 480-482.

Meewig, R. O.; Bassett, R. L. 1983. Pinyon-juniper. In: Silvicultural Systems for the Major Forest Types of the United States. Agric. Handb. 455, Washington, D.C.: U.S. Department of Agriculture: 84-86.

Miller, F. H. 1921. Reclamation of grasslands by Utah juniper on the Tusayan National Forest, Arizona. Journal of Forestry. 19: 647-651.

Miller, R. F.; Eddleman, L. E.; and Miller, J. M. 1992. The seasonal course of physiological processes in *Juniperus occidentalis*. Forest Ecology and Management. 48:185-212.

Miller, R. F.; Rose, J. A. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. Great Basin Naturalist. 55:37-45.

Miller, R. F.; Svejcar, T. J.; West, N. E. 1994. Implications of livestock grazing in the Intermountain region: plant composition. In: Vavra, M.; Laycock, W.A.; Pieper, R. D., eds. Ecological implications of herbivory in the west; Denver, CO: Society for Range Management: 101-146.

Nowak, R. S.; Moore, D. J.; Tausch, R. J. 1998. Ecophysiological patterns of pinyon and juniper. In: Monsen, S. B.; Stevens, R.; Tausch, R. J.; Miller, R.; Goodrich, S., eds. Proceedings: ecology and management of pinyon-juniper communities within the interior west. 1997 Sept. 15-18, Provo, UT. [This proceedings.]

Parker, K. W. 1945. Juniper comes to the grasslands. Why it invades southwestern grassland; suggestions and control. American Cattle Producer 27 (November): 12-14, 30-31.

Salomonson, M. G. 1978. Adaptations for animal dispersal of one-seed juniper seeds. Oecologia. 32: 333-339.

Salomonson, M. G.; Balda, R. P. 1977.Winter territoriality of Townsend's solitaires (Myadestes townsendi) in a piñon-juniper-ponderosa pine ecotone. Condor. 79: 148-161.

Schupp, E. W. 1993. Quantity, quality and the effectiveness of seed dispersal by animals. Vegetatio. 107/108: 15-29.

Schupp, E. W.; Fuentes, W.; Gomez, J. M. 1996. Dispersal of Utah juniper (*Juniperus osteosperma*) seeds by lagomorphs. In: West, N. E., ed. Proceedings of the Fifth International Rangeland Conress, Vol. 1. Denver, CO: Society for Range Management: 496-497.

Schupp, E.W.; Gomez, J. M.; Jimenez, J. E.; Fuentes, J. 1997a. Dispersal of *Juniperus occidentalis* (western juniper) seeds by frugivorous mammals on Juniper Mountain, southeastern Oregon. Great Basin Naturalist. 57: 74-78.

Schupp, E. W.; Heaton, H. J.; Gomez, J. M. 1997b. Lagomorphs and the dispersal of seeds into communities dominated by exotic annual weeds. Great Basin Naturalist. 57: 253-258.

Stark, J. M. 1994. Causes of soil nutrient heterogeneity at different scales. In: Caldwell, M. M.; Pearcy, R. W., eds., Exploitation of environmental heterogeneity in plants. San Diego, CA: Academic Press: 255-284.

Tausch, R. J.; West, N. E.; Nabi, A. A.1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34: 259-264.

Tueller, P. T.; Clark, J. E. 1975. Autecology of pinyon-juniper species of the Great Basin and Colorado Plateau. In: Gifford, G. F.; Busby, F. E., eds. The Pinyon-Juniper Ecosystem: a Symposium. Logan, UT: Utah State University: 27-39.

Van dersal, W. R. 1938. Native woody plants of the United States, their erosion-control and wildlife values. U.S. Department of Agriculture, Miscellaneous Publication 303.

Vander Wall, S. B. 1988. Foraging of Clark's nutcrackers on rapidly changing pine seed resources. Condor. 90: 621-631.

Vander Wall, S. B. 1990. Food hoarding in animals. Chicago, IL: University of Chicago Press.

Vander Wall, S B. 1997. Dispersal of singleleaf piñon pine (*Pinus monophylla*) by seed caching rodents. Journal of Mammalogy. 78: 181-191.

Vander Wall, S. B.; Balda, R. P. 1977. Coadaptation of the Clark's nutcracker and piñon pine for efficient seed harvest and dispersal. Ecological Monographs. 47: 89-111.

Vander Wall, S. B.; Balda, R. P. 1981. Ecology and evolution of food-storage behavior in conifer-seed-caching corvids. Z. Tierpsychol. 56: 217-242.

Vetaas, O. R. 1992. Micro-site effects of trees and shrubs in dry savannas. Journal of Vegetation Science. 3:337-344.

Wells, C. G.; Campbell, R. E.; DeBano, L. F.; Lewis, C. E.; Fredriksen, R. L.; Franklin, E.C.; Froelich, R. C.; Dunn, P. H.1979. Effects of fire on soil. Gen. Tech. Rep. WO-7. Washington, DC: U.S. Department of Agriculture, Forest Service, 34 p.

West, N. W.; Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. In: Everett, R. L., ed. Proceedings—Pinyon juniper conference; Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

Willson, M. F. 1993. Mammals as seed-dispersal mutualists in North America. Oikos. 67: 159-176.

Ecophysiological Patterns of Pinyon and Juniper

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Abstract—Although species that dominate over 30 million ha may be expected to have aggressive ecophysiological traits, pinyon and juniper generally are conservative in their acquisition and use of resources when measured on a per gram of foliage basis. Assimilation rates of pinyon and especially of juniper are very uniform over different types and scales of environmental gradients. Although pinyon and juniper often intermix, some subtle ecophysiological differences exist between the two genera that appear to influence plant distribution. These conservative ecophysiological traits help pinyon and juniper dominate the landscape in two ways: first, they allow the conifers to support a much greater amount of foliage biomass than co-occurring shrubs, given the same amount of resources; and second, when coupled with distinct ecophysiological differences between juvenile and adult plants, they help pinyon and juniper establish under, then tolerate, and ultimately outsize and outlive their shrub-steppe nurse plants.

Pinyon-juniper woodland are a major vegetation assemblage in southwestern North America. Pinyon and juniper occur on approximately 30 million ha (West, this volume), which is a 50 percent increase from estimates near 20 million ha in 1986 (Buckman and Wolters 1987). Three of the more common juniper species are one-seed juniper (*Juniperus monosperma*), western juniper (*J. occidentalis*), and Utah juniper (*J. osteosperma*), and two of the more common pinyon species are pinyon pine (*Pinus edulis*) and singleleaf pinyon (*P. monophylla*). Although many parts of this woodland type have one species of juniper co-dominant with one of pinyon, a single juniper or pinyon species can dominate particular sites, to the exclusion of other tree species.

Invasive species are often thought to have aggressive, opportunistic ecophysiological traits such as high photosynthetic rates, high growth rates, and rapid responses to changes in resource availability (Bazzaz 1986). For example, two of the most successful invasive exotics in western North America are cheatgrass (*Bromus tectorum*) and saltcedar (*Tamarix ramosissima*). Both species share a number of traits that may account for their aggressive invasiveness, such as flexibility in life history attributes, ability to germinate over a wide range of environmental conditions, rapid growth, and high allocation to root growth during plant establishment (Smith and others 1997).

The primary purpose of this paper is to provide a summary review of the physiological ecology of pinyons and junipers with the ultimate goal to understand how their ecophysiological traits may explain plant distribution, population dynamics, and the ability of these species to invade and ultimately dominate shrub communities. First, we summarize ecophysiological information about carbon gain and water relations of pinyons and junipers. In many cases, data on only one or a limited number of species are available. Next, ecophysiological traits of pinyon and juniper will be contrasted with each other, then contrasted with another major dominant of semiarid lands in the West, sagebrush (*Artemisia tridentata*), to investigate possible sources of tree dominance.

Ecophysiological Traits

Carbon Gain

Assimilation Rates—Diurnal changes in assimilation rates for western juniper (Miller and others 1992) follow a pattern similar to those of other Great Basin plants (Smith and Nowak 1990). During spring and early summer when soil moisture is plentiful, assimilation rates typically track irradiance (Miller and others 1992). Assimilation rate increases during the morning as the sun rises higher into the sky, stays near maximum rates for about six hours during the middle part of the day, then declines rapidly at the end of the day as irradiance decreases. As soil moisture decreases, assimilation rates peak earlier in the day, and a large midday depression in assimilation occurs. By the end of summer, assimilation often peaks within 2–3 h of sunrise and declines to near zero by early afternoon.

The maximum rate of assimilation that occurs during the day does not vary greatly from spring through fall (fig. 1A). During winter, maximum assimilation rates are very close to zero, which is similar to other Great Basin species such as crested and bluebunch wheatgrass (Nowak and Caldwell 1984). By April, maximum assimilation rates are relatively high and decline only slightly until fall, when maximum rates decline more rapidly. Presumably, cold air and leaf temperatures during fall and winter are the primary reason

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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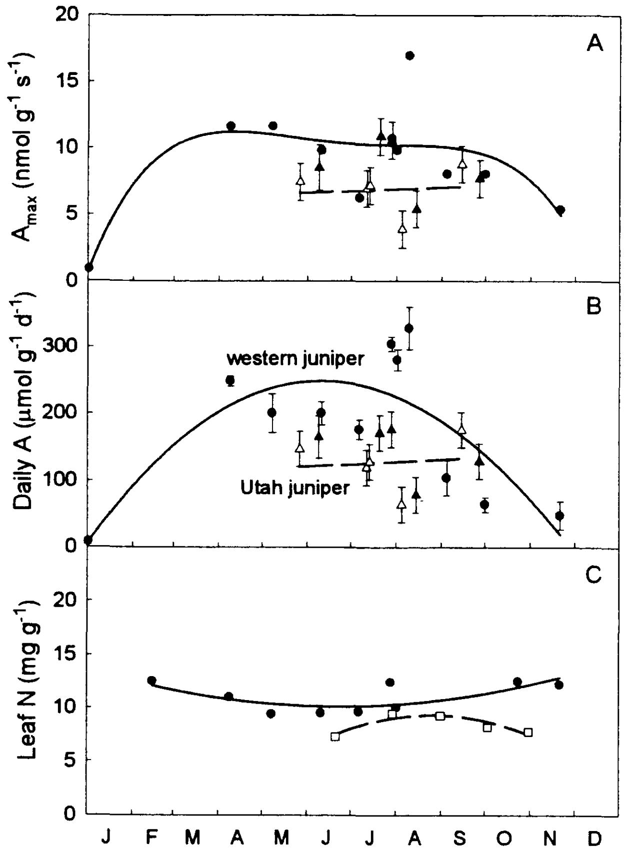

Figure 1—(A) Maximum assimilation rate during the day; (B) total daily carbon gain; and (C) nitrogen content of foliage on different dates during the year for western juniper (closed symbols, solid lines) and Utah juniper (open symbols, dashed lines). Error bars are standard errors. Different symbol shapes indicate sources of data: circles are data from Miller and others (1992: fig. 3, table 2), triangles are unpublished data of the authors, and squares are data from Ehleringer and others (1986: fig. 5). Although lines are from polynomial curve fitting, they are meant primarily as a guide to general trends of data.

for low maximum rates of assimilation during these time periods.

The total amount of carbon gained during the day follows a seasonal pattern similar to that for maximum assimilation rates except for an earlier decline in fall (fig. 1B). Daily carbon gain is low in winter, relatively high for much of the time period from April through August, then declines rapidly during fall. Both water stress and air temperature interact to produce this seasonal pattern of carbon gain, but the importance of temperature becomes apparent when comparisons are made at different elevations. Daily carbon gain of western and Utah junipers at low elevations tend to be highest earlier in the year and lower in the fall (table 1). In contrast at high elevations, daily carbon gain gradually increases from spring to its largest value in fall. Relatively cooler temperatures at higher elevation appear to decrease daily carbon gain in spring relative to that at lower elevation, even though both elevations had adequate soil moisture. However, despite these differences in the temporal pattern of *when* maximum daily carbon gain occurred, the average rates over the entire growing season were remarkably similar: 151 µmol g^{-1} d^{-1} for plants at low elevation sites and 147 µmol g^{-1} d^{-1} at high elevation sites.

The similarity in seasonal carbon gain extends to a regional scale of geography (fig. 2). Based on estimates of carbon gain over the entire time period from spring through fall, results from six mountain ranges sorted into 2 statistical groups despite large differences in climate: a north-northwest group of three ranges (Juniper Mountain, Virginia Mountains, and Monitor Range) and a south-southeast group of three ranges (Sonora Pass, Snake Range, and Spring Mountains). What is especially striking about both groups is that both contain one mountain range that has western juniper and two ranges that contain Utah juniper. Thus, even though climatic influences on carbon gain are relatively small, climatic influences appear to be more important than taxonomic influences.

Dependence of Assimilation on Environmental Factors—Patterns of assimilation response to irradiance and temperature for western juniper (Miller and others 1995) are similar to those for other Great Basin species

Table 1—Mean total carbon assimilation (µmol g^{-1} d^{-1}) over the 10-hour daylight period from 8 AM to 6 PM for Utah and western juniper. Measurements were made at 2-hour intervals with a LiCor 6200 (Lincoln, NE) under ambient conditions for each of 12 trees at a low elevation site and at a high elevation site on each of six mountain ranges. Low elevation sites were near the lower elevational limit of juniper on the particular range and high elevation sites were near the upper elevational limit. Measurements were made on two mountain ranges that had western juniper (Juniper Mountain and Sonora Pass) and on four ranges that had Utah juniper (Virginia Mountains, Monitor Range, Snake Range, and Spring Mountains).

Elevation	Late-May	Mid-July	Mid-September
Western juniper			
Low elevation	185	200	103
High elevation	126	152	154
Utah juniper			
Low elevation	155	129	152
High elevation	139	108	199

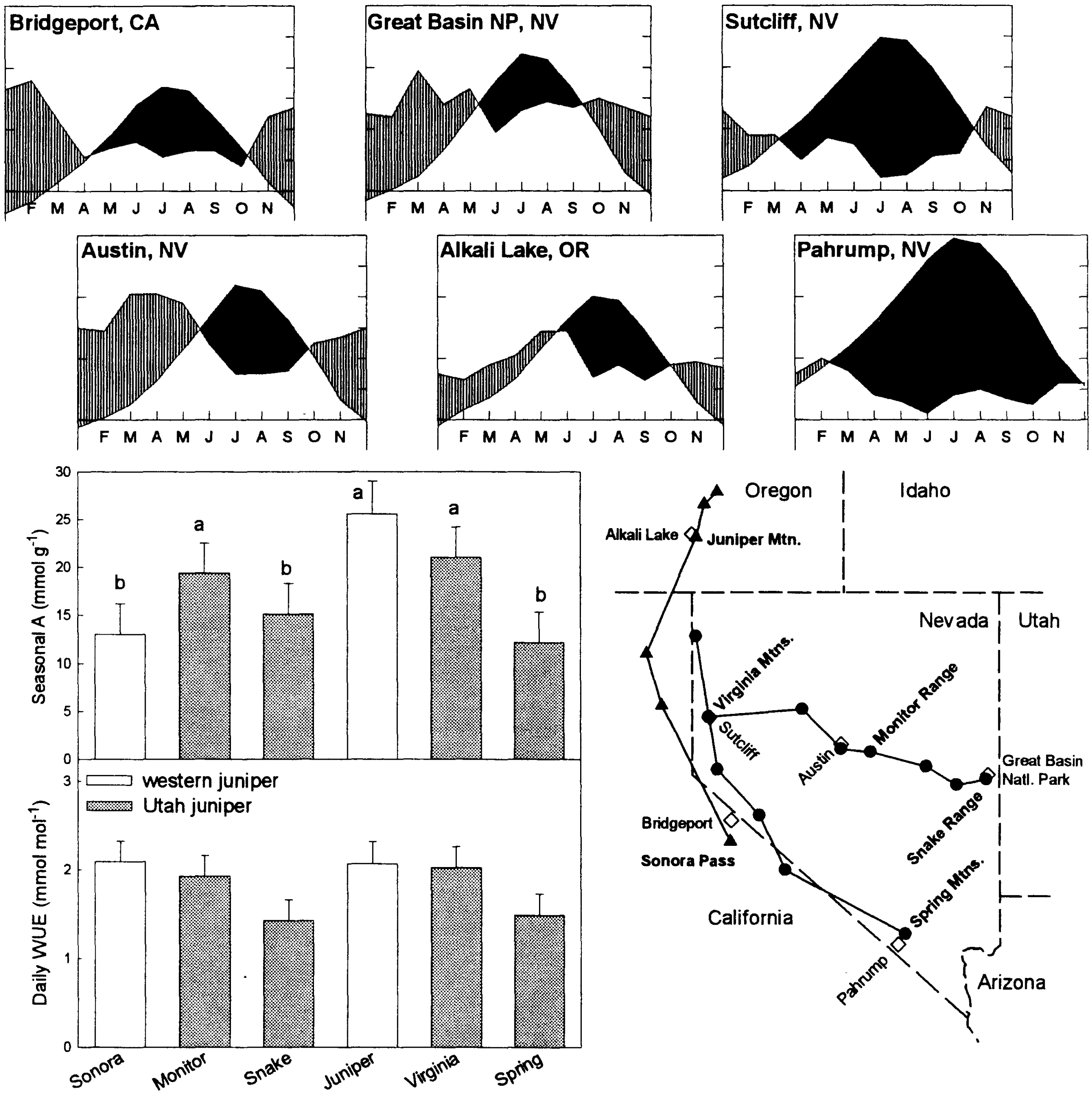

Figure 2—Climatic and leaf gas exchange data for six mountain ranges along three cross-basin transects. At the top are climate diagrams (*sensu* Walter and others 1975) for the climate station closest to each mountain range. Climate stations are ordered left to right based on increased annual drought severity; drought severity is estimated as the difference between the two types of shaded areas in the climate diagram. For each climate diagram, one line and left y-axis are mean monthly temperature, the other line and right y-axis are precipitation, area shaded with vertical lines represent periods during the year when precipitation is sufficient for plants, and solid area represents periods when water deficits occur. The two lower-left panels are carbon gain over and daily water use efficiency during the time period from mid-May through September. Ranges that include western juniper are indicated by open bars and those with Utah juniper are shaded. Ranges are ordered to correspond with their respective climate diagram. Data are unpublished data of the authors. Locations of each mountain range (bold text, solid symbols) and climate stations (open diamonds) are shown on the map, which also shows all study plot locations for western (triangles) and Utah (circles) juniper cross-basin transects of the authors.

(Smith and Nowak 1990). For adults trees, assimilation rates are saturated at an irradiance level approximately equivalent to one-half solar irradiance, that is approximately 1.1 mmol $m^{-2} s^{-1}$ photosynthetic photon flux density (PPFD). The light compensation point is relatively low for C_3 plants at approximately 0.05 mmol $m^{-2} s^{-1}$ PPFD. Western juniper appears to have a rather broad temperature optimum for assimilation; assimilation rates were within 80 percent of maximum values over a leaf temperature range of 15–35 C. Low temperature compensation point is near 0 C, and high temperature compensation point is near 45 C.

Assimilation rates decline with increased plant water stress for both pinyon and juniper species (fig. 3). The declines for pinyon pine and singleleaf pinyon are very steep, with assimilation rates near zero at leaf water potentials between –1.5 and –2.5 MPa. Assimilation rates of Utah and one-seed juniper foliage do not reach zero until leaf water potentials of approximately –3.3 and –4.5 MPa, respectively.

Assimilation and Leaf Nitrogen—Because nitrogen is essential for constructing enzymes, leaf nitrogen content is often related to assimilation rate. Leaf nitrogen content of both pinyon and juniper increase with nitrogen fertilization (Lajtha and Barnes 1991; Marshall and others 1994; Miller and others 1991). However, seasonal variations in leaf nitrogen content are small for both Utah and western junipers (fig. 1C).

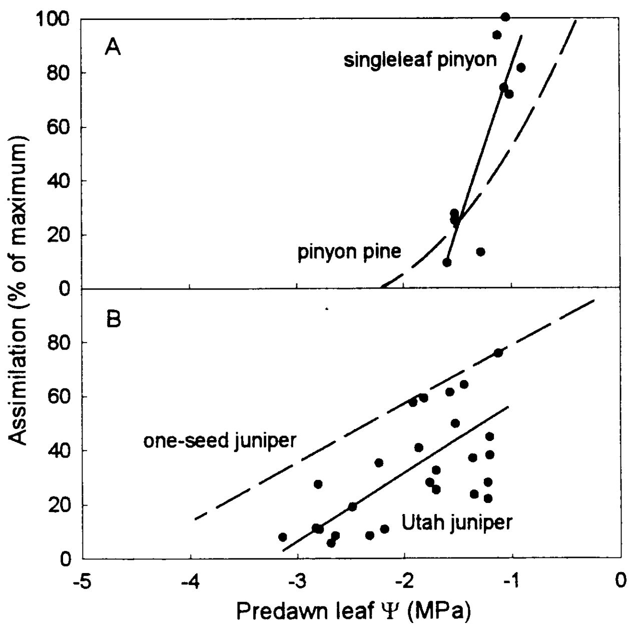

Figure 3—Relationship between assimilation rate (expressed as a percentage of maximum) and predawn leaf water potential for: (A) singleleaf pinyon (closed circles, solid line) and pinyon pine (dashed line); and (B) Utah juniper (closed circles, solid line) and one seed juniper (dashed line). Data for singleleaf pinyon and Utah juniper are from DeLucia and Schlesinger (1991: fig. 1), with solid lines as regressions of their data; dashed lines are second order and first order regression equations for pinyon pine and one-seed juniper, respectively, as reported by Lajtha and Barnes (1991: table 1).

As with many C_3 plants (Field and Mooney 1986), assimilation rate of pinyon pine increases linearly with increased leaf nitrogen (fig. 4A). Thus, fertilization of pinyon plants leads to increased leaf nitrogen and consequently increased assimilation rates; in other words, increased availability of nitrogen in soil benefits pinyon pine through increased assimilation rates. The linear relationship between assimilation and leaf nitrogen content holds during both dry and wet portions of the year, although the slope of the relationship is much less during the dry portion of the year. Interestingly, results for fertilized and non-fertilized plants are along the same regression line for a particular part of the year (dry or wet). Thus, soil water availability, but not soil nitrogen availability, fundamentally changes the functional relationship between assimilation and leaf nitrogen.

Evidence for a linear relationship between leaf nitrogen content and assimilation is mixed for juniper. Lajtha and Barnes (1991) did not find a significant linear relationship between assimilation rate and leaf nitrogen content for one-seeded juniper (fig. 4B). Although Marshall and others (1994) report a significant linear relationship for Utah juniper, the slope of the relationship for Utah juniper is

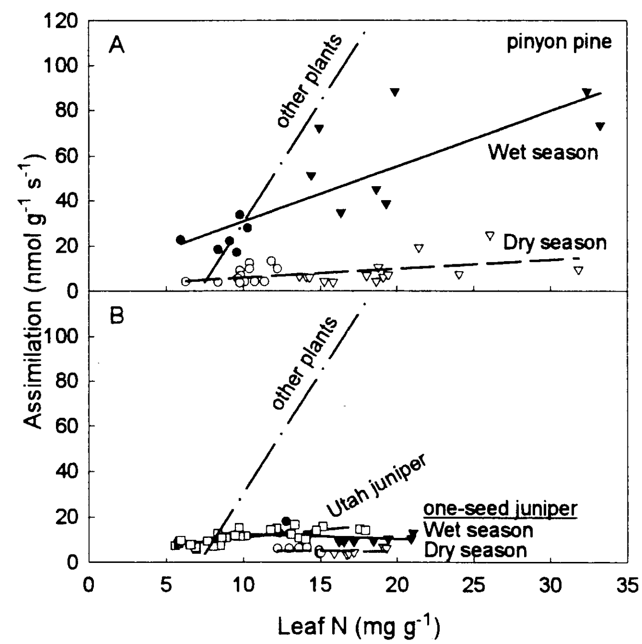

Figure 4—Relationship between assimilation and leaf nitrogen content for: (A) pinyon pine; and (B) Utah and one-seed junipers. For reference, the regression line for a number of other vascular plants from Field and Mooney (1986: fig. 1.2) (dot-dash line) is also shown in both panels. Data for pinyon pine and one-seed juniper are from Lajtha and Barnes (1991: fig. 3); closed symbols and solid line are data from the wetter portion of the year, open symbols and dashed lines are from the dryer portion, circles are from trees under natural soil nitrogen conditions, and triangles are from trees that were fertilized with nitrogen. Data for Utah juniper (open squares) are from Marshall and others (1994: fig. 2). All lines are first order regressions.

much smaller than that reported by Field and Mooney (1986) for a number of plant species as well as for pinyon pine (fig. 4B). Thus, increased soil nitrogen availability, at best, only marginally increases the assimilation rate of junipers.

Water Relations

Plant Water Potential—Diurnal changes in leaf water potential (Ψ) occur for most plants, including pinyon and juniper. For Utah juniper in spring, Ψ decreased from approximately –0.7 MPa to –1.7 MPa over the 4 hour time period from 6 AM to 10 AM, then remained near –1.7 MPa to about 1 PM (Ehleringer and others 1986). Between 1 and 5 PM, leaf water status improved slightly to –1.5 MPa, but after 5 PM the rate of recovery increased greatly. By the end of summer, however, diurnal changes in Ψ were very small for Utah juniper: Ψ was between –1.5 and –1.7 MPa for almost the entire time period from 8 AM to 6 PM. Diurnal measurements of Ψ for singleleaf pinyon over 2 years at three different sites indicate a very rapid decrease in Ψ from predawn measurements (Jaindl and others 1995). Typically, Ψ of singleleaf pinyon dropped to near its minimum value by 7 or 8 AM, then was relatively constant until 3 PM. Unfortunately, measurements were not made after 3 PM, and thus we do not know how rapidly leaf water status recovered during late afternoon and evening. Malusa (1992) also observed a very rapid drop in Ψ during early morning for pinyon pine and California pinyon (*Pinus californiarum*).

Seasonal variation in Ψ are relatively small for pinyon and juniper. Average values for predawn or midday measurements of Ψ vary by approximately 1 MPa for Utah juniper over the summer (fig. 5A). For example, predawn Ψ measurements averaged –1.8 MPa during midsummer in southern Utah, but averaged –0.6 MPa after a rainstorm at the end of summer. However, tree-to-tree variation under drought conditions was much larger than the seasonal variation: minimum and maximum predawn measurements in midsummer were –4.2 and –0.7 MPa, respectively, whereas those after the rainstorm were –1.0 and –0.5 MPa, respectively (Marshall and Ehleringer 1990). Seasonal variation in Ψ for western juniper is larger than that of Utah juniper: the difference between minimum and maximum predawn and midday Ψ measurements during the year were approximately 2.0 MPa (Miller and other 1992). Seasonal variations in Ψ for pinyon pine and California pinyon are generally less than 1.0 MPa for predawn measurements and quite small for midday measurements (figs. 5C, 5D).

A key characteristics that is used to distinguish groups of pinyon pines is the number of needles per fascicle, and this feature has been hypothesized to have physiological, and hence evolutionary, significance. Neilson (1987) speculated that number of needles per fascicle in pinyons follows a gradient in summer precipitation, with four-needle Parry pine (*Pinus quadrifolia*) and five-needle Sierra Juarez pinyon (*P. juarezensis*) occurring at the conjunction of two summer moisture gradients whereas singleleaf pinyon is confined primarily to the Great Basin, which receives predominately winter precipitation. The rational for this speculation is that lack of summer precipitation induces greater water stress on plants with a greater number of needles per fascicle, and hence selects for plants with fewer needles.

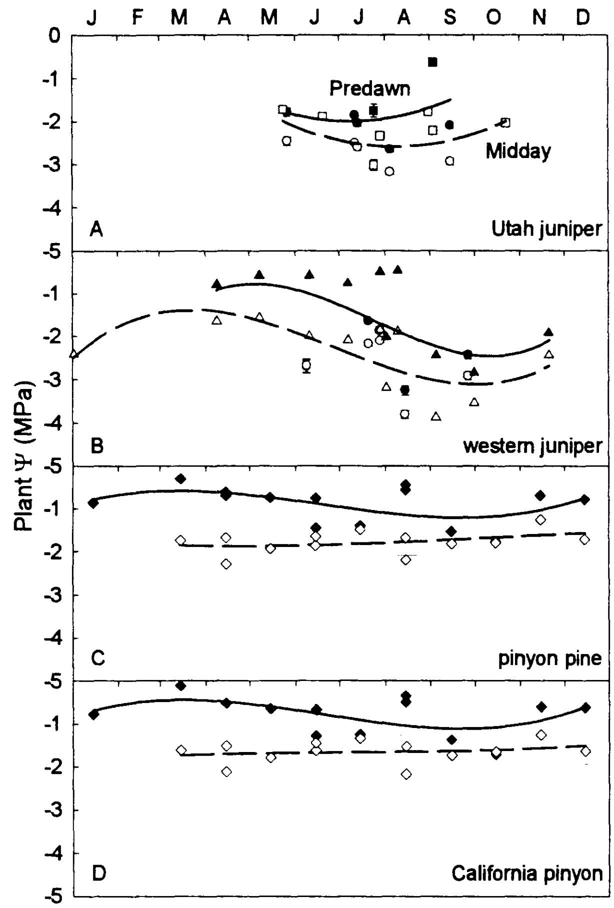

Figure 5—Changes in predawn (closed symbols, solid lines) and midday (open symbols, dashed lines) plant water potential during the year for: (A) Utah juniper; (B) western juniper; (C) pinyon pine; and (D) California pinyon. Different symbol shapes indicate sources of data: for Utah juniper, circles are unpublished data of the authors and squares are from Ehleringer and others (1986: fig. 3) and Marshall and Ehleringer (1990: table 1); for western juniper, circles are unpublished data of the authors and triangles are from Miller and others (1992: fig. 6); for both pinyon species, data are from Malusa (1992: fig. 2). Error bars are standard errors. Although lines are from polynomial curve fitting, they are meant primarily as a guide to general trends of data.

However, Malusa (1992) did not find any significant differences in midday Ψ between the single-needle California pinyon and the double-needle pinyon pine over 2 years. Although significant differences in predawn Ψ occurred, the trend was contrary to expectations: results from double-needle trees indicated less water stress than single-needle trees.

Leaf Conductance and Transpiration—Water loss through transpiration ultimately is controlled by stomata, but few researchers have measured changes in stomatal conductance with changes in environmental factors for pinyon and juniper. Angell and Miller (1994) successfully simulated leaf conductance of western juniper by relaying primarily on three environmental factors: soil temperature, soil water content, and vapor density deficit. In spring when soils are relatively moist, conductance increases as a hyperbolic function of soil temperature. Conductance is near its maximum value when soil temperature at 10 cm depth is above approximately 10 C, but conductance drops rapidly with decreased soil temperature to nearly complete stomatal closure when soil temperature is near 0 C.

The relationship between conductance and soil water content is more complex: conductance is at its maximum value when soils are near field capacity, but conductance drops as a logistic function of soil water. Similarly, Miller and others (1995) found a curvilinear relationship between conductance and plant water potential for western juniper: conductance is near its maximum value when plant Ψ is above approximately –1 MPa, but drops to less than 20 percent of its maximum value at plant Ψ less than –4 MPa. Finally, conductance linearly decreases with vapor density deficit: as relative humidity decreases and air becomes progressively dryer, stomata close. These patterns of stomatal response to environmental factors are not unlike those noted in other Great Basin species (Smith and Nowak 1990).

As with assimilation, diurnal variation in conductance occurs for Utah juniper, western juniper, and singleleaf pinyon (Ehleringer and others 1986; Miller and others 1992; Jaindl and others 1995). Maximum conductance almost always occurs in morning, and often conductance peaks within 2–3 hours after sunrise. As soil water availability decreases during the year, the amplitude of the diurnal change in conductance decreases markedly. In addition, singleleaf pinyon has a general pattern of decreased diurnal amplitude of conductance with decreased soil water availability where variation in soil water availability occurred along an environmental gradient (Jaindl and others 1995).

Variation in conductance over the year is somewhat larger than that of assimilation (figs. 6A, 6B). Conductance is highest in spring and early summer, then drops rapidly to a minimum value in late summer or early fall. Interestingly, both western juniper and singleleaf pinyon exhibit increased conductance in late fall, with or without significant fall precipitation in the case of juniper (Angell and Miller 1994)

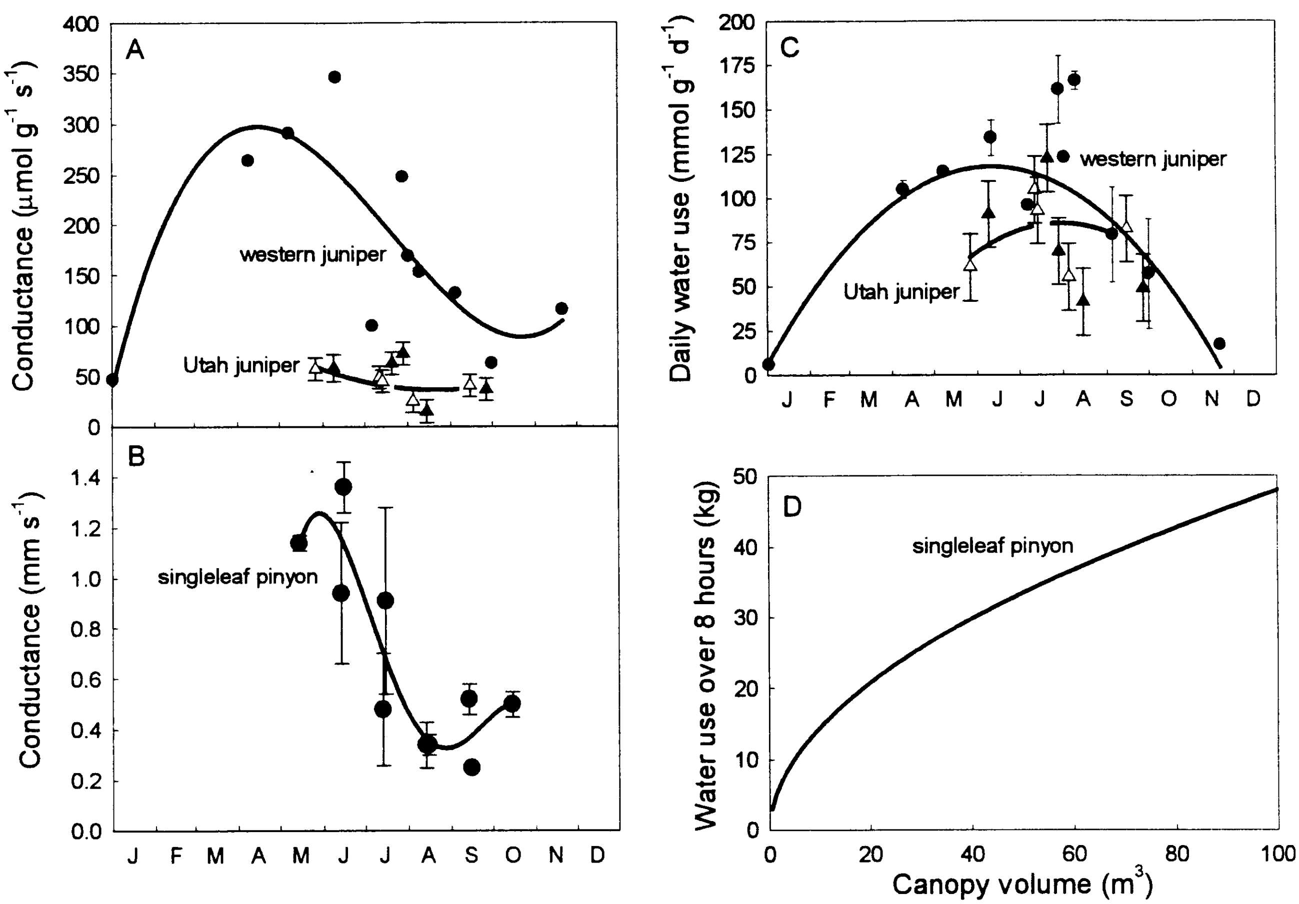

Figure 6—(A) Maximum conductance during the day for western (closed symbols, solid line) and Utah (open symbols, dashed line) junipers; (B) maximum conductance for singleleaf pinyon; (C) total daily water use for junipers; and (D) relationship between canopy volume of singleleaf pinyon and water use over the eight-hour period from 8 AM to 4 PM. Error bars are standard errors. Different symbol shapes in (A) and (C) indicate sources of data: circles are from Miller and others (1992: fig. 5); triangles are unpublished data of the authors. Data in (B) are from Jaindl and others (1995: figs. 4, 5). Regression line in (D) is from DeRocher and Tausch (1993: table 1). Except for (D), lines are meant primarily as a guide to general trends of data, even though they are from polynomial curve fitting.

or without significant fall precipitation in the case of pinyon (Jaindl and others 1995).

The total amount of water transpired by a leaf over the entire day does not follow the same seasonal pattern as conductance. Leaf water use reaches a maximum in mid- or late summer for western and Utah junipers (fig. 6C), whereas conductance tends to peak earlier (fig. 6A). This lag between conductance and transpiration occurs largely because vapor gradients have different effects on conductance and transpiration: everything else being constant, increased vapor gradients induce stomatal closure, but lead to increased transpiration rates. Although similar analyses have not been conducted for pinyons, whole tree water use over the day for singleleaf pinyon increased as amount of foliage increased (fig. 6D). As tree size increases, greater self-shading and stratification of the light environment within the canopy occur, and the exchange of water vapor from within the canopy to bulk air decreases, which in turn lead to the nonlinear relationship between tree size and water use (DeRocher and Tausch 1994). Thus, the amount of water used per *unit* of needle biomass was over six times greater for the smallest seedling than for the larger trees. In addition, number of resin canals greatly improved regressions between foliage biomass and whole tree water use; however, the functional significance of the increased number of resin canals to plant water use is not clear.

Water Use Efficiency—The effects of drought conditions on water use efficiency are not consistent for either pinyon or for juniper. Daily water use efficiency, as calculated from daily carbon gain divided by daily water loss, is highest in spring and fall and lowest in midsummer and winter for junipers (fig. 7A). During the year, lower water use efficiency tends to occur when plants experience greater water stress, unlike other Great Basin species that tend to increase water use efficiency with increased water stress (Toft and others 1989). However, results from sites across regional or elevational environmental gradients are not consistent with this inverse relationship between water use efficiency and drought stress. Daily water use efficiency was not significantly different among 6 mountain ranges that included either Utah or western juniper (fig. 2) nor was it significantly different between high and low elevations within each mountain range (unpublished results of authors). In further contrast, results from carbon isotope composition, which represents a long-term measure of water use efficiency, suggests the opposite trend for singleleaf pinyon, pinyon pine, and one-seed juniper: water use efficiency tends to be greater at low elevation sites (fig. 7B), which are assumed to represent sites with increased water stress. Jaindl and others (1993) corroborated this trend with irrigation treatments: more water decreased carbon isotope content, which indicates lower water use efficiency. Unfortunately, instantaneous measurements of water use efficiency do not help resolve the relationship between drought and water use efficiency. Instantaneous water use efficiency showed little variation as plant Ψ decreased in pinyon pine, but for one-seed juniper, it increased gradually from –0.5 to –3.5 MPa, then declined rapidly as Ψ decreased further (Lajtha and Barnes 1991).

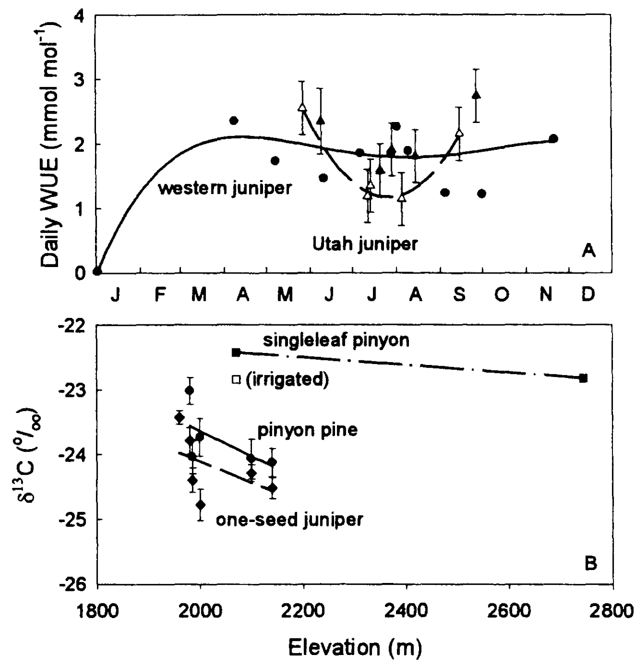

Figure 7—(A) Daily water use efficiency for western (closed symbols, solid line) and Utah (open symbols, dashed line) junipers during the year. Different symbol shapes indicate sources of data: circles are data from Miller and others (1992: fig. 12) and triangles are unpublished data of the authors. (B) Carbon isotope composition of singleleaf pinyon (squares, dot-dash line), pinyon pine (circles, solid line), and one-seed juniper (diamonds, dashed line) for plants on study sites located at different elevations. For singleleaf pinyon, results are also shown for an irrigated plot at the lower elevation (open square). Data for singleleaf pinyon are from Jaindl and others (1993: table 2), and data for pinyon pine and one-seed juniper are from Lajtha and Getz (1993: table 2). For both panels: error bars are standard errors, and lines are meant primarily as a guide to general trends of data, even though they are from polynomial curve fitting.

Comparative Ecophysiology

Pinyon Versus Juniper

Assimilation—Pinyon appears to have a greater potential for carbon gain than juniper. Maximum assimilation rates of pinyon pine are greater than those of one-seed juniper as measured under both controlled environment and natural, field-grown plants (Lajtha and Barnes 1991). Maximum rates for pinyon pine were 26–38 nmol g^{-1} s^{-1} in the controlled environment and slightly less under natural conditions. Maximum values for one-seed juniper were 13–28 nmol g^{-1} s^{-1} in the controlled environment, but did not exceed 20 nmol g^{-1} s^{-1} in the field. As noted above (fig. 4), N fertilization greatly increases assimilation of pinyon pine, but the response of assimilation to fertilization in one-seed juniper is very small.

Although pinyon has a greater potential for carbon gain, the photosynthetic apparatus of juniper is more tolerant of water stress than that of pinyon. Assimilation for pinyon pine and singleleaf pinyon drop much more rapidly with leaf Ψ than for one-seed and Utah junipers (fig. 3). Whereas pines have essentially lost their ability for positive carbon assimilation at a leaf Ψ of −2 MPa, assimilation is still at 35-50 percent of capacity for junipers.

Instantaneous water use efficiency of one-seed juniper were greater than those of pinyon pine under drought conditions, although they were similar under low water stress conditions (Lajtha and Barnes 1991). However, contrary to expectations, long-term water use efficiency as indicated by carbon isotope composition were slightly greater for pinyon pine than for one-seed juniper (fig. 7B) as well as greater for singleleaf pinyon than for Utah juniper (DeLucia and Schlesinger 1991); note that species comparisons of carbon isotope composition can be confounded by other factors, and direct interpolation to water use efficiency should be done cautiously. Interestingly, conflicting results have also been observed in studies of the effect of nitrogen on water use efficiency. Nitrogen fertilization increased instantaneous water use efficiency for pinyon pine whereas it did not affect that of one-seed juniper, but N fertilization did not affect long-term water use efficiency as indicated by carbon isotope composition in pinyon pine whereas it significantly increased that for one-seed juniper (Lajtha and Barnes 1991).

Water Relations—In addition to a greater tolerance of its photosynthetic apparatus to water stress, additional data also suggest that juniper has more favorable water relations than pinyon. In measurements of plant Ψ over an elevational gradient, Barnes and Cunningham (1987) noted that Ψ of one-seed juniper was less negative than that of pinyon pine when soils were wet, but more negative when soils were relatively dry. Hence, when water is plentiful, juniper has lower levels of water stress than pinyon; but as soils dry, juniper has a greater capability to tolerate water stress. Furthermore, this shift in relative ranking of Ψ for these two species is due to the small seasonal variation in Ψ for pinyon pine relative to that of one-seed juniper. Little variation in predawn Ψ for pinyon pine also occurs across a seral gradient, whereas Ψ of one-seed juniper becomes more negative as seral development nears climax (Schott and Piper 1987). Finally, water potential components such as Ψ at the turgor loss point are good indicators of drought tolerance, and Ψ at the turgor loss point was more negative for Utah juniper (mean over two sampling dates was −4.1 MPa) than for pinyon pine (mean was −3.7 MPa) (Wilkins and Klopatek 1987).

Recent evidence also suggests that one-seed juniper is better able to extract soil moisture from areas between canopies than pinyon pine (Breshears and others 1997). In a well-developed stand of pinyon-juniper woodland, Breshears and others (1997) documented a small, but significantly greater, difference in soil moisture in the area between tree canopies than that under tree canopies. By carefully measuring soil moisture content and both plant and soil Ψ under natural and irrigated conditions, they determined that one-seed juniper made better use of shallow soil moisture between canopies than pinyon pine.

Responses of Juveniles Versus Adults—Both pinyon and juniper have dimorphic foliage that is associated with plant growth stage, but the physiological importance of juvenile versus adult foliage has only been investigated for western juniper. The physiological performance of juvenile foliage differs from adult foliage when soil moisture is relatively plentiful (Miller and others 1995). The maximum assimilation rate during the day of juvenile foliage is significantly greater than that of adult foliage from April to July (fig. 8A). This difference is maximum assimilation is partially due to increased stomatal conductance (fig. 8B). The greater assimilation rates of juvenile foliage results in a 28 percent increase in carbon gain over the period from April to October, which likely aids in the rapid establishment of juvenile plants (Miller and others 1995).

Unfortunately, the strategy of juvenile foliage to increase assimilation by increasing conductance has the cost of increased water use. The increased water use does decrease instantaneous water use efficiency of juvenile foliage with respect to adult foliage in late-summer (fig. 8C). However, water use efficiency of the two types of foliage does not differ during late spring and early summer, and water use efficiency of juvenile foliage is actually greater than that of adult foliage in early spring. None-the-less, increased water use does impact plant water status: midday Ψ of juvenile foliage was lower than that of adult foliage over the entire measurement period of April through October, and predawn Ψ of juvenile foliage was lower than that of adult foliage from July through October (fig. 8D). Thus, although increased water use of juvenile foliage only decreased water use efficiency in late summer, juvenile foliage experienced greater water stress over much of spring, summer, and fall. The more negative predawn Ψ are especially intriguing: they suggest that juvenile western juniper depletes soil moisture faster than adults and/or have a smaller rooting volume.

Juvenile and adult plants also differ in how they allocate their resources: juvenile plants allocate a larger proportion of their biomass to belowground tissues. Both the root:shoot ratio and the ratio of fine root:foliage are larger for juvenile western junipers than for sub-adults (fig. 8E). Although this greater allocation to roots likely helps juvenile junipers acquire soil moisture, greater allocation does not completely mitigate greater water use of juvenile foliage, as evidenced by more negative Ψ of juvenile foliage. The greater allocation to roots may also increase the ability of juvenile plants to compete with co-occurring species.

Contrasts with Sagebrush

Carbon Gain and Water Relations—The potential for carbon gain on a per gram of foliage basis are much lower for both juniper and pinyon than for co-occurring shrub-steppe species such as sagebrush. For example, maximum assimilation for sagebrush is approximately an order of magnitude greater than that for Utah juniper and about six times greater than that for singleleaf pinyon (fig. 9A). When expressed on a per unit nitrogen basis, differences between sagebrush and the conifers decrease, but sagebrush is still six and four times greater than Utah juniper and singleleaf

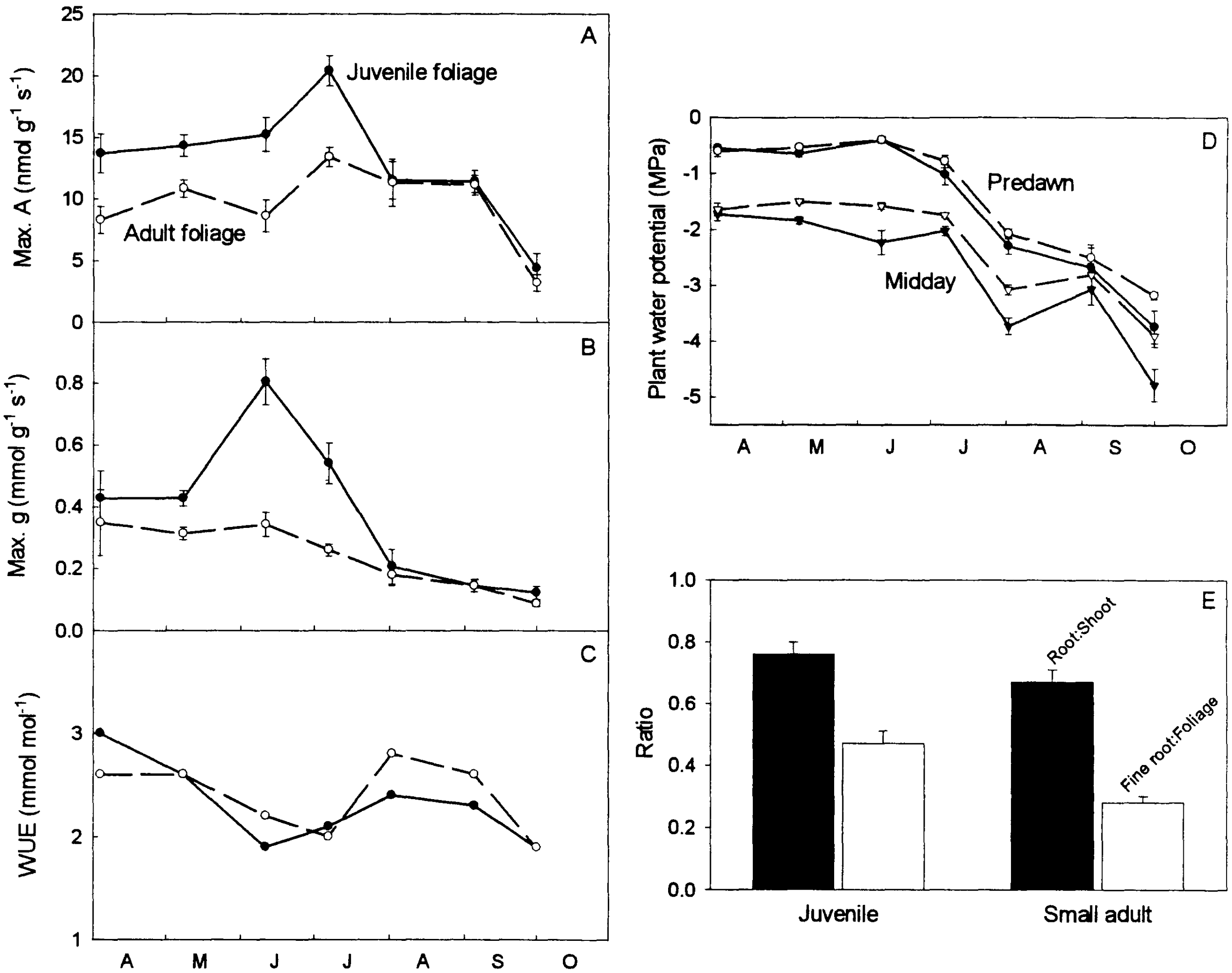

Figure 8—(A) Maximum assimilation rate during the day; (B) maximum stomatal conductance during the day; (C) instantaneous water use efficiency; (D) predawn (circles) and midday (inverted triangles) plant water potentials; and (E) root:shoot (solid bars) and fine root:foliage (open bars) ratios for juvenile and adult western juniper. Closed symbols in panels (A)-(D) are for juveniles, and open are for adults. Error bars are standard errors. Data are from Miller and others (1995: tables 1, 3) except for data in (E), which is from Miller and others (1990: table 5).

pinyon, respectively. In addition, stomatal conductance, leaf nitrogen content, and leaf phosphorous content of sagebrush are also significantly greater than those for the conifers (DeLucia and Schlesinger 1991).

Assimilation of sagebrush is also more drought tolerant than that of the conifers. The drop in assimilation with increased drought stress is more gradual for sagebrush than for one-seed and Utah junipers, and much more gradual than for singleleaf pinyon and pinyon pine (fig. 9B). To extend comparisons made above: when predawn Ψ is near –2 MPa, assimilation rates of the 2 pinyon species are near zero, that of Utah juniper is approximately ⅓ of maximum, that of one-seed juniper is near ½ of maximum, while that of sagebrush is near ⅔ of maximum. Interestingly, water use efficiency of sagebrush is less than that of the conifers. However, high water use efficiency under competitive, water-limited conditions may not confer a large ecological advantage (DeLucia and Schlesinger 1991): during the first part of the growing season when water-limited conditions have yet to occur, water that is not used by the more efficient conifers will likely be used by co-occurring species.

Water and Nitrogen Sources—Pinyon pine and Utah juniper are more dependent on the episodic availability of water near the soil surface than sagebrush. Using the stable isotope deuterium in water, Flanagan and others (1992) demonstrated that pinyon pine and Utah juniper have a greater reliance on summer precipitation than sagebrush. They measured the deuterium content (δD) of precipitation at their study site (closed diamonds and solid line in fig. 10A). If δD of water in xylem of plants is near or above this precipitation line, then the plant is predominantly utilizing current precipitation as its water source. In April, all three species had similar δD values, which means that all three species were utilizing similar sources of water (current precipitation as well as water stored in the soil profile). However, from late spring to midsummer, the two conifer

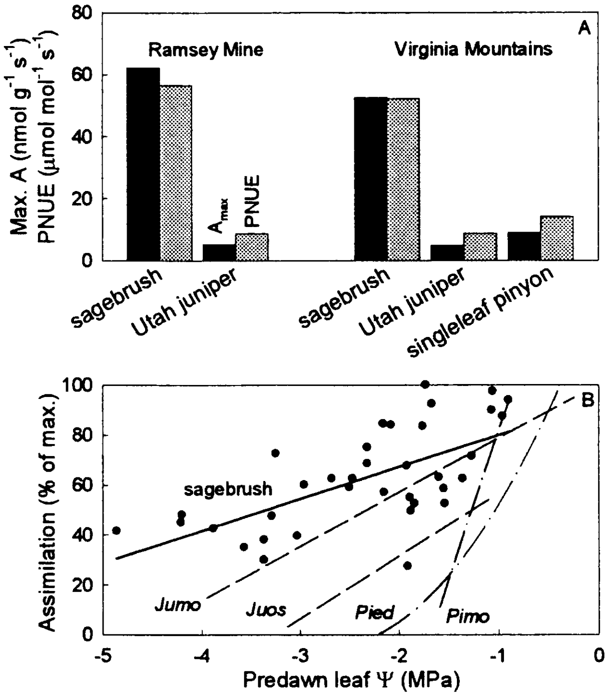

Figure 9—(A) Maximum assimilation (solid bars) and photosynthetic nitrogen use efficiency (shaded bars) for sagebrush and Utah juniper at two study sites and for singleleaf pinyon at the second study site. (B) Relationship between assimilation rate (expressed as a percentage of maximum) and predawn plant water potential for sagebrush (circles and solid line), contrasted with those for junipers (dashed lines; Jumo = one-seed juniper and Juos = Utah juniper) and pinyons (dot-dash lines; Pied = pinyon pine and Pimo = singleleaf pinyon). Lines are first order regressions, and lines for junipers and pinyons are the same as shown in figure 3. Data in (A) and for sagebrush in (B) are from DeLucia and Schlesinger (1991: table 1, fig. 1).

species had δD values near or above the precipitation line whereas δD of sagebrush was substantially below the line. Hence, the two conifers had greater reliance on current precipitation during late-spring to midsummer time period. Even by late summer, when δD of sagebrush suggests use of current precipitation, the relative ranking of the three species suggest that a greater proportion of water for the conifers came from shallow soils. These results plus measurements of plant water potential suggest that the conifers have a greater proportion of their active roots in shallow soils than sagebrush (Flanagan and others 1992). This greater proportion of roots in shallow soils for the conifers does not necessarily imply that they are more able to exploit summer precipitation than sagebrush: in a year with a dry spring and early summer, roots of sagebrush were more responsive to small precipitation events during summer than Utah juniper (Flanagan and others 1992).

Utah juniper appears to receive a large proportion of its nitrogen from shallow soils. Evans and Ehleringer (1994) used measurements of the nitrogen stable isotope content ($\delta^{15}N$) of plant tissues to determine the source of nitrogen for Utah juniper, pinyon pine, and sagebrush. $\delta^{15}N$ of nitrogen fixed by nitrogen fixation, including that fixed by cryptobiotic crust at their study site, is zero (fig. 10B). If $\delta^{15}N$ of plant tissues is near zero, than the plant acquires most of its nitrogen from nitrogen fixation; as $\delta^{15}N$ increases, the proportion of nitrogen from nitrogen fixation decreases. $\delta^{15}N$ of Utah juniper was very close to zero, whereas those for pinyon pine and sagebrush were greater than zero, although similar to each other (fig. 10B). Thus, Utah juniper appears to acquire most of its nitrogen from nitrogen fixation by the cryptobiotic crust, and the portion of the root system that is most active in nitrogen uptake must be in close proximity to the cryptobiotic crust.

Community-level Foliage Biomass—For sites with the same potential resources, foliage biomass of singleleaf pinyon communities greatly exceeds that of shrub communities. Total foliage biomass per unit ground area of both singleleaf pinyon and sagebrush dominated communities have significant positive relationships with site potential (Tausch and Tueller 1990). In addition, total foliage biomass

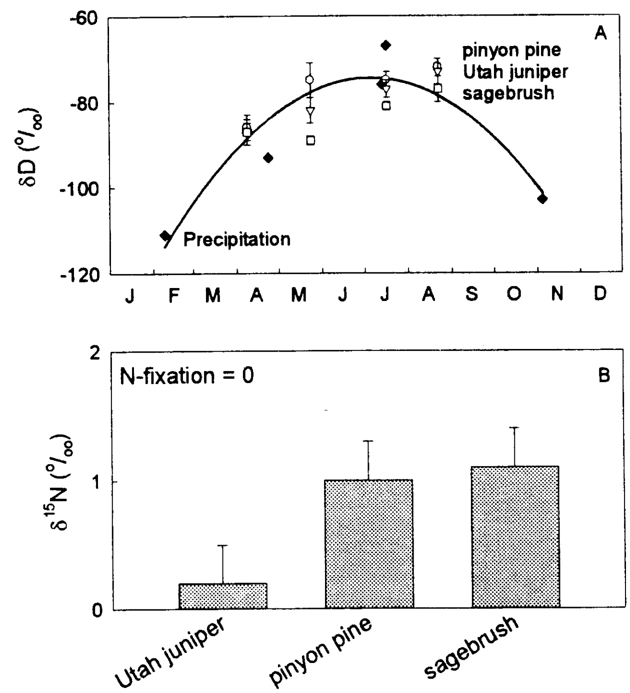

Figure 10—(A) Deuterium stable isotope content (δD) of precipitation (solid diamonds, solid line) and of xylem water from pinyon pine (open circles), Utah juniper (open inverted triangles), and sagebrush (open squares) during the year. Line is a second order regression of the precipitation data, and error bars are standard errors. Data are from Flanagan and others (1992: fig. 1, table 1). (B) Nitrogen stable isotope content ($\delta^{15}N$) of foliage from Utah juniper, pinyon pine, and sagebrush. Data are from Evans and Ehleringer (1994: table 1).

of shrub-dominated communities has a significant positive relationship with that of adjacent singleleaf pinyon-dominated communities with the same site potential (fig. 11A). However, this relationship is heavily weighted in favor of the trees. Furthermore, the relationship is not uniform over the range of site potential: foliage biomass of pinyon exceeds that of the sagebrush-dominated community by a factor of 25 on low potential, drier sites but only by a factor of 12 on the sites with the highest potential (fig. 11B). Thus, given the same water and nutrient resources on a site, pinyon is able to sustain considerably more foliage biomass than sagebrush. The lower nutrient content of pinyon foliage likely contributes to the ability of pinyon to support much more foliage per unit ground area on any particular site.

Although the physiological performance of sagebrush exceeds that of pinyon when measured on a per unit foliage basis, the greater foliage biomass per unit ground area for the conifers appears to compensate for their conservative ecophysiology. The average increase in foliage biomass over the range of sites in figure 11B was about 16. Thus, even though the assimilation rate per unit foliage of sagebrush is four to six times greater than that of pinyon, the pinyon-dominated community has the potential to assimilate at least two to three times more carbon than sagebrush-dominated communities when measured on a ground area basis. The differences in foliage biomass in figure 11B were determined at peak biomass in early to mid summer. During late-fall, winter, and early-spring, sagebrush and associated perennial grasses lose a large proportion of their foliage, whereas pinyon loses almost none. Thus, during these time periods, and especially in early spring when growth starts, the potential for carbon gain by pinyon is even greater than the 2–3 times indicated above. Water use would follow an analogous pattern: greater foliage biomass per unit ground area of pinyon overcompensates for more conservative water use per unit foliage, with the difference between pinyon and the shrub-steppe community enhanced during earlier spring when water availability is near its peak. However, the extent that these differences in phenology and size confer a competitive advantage for pinyon needs a thorough investigation. None-the-less, these opposite differences in ecophysiology and foliage biomass between sagebrush and pinyon appear to be important for community changes. Tausch and West (1995) found that the period of rapid increase in tree dominance and in understory suppression began when pinyon foliage biomass was over twice that of the sagebrush community on a unit ground area basis, which corresponds with the time that potential carbon gain as well as potential water use of pinyon on a per unit ground area is roughly equivalent to that of the shrub-steppe community. Interestingly, the shift in species dominance also occurs after the pinyons have largely lost their juvenile foliage.

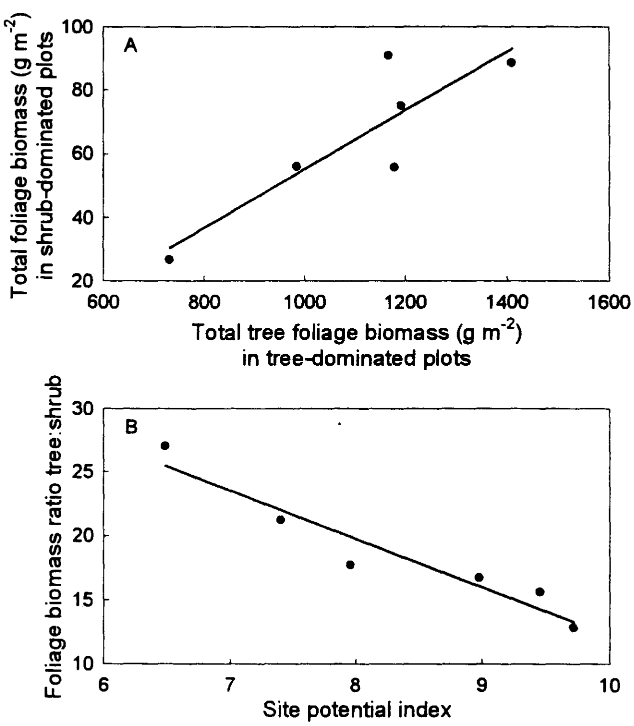

Figure 11—(A) Relationship between total foliage biomass of singleleaf pinyon in plots dominated by pinyon and total foliage biomass of all species in plots dominated by shrubs for paired plots on sites with different site potential. (B) Relationship between site potential, as indicated by a site index based upon tree height at age 200 years, and the ratio of foliage biomass of pinyon in plots dominated by pinyon to foliage biomass of all species in plots dominated by shrubs. For both (A) and (B), lines are linear regressions. Redrawn from Tausch and Tueller (1990; figs 4 and 5).

Discussion

The generally conservative ecophysiological traits of pinyon and juniper appear to be at odds with its ability to almost triple its dominance of the landscape over the last 20 years. If sagebrush has superior ecophysiological traits, then why have the conifers been so successful at invading shrub-steppe? Clearly, ecophysiological traits do not provide, by themselves, the mechanism for success. However, these conservative traits may benefit the conifers in at least two major ways. First, accumulating evidence that nurse plants are important for establishment of juniper and almost essential for pinyon (Chambers and others, this volume) suggests one important role. Although nurse plants likely moderate microclimate for pinyon and juniper seedlings, the conifers still must be able to tolerate reduced resource availability as well as compete effectively for resources. Interestingly, the ecophysiological performance of singleleaf pinyon seedlings is generally better when growing under sagebrush plants than when they grow in the open or in a location where sagebrush has been removed (Callaway and others 1996). A generally conservative ecophysiology as well as the attributes of juvenile foliage likely enhance the establishment and growth of pinyon and juniper under nurse plants.

Second, their conservative ecophysiology, especially the low nutrient content per unit foliage, allow the conifers to produce much more foliage biomass per unit ground area than sagebrush. Thus, the conservative ecophysiological traits of these conifers coupled with their greater longevity allow pinyons and junipers to establish, maintain growth under competitive conditions, and ultimately outsize and outlive their nurse plants and other shrub-steppe competitors.

References

Angell, R. F.; Miller, R. F. 1994. Simulation of leaf conductance and transpiration in *Juniperus occidentalis*. For. Sci. 40:5–17.

Barnes, F. J.; Cunningham, G. L. 1987. Water relations and productivity in pinyon-juniper habitat types. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference. 1986 Jan. 13–16, Reno, NV. Gen. Tech. Rep. INT-GTR-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 406–411.

Bazzaz, F. A. 1986. Life history of colonizing plants: Some demographic, genetic, and physiological features. In: Mooney, H. A.; Drake, J. A., eds. Ecological Studies Vol. 58. Ecology of Biological Invasions of North America and Hawaii. Springer-Verlag, New York: 96–110.

Breshears, D. D.; Myers, O. B.; Johnson, S. R.; Meyer, C. W.; Martens, S. N. 1997. Differential use of spatially heterogeneous soil moisture by two semiarid woody species: *Pinus edulis* and *Juniperus monosperma*. J. Ecol. 85:289–299.

Buckman, R. E.; Wolters, G. L. 1987. Multi-resource management of pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference. 1986 Jan. 13–16, Reno, NV. Gen. Tech. Rep. INT-GTR-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 2–4.

Callaway, R. M.; DeLucia, E. H.; Moore, D.; Nowak, R.; Schlesinger, W. H. 1996. Competition and facilitation: contrasting effects of *Artemisia tridentata* on desert vs. montane pines. Ecology 77: 2130–2141.

DeLucia, E. D.; Schlesinger, W. H. 1991. Resource-use efficiency and drought tolerance in adjacent great Basin and Sierran plants. Ecology 72:51–58.

DeRocher, T. R.; Tausch, R. T. 1994. Predicting potential transpiration of singleleaf pinyon: an adaptation of the potometer method. For. Ecol. Manage. 63:169–180.

Ehleringer, J. R.; Cook, C. S.; Tieszen L. L. 1986. Comparative water use and nitrogen relationships in a mistletoe and its host. Oecologia 68:279–284.

Evans, R. D.; Ehleringer, J. R. 1994. Water and nitrogen dynamics in an arid woodland. Oecologia 99:233–242.

Field, C.; Mooney, H. A. 1986. The photosynthesis-nitrogen relationship in wild plants. In: Givnish, T. J., ed. On the economy of plant form and function. Cambridge: Cambridge University Press.

Flanagan, L. B.; Ehleringer, J. R.; Marshall, J. D. 1992. Differential uptake of summer precipitation among co-occurring trees and shrubs in a pinyon-juniper woodland. Plant Cell Environ. 15: 831–836.

Jaindl, R. G.; Doescher, P. S.; Eddleman, L. E. 1993. Influence of water relations on the limited expansion of *Pinus monophylla* into adjacent *Cercocarpus ledifolius* communities in the central Great Basin. For. Sci. 39:629–643.

Jaindl, R. G.; Eddleman, L. E.; Doescher, P. S. 1995. Influence of an environmental gradient on physiology of singleleaf pinyon. J. Range Manage. 48:224–231.

Lajtha, K.; Barnes, F. J. 1991. Carbon gain and water use in pinyon pine-juniper woodlands of northern New Mexico: field versus phytotron chamber measurements. Tree Physiol. 9:59–67.

Lajtha, K.; Getz, J. 1993. Photosynthesis and water-use efficiency in pinyon-juniper communities along an elevational gradient in northern New Mexico. Oecologia 94:95–101.

Malusa, J. 1992. Xylem pressure potentials of single- and double-needled pinyon pines. Southwestern Natur. 37:43–48.

Marshall, J. D.; Ehleringer, J. R. 1990. Are xylem-tapping mistletoes partially heterotrophic? Oecologia 84:244–248.

Marshall, J. D.; Dawson, T. E.; Ehleringer, J. R. 1994. Integrated nitrogen, carbon, and water relations of a xylem-tapping mistletoe following nitrogen fertilization of the host. Oecologia 100: 430–438.

Miller, P. M.; Eddleman, L. E.; Kramer, S. 1990. Allocation patterns of carbon and minerals in juvenile and small-adult *Juniperus occidentalis*. For. Sci. 36:734–747.

Miller, P. M.; Eddleman, L. E.; Miller, J. M. 1991. The response of juvenile and small adult western juniper (*Juniperus occidentalis*) to nitrate and ammonium fertilization. Can. J. Bot. 69:2344–2352.

Miller, P. M.; Eddleman, L. E.; Miller, J. M. 1992. The seasonal course of physiological processes in *Juniperus occidentalis*. For. Ecol. Manage. 48:185–215.

Miller, P. M.; Eddleman, L. E.; Miller, J. M. 1995. *Juniperus occidentalis* juvenile foliage: advantages and disadvantages for a stress-tolerant, invasive conifer. Can. J. For. Res. 25:470–479.

Neilson, R. P. 1987. On the interface between current ecological studies and the paleobotany of pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference. 1986 Jan. 13–16, Reno, NV. Gen. Tech. Rep. INT-GTR-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 93–98.

Nowak, R. S.; Caldwell, M. M. 1984. Photosynthetic activity and survival of foliage during winter for two bunchgrass species in a cold-winter steppe environment. Photosynthetica 18:192–200.

Schott, M. R.; Pieper, R. D. 1987. Water relationships of *Quercus undulata*, *Pinus edulis*, and *Juniperus monosperma* in seral pinyon-juniper communities of south-central New Mexico. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference. 1986 Jan. 13–16, Reno, NV. Gen. Tech. Rep. INT-GTR-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 429–434.

Smith, S. D.; Monson, R. K.; Anderson, J. A. 1997. Physiological ecology of North American desert plants. Springer, New York. 286 p.

Smith, S.D.; Nowak, R. S. 1990. Ecophysiology of plants in the Intermountain lowlands. In: Osmond, C. B.; Pitelka, L. F.; Hidy, G. M., eds. Ecological Studies, Vol. 80. Plant Biology of the Basin and Range. Springer-Verlag, Heidelberg: 179–241.

Tausch, R. J.; Tueller, P. T. 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon-juniper woodlands. Great Basin Naturalist 50:121–134.

Tausch, R. J.; West, N. E. 1995. Plant species composition patterns with differences in tree dominance on a southwestern Utah piñon-juniper site. In: Shaw, D. W.; Aldon, E. F.; LoSapio, C., technical coordinators. Desired Future Conditions for Piñon-Juniper Ecosystems. 1994 August 8–12, Flagstaff Arizona. Gen. Tech. Rep. RM-258. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 16–23.

Toft, N. L.; Anderson, J. E.; Nowak, R. S. 1989. Water use efficiency and carbon isotope composition of plants in a cold desert environment. Oecologia 80:11–18.

Walter, H.; Harnickell, E.; Mueller-Dombois, D. 1975. Climate-diagram maps of the individual continents and ecological climatic regions of the earth. Springer-Verlag, Berlin.

Wilkins, S. D.; Klopatek, J. M. 1987. Plant water relations in ecotonal areas of pinyon-juniper and semi-arid shrub ecosystems. In: Everett, R. L., compiler. Proceedings—pinyon-juniper conference. 1986 Jan. 13–16, Reno, NV. Gen. Tech. Rep. INT-GTR-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 412–417.

Harvesting Energy from 19th Century Great Basin Woodlands

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Abstract—The pinyon/juniper woodlands of the Great Basin were a vital source of structural wood and energy products for the mining industry from the 1860's to the 1930's. Pinyon and juniper were cut extensively for fuel wood and for the production of charcoal, the only available fuel or energy source for the smelters of central Nevada. Firewood and fence post for ranches were also important uses of pinyon and juniper. Deforestation by cutting, promiscuous burning continued unabated until the 1920's and 1930's, when fossil fuels, substitute types of structural wood, and fire control combined to decrease disturbance in this vegetation type.

This presentation is an updated adaptation of historical reviews first presented by Budy and Young (1979) and Young and Budy (1987). The vestiges of a once-flourishing wood products industry haunt the current managers of the pinyon-juniper woodlands. Land managers, users, and environmentalists alike suffer from a lack of historical perspective when they contend with management practices in pinyon-juniper woodlands. This is most apparent in the management of shrubs in pinyon-juniper woodlands as habitat for mule deer (*Odocoileus hemionus* subsp. *hemionus*).

The pinyon-juniper woodlands of the Great Basin are unique in how they relate to other types of vegetation. In the Rocky Mountains and the Southwest a forest of pine (often *Pinus ponderosa*) is usually located above the pinyon-juniper zone. In the central Great Basin, a mountain brush community occupies this site. The species composition of shrubs, forbs, and grasses in this community suggest a forest, but the trees are absent. In the Southwest, pinyon-juniper communities often merge with oak (*Quercus*) woodlands. Oaks are absent from central Nevada with the lower edge of the pinyon-juniper zone merging with *Artemisia* plant communities. Thus the central Great Basin was unique among nineteenth century mining areas where energy was a problem. Other portions of the west usually had some forest resources besides pinyon and juniper available for use.

The mountain crest of the highest ranges of the Great Basin support five-needled pines, of which bristlecone (*Pinus longaeva*) and limber pine (*Pinus flexilis*) are best known. Although the sparse forest were generally remote and limited in area, they were still heavily cut to supply mines with structural timbers and lumber.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Mining in the West-Central Great Basin

The mining era in Nevada was ushered in by discovery of the silver-rich Comstock Lode in 1859 and subsequent developments during the 1860's (Elliot 1973). As the mining districts on the Comstock grew in size, the supply of fire wood seldom met demand. The pinyon and juniper in the Virginia Range were removed in an ever expanding circle. In 1864, for example, several hundred American laborers were constantly cutting and hauling firewood from nearby woodlands. Chinese laborers followed the wood cutters, pulling up the brush, stumps, and roots from overcut hills. It was a common experience for boys growing up on the Comstock to spend their after-school hours searching mine dumps for discarded wooden candle boxes to feed the family heating stove (Galloway 1947). When 6 ft of snow covered the roads during the winter of 1866-1867, a cord of wood cost from $40 to $50. An estimated 120,000 cords of firewood were used in the district in 1866 (Lord 1883). The scant supply of pinyon and juniper on the neighboring hills was rapidly exhausted, and wood cutters moved to the eastern slopes of the Sierra Nevada, some 20 miles from the mines.

Although the pine-fir forest of the eastside Sierra assured an abundant supply of timber and fuel, transportation to the mines was expensive. The construction and maintenance of mountain roads became so costly that natural waterways were used whenever possible to move logs down to the mills in the valley below Virginia City. Because of the limited number and size of waterways, water transportation was not satisfactory until the 1870's when the V-flume was developed and proven practical. Then sawmills were erected in the mountains, and cordwood and timbers were transported down the flume from the Sierra. More than 700 cords of fuel wood and 500,000 board feet of mining timbers were transported down the Carson and Tahoe Lumber Company's flume daily (DeQuille 1889). Spring floods on the Carson River also were used for transporting wood. More than 150,000 cords of wood were floated down the Carson in a typical season.

Although the adjacent Sierra slope fulfilled much of the Comstock's demand for wood products, its use of pinyon and juniper was still extensive. The Comstock is located on the edge of these woodlands in the Great Basin. Utah juniper extends north of the Comstock, but singleleaf pinyon occurs south of a line running diagonally across Nevada, from Virginia City to the Idaho-Utah-Nevada corner (Beason 1974). Mining operations along the Comstock Lode from the early 1860's until well into the present century drew upon this adjacent wood resource. As a result, more than 190,000 acres of second-growth pinyon-juniper woodland now cover Douglas, Ormsby, and southernmost Washoe Counties (Wilson 1941).

Use of wood in subsequent mining strikes and boomtowns in western Nevada and eastern California (for example, Aurora and Bodie) more or less followed the same pattern: transportation of fuelwood and timbers from the adjacent Sierra Nevada and secondary reliance on pinyon-juniper woodlands, especially for firewood.

Mining in Central Nevada

In 1862 a former Pony Express rider who was cutting wood discovered silver ore in the Toiyabe Range, 175 miles east of Virginia City. This new find, around which grew the town of Austin and the Reese River Mining District, brought the wood energy crisis into sharp focus. Central Nevada was too far removed from the Sierra Nevada for the transportation of huge quantities of fuel. The pinyon-juniper woodlands alone had to sustain the mining industry.

In contrast to the free-milling ores on the Comstock, the Reese River ores were called refractory or rebellious (Oberbillig 1967). The Reese River ores were dry crushed and roasted with salt to permit amalgamation with mercury. Although dry crushing was a terrible health hazard to the millworkers, it saved the cost of drying the crushed ore before roasting and prevented losses from oxidation of wet ores. The salt was harvested from playas in the desert valleys and often packed to the mines using camels (Young 1982).

During the 1860's, the Reese River mills used reverberatory furnaces in which the ore was heated on hearths and roasted, with the flame passing across the top of the bed of ore. These furnaces took 7 hours to roast each charge of ore, consumed salt amounting to 8 or 10 percent of the ore volume, and burned a cord of wood per ton of capacity (Rossiter 1870). There was only one source of fuel for roasting the ore, and that was the pinyon-juniper woodlands. Roughly 60 percent of the expense of milling ore was for fuelwood.

The efficiency of roasting was greatly improved by the development in 1869 of a new furnace by C. A. Stetefeldt. The principle of this furnace is that finely ground silver ore and salt are completely chloridized when they fall against a current of hot gas. The Stetefeldt furnace became the standard roasting mechanism for the central Great Basin until all amalgamation processes were replaced by the cyanide process early in the twentieth century (Oberbillig 1967).

Only one-third as much wood was required with the Stetefeldt furnace as compared to earlier furnaces, and the labor requirement was greatly reduced. The technology developed on the Reese River Mining District provided the model for next three decades.

Charcoal Production

Despite savings in wood with the new technology, the energy source became very expensive once stands of pinyon and juniper adjacent to the mills were cut. There was no water transportation available in the arid mountains, so costs were reduced by carbonizing the raw wood to charcoal before transportation to the mills.

The production of charcoal had a long history in Europe and was a part of all ancient civilizations. Industrial charcoal production, such as was practiced by the early iron smelting industry in Sweden, was a major cause of extensive deforestation. Spanish cultures had a long heritage of charcoal production from oak. Charcoal from oak was burned in California long before the gold rush. By carbonizing wood through controlled combustion, it was possible to obtain fairly high-energy-value fuel with a 60 percent savings in volume and about 80 percent savings in weight over raw cordwood. During the 1860's and 1870's, several million bushels of charcoal were produced in the northeastern United States for use in the manufacturing of iron (Hough 1878). The charcoal industry started in what became the United States with the construction of a kiln about 80 miles from Jamestown, Virginia in 1620 (Baker 1985). As the iron industry moved west to Pittsburgh, the demand for charcoal greatly increased. Charcoal iron production increased until 1880, when about 800,000 tons were produced.

Making charcoal from wood is essentially the process of partially burning the wood. The degree to which the wood is burned is controlled by regulating the amount of air admitted. Heat generated by burning the wood distills combustible vapors, which arise from wood surrounding the burning zone. The heat caused by the burning of these gases distills more gas from surrounding wood, and the zone of distillation moves progressively through the pile. Enough air is admitted to burn the gases, but not enough to burn the carbon residue, which is charcoal. If the burning process is correctly done, the result is good charcoal, relatively free from volatile and vaporous material (Anonymous 1943).

A common industry in the eastern United States during the nineteenth century was the capture of and condensation of gases released by the charcoal burning process. Before petrochemical production, all industrial important organic chemicals were obtained from wood (Baker 1985). Most of these chemicals were obtained from hardwood-distillation. Longleaf pine (*Pinus palustris*) was important for the production of pine tars and oils from which turpentine was refined. Early miners in California and Nevada did distill pine oils from native trees. The sap of digger (*Pinus sabiniana*) and Jeffrey pine (*Pinus jeffreyi*) contain a volatile, explosive chemical which caused stills to explode (Mirov and Kraebel 1939). The precious metal milling and recovery industry in the Great Basin would have required large amounts of pine tar for waterproofing the largely hydraulic milling operations, but there is no record of singleleaf pinyon being distilled for pine tar production.

Cutting singleleaf pinyon, Utah or western juniper for fuelwood is a miserable job. Mature pinyon and juniper trees seldom exceed 30 to 35 ft in height and 20 inches in diameter at the base. In addition to their small size, both species usually have poor growth form. Open grown trees are often multi-stemmed and exceedingly bushy. Both species lack natural pruning, and thus retain branches right down to the ground. These characteristics make pinyon and juniper difficult to fell and buck into cordwood. We estimate that cutting a cord of pinyon wood required at least two or three times as much labor as cutting a cord of ponderosa pine.

Pinyon logs were cut and allowed to dry before they were burned in earth-covered pits. The term charcoal pit is misleading. Although in the finished kiln the wood was completely covered with soil, the base was usually located at the soil surface. In construction of the pit, a center chimney was made, either by driving three poles into the ground and keeping them separate, or by building a triangular crib of wood in the center. The chimney was packed to part of its height with dry grass, twigs, or other loose combustible material. This material was used to start the fire. The chimney served as a support for the pile of wood and as a flue to aid the draft and carry off smoke. The charge of wood was piled around the central chimney, standing on end and leaning slightly toward the center. Top layers were put on flat, so the kiln was dome shaped.

The entire mound, except for the central opening at the top, was covered with grass and pine needles to a depth of 3 to 5 inches. This fine organic material was topped with 2 to 5 inches of clay soil; sandy soil would not provide the correct seal. Care was taken to make the soil layer as air tight as possible. Small openings were left around the bottom for draft. The size of these holes was varied or controlled by putting in or taking out soil.

Management of the burning process required considerable skill. The kiln was lit through the central chimney. After the fire was well started, the draft was reduced. Burning conditions were judged by the color of the smoke. The kiln had to be watched night and day, and wet clay was kept on hand to repair any cracks. A 100-cord pit kiln probably required from 3 weeks to a month to burn.

When it was judged that all wood in the kiln had been completely burned, all openings were closed. The cooling process required a week to 10 days for large kilns. Opening the cooled kiln was a dangerous operation, best carried out when the wind was still. Unless it was completely cold, the kiln was always in danger of igniting the charcoal during the opening process.

Utah juniper and curlleaf mountain mahogany (*Cercocarpus ledifolius*) were also converted to charcoal. These species required higher temperatures for conversion to charcoal than can be obtained with ground pits. To properly control overdrafts, beehive-shaped ovens were constructed from native stone (Grazeola 1969). Many perfectly symmetrical ovens remain today in isolated parts of Nevada as monuments to the back-breaking labor of a forgotten industry.

The yield of cordwood from pinyon-juniper woodlands can vary from less than 1 cord to more than 12 cords per acre. A charcoal pit produced from 2,000 to 3,300 bushels of charcoal from a supply of 100 cords of wood. Therefore, roughly 10 to 100 acres of woodland had to be cut for each pit. Probably the lower yielding woodlands were too sparse for their use to be economical. A yield of 300 bushels of charcoal per acre may have been a reasonable average.

Eureka, about 60 miles east of Austin, Nevada, became important in the 1870's and 1880's. From 1869 to 1863 the Eureka District produced $60,000,000 of gold and silver and 225,000 tons of lead. Smoke from roasted ores was so severe, elongated stacks were run up the canyon walls and then vertically to vent the fumes from this Pittsburgh of the West. The major milling companies were processing 750 tons of ore per day. The milling process required 25 to 35 bushels of charcoal per ton of ore. An estimated 1.25 million bushels of charcoal were consumed at Eureka in 1875 (Anonymous 1875).

The demand for charcoal was so great that deforestation became a severe problem. From our estimates of wood yield, 4,000 to 5,000 acres of woodland had to be cut annually to supply Eureka mills. By 1874 the mountain slopes around Eureka were denuded of pinyon and juniper for a radius of 20 miles. The average hauling distance from pit to smelter was 35 miles (Anonymous 1875).

Deforestation pushed shipping costs higher until the price of charcoal topped 30 cents per bushel. The standard transportation unit was 16- to 20-mule teams pulling four wagons, hitched in tandem, each loaded with 4 tons of sacked charcoal.

Eureka is a well-documented, but not isolated, example of the use of pinyon-juniper woodlands. The spread of mining brought prospectors, with little and big boomtowns, to virtually every mountain range in Nevada (Paher 1970).

In the far Northwestern Great Basin there is little evidence that western juniper (*Juniperous occidentalis*) was extensively cut during the settlement period (1870-1920) (Miller and Rose 1995). There was no large mining industry in eastern Oregon, and other wood resources were available through much of the region. It also appears the western juniper woodlands were limited in area compared to current conditions. Pre-settlement western juniper was often found on ridge-tops or on low sagebrush sites that were relatively safe from wildfires. In 1936 and 1937, during the establishment of the Squaw Butte Experimental Range near Burns, Oregon, crews traveled 40 miles to cut juniper posts to fence the range. Today, there are extensive western juniper woodlands on the experimental range. The pulse of western juniper establishment that has occurred in eastern Oregon is too recent to have provided wood resources during the early settlement period.

Miners who operated north of the pinyon-juniper distribution in the Great Basin used drastic measures to obtain energy. The Dexter Mine at Tuscarora, Nevada, used sagebrush (*Artemisia tridentata*) to fire boilers. Sagebrush was cut and delivered to the mine for $2.50 per "cord." The hoisting woks smoked like a miniature Vesuvius and the entire area was covered with ashes (Paher 1970).

In the early twentieth century, sagebrush was a major source of fuel for settlers on the Minidoka irrigation project located in south-central Idaho. It was a mark of economic achievement when a family, trying to establish an irrigated farm in the desert reclamation project, could afford to switch from collecting sagebrush to purchased juniper or lodgepole pine (*Pinus contorta*) as a source of fuelwood (Anonymous 1924).

Other Uses of Pinyon-Juniper Wood

Despite the huge demand for charcoal in mills, the use of pinyon and juniper wood in home heating and cooking may have had an even greater effect on the total woodland environment. The denuded area around Eureka, Nevada, accounted for a relatively small percentage of the pinyon-juniper woodlands in the Great Basin. The 70-mile-diameter cutting circle contained roughly 2.5 million acres, of which 0.6 million acres or 24 percent was pinyon-juniper woodlands; this equals 3.4 percent of the 17.6 million acres of this vegetation type in the Great Basin. Every isolated mine and ranch had to have wood as a source of fuel and building material. The corrals, for example, at the Walti Hot Springs ranch in central Nevada are constructed of 3,000 juniper poles. Some 50 miles of barbed wire fence is supported by juniper posts, with 260 posts per mile. The woodlands above the ranch are laced with wagon roads among the stumps left from past use. One may multiply this example by the hundreds of ranches and thousands of mining prospects to estimate the true extent of use of the pinyon-juniper woodlands.

When large ranches in the Humboldt Valley of Nevada were first fencing with barbed wire during the 1880's, they could buy redwood posts from California cheaper than juniper posts from the over-utilized woodlands of the Great Basin (Gordon 1880). Many ranchers employed Indian woodcutters to supply posts. Thirty Mile Charley was an enterprising Paiute resident of Montello, Nevada, who contracted with the giant ranches of the Utah Construction Company. His crews cut 3,000 to 4,000 posts per season (Bowman 1958).

The accelerated use of pinyon-juniper woodlands also brought promiscuous burning. David Griffiths, a trained scientific observer, reported in 1902 that every mountain range in the northern Great Basin showed evidence of recent wildfires. He attributed most of the fires in areas remote from railroads to promiscuous burning.

Sheep, cattle, and horses, Griffiths noted, heavily utilized the Great Basin ranges at the turn of the century. Domestic livestock did not eat the pinyon or juniper reproduction, but, by depleting the herbaceous understory vegetation, they favored the re-establishment of woody plants by reducing competition and changing the fuels available for wildfires.

Depleted by promiscuous hunting to near extinction, mule deer herds grew at exponential rates during the first half of the twentieth century (Clements and Young 1997). This growth in mule deer populations paralleled the growth of shrub populations, especially in former pinyon-juniper woodlands. As trees re-established and eventually grew to dominance that depleted shrub populations, many mule deer populations have crashed.

After World War I, the Great Basin gradually became dependent on fossil fuels for energy; first the cities and towns, and then, even more slowly, the rural areas. A declining rural population also helped to lessen use of pinyon-juniper woodlands.

References

Anonymous. 1875. Report of the state mineralogist. Carson City, NV; Appendix to the Journals of the Senate and Assembly, Seventh Session, Nevada State Legislature. 681.

Anonymous. 1924. Federal reclamation by irrigation. A report submitted to the Secretary of the Interior by the Committee of Special Advisors on Reclamation. 68th Congress, 1st Session Document #92. GPO, Washington, DC. 104 p.

Anonymous. 1943. How to make charcoal on the farm. Washington, DC; U.S. Department of Agriculture. 6 p.

Baker, A. J. 1985. Charcoal industry in the U.S. A. In: Symposium on Forest Products Research International—Achievements and the Future: Vol. 5. 1985 April 22-26: Pretoria, Republic of South Africa. South African Council for Scientific and Industrial Research, National Timber Research Institute. 15 p.

Beason, C. D. 1974. The distribution and synecology of Great Basin pinyon-juniper. M.S. Thesis, University of Nevada, Reno, NV. 95 p.

Bowman, N. L. 1958. Only the mountains remain. Caxton Printers, Caldwell, ID. 93 p.

Budy, J. D., and Young, J. A. Historical use of Nevada's pinyon/juniper woodlands. J. Forest History. 23: 112-121.

Clements, C. D., and J. A. Young. A viewpoint: Rangeland health and mule deer habitat. J. Range Manage. 50:129-138.

DeQuille, D. A 1889. History of the Comstock Silver Lode and Mines. F. Boogle, Virginia City, NV. 127 p.

Elliot, R. R. 1973. History of Nevada, University of Nebraska Press, Lincoln, NE: 62-65.

Galloway, J. D. 1947. Early engineering works contributing to the Comstock. Geology and Mining Series No. 45. Nevada Bureau of Mines and Mackay School of Mines, University of Nevada, Reno, NV. 17 p.

Gordon, C. Report on cattle, sheep, and swine: supplementary to enumeration of livestock on farms in 1880. Tenth Census of the United States, Vol. II, Washington, DC. 280 p.

Grazeola, F. 1969. The charcoal burner's war of 1878: A study of Italian immigrants in Nevada. M.A. Thesis, University of Nevada, Reno, NV.

Griffiths, D. 1902. Forage conditions on the northern borders of the Great Basin. Bulletin No. 15, Bureau of Plant Industry, U.S. Department of Agriculture. GPO, Washington, DC. 32 p.

Hough, F. B. 1878. Report upon forestry, Vol. 1. GPO, Washington, DC: 127-128.

Lord, E. 1883. Comstock mining and miners. U.S. Geological Survey; GPO, Washington, DC: 203-205.

Miller, R. F. and J. A. Rose. 1995. Historic expansion of *Juniperous occidentalis* (western juniper) in southeastern Oregon. Great Basin Naturalist. 55: 37-45.

Mirov, N. T. and Kraebel, C. J. 1939. Collecting and handling seeds of wildland plants. Civilian Conservation Corps, Berkeley, CA.

Oberbillig, E. 1967. Development of Washoe and Reese River silver processes. Nevada Historical Society. 10: 30.

Paher, S. 1970. Nevada ghost towns and mining camps. Howell-North Books. Berkeley, CA. 492 p.

Rossiter, R. 1870. Statistics of mines and mining in the states and territories west of the Rocky Mountains. GPO, Washington, DC: 122-123.

Wilson, R. C. 1941. Vegetation types and forest conditions of Douglas, Ormsby, and southwestern Washoe County, Nevada. California Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Forest Service Release No. 2. Berkeley, CA. 1 p.

Young, J. A. 1982. Camels on the western range. Rangelands. 4: 248-251.

Young, J. A. and Budy, J. D. 1987. Energy crisis in 19th century Great Basin woodlands. In: R. L. Everett. Proceedings-Pinyon-Juniper Conference. 1986 January 13-16 Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Station: 23-29.

Biotic, Edaphic, and Other Factors Influencing Pinyon-Juniper Distribution in the Great Basin

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Abstract—Drought and severe frost events during the growing season often limit the distribution of pinyon-juniper woodlands to relatively narrow altitudinal belts on mountain sides throughout the Great Basin and across the Colorado Plateau. Dramatic zone inversions may arise to confound more common patterns and place pinyon-juniper woodlands above the mountain brush zone. Such a zone inversion occurs on a grand scale in Spanish Fork Canyon, Utah County, Utah, where Utah juniper and Colorado pinyon have an ecological advantage over Gambel oak and associated mountain brush species. Utah juniper and associated pinyons are insensitive to differences in geologic parent materials and soils derived therefrom. Regional floristic patterns and climatic changes associated with differences in elevation exert a far stronger impact. Woodland successional processes proceed more quickly on deep deposits of volcanic ash and alluvium or lacustrine deposits than on soils derived in place from consolidated bedrock of volcanic or sedimentary origin.

The pinyon-juniper forests of the Intermountain Region of western North America dominate literally millions of hectares of the landscapes of that area (West and others 1975). In this paper, we evaluate the composition of pinyon-juniper forests growing on some of the most widespread and edaphically different geologic parent materials present in the Great Basin portions of Utah.

Methods

Our sample has been gleaned from the files of the Utah Division of Wildlife Resources (DWR). For almost half a century, DWR personnel have monitored composition and health of big game winter ranges throughout the state. In our analysis of those records, we had three basic requirements for study site inclusion in this study: (1) geologic parent material at the site must be designated, (2) vegetational data must be quantified, and (3) soil physical and chemical characteristic must be reported. A total of 29 sites were found in the DWR record file that satisfied all (or essentially all) of our requirements. In addition, we include some original data from our own work in Spanish Fork Canyon, Utah County, Utah.

Vegetational data were taken along transects, each 270 m in length. Each transect line consisted of five transects 30 m in length. Transects alternated with 30 m segments that were not inventoried. Quadrats (1.0 m^2) were placed at 3 m intervals along each transect beginning at the 0 point and alternating from the right to left sides of the survey tape. Cover was determined within each quadrat for each species using a slightly modified procedure from that described by Daubenmire (1959). Plant densities for grasses and forbs were determined by counting individuals rooted within the quadrats. Shrub densities were estimated along a 0.005 ha strip plot on each of the five transects centered over the survey tape. Frequencies for shrubs were based on occurrence within each of the 0.005-ha strips. Frequencies for forbs and grasses were based on species presence within any of the quadrats. Plant nomenclature follows Welsh and others (1993). Geologic stratigraphy in Spanish Fork Canyon has been taken from Hintze (1973, 1982). Climatic data were taken from National Oceanic and Atmospheric Administration (1992) summaries and from rain gauges maintained by us at Millfork during the frost-free seasons of 1991-1994. Soils were analyzed by the Soil and Plant Analysis Laboratory, Department of Agronomy and Horticulture, Brigham Young University using analytical methods recommended by Black and others (1965). Statistical analyses (analysis of variance, multiple range tests, and regression analyses) were made following procedures recommended by Sokal and Rohlf (1969).

Results

Our sample represents pinyon-juniper woodlands growing on five major geologic parent materials in the Great Basin physiographic province of Western Utah (table 1). Each major parent material is represented by six or seven sites except for quartzite for which only three sites could be found and all of those lacked information on most chemical and physical characteristics of the soil. The study sites are similar with respect to elevation with sites on granite having the greatest average elevation (1,926 m) and those on sandstone the lowest elevations (1,341 m), but none of those differences are statistically significant at the p 0.05 level. Soil reaction averages were even more similar among sites (average values ranging from 7.5 to 7.7) (table 1). All soils were high in sand (41 to 57 percent). Soil skeletal (stone) content and available P were more variable. Sandstone

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Table 1—Physical and chemical characteristics of pinyon-juniper sites and their soils on each of five different geologic parent materials in western Utah. Soil characteristics pertain to the surface 15 cm of the profile. Means followed by the same letter in superscript do not differ significantly.

Characteristic	Parent material				
	Alluvium	Granite	Limestone	Quartzite	Sandstone
No. of sites	7	6	7	3	6
Average elevation (m)	1,709[a]	1,926[a]	1,824[a]	1,819[a]	1,341[a]
Average soil pH	7.5[a]	7.5[a]	7.7[a]	NA	7.5[a]
Skeletal material (percent by vol.)	12[a]	24[a]	25[a]	43[a]	6[a]
Sand (percent by wt.)	57[b]	46[ab]	41[a]	NA	43[ab]
Available P (ppm)	73[a]	106[a]	31[a]	NA	71[a]

NA = not available

sites had the least skeletal material (6 percent) in the upper soil profile, and quartzite sites had the most (43 percent). Available P was greatest (106 ppm) in soils derived from granite and least (31 ppm) in soils of limestone origin. However, since variances were great and sample sizes were small, none of the foregoing differences were statistically significant at the 0.05 probability level.

Geologic substrate had ambiguous effects on vegetational characteristics of the pinyon-juniper woodlands examined (table 2). Because sample sizes are small and variances are large for all variables considered, almost none of the vegetational differences among parent material categories differed significantly ($p < 0.05$). Variables that did show some significant differences included proportions of species that were woody and proportions of species that were introduced. Woody species accounted for almost half of all species on sandstone parent materials and less than a quarter of the species on pinyon-juniper sites where soils were derived from limestone. Introduced species accounted for over 20 percent of all species at pinyon-juniper sites on limestone, but both quartzite and sandstone soils had fewer than 6 percent of their flora contributed by introduced species. *Symphoricarpos oreophilus* was a dominant understory species from sites above 1,800 m on quartzite parent material, but not on sites at similar elevations where parent materials were limestone or granite.

The foregoing data show few indications that geologic parent materials alone have strong and predictable impacts on composition of vegetation in the pinyon-juniper zone in western Utah. In Spanish Fork Canyon, Utah County, Utah, however, strong differences in parent material do seem to interact with climatic differences to produce a major change

Table 2—Characteristics of the vegetation of pinyon-juniper woodlands growing on various geological substrates in western Utah. Tree composition data were not tested for significance of differences because stands were at different successional stages. Other data were tested for significance of differences among parent material groups. Means followed by the same letter do not differ significantly.

Characteristic	Parent material				
	Alluvium	Granite	Limestone	Quartzite	Sandstone
Percent sum-tree-density					
Juniperus osteosperma (percent)	90.5	67.1	84.9	100.0	60.2
Pinus edulis (percent)	0.00	0.00	14.8	0.00	39.8
P. monophylla (percent)	9.5	32.9	0.3	0.00	0.00
Average No. species sampled per site	19.7[a]	29.6[a]	27.3[a]	23.0[a]	18.8[a]
Proportion species that are woody (percent)	27.2[ab]	26.3[ab]	23.4[a]	32.1[ab]	45.4[b]
Understory living cover (percent)	36.9[a]	29.2[a]	29.1[a]	NA	23.3[a]
Proportion of species that are:					
Annual (percent of all species)	18.3[a]	16.8[a]	14.6[a]	3.9[a]	14.5[a]
Introduced (percent of all species)	15.0[bc]	18.3[bc]	21.5[b]	5.9[ac]	5.5[ac]
Dominant species[1]					
Shrub	*Artemisia tridentata*	*A. tridentata*	*Gutierrezia sarothrae*	*Artemisia nova*, *Symphoricarpos oreophilus*	*Ephedra viridis*, *G. sarothrae*, *Opuntia polyacantha*
Perennial grass	*Poa secunda*	None	*Elymus spicatus*	*Elymus spicatus*, *Sitanion hystrix*, *Stipa hymenoides*	None
Perennial forb	None	None	None	*Cryptantha* sp.	*Astragalus* sp., *Eriogonum* sp., *Penstemon* sp.

[1]Dominant species were here considered to be those that produce measurable cover in over half the stands considered in a geological subgroup.

Table 3—Soil and site characteristics under pinyon-juniper woodlands in the Mill Fork area of Spanish Fork Canyon. For comparison, we also report soil and site characteristics reported for Gambel oak sites. Data are derived from literature references as noted. Data for pinyon-juniper woodlands near Mill Fork are taken from Farmer (1995).

	Dominant vegetation	
Characteristic	Pinyon-Juniper	Oak
Elevation (m)	1,920	1,676-2,286 (Harper and others 1985)
Soil pH	7.9 (Farmer 1995) 7.5 (Statewide ave., Bunderson and others 1985)	6.6 (Allman 1953) 7.4 (Yake and Brotherson 1979) circumneutral (Harper and others 1985)
Clay (percent by wt. in mid-profile)	28 (Farmer 1995) 24 (Bunderson and others 1985)	38 (Allman 1953) 25 (Yake and Brotherson 1979)
Sand (percent by wt. in mid-profile)	44 (Farmer 1995) 46 (Statewide ave., Bunderson and others 1985	39 (Allman 1953) 24 (Yake and Brotherson 1979)

in relative placement of the pinyon-juniper zone in the vegetational sequence along an altitudinal gradient. Normally pinyon-juniper woodlands occur between sagebrush-grass and mountain brush vegetation (Woodbury 1954), but at the mouth of Spanish Fork Canyon, the mountain brush zone borders sagebrush-grass vegetation along the Wasatch Front. Dominated by Gambel oak (*Quercus gambelii*), bigtooth maple (*Acer grandidentatum*), Vasey sagebrush (*Artemisia tridentata* var. *vaseyana*), and a large number of other montane shrubby species, the mountain brush zone prevails between the valley edge at about 1,585 m and roughly 1,750 m elevation. At that general elevation, Green River Shale becomes the dominant parent material. Green River Shale supports pinyon-juniper woodlands of typical composition and structure over large areas at this location. Green River Shale gives way to the Colton Formation near Gilluly at roughly 2,000 m. The Colton material, however, is much like Green River Shale in terms of degree of consolidation, texture, and chemistry and vegetational response is similar on the two parent materials. Thus pinyon-juniper vegetation is apparent on steep, south-facing slopes almost to Soldier's Summit Pass at 2,275 m. In the middle of the elevational belt where Green River Shale occurs, pinyon-juniper woodlands are present on both south-facing and north-facing slopes. On north-facing slopes, *Symphoricarpos oreophilus* is the major understory shrub. That species is uncommon on south-facing slopes except above 1,900 m. Vasey sagebrush and Oregon grape (*Mahonia repens*) are other common understory shrubs on north-facing slopes.

Characteristics of soils developed on Green River Shale in the Mill Fork area of Spanish Fork Canyon are presented in table 3. Results suggest that soils in that zone are more basic and coarser textured than soils that underlie Gambel oak communities at that elevation elsewhere in eastern Utah County. Bunderson and others (1985) statewide averages for pinyon-juniper woodland are close to those observed for Green River Shale at Mill Fork (table 3). Leonard and others (1987) summarized all published information concerning soil characteristics associated with Utah juniper, Colorado pinyon, and single-leaf pinyon in Utah. They report that all three species have broad tolerances, but are best represented on loamy to silt loam soils. Juniper and single-leaf pinyon are most often found on soils that contain 15-35 percent skeletal material by volume. Colorado pinyon occurred most often on soils that had 35-60 percent skeletal material. Leonard and others (1987) concluded that Utah juniper and Colorado pinyon occurred "often" on strongly alkaline soils.

The data show that a distinct rain shadow occurs in the Mill Fork area (table 4). The normal pattern is for precipitation to increase with elevation (Harper and others 1980), thus providing more precipitation at mid-elevations where

Table 4—Precipitation and average annual temperature along an altitudinal gradient that parallels Spanish Fork Canyon. Data for Spanish Fork Power House, Birdseye, and Scofield Dam are from a 30 year summary published by National Oceanic and Atmospheric Administration (1992). Result for Mill Fork were either measured directly by Farmer (1995) or were estimated using a linear regression model based on elevation at the three sites reported by NOAA.

	Location			
Characteristic	Spanish Fork Power House	Birdseye	Mill Fork	Scofield Dam
Elevation (m)	1,439	1,750	1,920	2,326
May - Oct. precip. (cm)	22.5	19.0	21.8 (4 yr measured ave.)	17.9
Nov. - Apr. precip. (cm)	30.0	25.5	23.4 (estimated)	17.9
Mean annual precip. (cm)	52.5	44.5	45.2	35.8
Mean annual temperature (C)	10.9	6.1	5.6 (estimated)	2.3

mountain brush vegetation normally occurs than at lower elevations where pinyon-juniper woodlands commonly occur. Near the mouth of Spanish Fork Canyon, however, high mountains (>3,000 m) form the western edge of the Wasatch Front immediately adjacent to the Utah Valley (elevation <1,525 m). Elevations to the east of that initial crest are almost everywhere lower all the way to Soldier's Summit (some 26 km to the east), the watershed divide between the Great Basin and the Colorado River drainage system. As shown in table 4, precipitation steadily declines from Spanish Fork to Scofield Dam despite a consistent increase in elevation. The unexpectedly high precipitation at Spanish Fork apparently owes its existence to a phenomenon known as the approach effect. Daubenmire (1947) has described the approach effect as a situation in which approaching air masses driven before prevailing winds begin to ascend before they reach a mountain barrier more-or-less at right angles to the dominant winds. The ascending air cools to dew point and releases some of its vapor as liquid (or crystalline) precipitation.

Discussion

Our results support the assumption that regional dominants should be somewhat indifferent to geologic parent materials that may differ on a small scale within a common macroclimatic zone. Both pinyon and juniper occur on a variety of parent materials in the eastern Great Basin without conspicuous and predictable differences in vegetational structure or composition.

Regional differences are apparent in the pinyon-juniper woodlands of Utah, but they are better correlated with macroclimatic and floristic province differences than with geologic parent materials. Among the tree species, *P. edulis* occurs primarily east of the Wasatch Front and the high plateau complex that forms a mountainous border between the Colorado Plateau and the Great Basin. In contrast, *P. monophylla* is largely confined to the Great Basin portions of western Utah. Cliffrose (*Purshia mexicana*) is a conspicuous component of pinyon-juniper woodland in an area largely congruent with *P. edulis*, but it is replaced by bitterbrush (*Purshia tridentata*) in most of the Great Basin. *Orthocarpus purpureo-albus* is a common native annual in understories of woodlands of southeastern Utah, but it is absent in the Great Basin. *Shepherdia rotundifolia*, a striking shrub of the Colorado Plateau woodlands, is unknown in the Great Basin.

The remarkable zone inversion in Spanish Fork Canyon apparently owes its existence to a chance occurrence of a strongly alkaline parent material (Green River Shale) in an area affected by a persistent rain shadow. Steep topography throughout the area dominated by pinyon-juniper woodlands ensures that erosional rates remain rapid enough to preclude or seriously interfere with soil development processes that would likely make the sites more favorable for mountain brush species. It is doubtful that the reversal of mountain brush and pinyon-juniper in the altitudinal sequence of vegetational types could occur without the co-occurrence of strongly alkaline parent material, reduced precipitation and rapid geologic erosion. The rarity of such a reversal in the landscapes of western United States would seem to indicate that the congruence of the causal agents noted above is uncommon.

Although our data show no consistent effects of geological parent materials on pinyon-juniper woodlands composition, cursory observations in southwestern Utah suggest that successional processes are faster on deep volcanic ash deposits. Such sites also support what appear to be the more dense pinyon-juniper woodlands in the region. Tree growth rates seem more rapid as well. Although we have inadequate data to evaluate these observations, we suggest that they may have management implications and deserve study.

Acknowledgments

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References

Allman, V. P. 1953. A preliminary study of the vegetation in an exclosure in the chaparral of the Wasatch Mountains, Utah. Utah Academy of Sciences, Arts and Letters Proceedings. 30: 63-73.

Black, C. A.; Evans, D. D.; White, J. L.; Ensminger, L. E.; Clark, F. E. (eds.). 1965. Methods of soil analysis, part 1: Physical and mineralogical properties, including statistics of measurement and sampling. American Society of Agronomy, Inc. Madison, Wisconsin. 770 p.

Bunderson, E. D.; Weber, D. J.; Davis, J. N. 1985. Soil mineral composition and nutrient uptake in Juniperus osteosperma in 17 Utah sites. Soil Science. 139: 139-148.

Daubenmire, R. 1947. Plants and Environment. John Wiley and Sons, New York. 424 p.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science. 33: 43-66.

Farmer, M. E. 1995. The effect of anchor chaining pinyon-juniper woodland on watershed values and big game animals in central Utah. Master's thesis, Brigham Young University, Provo, UT. 46 p.

Harper, K. T. 1989. Soil pH beneath Gambel oak canopies in Spanish Fork Canyon, Utah County, Utah. Unpublished.

Harper, K. T.; Wagstaff, F. J.; Kunzler, L. M. 1985. Biology and management of the Gambel Oak vegetative type: A literature review. U.S. Department of Agriculture, Forest Service, General Technical Report INT-179. 31 p.

Harper, K. T.; Woodward, R. A.; McKnight, K. 1980. Interrelationships among precipitation, vegetation, and streamflow in the Uinta Mountains, Utah. Encyclia. 57: 58-86.

Hintze, L. F. 1973. Geologic history of Utah. The Department of Geology, Brigham Young University, Provo, UT. 181 p.

Hintze, L. F. 1982. Geologic highway map of Utah, reprinted. Department of Geology, Brigham Young University, Provo, UT.

National Oceanic and Atmospheric Administration, National Climatic Data Center. 1992. Monthly station normals of temperature, precipitation, and heating and cooling degree days: 1961-1990, Utah. Climatography of the United States No. 81. 31 p.

Sokal, R. R.; Rohlf, F. J. 1969. Biometry. W. H. Freeman and Co., San Francisco. 776 p.

Welsh, S. L.; Atwood, N. D.; Goodrich, S.; Higgins, L. C. 1993. A Utah flora, 2nd ed., revised. Brigham Young University Print Services, Provo, UT. 986 p.

West, N. E.; Rea, K. H.; Tausch, R. J. 1975. Basic synecological relationships in juniper-pinyon woodlands. pp 41-53 In: Gifford, G. F. and Busby, F. E. (eds.). The pinyon-juniper ecosystem: A symposium. Utah State University, College of Natural Resources and Utah Agricultural Experiment Station, Logan.

Woodbury, A. M. 1954. Principles of general ecology. McGraw-Hill Book Co., Inc., New York. 503 p.

Yake, S.; Brotherson, J. D. 1979. Differentiation of serviceberry habitats in the Wasatch Mountains of Utah. Journal of Range Management. 32: 379-383.

Description of Pinyon-Juniper and Juniper Woodlands in Utah and Nevada From an Inventory Perspective

Renee A. O'Brien
Sharon W. Woudenberg

Abstract—Forests composed mostly of pinyon and/or juniper species cover more than 45.3 million acres in the Intermountain West. About 40 percent (18.0 million acres) of that area is in Nevada and Utah, where roughly 71 percent of the total forest land is pinyon-juniper and juniper forest type. The net volume of pinyon and juniper species in the two States is estimated at over 10.3 billion cubic feet, or about 137.5 million cords. Juniper makes up 63 and 47 percent of the pinyon-juniper volume in Utah and Nevada, respectively. Fifty-eight percent of the total number of pinyon and juniper trees in Nevada, and 49 percent in Utah are pinyon. About 53 percent of pinyon-juniper and juniper stands in Utah and about 67 percent in Nevada are estimated to be between 40 and 120 years old. Almost 20 percent of stands in Utah and 9 percent of stands in Nevada have an age over 200 years. Only about 6 percent of Utah stands and less than 1 percent of Nevada stands show evidence of chaining.

The objective of this paper is to present an overview of composition, structure, and productivity of pinyon-juniper and juniper ecosystems, focusing on data from recent Utah and Nevada State inventories. This paper will also demonstrate the use of large-scale inventory data for planning and decision making.

Forest types composed of pinyon and/or juniper species cover approximately 45.3 million acres in the western States of Montana, Idaho, Wyoming, Nevada, Utah, Colorado, Arizona, and New Mexico. The Interior West Resource Inventory, Monitoring, and Evaluation (IWRIME) Program of the U.S. Forest Service, Rocky Mountain Research Station, conducts forest land inventories in these eight States as part of its national Forest Inventory and Analysis (FIA) duties. About 40 percent of the pinyon-juniper and pure juniper ecosystems in the area inventoried by IWRIME occurs in Nevada and Utah, where roughly 71 percent of the total forest land is pinyon-juniper or pure juniper forest type.

This paper will focus only on the pinyon-juniper and juniper forest types in Utah and Nevada, with special emphasis on Utah. Utah is the Interior West State with the most complete and current forest inventory data base. In the past, IWRIME did not usually inventory National Forest System (NFS) lands, obtaining the numbers instead from NFS inventories for State and regional reporting. However, a cooperative agreement and funding from the U.S. Forest Service Intermountain Region resulted in a comprehensive inventory of Utah's forests that included NFS lands and all reserved lands and was completed in 1995. A Utah State report is currently being prepared (O'Brien, in preparation). Nevada also has a fairly comprehensive State inventory, which was conducted between 1978 and 1982. An area update was done in 1989, and the results of the Nevada inventory were published in 1992 (Born and others). The number of field plots on pinyon-juniper and juniper forest types in Nevada was 1,104, and in Utah, 1,212 (fig. 1).

Also shown in figure 1 are parts of six ecoregions that occur in Nevada and Utah, as described by Bailey (1995): (1) American Semi-Desert and Desert Province, (2) Colorado Plateau Semi-Desert Province, (3) Intermountain Semi-Desert Province, (4) Intermountain Semi-Desert and Desert Province, (5) Nevada-Utah Mountains-Semi-Desert-Coniferous Forest-Alpine Meadow Province, and (6) Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province.

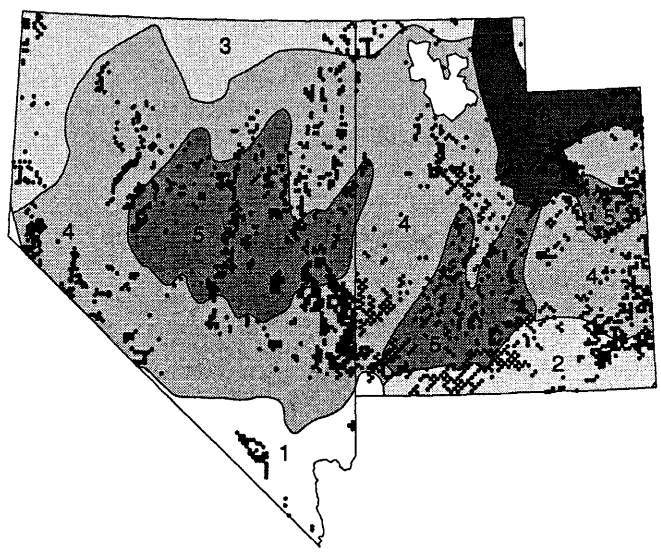

Figure 1—Utah and Nevada ecoregions and IWRIME pinyon-juniper or juniper field plots.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Table 1—Area and net volume with percent standard error for pinyon-juniper and juniper forest types in Utah 1993, and Nevada 1989.

State	Forest type	Attribute	Area	Volume	Percent standard
			acres	*thousand*	*error*
Utah	Pinyon-juniper	Area	7,766,307		2.3
		Volume		5,365,955	3.2
	Juniper	Area	1,382,400		7.3
		Volume		660,683	8.9
Nevada	Pinyon-juniper	Area	7,155,970		1.3
		Volume		3,498,881	2.9
	Juniper	Area	1,683,566		5.6
		Volume		560,305	7.7

Sampling Procedures

IWRIME uses a two-phase sampling procedure for State inventories, described in detail by Chojnacky (1998). The first, or photo interpretive, phase is based on a grid of sample points systematically located every 1,000 m across all lands in a State. Forestry technicians use maps and aerial photos to obtain ownership and stratification information. Field crews conduct the second, or field, phase of the inventory on a subsample of the phase one points that occur on forest land. Field procedures for Utah are described in detail in USDA (1994), and in USDA (1982) for Nevada.

For the most part, the IWRIME sampling intensity on lands outside NFS lands in the Interior West is one field plot every 5,000 m, or about every 3 miles. The sampling intensity on NFS lands in Utah was double that of outside lands. In Nevada, National Forest System lands were not field sampled. Most data summaries presented in this report for Nevada are based on the 6,526,784 acres that were actually sampled. Area estimates for the 2,312,752 acres of NFS lands were based on photo interpretation information, and volume estimates in tables 1 and 2 were developed using stratum means (field plots) from other ownerships.

The IWRIME sample was designed to meet national standards of precision for forest attributes at State and regional levels. Standard errors, which denote the precision of an estimate, were computed for State totals of area and volume of the pinyon-juniper and juniper types in Nevada and Utah, and are presented in table 1. Standard errors are usually higher for smaller subsets of the data.

Forest Composition and Structure

Area

FIA differentiates pinyon-juniper forest type (stands that have juniper and any pinyon present) from juniper forest type (purely juniper). It is estimated that Nevada has 7,155,970 acres of pinyon-juniper forest type, composed mostly of singleleaf pinyon (*Pinus monophylla*) in association with Utah juniper (*Juniperus osteosperma*) or occasionally Rocky Mountain juniper (*Juniperus scopulorum*). Two needle pinyon (*Pinus edulis*) may also occasionally be found. Juniper occurs without pinyon on about 1,683,566 acres, usually on drier and lower elevation sites. The total area of pinyon-juniper and juniper combined is 8,839,536. An additional 25,043 acres of pinyon-juniper is estimated to occur on reserved areas, for a total of 8,864,579, with about 19 percent being pure juniper. Sixty-nine percent of the pinyon-juniper and juniper forests in Nevada are administered by the Bureau of Land Management (BLM), 26 percent by NFS, and 5 percent are privately owned.

It is estimated that Utah has 7,766,307 acres of pinyon-juniper forest type composed mainly of twoneedle pinyon or occasionally singleleaf pinyon in association with Utah juniper or occasionally Rocky Mountain juniper. Approximately 1,382,400 acres are occupied by juniper species occurring without pinyon. The total area of pinyon-juniper and juniper combined is 9,148,707 acres, with 15 percent being pure juniper (fig. 2). Sixty-one percent of the pinyon-juniper and juniper forests in Utah are administered by the BLM, 15 percent by NFS, 10 percent by other public, and 13 percent are privately owned.

Number of Trees

The composition of the forest by individual tree species is one measure of forest structure. In Utah, it is estimated that the number of pinyon and juniper trees is about equal

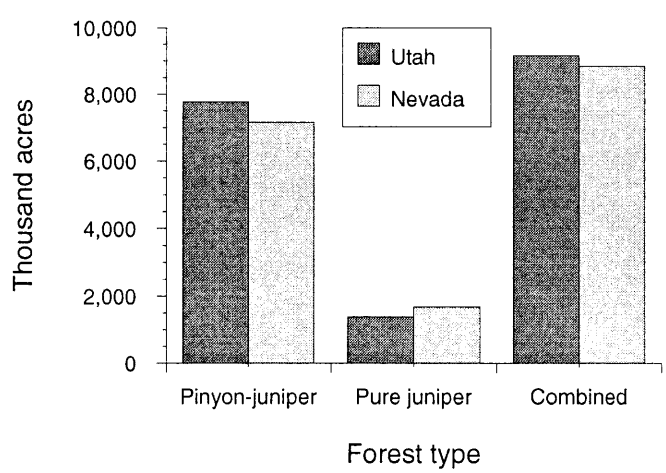

Figure 2—Area of pinyon-juniper and juniper forest types in Utah and Nevada.

(49 and 51 percent). Utah juniper makes up 92 percent, and Rocky Mountain juniper makes up 8 percent of the juniper trees. Twoneedle pinyon makes up 78 percent, and singleleaf pinyon makes up 22 percent of the pinyon trees. Pinyon makes up more of the small trees, with juniper comprising more of the trees greater than 7 inches diameter at root collar (d.r.c.). Fifty-eight percent of the total number of pinyon and juniper trees in Nevada are pinyon, but more of the trees 11 inches d.r.c. or greater are juniper.

Stand Density

Stand density index (SDI), as developed by Reineke (1933) is a relative measure of stand density that quantifies the relationship between trees per acre, stand basal area, average stand diameter, and stocking of a forested stand. The concept was developed for even-aged stands, but can also be applied to uneven-aged stands (Long and Daniel 1990). SDI is usually presented as a percentage of the maximum SDI for the type. A maximum SDI value of 465 was used for pinyon-juniper, and 344 for pure juniper. SDI was computed for each plot using those maximums, and the results were grouped into three classes. Figure 3 shows the three classes of SDI for each State. A site was considered to be fully occupied at 35 percent of SDI maximum, which marks the onset of competition related stresses and slowed growth rates. IWRIME estimates that 53 percent of pinyon-juniper stands in Utah and 49 percent in Nevada are at or above 35 percent of SDI maximum.

Stand Age

Age information is relatively difficult to obtain for pinyon-juniper stands because of tree form and the difficulty of counting growth rings. In Nevada, 3 trees reflecting the average or above average size in the stand were bored to get stand age. Junipers were not included because of perceived difficulty in boring, so ages on pinyon-juniper forest land in Nevada only came from pinyons. This represents a bias, because pure juniper stands were not aged. Age data were obtained for about 62 percent of stands sampled in Nevada. In Utah, only one woodland tree of any species reflecting the average of the stand (based on cruiser judgement) was aged, but cores were collected at all locations. Cores for all woodland trees sampled in Utah were sent into the office for aging and storage.

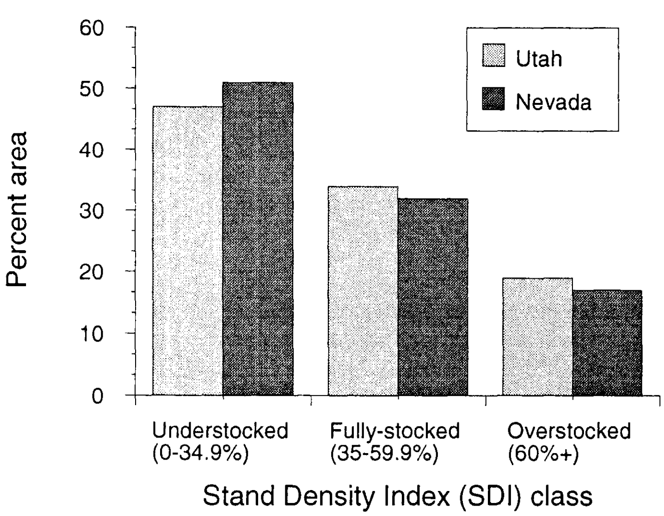

Figure 3—Percent area of combined pinyon-juniper and juniper forest types by SDI class, Nevada 1989 and Utah 1993.

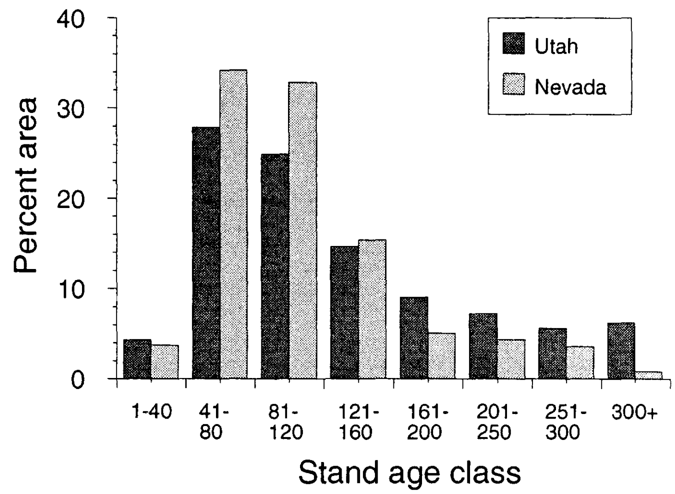

Figure 4—Percent area of combined pinyon-juniper and juniper forest types where ages were collected by stand age class, Nevada 1989 and Utah 1993.

Even though the two States had different protocols for tree selection, the pattern of age distribution was similar for both States. Based on this admittedly scanty age data, it is estimated that about 53 percent of the stands in Utah, and about 67 percent of the stands where age was sampled in Nevada were between 40 and 120 years old (fig. 4). Only about 20 percent of the stands in Utah and 9 percent in Nevada were over 200 years. A report on old growth, "Characteristics of Old-growth Forests in the Intermountain Region" (USDA 1993), defines old-growth criteria for pinyon-juniper forest types using trees per acre, tree diameters, and tree ages. Screening with a combination of just two of the criteria, stand age and stand-size class, showed that 14 percent of all Utah stands had an age of 200 years or greater and a stand size of 9 inches (d.r.c.) or greater.

Figure 5 presents the percent area of pinyon-juniper and juniper forest types (combined) by stand age class and ecoregion, and gives a rough indication of the differences among ecoregions. For example, more of the pinyon-juniper and juniper forest types in the Colorado Plateau Semi-Desert Province have a stand age between 161 to 300 years than in the other ecoregions. The American Semi-Desert and Desert Province has the most extreme differences by age class, due probably to the small number of plots in that ecoregion.

Because 120 years is roughly the amount of time since significant impacts from mining and settlement would have first been felt in these areas, the data for stands 120 years old or less was separated from stands greater than 120 years for

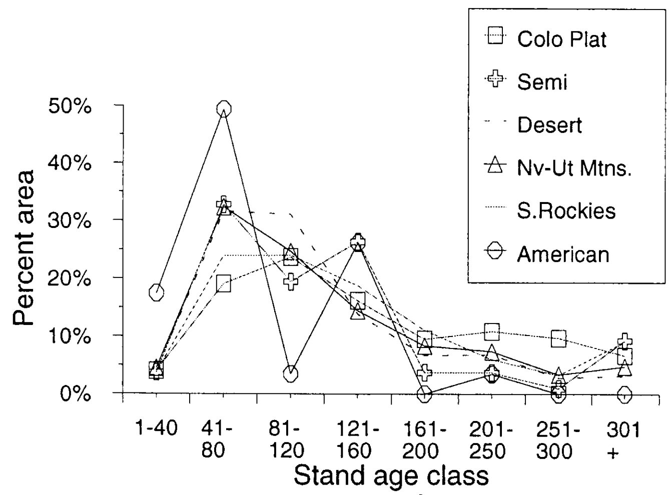

Figure 5—Percent area of combined pinyon-juniper and juniper forest types by stand age class and ecoregion, Nevada 1989 and Utah 1993.

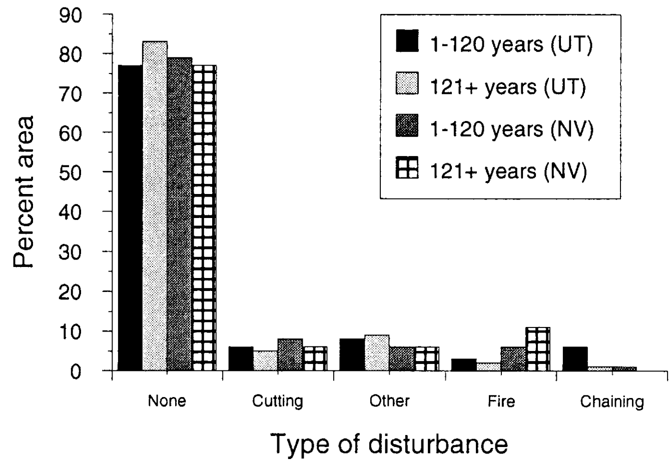

Figure 6—Percent area of combined pinyon-juniper and juniper forest types in each age category by type of visible disturbance, Nevada 1989 and Utah 1993.

additional analysis. About 71 percent of the pinyon-juniper stands sampled for age in Nevada, and about 57 percent in Utah are estimated to be less than 120 years old. Crews make a subjective field assessment of the predominant human or natural disturbance on each plot that impacts the entire condition. The percent of area with stand age 120 years or less is compared to the percent of area with stand age greater than 120 years in terms of evidence of disturbance in figure 6. The overwhelming majority of pinyon-juniper or juniper stands have no visible evidence of disturbance in either State. One of the categories of disturbance was chaining, which was evident on about only 6 percent of Utah plots 120 years old or less, and about 1 percent of Nevada plots 120 years old or less.

Volume

The total volume of wood in live pinyon and juniper trees on all forest types in both States is estimated to be in excess of 10.3 billion cubic feet. This number divided by a standard FIA conversion factor of 75 gives an estimate of the number of cords—137.5 million. Table 2 displays cubic foot volume by species, owner, and State.

Volume of all species on pinyon-juniper and juniper forest types averages about 459 cubic feet (6.1 cords) per acre in Nevada, and 659 cubic feet (8.8 cords) per acre in Utah.

Figure 7 shows the difference in cubic foot volume per acre between ecoregions. The range is from less than 200 cubic feet per acre in the American Semi-Desert and Desert Province to over 800 cubic feet per acre in the Southern Rocky Mountain Steppe-Open Woodland-Coniferous Forest-Alpine Meadow Province. These differences in average volume per acre may reflect the climatic and geographic differences among the ecoregions. These estimates include other species that might occur on pinyon-juniper and juniper forest types.

Growth and Mortality

Growth for pinyon and juniper species is characteristically low, and is difficult to measure. However, it is estimated that the gross growth rate for Nevada and Utah is 1 percent or less per year. The total mortality observed was only about 5 percent of growth in Nevada, and 15 percent of growth in Utah.

Table 2—Net volume of pinyon and juniper species by state and owner group, (thousand cubic feet).

State	Species	National forest	Owner: Other public	Owner: Private	Total
Utah	Pinyon	501,116	1,536,240	258,148	2,295,504
	Juniper	694,610	2,800,847	491,095	3,986,552
Nevada	Pinyon	548,906	1,437,842	153,811	2,140,559
	Juniper	361,110	1,407,143	120,898	1,889,151
Total		2,105,742	7,182,072	1,023,952	10,311,766

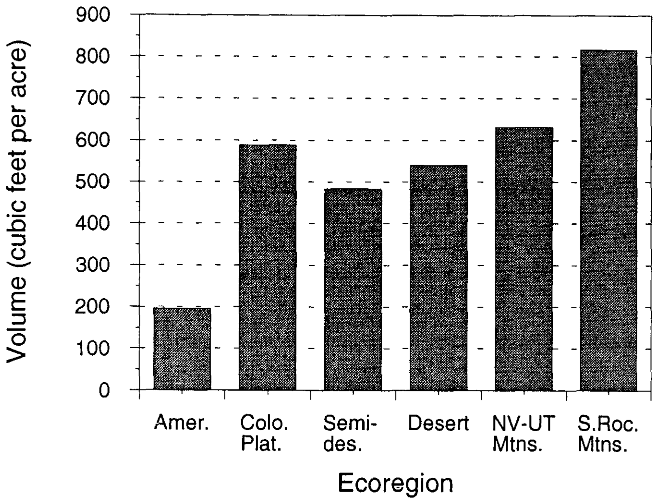

Figure 7—Cubic foot volume per acre on combined pinyon-juniper and juniper forest types, by ecoregion in Nevada 1989 and Utah 1993.

References

Bailey, Robert G., compiler. 1995. Descriptions of the ecoregions of the United States. 2nd ed. Misc. Pub. No. 1391. Washington DC: U.S. Department of Agriculture, Forest Service, Washington, DC. 108 p.

Born, J. David; Tymcio, Ronald P.; Casey, Osborne E. 1992. Nevada Forest Resources. Resour. Bull. INT-76. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 64 p.

Chojnacky, David C. 1998. Double sampling for stratification: a forest inventory application in the Interior West. Res. Pap. RMRS-RP-7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Long, James N.: Daniel, Theodore W. 1990. Assessment of growing-stock in uneven-aged stands. Western Journal of Applied Forestry 5(3):93-96.

O'Brien, Renee A. [In preparation]. Utah forest resources. Resour. Bull. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Reineke, L. H. 1933. Perfecting a stand-density index for even-aged forests. J. Agric. Res. 46:627-638.

U.S. Department of Agriculture, Forest Service. 1982. Nevada forest survey field procedures. Unpublished field guide on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, Interior West Resource Inventory, Monitoring, and Evaluation Program, Ogden, UT.

U.S. Department of Agriculture, Forest Service. 1993. Characteristics of old-growth forests in the Intermountain Region. Hamilton, Ronald C., compiler. Unpublished report on file at Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

U.S. Department of Agriculture, Forest Service. 1994. Utah forest survey field procedures, 1994-1995. Unpublished field guide on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Forestry Sciences Laboratory, Interior West Resource Inventory, Monitoring, and Evaluation Program, Ogden, UT. 232 p.

An Example of Pinyon-Juniper Woodland Classification in Southeastern Utah

Robert M. Thompson

Abstract—In a study on the Monticello Ranger District, Manti-LaSal National Forest, a continuous process was used in vegetation cover type classification, plant community classification, and mapping. Included are guidelines for dividing and classifying, as well as mapping instructions.

The pinyon-juniper woodland vegetative type occurs on about 21 percent of Manti-LaSal National Forest lands. This woodland type forms dense, closed stands on mesa tops, in canyon bottoms, on alluvial outslopes, and as scattered open stands on steeper side slopes and canyon walls.

The pinyon-juniper woodland vegetative type occurs in the 8 to 18 inch precipitation zone and at elevations between 5,000 and 8,500 ft. Soils within this type have a wide variety of textures and depths. Some of the soil groups are Ustochrept, Ustorthents, and Mollic eutroboralfs. Parent materials range from sedimentary, limestone, sandstone, and shales to igneous formations.

Vegetative cover type classification, plant community classification, and mapping is a continuous process. This paper describes a method for mapping and classification of some pinyon-juniper woodlands and plant communities found on the Monticello Ranger District, Manti-LaSal National Forest, UT.

Study Area

The study area (fig. 1) selected for site-specific pinyon-juniper woodland classification and plant community type mapping is located on the western half of the Monticello Ranger District, Manti-LaSal National Forest (South Cottonwood assessment area), UT. Generally, it includes all of the South Cottonwood drainage, the Dark Canyon Wilderness area, and the North and South Elk Ridges. There are 176,548 acres in this study area. Pinyon-juniper woodland covers 68,782 acres or 39 percent of the study area.

Classification of the Pinyon-Juniper Woodlands

The pinyon-juniper woodlands within the study area were classified and mapped at three different levels: Level 1—Pinyon-juniper (woodlands); Level 2—Pinyon-juniper (associations); and Level 3—Pinyon-juniper (plant communities).

Level 1—Pinyon-Juniper Woodlands

Pinyon-juniper woodlands can be divided into four broad types: (1) Pinyon-juniper mixed woodlands; (2) Utah juniper woodlands; (3) Pinyon woodlands; and (4) Rocky Mountain juniper woodlands.

Guidelines were developed to divide and classify the various woodland types.

Data obtained from study plots and site ocular observations are used to determine the composition of the overstory trees.

Woodland Classification

Dominant tree species make up 90 to 100 percent of the overstory composition.

- Utah juniper trees dominate
  - -Utah juniper woodlands
- Pinyon pine trees dominate
  - -Pinyon woodlands
- Rocky Mountain juniper trees dominate
  - -Rocky Mountain juniper woodlands

Dominant tree species make up 20 to 70 percent of the overstory composition.

- Mixed stands of pinyon and Utah juniper
  - -Pinyon-juniper mixed woodlands
- Mixed stands with Rocky Mountain juniper
  - Rocky Mountain juniper make up 50 to 70 percent of the tree composition
    - -Rocky Mountain juniper woodlands
  - Rocky Mountain juniper make up 10 to 30 percent of the tree composition
    - -Pinyon-juniper mixed woodlands

Level 2—Pinyon-Juniper Plant Association

A plant association is a combination of the dominant overstory tree species with a dominant understory plant species. When combined, they form a characteristic ecologic association.

Some plant species tend to give a dominant visual character to a site even though they are not the most abundant plant on the area. These plants may also be used to classify or determine a plant association. Introduced species should not be used.

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Select those dominant plant species that are common to the site, soils, aspects, geologic formations, and elevations.

Association Classification

Existing dominant shrub species make up 70 to 100 percent of the understory composition.

Associated Dominant Understory Shrub Species

Black sagebrush	*Artemisia nova* (ARNO)
Basin big sagebrush	*Artemisia* Tr. *tridentata* (ARTRT)
Mountain big sagebrush	*Artemisia* Tr. *vaseyana* (ARTRV)
True mountain-mahogany	*Cercocarpus montanus* (CEMO)
Littleleaf mahogany	*Cercocarpus intricatus* (CEIN)
Bitterbrush	*Purshia tridentata* (PUTR)
Serviceberry	*Amelanchier alnifolia* (AMAL)
Snowberry	*Symphoricarpos oreophilus* (SYOR)
Roundleaf buffaloberry	*Sheperdia rountifolia* (SHRO)
Oakbrush	*Quereus gambelii* (QUGA)
Green ephedra	*Ephedra viridis* (EPVI)
Greenleaf manzantia	*Arctostaphylos patula* (ARPA)

Shrub species make up only 10 to 40 percent of the understory species composition. Several species may be present, none dominate.

Mixed mountainbrush

No understory shrub species present

Use dominant understory ground cover plant species present.

Level 3—Pinyon Juniper Plant Communities and Habitats

A plant community is a combination of the overstory dominant tree species, shrub or dominant understory species, and dominant ground cover species three-layered.

Study plot data and some visual observation can be used to determine the dominant ground cover species. Plant species that are common to the existing soils, geologic formations, aspects, and elevations should be the prime candidate for selection for community classification.

Dominant species make up 40 to 100 percent of the ground cover species composition.

Select most dominant plant species for community.

Dominant species make up only 20 to 30 percent of the species composition. (Some once-dominant species that have been reduced to less than 5 to 20 percent of the composition, but are characteristic of a site, may be used to classify a type.)

Select most representative plant species.

No ground cover species present.

Lichens present
Annuals present

Dominant Ground Cover Plant Species

Rosses sedge	*Carex rossii* (CARO)
Dwarf lousewort	*Pedicularis centranthera* (PECEN)
Desert goldenrod	*Petradora pumila* (PEPU)
Western wheatgrass	*Agropyron smithii* (AGSM)
Salina wild ryegrass	*Elymus salinus* (ELSA)
Indian ricegrass	*Oryzopsis hymenoides* (ORHY)
Needlegrass	*Stipa comata* (STCO)
Galleta grass	*Hilaria jamesii* (HIJA)
Mutton grass	*Poa fondleriana* (POFE)
Sandberg bluegrass	*Poa secunda* (POSE)

Pinyon-Juniper Woodland Classification

Using the three-level concept, a pinyon-juniper woodland site can be classified as follows:

Pinyon-Utah Juniper Woodlands Type

Level 1—Pinyon-Utah juniper mixed woodlands.

Level 2—Pinyon-Utah juniper, black sagebrush (association).

Level 3—Pinyon (PIED), Utah juniper (JUOS), black sagebrush (ARNO), western wheatgrass (AGSM), (plant community).

Field Mapping and Plant Community Type Numbering

Each community site was located on the ground and its boundaries delineated on the aerial photo. The site was then classified into its level of classification (woodland, association, or plant community), and a descriptive name was applied.

Mapping Numbers

For mapping purposes and ease of designating each plant community type, a numbering system was developed. (The pinyon-juniper type based on the old Range Survey and Range Analysis was designated as a "9" type. The number "9" is used as a prefix for coding all pinyon-juniper types in the study area.)

The following woodland types, plant association, and plant communities were found within the study area.

Woodland Types

Map No.	Type
90	Pinyon-juniper (woodland)
91	Utah juniper (woodland)
92	Pinyon (woodland)
93	Rocky Mountain juniper (woodland)

Map No.	Type
90	Pinyon Utah juniper (woodland) This woodland type includes all sites where pinyon and Utah juniper occur in mixed stands. Tree composition may vary from 20 to 70 percent of either tree present on the site. It occurs mostly at the lower to mid elevations (6,000 to 7,500 ft), on rocky ridges, open bench lands, alluvial fans, and other slopes.
91	Utah juniper (woodland) This woodland type is dominated by Utah juniper (90 to 100 percent of the tree overstory is Utah juniper). It occurs mostly at the lower elevations

of the type (5,500 to 6,500 ft) and on rocky ridges, benchlands, and alluvial slope lands.

92 Pinyon (woodland)
This woodland type is dominated by pinyon, with 95 to 100 percent of the overstory being pinyon trees. It occurs at the mid to higher elevations of the woodland type (7,500 to 8,500 ft), on benchlands, mesa tops, and upper slope lands.

93 Rocky Mountain juniper (woodland)
This woodland type includes all of the sites dominated by Rocky Mountain juniper trees (50 to 90 percent). Some pinyon may be present (5 to 20 percent), and at the lower elevations, some Utah juniper may be present (1 to 5 percent). It occurs mostly at the mid elevations of the woodland type (7,000 to 8,000 ft), on benchlands and north slopes, along streams, and around some meadows and wet sites.

Plant Association

Map No. Type

Pinyon-Utah juniper woodland plant association

901 Pinyon-Utah juniper-black sagebrush
902 Pinyon-Utah juniper-mountain big sagebrush
903 Pinyon-Utah juniper-true mountainmahogany
904 Pinyon-Utah juniper-bitterbrush
905 Pinyon-Utah juniper-serviceberry/oakbrush
906 Pinyon-Utah juniper-snowberry
908 Pinyon-Utah juniper-roundleaf buffaloberry

Utah juniper woodland plant association

910 Utah juniper-black sagebrush

Pinyon woodland plant association

920 Pinyon-oakbrush
921 Pinyon-serviceberry
922 Pinyon-snowberry
923 Pinyon-mixed mountain brush

Plant Communities

Map No. Plant communities and habitats

901 Pinyon-Utah juniper-black sagebrush

9010 Pinyon (PIED), Utah juniper (JUOS), black sagebrush (ARNO), western wheatgrass (AGSM), Sandberg bluegrass (POSE)
9011 Pinyon (PIED), Utah juniper (JUOS), black sagebrush (ARNO), needlegrass (STCO), Indian ricegrass (ORHY)
9013 Pinyon (PIED), Utah juniper (JUOS), black sagebrush (ARNO), blue grama grass (BOGR)
9014 Pinyon (PIED), Utah juniper (JUOS), black sagebrush (ARNO), chained and reseeded
9017 Pinyon (PIED), Utah juniper (JUOS), basin big sagebrush (ARTRW), squirreltail (SIHY)

902 Pinyon-Utah juniper-mountain big sagebrush

9020 Pinyon (PIED), Utah juniper (JUOS), big mountain sagebrush (ARTRV), western wheatgrass (AGSM)
9023 Pinyon (PIED), Utah juniper (JUOS), mountain big sagebrush (ARTRV), needlegrass (STCO)
9024 Pinyon (PIED), Utah juniper (JUOS), mountain big sagebrush (ARTRV), chained and reseeded (AGER, BRIN, AGIN)

903 Pinyon (PIED), Utah juniper (JUOS), true mountainmahogany

9032 Pinyon (PIED), Utah juniper (JUOS), true mountainmahogany (CEMO), needlegrass (STCO), Indian ricegrass (ORHY)
9033 Pinyon (PIED), Utah juniper (JUOS), little leaf mahogany (CEIN), Rosses sedge (CARO), (slick rock)

904 Pinyon (PIED)-Utah juniper (JUOS)-bitterbrush

9040 Pinyon (PIED), Utah juniper (JUOS), bitter brush (PUTR), needlegrass (STCO), Indian ricegrass (ORHY)
9041 Pinyon (PIED), Utah juniper (JUOS), bitterbrush (PUTR), western wheatgrass (AGSM), Sandberg bluegrass (POSE)
9042 Pinyon (PIED), Utah juniper (JUOS), bitterbrush (PUTR), western wheatgrass (AGSM)
9043 Pinyon (PIED), Utah juniper (JUOS), bitterbrush (PUTR), chained and reseeded (AGCR, BRIN, AGIN)
9044 Pinyon (PIED), Utah juniper (JUOS), bitterbrush (PUTR), cliff rose (COST), needlegrass (STCO), lichen

908 Pinyon (PIED), Utah juniper (JUOS), roundleaf buffaloberry

9081 Pinyon (PIED), Utah juniper (JUOS), roundleaf buffaloberry (SHRO), Sandberg bluegrass (POSE)

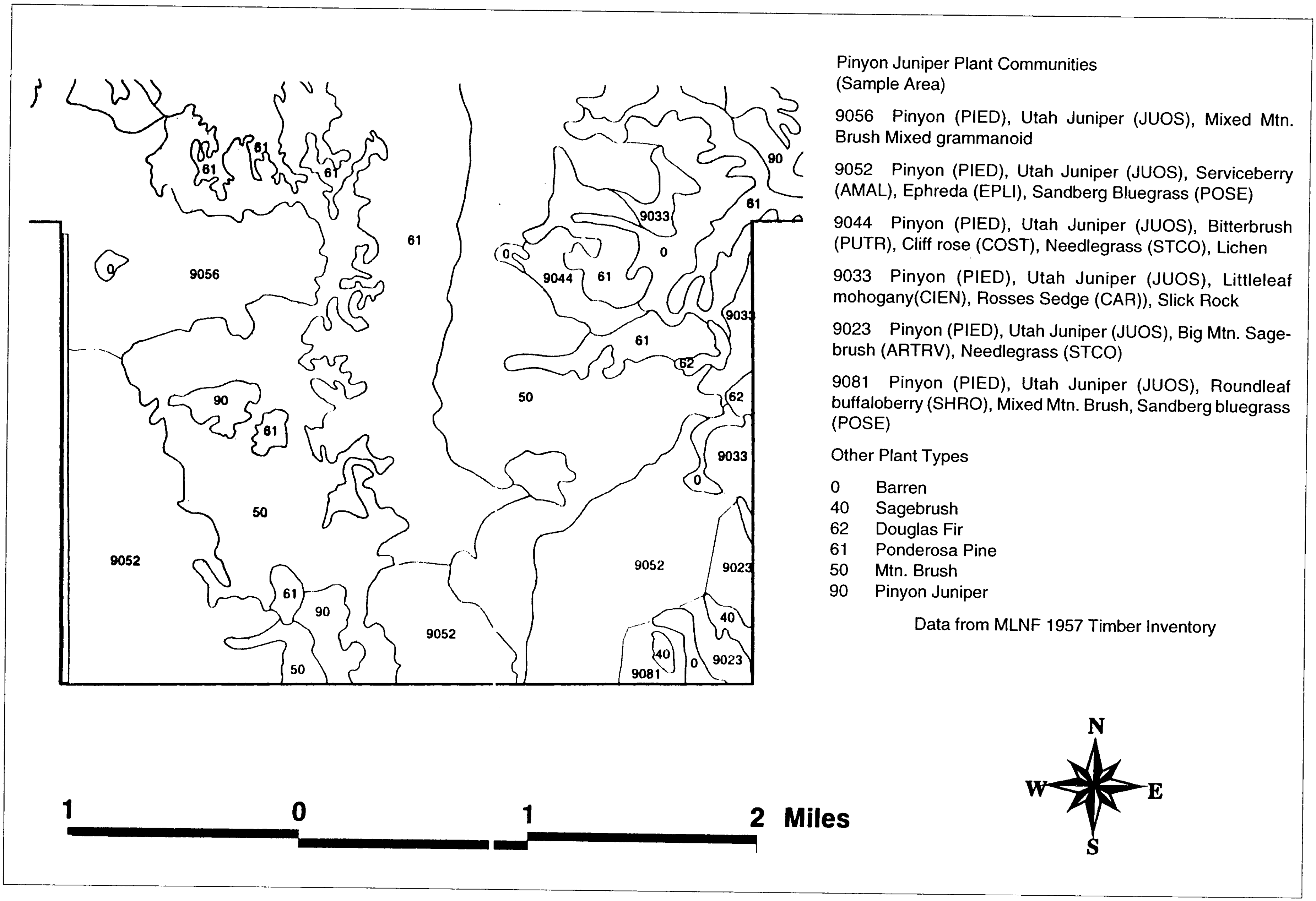

Figure 1—Vegetative cover, South Cottonwood assessment area, Moab-Monticello Ranger Disrict, Manti-La Sal National Forest.

Gradient Analysis of Pinyon-Juniper Woodland in a Southern Nevada Mountain Range

Simon A. Lei

Abstract—The environmental variables and distribution of singleleaf pinyon-Utah juniper woodland were examined along an elevational gradient in Lee Canyon of southern Nevada. TWINSPAN classification identified four primary species groups that were dominated by blackbrush, big sagebrush, singleleaf pinyon, and ponderosa pine, respectively, as elevation increased. DECORANA analysis indicated that the distribution of stand and species groups was strongly associated with elevation, soil moisture, air temperature, percent bare soil and rock cover, and soil depth. These attributes associated with changing elevation appeared to be important in organizing the current vegetation assemblages in southern Nevada.

Creosote bush-bursage (*Larrea tridentata-Ambrosia dumosa*), blackbrush (*Coleogyne ramosissima*), singleleaf pinyon-Utah juniper (*Pinus monophylla-Juniperus osteosperma*), and ponderosa pine-white fir (*Pinus ponderosa-Abies concolor*) are four common vegetation types as elevation increases in southern Nevada. Previous studies in the mountain ranges of southern Utah and Nevada have been documented regarding changes in vegetation types that corresponded largely with abiotic factors (Beatley 1974; Bowns 1973; Bowns and West 1976; Turner 1982). Such factors include precipitation, soil moisture, soil depth, and air and soil temperatures. Soil moisture and cold winter air temperatures appear to control the distribution of pinyon-juniper trees at their lower and upper elevational boundaries, respectively, in Utah (Wright and others 1979). Shallow soils are typical of blackbrush shrublands due to the presence of caliche layers, and may partially determine the distribution and abundance of blackbrush shrubs in Utah (Callison and Brotherson 1985). Decreased air and soil temperatures, increased precipitation, and increased soil moisture were strongly associated with increasing elevation in the Spring Mountains (Lei and Walker 1995, 1997a,b). However, other abiotic factors that potentially influence the distribution of pinyon-juniper woodlands in southern Nevada are not properly understood.

In this study, elevation was designed to determine which abiotic factors change with changing elevation. The objectives of this study were (1) to calculate relative density of woody perennial species, (2) to classify vegetation types, and (3) to investigate the relationships between stand and species groups and environmental variables. Examining environmental parameters help elicit the ecological requirements of woody plant species and the specific environment they occupy in a current pinyon-juniper vegetation zone in southern Nevada.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Methods

Study Site

The study was conducted in Lee Canyon (roughly 36°05' N, 115°45' W), located 50 km northwest of Las Vegas, Nevada, on the east-facing slope of the Spring Mountains. The temperature and precipitation data were obtained from the nearest long-term weather station (record of climatological observations; National Weather Service) in Kyle Canyon, located approximately 15 km from Lee Canyon. Lee Canyon is an area of temperature extremes with a mean minimum January temperatures of –12 °C ranging to 26 °C for a mean July maximum. Winter months are frigid, often associated with strong winds, whereas summer months are cool with air temperatures rarely surpass 32 °C.

The Precipitation patterns include summer storms and winter rains. Summer storms and rainfalls generally occur in July and August, and can sometimes be locally intense. Winter rainfalls tend to be mild, and may last several days. Snow is frequent at high elevations. Winter precipitation contributes significantly to the annual precipitation, which ranges from 300 to over 600 mm in the ponderosa-fir woodland, and usually less than 400 mm in the pinyon-juniper woodland.

The bajada consists of benches interspersed by dry washes, which become more abundant and shallow when moving down slope near the bottom of the canyon. A nearly monospecific blackbrush shrubland occurs at mid-elevations on well-drained colluvial slopes. Caliche outcroppings are evident along the banks of washes on the bajada of the blackbrush zones. A pinyon-juniper woodland exists above the blackbrush shrublands, and a montane ponderosa pine-white fir forest occurs above the pinyon-juniper zone on relatively high mountain slopes in Lee Canyon.

Field Surveys

Vegetation and soil measurements were conducted at Lee Canyon in the Spring Mountains during the summer of 1996. An elevational gradient was established that began in the upper portion of the blackbrush shrubland, crossed the entire pinyon-juniper belt, and terminated in the lower portion of the montane ponderosa pine-white fir forest. Five 200-m^2 (8.0 m radius) circular stands (plots) were established at 18 sample points, located at 65-m elevation increments between 1,700 and 2,600 m. The total elevational change was 900 m and 90 stands were measured. Topographies of the transect included bench terraces, hill slopes, and dry washes. However, when cliff and stream bed sites were encountered, a substitute stand was placed approximately 50 m from the original transect at the identical elevation.

Within each stand, all woody perennial plant species (>10 cm tall), including subshrubs (suffrutescent), were identified (Munz 1974) and counted. Elevation and aspect of each plot were recorded using an altimeter and a compass, respectively. Soil depth to hardpan was estimated by striking a steel rod into the undisturbed soils until the rod could no longer penetrate. Soil depth was estimated by averaging 10 random samples within each stand. Gravimetric soil moisture was determined by calculating the differences between the fresh and oven-dried mass. Air temperatures at 1.5 m above ground were recorded. The ground surface of each stand was characterized as cemented or non-cemented desert pavement, loose rocks, sandy, or sandy with boulders. Percent soil and rock cover were visually quantified, and were assigned a cover class using the following scales: 0 = <1 percent; 1 = 1-5 percent, 2 = 6-25 percent, 3 = 26-50 percent, 4 = 51-76 percent, and 5 = 76-100 percent. Each circular stand was located at least 50 m away from any main and secondary roads to eliminate direct and indirect road effects.

Statistical Analyses

Classification and ordination techniques were applied from the 90 sampled stands in Lee Canyon. The relative density of each species was calculated for each stand by dividing the number of individuals of a species by the total number of individuals, and multiplying by 100 (Muller-Dombois and Ellenberg 1974). Each species relative density was entered into a species-stand matrix and classified with TWINSPAN (Hill 1979a), a divisive hierarchical classification technique that yields a two-way classification of species and stands. The dichotomy was terminated when a group consisted of four or fewer plots (Kent and Coker 1992).

For each sample location, the species relative densities and the environmental variables were ordinated with DECORANA (Hill 1979b), a method utilized for defining the environmental gradients within a set of vegetation data. The species relative densities were also subjected to DECORANA analysis that generated stand and species ordination diagrams where each point represented a stand and a species, respectively. Environmental parameters at each sample location included elevation, stand aspect, topography, soil depth, type of ground surface, as well as percent bare soil and rock cover. Each environmental parameter was then matched with axes 1 and 2 of the stand ordination scores acquired from DECORANA to determine correlations between stand groups and environmental factors (Analytical Software 1994).

Results

Desert vegetation at upper elevations in Lee Canyon of the Spring Mountains consisted of 33 woody perennial species. The TWINSPAN classification suggested that these 33 species were organized into four primary species groups along the elevational gradient at Lee Canyon of southern Nevada (fig. 1; table 1).

Species in group A were typical of monospecific blackbrush vegetation zone. Joshua tree, turpentine bush (*Thamnosma*

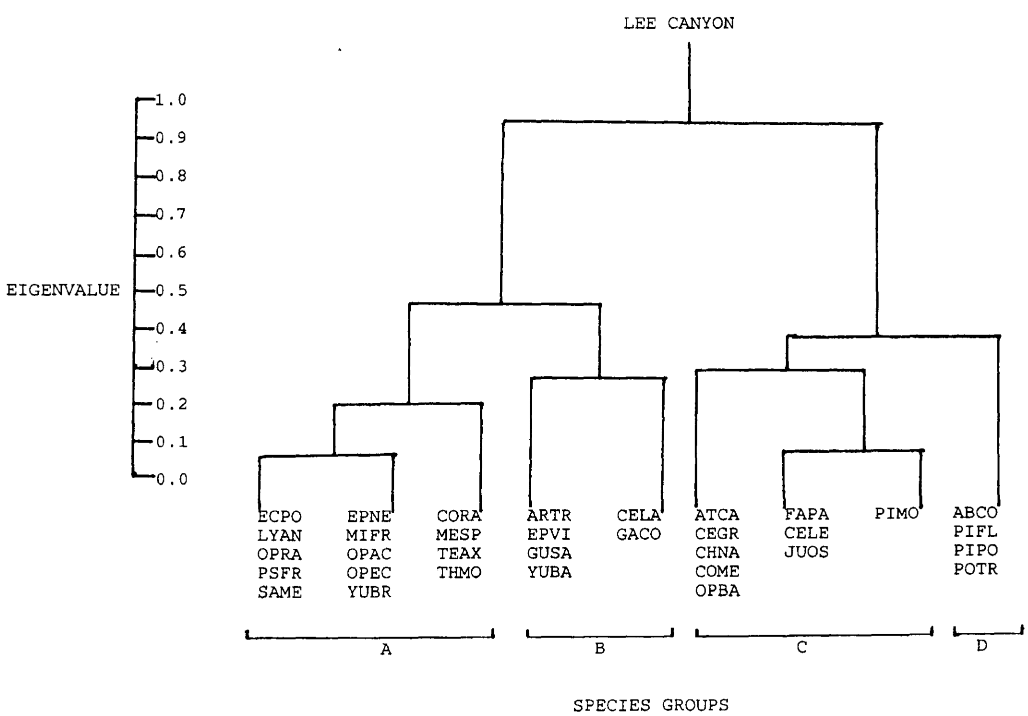

Figure 1—Dendrogram of TWINSPAN analysis of 33 woody taxa surveyed in Lee Canyon of the Spring Mountains. The four major species groups are segregated by brackets, and are arranged from the lowest (Group A) to the highest (Group D) elevational groups. Species within each group are arranged alphabetically. Species abbreviations corresponded to the first two letters of the genus and species listed in table 1.

Table 1—Woody and suffrutescent taxa establishing at Lee Canyon of the Spring Mountains. Symbols of lifeforms: T = Tree; S = Shrub; Ss = Subshrub (suffrutescent); and Su = Succulent.

Species	Lifeform	Abbreviation
Abies concolor	T	ABCO
Artemisia tridentata	S	ARTR
Atriplex canescens	S	ATCA
Ceanothus greggii	S	CEGR
Ceratoides lanata	S	CELA
Cercocarpus ledifolius	T	CELE
Chrysothamnus nauseosus	S	CHNA
Coleogyne ramosissima	S	CORA
Cowania mexicana	S	COME
Ephedra nevadensis	S	EPNE
Ephedra viridis	S	EPVI
Fallugia paradoxa	S	FAPA
Gaura Coccinea	S	GACO
Gutierrezia sarothrae	Ss	GUSA
Juniperus osteosperma	T	JUOS
Lycium andersonii	S	LYAN
Menodora spinescens	S	MESP
Mirabilis froebelii	S	MIFR
Opuntia acanthocarpa	Su	OPAC
Opuntia basilaris	Su	OPBA
Opuntia echinocarpa	Su	OPEC
Opuntia ramosissima	Su	OPRA
Pinus flexilis	T	PIFL
Pinus monophylla	T	PIMO
Pinus ponderosa	T	PIPO
Populus tremuloides	T	POTR
Psorothamnus fremontii	S	PSFR
Salazaria mexicana	S	SAME
Tetradymia axillaris	S	TEAX
Thamnosma montana	S	THMO
Yucca baccata	S	YUBA
Yucca brevifolia	T	YUBR

montana), and Mormon tea (*Ephedra nevadensis*) were some of the common associated species occurring at mid-elevation (fig. 1). Species in group B were typical of lower pinyon-juniper ecotone (fig. 1), with big sagebrush (*Artemisia tridentata*) as the dominant species in terms of density and total vegetation cover. Big sagebrush became less abundant and were an understory shrub in the pinyon-juniper woodland. Species in group C were characterized by pinyon-juniper woodland, with singleleaf pinyon as the most abundant species (fig. 1). Pinyon-juniper woodland often shared a relatively broad lower ecotone with blackbrush. Species in group D were characterized by montane ponderosa-fir forest, and were established on desert mountain slopes at high elevations above the pinyon-juniper woodland. Limber pine (*Pinus flexilis*) and quaking aspen (*Populus tremuloides*) were the representative species (fig. 1).

The DECORANA ordination of the 90 stands on axes 1 and 2 is shown in figure 2, and revealed the distribution of the four TWINSPAN-based vegetation types. The DECORANA analysis detected a significant stand group segregation along axis 1, but not along axis 2 (fig. 2). Results of Pearson's correlation analysis (table 2) showed that axis 1 of the stand ordination was significantly correlated with elevation, soil moisture, air temperature, percent bare soil, percent rock cover, and soil depth in descending order of significance. However, axis 2 was not significantly correlated with any

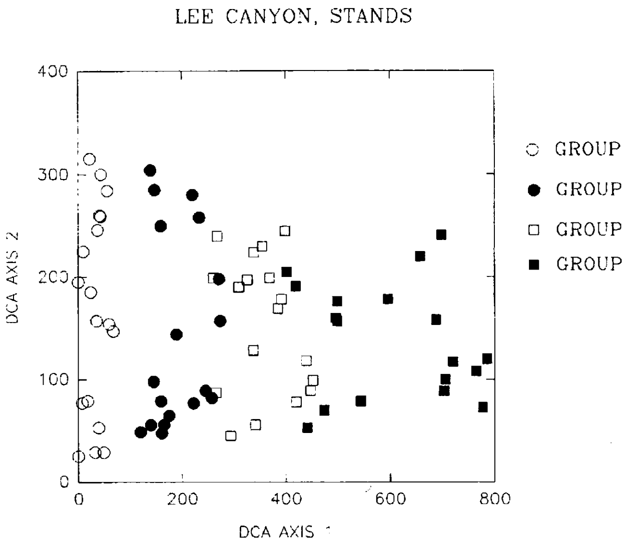

Figure 2—DECORANA ordination of 90 stands in Lee Canyon of the Spring Mountains. Different symbols represent major groups delimited by TWINSPAN. Axis 1 of the stand ordination was significantly correlated with elevation, soil moisture, air temperature, percent bare soil and rock cover, and soil depth. Some points were eliminated to aid visualization.

environmental variables (table 2). Ordination of the four TWINSPAN-based species groups and individual species on axes 1 and 2 is illustrated in figure 3, showing that different plant species occupied different elevations and vegetation zones in southern Nevada.

Discussion

Significant correlations between the distribution of plant communities and environmental variables were detected at Lee Canyon of the Spring Mountains in southern Nevada. Blackbrush, big sagebrush, singleleaf pinyon, and

Table 2—Pearson's correlation coefficient (r-value) corresponding with the first and second axes of stand ordination scores acquired from DECORANA to various environmental factors. r-values were determined from the analysis of 90 sampled stands located at Lee Canyon of the Spring Mountains. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$, and NS: Non-Significant.

Factor	Axis 1	Axis 2
	- - - - - - - - - - *r* - - - - - - - - - -	
Elevation	-0.97^{***}	-0.04^{NS}
Soil moisture	0.95^{***}	0.16^{NS}
Air temperature	-0.89^{***}	-0.08^{NS}
Percent soil cover	0.87^{***}	-0.12^{NS}
Percent rock cover	-0.85^{***}	0.09^{NS}
Soil depth	0.83^{***}	-0.06^{NS}
Ground surface	-0.37^{NS}	-0.29^{NS}
Topography	-0.17^{NS}	-0.38^{NS}
Plot aspect	$\leq 0.01^{NS}$	-0.42^{NS}

ponderosa pine were the strong indicators of the species groups A, B, C, and D, respectively, distributed along a gradient of increasing elevation. The most important environmental factors associated with the distribution of stand and species groups were elevation, soil moisture, air temperature, percent bare soil and percent rock cover, and soil depth, in descending order of significance.

TWINSPAN results revealed a major dichotomy between high and low elevation communities, with each community splitting into two elevational phases. The first TWINSPAN dichotomy segregated low elevational communities, with a high abundance of blackbrush and big sagebrush shrubs, from high elevational communities, with pinyon-juniper and ponderosa-fir trees (fig. 1). Precipitation and soil moisture are positively correlated with elevation, while air and soil temperatures are negatively correlated with elevation (Lei and Walker 1997b). The first dichotomy within species groups A and B separated species generally existing in the big sagebrush stands (upper blackbrush ecotone) from the nearly monospecific blackbrush vegetation, which had an increase in soil moisture and soil organic matter and a decrease in soil compaction and soil temperatures (Lei and Walker 1997b).

Species in group B were characterized by big sagebrush shrubs with snakeweed (*Gutierrezia sarothrae*) as the most common associated species (fig. 1). Although Joshua tree may occur in abundance with creosote bush or Utah juniper, it frequently coexists with blackbrush in the Mojave Desert (Turner 1982). The dominance of Joshua tree is more visual than real and contributes little to the total stand composition and vegetation cover (Turner 1982).

The second TWINSPAN dichotomy segregated species existing at the upper blackbrush ecotone (group C) from those existing at higher elevations (group D; fig. 1). Blackbrush vegetation zones often form relatively broad upper ecotones. Singleleaf pinyon was the most abundant species in group C, and frequently establishes above the upper blackbrush ecotones in southern Nevada. Species in group D (fig. 1) were typical of high mountain slope vegetation with frigid winter air temperatures accompanied by relatively strong winds. Precipitation is usually in the form of snow, which can remain on the ground for extended periods in the winter and early spring (Turner 1982).

Axes 1 and 2 of the DECORANA stand and species ordination (figs. 2 and 3, respectively) were used to generate hypotheses in identifying probable environmental attributes on the distribution of individual stands and species. DECORANA ordination of the 90 sampled stands (fig. 2) revealed a significant stand group segregation along axis 1 only. Zonation of woody desert vegetation with respect to elevation is conspicuous in Lee Canyon. Environmental attributes, such as temperature, precipitation, and associated soil development processes, are important in organizing the final groupings of stands and species. Ecological attributes associated with changing elevation largely determine species distribution and vegetation associations.

Soil depth declined at mid-elevations and was typical blackbrush zones (Lei and Walker 1997a and b). The greatest root biomass in these shrubland is located between 10 to 30 cm (Bowns 1973). The low root:shoot ratio is related to shallow soil depth, impeding by the presence of caliche layers (West 1983). Soil depth began to increase at the upper blackbrush ecotone and increased considerably in each of the two vegetation zones above blackbrush (Lei and Walker 1997a). Hence, shallowness of soils appeared to be an important feature of the blackbrush zones and may partially determine the presence and absence of blackbrush shrubs in southern Nevada (Callison and Brotherson 1985; Lei and Walker 1997a,b). Shallow soils do not store abundant water, and more water is stored in deeper soils which can support relatively large trees, such as limber pine, ponderosa pine, and white fir. Soil texture, air temperatures, and precipitation patterns are also an important influence on soil moisture storage. Persistent snow cover at higher elevation and slow melt later into the spring can lengthen the period of recharge and provide more soil water, which can permit larger and more productive individuals or species.

The percent bare soil cover generally increased with elevation, while the percent rock cover decreased with elevation in Lee Canyon. Percent bare soil and rock cover are not likely to be causal agents in the vegetational mosaic. They are probably the consequence of vegetation cover, rather than a cause for vegetation patterns. Moreover, dense woodland vegetation normally does not establish well with abundant rocks on the soil surface (Lei 1994, 1995). Nevertheless, limited small pockets of soft materials may exist among the rock fragments where seedlings may grow and survive (Lei 1994, 1995).

Implications and Future Directions

The results of classification and ordination analyses using vegetation and environmental data from Lee Canyon support previous studies in Utah and southern Nevada that certain abiotic factors limit the distribution of vegetation

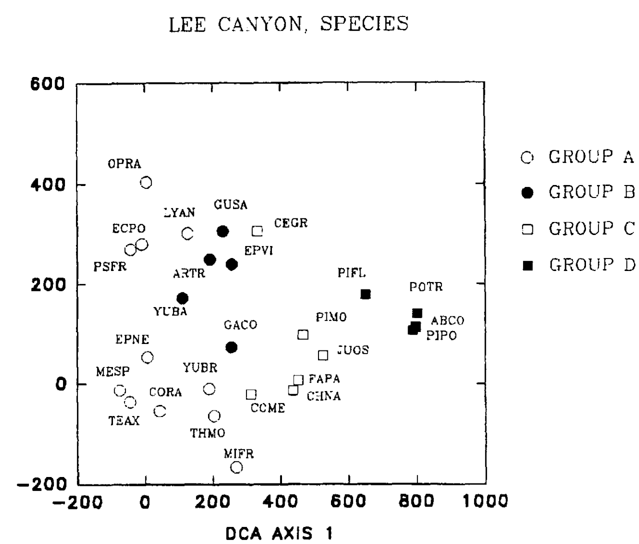

Figure 3—DECORANA ordination of 33 species in Lee Canyon of the Spring Mountains. Different symbols represent major groups delimited by TWINSPAN. Species abbreviations are corresponded to the first two letters of the genus and species listed in table 1.

zones (Beatley 1974; Bowns and West 1976). Plant assemblages in Lee Canyon may be representative of vegetation and landscape conditions at high mountain slopes throughout southern Nevada. However, relationships between environmental factors and the distribution of species are strictly correlative. Correlation between two variables does not necessary mean that a cause-effect relationship exists between them. Understanding additional ecological attributes or processes are essential for developing a local model that can accurately predict species and community distribution and abundance. Establishment of long-term plots, as well as experimental, physiological, and ecosystem approaches are necessary to determine cause-effect relationships between the distribution of the Mojave Desert plant communities and associated abiotic factors in southern Nevada.

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References

Analytical Software. 1994. Statistix 4.1, an interactive statistical program for microcomputers. Analytical Software. 329 p.

Beatley, J. C. 1974. Effects of rainfall and temperature on the distribution and behavior of *Larrea tridentata* (creosote-bush) in the Mojave Desert of Nevada. Ecology. 55: 245-261.

Bowns, J. E. 1973. An autecological study of blackbrush (*Coleogyne ramosissima* Torr.) in southwestern Utah. Unpublished dissertation, Utah State Univ., Logan, Utah.

Bowns, J. E. and N. E. West. 1976. Blackbrush (*Coleogyne ramosissima* Torr.) on southern Utah rangelands. Department of Range Science, Utah State University. Utah Agricultural Experimental Station, Research report 27.

Callison, J. and J. D. Brotherson. 1985. Habitat relationship of the blackbrush community *(Coleogyne ramosissima)* of southern Utah. Great Basin Naturalist 45:321-326.

Hill, M. O. 1979a. TWINSPAN: A Fortran program for arranging multivariate data in an ordered two-way table by classification of individuals and attributes. Ecology and Systematics, Cornell University, Ithaca, New York.

Hill, M. O. 1979b. DECORANA: A Fortran program for detrended correspondence analysis and reciprocal averaging. Ecology and Systematics, Cornell University, Ithaca, New York.

Kent, M. and P. Coker. 1992. Vegetation description and analysis: a practical approach. Belhaven Press, London, United Kingdom. 363 p.

Lei, S. A. 1994. Plants of the North American deserts. Unpublished research report, University of Nevada, Las Vegas.

Lei, S. A. 1995. A gradient analysis of *Coleogyne ramosissima* communities in southern Nevada. Unpublished master's thesis, University of Nevada, Las Vegas.

Lei, S. A. and L. R. Walker. 1995. Classification and ordination of *Coleogyne* communities in southern Nevada. Abstract of the 80th Annual Ecological Society of American Meeting. 158 p.

Lei, S. A. and L. R. Walker. 1997a. Classification and ordination of *Coleogyne* (blackbrush) communities in southern Nevada. Great Basin Naturalist. 57: 155-162.

Lei, S. A. and L. R. Walker. 1997b. Biotic and abiotic factors influencing the distribution of *Coleogyne* communities in southern Nevada. Great Basin Naturalist. 57: 163-171.

Muller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York. 547 p.

Munz, P.A. 1974. A flora of Southern California. University of California Press, Berkeley, California. 1086 p.

Smith, S. D.; [and others]. 1995. Structure of woody riparian vegetation in Great Basin National Park. In: Roundy, Bruce A.; McArthur, E. Durant; Haley, Jennifer S.; Mann, David K., comps. 1995. Proceedings: Wildland Shrub and Arid Land Restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 246-251.

Turner, R. M. 1982. Biotic communities of the American southwest—United States and Mexico. Geological Survey, U.S. Department of the Interior.

West, N. E. 1983. Colorado plateau-Mohavian blackbrush semidesert. In: Temperate desert and semi-deserts. Elsevier Scientific Publishing Company, Amsterdam, Netherlands: 399-411.

Wright, H. A.; L. F. Neuenschwander, and C. M. Britton. 1979. The role and use of fire in sagebrush-grass and pinyon-juniper plant communities. USDA Forest Service. Gen. Tech. Rep. INT-58. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Cheatgrass Frequency at Two Relic Sites Within the Pinyon-Juniper Belt of Red Canyon

Sherel Goodrich
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Abstract—Frequency of cheatgrass (*Bromus tectorum*) is reported for two relic sites within a belt of Colorado pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*), where non-Native Americans and their livestock are likely to have had little effect.

Young and Tipton (1990) suggested the concept of cheatgrass spreading in a biological vacuum created by grazing may be somewhat misleading or overstated, and they cited two works from Washington that documented observations of cheatgrass successfully inserting itself into climax perennial grass/shrub communities that had been protected from fire and grazing for as long as 50 years. While livestock grazing is a factor in the spread of cheatgrass, other works collaborate the idea that livestock grazing and other human-induced disturbance are not the only factors. Kindschy (1994) reported the presence and increase of cheatgrass in southeastern Oregon's Jordan Crater Research Natural Area that has been protected from human activities including livestock grazing. Tausch and others (1994) found cheatgrass has displaced native perennial species on Anaho Island in Nevada despite a general absence of human-caused disturbance and fire. They attributed the increase to the competitive ability of cheatgrass. Knight (1994) reported the cheatgrass problem is not restricted to land managed for livestock, and he gave an example of an increase of cheatgrass following fire in Little Bighorn Battlefield National Monument in southern Montana. He suggested that managing vegetation of a National Monument so it reflects presettlement conditions is a goal that may be impossible once certain introduced species become established.

The sites of this study are located within a belt of Colorado pinyon (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) within the Green River corridor, Daggett County, Utah. They are located on steep, warm exposures within Red Canyon above the Flaming Gorge Reservoir at about 1,890 to 1,950 m (6,200-6,400 ft) elevation and about 9.7 km (6 miles) west of Dutch John, UT, where data from the Flaming Gorge Weather Station indicates mean annual precipitation for the area of 31.75 cm (12.50 inches) (Ashcroft and others 1992).

In the Bare (Bear) Mountain area of the Green River corridor, Smith (1992) and Greenwood and others (these proceedings) found older pinyon-juniper burns were highly preferred by bighorn sheep (*Ovis canadensis*). In these studies, bighorn sheep were also found to frequently use areas where fire (including recent fire) kept pinyon and juniper at low levels. However, these workers also found the sheep avoided moderate or dense stands of pinyon-juniper, and recent burns in dense stands of pinyon-juniper where tree skeletons were still standing. Radio monitored sheep were found repeatedly in a pinyon-juniper burn site (Site 5-26) in which size and growth form of the trees that established since the fire indicate the burn to have been about 80 years old. Trees at the site were small and scattered and the site was dominated by grasses. Another site, which apparently had not been burned in the past 150 years or more, had open tree cover (Site 5-18), and it was also used by bighorn sheep in preference to surrounding areas with greater canopy cover of pinyon-juniper. Rock debris covered about 50 percent of both sites, which were located below massive cliffs. These sites were visited in 1988 and 1991 to monitor forage conditions in relation to bighorn sheep. The bighorn sheep herd is not expected to have played an important role in plant community dynamics and composition since this was a transplanted herd of 1983 and 1984.

Domestic livestock use is expected to have been minimal as the sites were protected by massive cliffs and steep slopes. The sites are within a large area that has been closed to permitted livestock grazing since the early 1960's.

Methods and Results

Frequency of plant species was determined in 100 quadrats of 50 by 50 cm at intervals of 1.5 m (5 ft) along five belts of which each was 30.5 m (100 ft) long. Within these quadrats, presence of species was recorded in nested frequency plots of 5 by 5 cm, 25 by 25 cm, and 25 by 50 cm as well as the 50 by 50 cm quadrat.

Table 1 shows quadrat frequency and nested frequency values. Sampling methods are those outlined by U.S. Department of Agriculture, Forest Service (1993) in which each species has a potential nested frequency score of 400.

Other species of low frequency (not listed in table 1) were also found on the sites. Ground cover was also determined by a point method that indicated 54 percent of the surface was covered by rock at both sites. Ground cover provided by vegetation and litter was about 30 percent at both sites, and

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Table 1— Quadrat frequency percent (QF) and nested frequency (NF) score based on a potential score of 400.

Species	Site 5—26		Site 5—18	
	QF%	NF Score	QF%	NF Score
Cheatgrass (*Bromus tectorum*)	94	286	67	143
Bluebunch wheatgrass (*Elymus spicatus*)	53	110	2	6
Hairy goldenaster (*Heterotheca villosa*)	39	89	—	—
Louisiana wormwood (*Artemisia ludoviciana*)	23	50	—	—
Brickellbush (*Brickellia scabra*)	13	19	—	—
Plains mustard (*Schoencrambe linifolia*)	8	19	—	—
Muttongrass (*Poa fendleriana*)	8	18	—	—
Prickleypear (*Opuntia* sp.)	7	16	—	—
Tansy—mustard (*Descurainia pinnata*)	12	16	2	5
Broom snakeweed (*Gutierrezia sarothrae*)	4	12	6	14
Fringed sagebrush (*Artemisia frigida*)	5	11	—	—
Needle—and—thread grass (*Stipa comata*)	5	11	—	—
Sanddrop seed (*Sporobolus cryptandrus*)	3	5	1	3
Yellow—eye cryptanth (*Cryptantha flavoculata*)	5	9	—	—
Indian ricegrass (*Stipa hymenoides*)	1	1	3	8
Bottlebrush squirreltail (*Elymus elymoides*)	—	—	3	9
Black sagebrush (*Artemisia nova*)	—	—	4	10
Big sagebrush (*Artemisia tridentata*)	—	—	5	9

15 to 20 percent of both sites showed exposed soil and pavement (gravel fragments less than 2 cm or 0.75 inches in diameter).

Discussion

Cheatgrass was by far the most frequent species at both study sites. Its high frequency indicates its high capacity to drive plant community dynamics for many years following fire in the pinyon-juniper belt on steep, south-facing, rocky slopes of Red Canyon in the absence of livestock and with little use by humans. It was also found with high capacity for spreading into areas without post-European settlement fires on these steep slopes. Bighorn sheep were known from the area in the past (Smith 1992), and presence of bighorns on the site represents use that predates European settlement. However, these sheep had been extirpated from the area for many years. The current presence of bighorn sheep is a function of a transplant of less than 10 years prior to the data taken from these sites. Little community change is expected from this use.

The introduction of cheatgrass to the American continent is a function of human activity. However, non-Native American influence has been low at these specific sites. The ability of cheatgrass to drive plant community dynamics where human and domestic livestock activities have been low is vividly demonstrated in Red Canyon.

Management Implications

Within the past century, cheatgrass has become one of the most potent ecological forces in parts of the West. Peters and Bunting (1994) have suggested the introduction of exotic annual grasses including cheatgrass into the Snake River Plain in Idaho may have been the most important event in the natural history of that region since the last glacial period. Catastrophic ecosystem change for the western Great Basin has been suggested by Billings (1994) as function of cheatgrass. Spread of this plant is often associated with disturbance by humans. However, it has inserted itself into and has dominated communities without human disturbance.

Cheatgrass can be expected to be a major ecological force within its ecological amplitude, which includes some cold desert shrub, many sagebrush, pinyon-juniper, and mountain brush communities. Its influence is accelerated by disturbance. However, disturbance is often a matter of "when" more than a matter of "if." Management goals that do not include potential for disturbance are not realistic in many ecological settings.

The concept of potential natural communities based only on native species is seriously challenged by cheatgrass. With reference to cheatgrass, Knight (1994) suggested: "Managing vegetation so it reflects presettlement conditions is a goal that may be impossible once certain introduced species become established." The status of cheatgrass in Red Canyon and the reports in the literature cited in this text collaborate Knight's suggestion. Where cheatgrass is highly adapted, it might have to be recognized within potential. Refusing to do so will not reduce its presence, and this will not reduce its potential for dominance.

However, the concept that preservation of native plant communities will prevent, eliminate, or control cheatgrass often prevails in planning, management, and legal maneuvering dealing with cheatgrass prone rangelands. Dynamics of plant communities of warm exposures in Red Canyon do not support this concept, and there seems to be little in literature dealing with cheatgrass to support this concept.

References

Ashcroft, G. L.; Jensen, D. T.; Brown, J. L. 1992. Utah climate. Logan, UT: Utah State University, Utah Climate Center. 125 p.

Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. In: Monsen, S. B.;

Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 22-30.

Greenwood, C.; Goodrich, S.; Lytle, J. These proceedings. Response of bighorn sheep to burning in the Green River corridor, Daggett County, Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West: 1997 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Kindschy, R. R. (1994). Pristine vegetation of the Jordan Crater Kipukas: 1978-91. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 85-88.

Knight, D. H. 1994. Mountains and plains: the ecology of Wyoming landscapes. New Haven, Conn., Yale University Press. 338 p.

Peters, E. F.; Bunting, S. C. 1994. Fire conditions pre- and post-occurrence of annual grasses on the Snake River Plain. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 31-36.

Smith, T. S. 1992. The bighorn sheep of Bear Mountain: ecological investigations and management recommendations. Provo, UT: Brigham Young University. 425 p. Dissertation.

Tausch, R. J.; Svejcar, T.; Burkhardt, J. W. 1994. Patterns of annual grass dominance on Anaho Island: implications for Great Basin vegetation management. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 120-125.

U. S. Department of Agriculture, Forest Service. 1993. Rangeland ecosystem analysis and management handbook. FSH 2209-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 4 ch.

Young, J. A.; Tipton, F. 1990. Invasion of cheatgrass into arid environments of the Lahontan Basin. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 37-40.

A Comparison of Understory Species at Three Densities in a Pinyon-Juniper Woodland

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Abstract—The relationship between pinyon-juniper density and associated understory were examined at three sites at Pigeon Hollow north of Ephraim, UT. Historically the study site was grazed from the turn of the century to the 1980's when Utah Division of Wildlife Resources acquired the land. The area has since been used as critical winter range for wildlife with little livestock grazing, except for some trespass. All sites were north facing with 4 percent slope. Tree canopy cover was compared across three tree densities. Frequency and percent cover were reported across a gradient of pinyon-juniper densities. As pinyon-juniper tree density increases, associated understory and interspace herbaceous percent cover and diversity decreases. Decrease of perennial grasses amid tree interspaces was as significant as beneath tree canopy.

The pinyon-juniper forest complex is an important component of the vegetation of the Intermountain West. This forest complex is mainly comprised of two leaf pinyon pine (*Pinus edulis* [Engelm.]), Utah juniper (*Juniperus osteosperma* [Torr.]), one seed juniper (*Juniperus monosperma* [Engelm.]), and Rocky Mountain juniper (*Juniperus scopulorum* [Sarg.]). This community complex provides the majority wintering range for big game and associated animals in Utah (Stevens and Walker 1996). The pinyon-juniper woodlands comprise nearly 25 million ha (62 million acres) throughout the western United States (West 1986). Since settlement of the Great Basin, pinyon-juniper has expanded its range from steeper mountain slopes to alluvial fans and steppes. Increase of pinyon-juniper is primarily due to suppression of fires and overgrazing by livestock during the last 100 to 150 years. Cottam (1961) reported western Utah's pinyon-juniper woodlands were among the most heavily impacted by domestic livestock during the period following settlement in the 1800's. The increased acreage of pinyon-juniper has led to problems in watershed management, loss of big game habitat, and reduced plant diversity. As the trees obtain dominance the remaining understory is severely reduced (Dye and others 1995). Pinyon-juniper trees influence other plants in several ways: shading, litter accumulation under the tree canopy, interception and retention of rainfall by the branches and by the root system in the interspaces, and the development of an extensive, shallow, competitive root system (Schott and Pieper 1985). Junipers have a large lateral root system that extends well beyond the crown (Jameson 1967). The influence of individual trees on soil chemical properties has been demonstrated by many studies (Follet 1969; Garcia-Moya and Mckell 1970; Tiedemann and Klemmedson 1973; Zinke 1962).

Arnold and others (1964) found conclusive reductions in the basal cover of grasses and forbs with the increase of canopy cover. Previous studies reveal a vast difference in herbaceous composition directly below the tree canopy and within the interspaces among trees (Armentrout and Pieper 1988; Schott and Pieper 1985). The objective of this study was to determine if tree density and tree canopy cover influenced the composition and presence of understory species. The question then arises, if tree density is decreased through management will the understory become more diverse and percent ground cover increase? Also, at what tree density can one expect to meet management objectives for forage availability? Understanding this relationship with tree density and understory herbaceous composition will aid in management of pinyon-juniper woodlands.

Study Site

The Pigeon Hollow study area is located in Sanpete County, Utah, approximately 8 km (5 miles) north of Ephraim (S 12, T 16, R 3). The elevation of the area ranges from 1,700 m (5,575 ft) to 1,900 m (6,235 ft). The average yearly precipitation is 321 mm, (12.6 inches) falling mostly during October and December. The average temperature ranges from 7.2 to 8.8 °C (45 to 47 °F). Soils at Pigeon Hollow are excessively drained, gently sloping to very steep gravelly sandy loams that are 25.4 to 50.8 cm (10 to 20 inches) deep over limestone. Soils formed in colluvium, local alluvium, and residuum are derived from limestone on hillsides and ridges. They are of the Amtoft Series, most commonly associated with Sanpete and Sigurd soils (USDA, SCS, USDI, and BLM 1981). The Pigeon hollow area is owned by the Utah Division of Wildlife Resources and is managed as a wintering ground for wildlife. Habitat is provided for mule deer (*Odocoileus hemionus* [Rafinesque]) and Rocky Mountain elk (*Cervus elaphus nelsoni* [Bailey]), allowing both shelter and forage during the winter. All study sites

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are located on north aspects with slopes of 4 to 5 percent. This area has not been grazed by livestock for 15 years except for periodic grazing by sheep.

The prevalent grass species are: bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh]), Sandberg bluegrass (*Poa secunda* [Presl.]), cheatgrass (*Bromus tectorum*), Indian ricegrass (*Achnatherum hymenoides* [Roem & Schult]), Needle-and-thread grass (*Hespro stipa* [Trin. Rupr.] Barkw.), and bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey). The shrub component includes: big sagebrush (*Artemisia tridentata* [Nutt.]), narrowleaf low rabbitbrush (*Chrysothamnus viscidiflorus* [Hook]), winterfat (*Ceratoides lanata* [Pursh]), shadscale (*Atriplex confertifolia* [Torr. & Frem.]), and broom snakeweed (*Gutierrezia sarothrae* [Pursh]). Major forbs are: Hoods phlox (*Phlox hoodii* [Richards]), burr buttercup (*Ranunculus testiculatus* [Crantz]), aster species, and various annual mustards. Utah juniper, Two leaf, and pinyon pine are the main tree components.

Methods

Three north facing slopes were chosen for sampling. Pinyon-juniper tree density decreased from east to west on each slope relating to the advancing front of a pinyon-juniper population. To sample different tree densities, each slope was divided into three tree density categories: high, moderate, and low. The assigned title to the categories does not necessarily represent exact or fixed densities but are high, moderate, and low, relative to one another. A 40 m^2 site was sampled within each tree density category on each slope. All pinyon and juniper trees were counted in each 40 m^2 site to establish tree density. In addition, five stratified random points were selected in each plot for sampling herbaceous plant composition and tree canopy cover. A modified quarter method was used at each of these five points. In each cardinal quarter the distance to the nearest tree was measured and the species of tree identified. The quarter method and tree number counts were used at each site to calculate and verify tree density. Trees were classed into seedling, juvenile, adult, or decadent. Two 0.25 m^2 nested frequency frames were placed along the line connecting the sampling point and the nearest tree. One quadrat frame was placed under the tree canopy and another was placed in the tree interspace. The understory sample frame was placed midway between the trunk and canopy edge of each tree sampled. The interspace quadrat frame was placed within the nearest interspace along a line connecting the sampling point and the nearest tree trunk. To qualify as an interspace there could be no tree canopy cover within 2 m of the quadrat frame. Nested frequency data and eight cover points were recorded for each sample. Data were collected from 20 frames under the tree canopy and 25 frames in the interspace at each site. Summed frequency values were used to compare understory and interspace species. Smith and others (1987) have shown summed frequency values to be useful in comparing vegetation differences. A soil penetrometer was used at each sampling point to determine soil depth. Data were subject to analysis of variance using the General Linear Model (Ott 1984). Significant differences at $p < 0.05$ among means were determined using Student-Newman-Kuels multiple range test on all main effect means.

Results And Discussion

Previous studies have demonstrated that as tree density increases understory decreases (Arnold and others 1964; Barney and Frishnecht 1974). In this study three categories of tree density were sampled to determine understory and interspace herbaceous composition at varying pinyon-juniper densities. The high and moderate tree densities contained 885 trees per ha (357 trees per acre) and 714 trees per ha (289 trees per acre). The low tree density contained 394 trees per ha (159 trees per acre). The low tree density was significantly different from the moderate and high tree densities but moderate and high tree densities did not vary significantly from each other. A wider range of densities would have been helpful to separate moderate and high values. For this report high tree density will be compared to low tree density to examine the relationship between the undercanopy and interspace herbaceous composition.

Four species consistently appeared in the sampling. The species included bluebunch wheatgrass, Sandberg bluegrass, cheatgrass and bur buttercup. These species are associated with pinyon juniper communities and serve as indicators of community health. Everett and Koniak (1981) found Sandberg bluegrass to be the most consistent perennial grass component in the understory of pinyon-juniper community, and cheatgrass was a common annual grass component. Figures 1, 2, and 3 report significant differences among understory and interspace frequency values for these species.

Fewer species were encountered in the interspaces than in the understory. A total of 18 species were encountered in the understory while only 12 species appeared in the

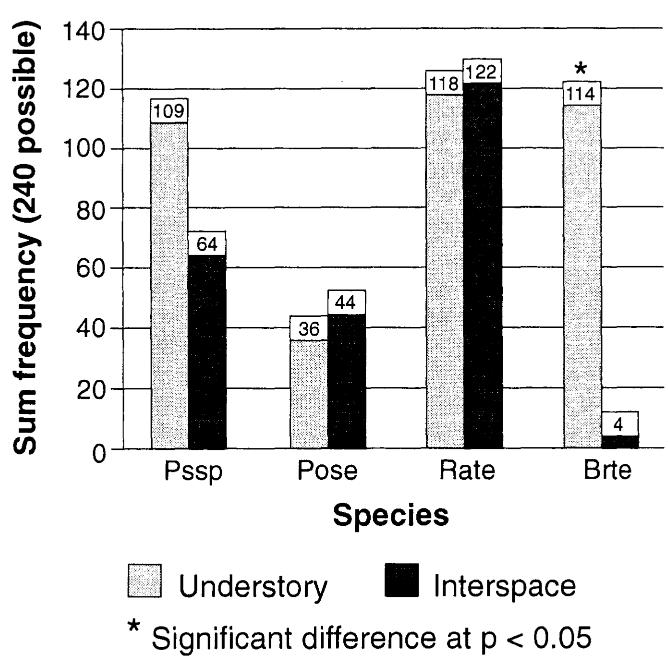

Figure 1—Sum frequency at high tree density for bluebunch wheatgrass (Pssp), Sandberg bluegrass (Pose), bur buttercup (Rate), and cheatgrass (Brte).

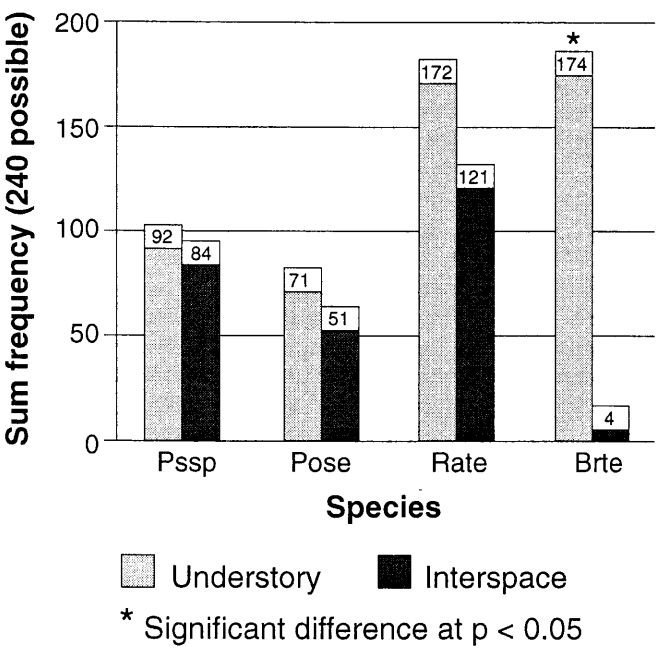

Figure 2—Sum frequency at moderate tree density for bluebunch wheatgrass (Pssp), Sandberg bluegrass (Pose), bur buttercup (Rate), and cheatgrass (Brte).

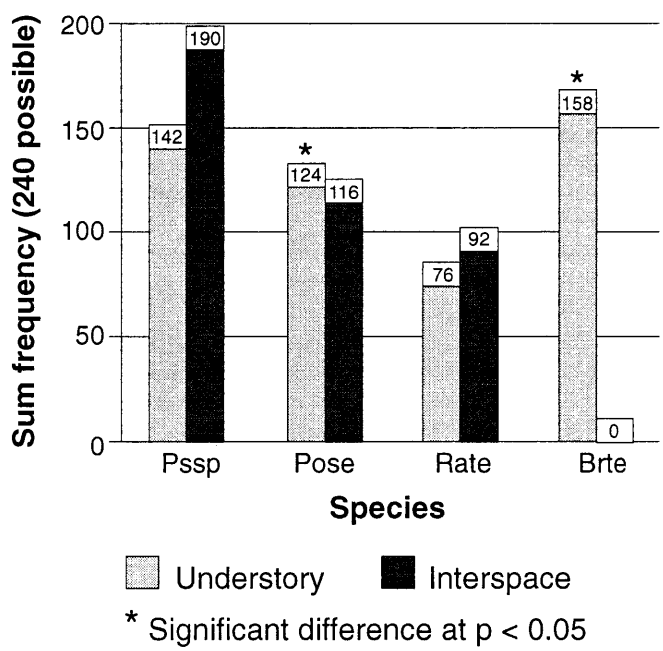

Figure 3—Sum frequency at low tree density for bluebunch wheatgrass (Pssp), Sandberg bluegrass (Pose), bur buttercup (Rate), and cheatgrass (Brte).

interspace. Fewer annual species were recorded in the interspace than in the understory.

At all tree densities, cheatgrass sum frequency values were significantly greater in the understory compared to the interspaces. At low tree density cheatgrass did not appear in the interspace but was limited entirely to the juniper understory. These findings are similar to reports of Everett and Koniaks (1981). Where cheatgrass is present it is closely associated with juniper canopy understory.

Sandberg bluegrass had significantly higher sum frequency values in the understory of the low tree density than in the interspace (fig. 3). At the high tree density there was no difference between understory frequency and interspace frequency. The interspace was small enough and influenced by the tree density that herbaceous composition did not vary under the canopy or in the interspace. Sum frequency values were less for higher tree density indicating that as tree density increases Sandberg bluegrass decreases. There was less bur buttercup in the understory and interspace of the low tree density than the high tree density although not significantly less.

Mean height of each juniper in the highest tree density area was 2.5 m. In the lowest tree density areas mean height was 3.01 m. Trees in the lowest tree density were 17 percent taller than those in the highest tree density areas. A decrease in average tree height may indicate competition for available resources among trees in the high density. Correlating with a decrease of tree height with increased tree density was a decrease in mean canopy cover by each individual tree as density increased. The mean canopy cover for the high density was 3.6 m^2 as compared to 6.4 m^2 for the low density. Canopy cover was 47 percent less per individual tree in the high tree density compared to the low tree density. The tree density significantly effected the tree size. The greater the tree density the smaller canopy cover of each tree.

The data support the relationship of pinyon-juniper density to understory. In this sampling, as tree density increased understory and interspace herbaceous composition became less desirable and canopy cover declined. Considering this relationship very dense stands of pinyon-juniper woodlands are likely candidates for tree removal if management objectives warrant such an action. Low density pinyon-juniper woodlands can be more diverse and productive than very dense forest.

References

Armentrout, Susan M.; Pieper, R. D. 1988. Plant distribution surrounding Rocky Mountain pinyon pine and one-seed juniper in south-central New Mexico. Journal of Range Management. 41(2): 139-143.

Arnold, Joseph F. 1964. Zonation of vegetation around a Juniper tree. Journal of Range Management. 17: 41-42.

Arnold, J. F.; Jameson, D. A.; Reid, E. H. 1964. The pinyon-juniper type of Arizona: effects of grazing , fire, and tree control. Production Res. Rep. No. 84. Fort Collins, CO: U.S Department Of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Cottam, W. P. 1961. Our renewable wild lands—a challenge. Salt Lake City, UT: University of Utah Press.

Barney, M. A.; Frischnecht, N. S. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management. 27(2): 91-96.

Dye, K. L., II; Ueckert, D. N.; Whisenant, S. G. 1995. Redberry juniper-herbaceous understory interactions. Journal of Range Management. 48: 100-107.

Everett, R. L.; Koniak, S. 1981. Understory vegetation in fully stocked pinyon-juniper stands. Great Basin Naturalist. 41: 467-475.

Follet, R. H. 1969. Zn, Fe, Mn and Cu in Colorado soils. Fort Collins, CO: Colorado State University. Dissertation.

Garcia-Moya, E.; McKell, C. M. 1970. Contribution of shrubs to the nitrogen economy of a desert-wash plant community. Ecology. 51: 81-88.

Jameson, D. A. 1967. The relationship of tree overstory and herbaceous understory vegetation. Journal of Range Management. 20: 247-249.

Ott, Lyman. 1984. An introduction to statistical methods and data analysis. Boston; PWS Publishers. 773 p.

Schott, M. R.; Pieper, R. D. 1985. Influence of canopy characteristics of one-seed juniper on understory grasses. Journal of Range Management. 38: 328-331.

Smith, S. D.; Bunting, S. C.; Hironaka, M. 1987. Evaluation of the improvement in sensitivity of nested frequency plots to vegetational change by summation. Great Basin Naturalist. 47: 299-307.

Stevens, R.; Walker, S. C. 1996 Juniper-pinyon population dynamics over 30 years following anchor chaining. In: Barrow, Jerry, R.; McArthur, E. Durrant; Sosebee, Ronald, E.; Tausch, Robin, J.; Proceedings: Shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 125-128.

Tiedemann, A. R.; Klemmedson, J. O. 1973. Effect of mesquite on physical and chemical properties of the soil. Journal of Range Management. 26: 27-29.

U.S. Department of Agriculture, Soil Conservation Service and U.S. Department of the Interior, Bureau of Land Management. 1981. In cooperation with Utah Agricultural Experiment Station and Utah State Department of Wildlife Resources. Soil survey of Sanpete Valley area, Utah; Parts of Utah and Sanpete Counties. 179 p.

West, N. E.; Van Pelt, N. S. 1986 Successional patterns in pinyon-juniper woodlands. In: Everett R. L.; Proceedings: pinyon-juniper conference; 1986 Jan. 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

Zinke, P. T. 1962. The pattern of influence of individual forest trees on soil properties. Ecology. 43: 130-133.

Effects of Succession on Species Richness of the Western Juniper Woodland/ Sagebrush Steppe Mosaic

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Eva Strand

Abstract—The development of mature juniper woodlands has often been associated with decreases in the herbaceous and shrub components of the community. This study focused on changes in species richness and diversity along a successional gradient at both the community and watershed scale in the Owyhee Mountains in southwestern Idaho. Community species richness was relatively constant across the sere. Community species diversity changed as species became less equitably distributed when juniper dominated the site in the later stages of succession. Landscape-scale species richness is predicted to be greatest when all successional stages are represented in the watershed.

Western juniper (*Juniperus occidentalis* subsp. *occidentalis*) dominates approximately 17 million ha in the northwestern portion of the Great Basin and southern Columbia Basin (West 1988). During the Pre-Euro-American period western juniper is thought to have primarily occurred as dense stands on the more dissected topography or to have occurred as open savanna-like woodlands on canyon slopes and more regular topography (Burkhardt and Tisdale 1969, 1976, Miller and Rose 1994, Miller and Wigand 1994). Western juniper has primarily encroached into many adjacent vegetation types but the expansion of dominance has been most dramatic on the deeper soils (Young and Evans 1981, Eddleman 1987, Miller and Rose 1994, Miller and Wigand 1994, Miller and others 1995). These types include those dominated by mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) steppe, aspen woodlands and Idaho fescue (*Festuca idahoensis*)/ bluebunch wheatgrass (*Agropyron spicatum*) grassland. Encroachment has also occurred into low sagebrush (*Artemisia arbuscula*) dominated vegetation but the rate has been much lower due to the less productive site conditions.

The causes of encroachment have been attributed to effects of overgrazing on plant competition by domestic livestock, climatic change and reduction wildfire occurrence by active suppression and livestock grazing (Blackburn and Tueller 1970, Burkhardt and Tisdale 1976, Young and Evans 1981, Gruell 1986, Miller and Wigand 1994). Research has shown that change in plant competition is probably not a factor in western juniper encroachment since plant composition did not affect the rate of establishment (Burkhardt and Tisdale 1976, Eddleman 1987, Miller and Rose 1994). However, heavy utilization of rangelands by livestock in the 19th and early 20th centuries would have facilitated juniper establishment through secondary effects. The resulting low fine fuel loads due to high forage utilization would have decreased fire occurrence (Miller and others 1995) and increased sagebrush seedling establishment (Ellison 1960, Tisdale 1969). Increased sagebrush density provides greater availability of safesites for juniper since the majority of seedlings are found under sagebrush or other shrub canopies (Burkhardt and Tisdale 1976, Eddleman 1987, Miller and Rose 1994, Miller and others 1995).

Fire history studies in western juniper have indicated that pristine fire-free intervals (FFI) varied from 25-30 years (Burkhardt and Tisdale 1969, 1976) but may have been shorter than 25 years in associated mountain big sagebrush steppe (Bunting and others 1987, Miller and others 1995). Young and Evans (1981) estimated, based on the growth rate of young western juniper seedlings, that a fire every 50 years would control the encroachment process in northern California. The encroachment of juniper usually reduces the herbaceous production on the site (Tausch and Tueller 1990) and thereby greatly reduces fire potential (Bunting and others 1987, Everett 1987). In dense stands of mature juniper fires may burn only under the most severe weather conditions.

The effects of encroachment are well documented for many juniper woodlands and are remarkably similar across the different juniper species and vegetation types. In general, there is a reduction in the herbaceous and shrub biomass production (Everett and Koniak 1981, Tress and Klopatek 1987, Wilson and Schmidt 1990, Vaitkus and Eddleman 1991). Other ecological changes which have been attributed to juniper encroachment include: increased soil erosion (Carrara and Carroll 1979), increased water use (Miller and Schultz 1987, Angel and Miller 1994, Miller and Wigand 1994), altered nutrient cycles (Klopatek 1987, Doescher and others 1987, Tiedemann and Klemmedson 1995), reduced seed reserves (Koniak and Everett 1982) and reduced fire potential (Bunting and others 1987, Everett 1987).

Often associated with this reduction of herbaceous and shrub species is a reduction in plant and animal species diversity (Blackburn and Tueller 1970, West and others 1979, Balda and Masters 1980, Koniak and Everett 1982,

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Severson 1986, Miller and others 1995). The effects of encroachment of western juniper woodlands into adjacent sagebrush steppe results in a decrease of herbaceous and shrub biomass production (Vaitkus and Eddleman 1991, Miller and Wigand 1994, Miller and others 1995). A reduction of plant species richness and species diversity has been documented for western juniper and other Great Basin woodlands (Blackburn and Tueller 1970, West and others 1979, Koniak and Everett 1982, Miller and others 1994). Studies indicate that breeding bird density and species richness increases as western juniper stands become more mature and structurally diverse (Maser and Gashwiler 1978, Sedgwick and Ryder 1987). Sedgwick and Ryder (1987) found that while bird densities decreased with juniper control, small mammals increased in response to greater herbaceous production. It seems most probable that in the process of conversion between juniper woodland and sagebrush steppe, some species will be affected positively and others negatively (Belsky 1996). The primary focus of this study is the landscape-scale influence of encroachment on vascular plant species diversity and richness.

Methods

Two watersheds, Red Canyon Creek and Smith Creek, were selected for analysis (fig. 1). They are tributaries of the South Fork of the Owyhee River in southwestern Idaho and contain a variety of successional stages. The areas of Red Canyon Creek and Smith Creek watersheds are 63.7 and 140.2 km^2, respectively. Elevation varies from 1,500 to 2,000 m. Domestic livestock have grazed the watersheds for over 100 years and currently cattle grazing occurs under a rest-rotation system. Less than 10 percent of each watershed has been treated with prescribed fire during the past 20 years.

Forty macroplots of approximately 0.25 ha within the western juniper-mountain big sagebrush mosaic were selected for sampling. These occurred over the successional gradient from herbaceous dominated (recently burned) to those dominated by stands of old juniper (greater than 500 years in age). Sampling was limited to sites which currently or potentially may support sagebrush steppe vegetation in the successional sequence. This restriction was based on soil type and the presence of sagebrush plants or dead material. Macroplot vegetation was classified into one of 9 structural stages based on composition and structure which were developed by the Interior Columbia Basin Ecosystem Management Project (ICBEMP) (Quigley and others 1996) (table 1). Macroplots were sampled for composition based on canopy coverage. The line intercept method was used to estimate shrub and tree coverage (Canfield 1941, Hanley 1978). A modification of Daubenmire's (1959) cover class method was used to estimate coverage of the herbaceous species. A total macroplot inventory was done to determine the total number of species present on the site at the time of sampling. Species not included in the microplot or line intercept data were ranked from 0 to 5 based on foliar coverage and distribution. Sampling occurred near peak biomass production for the sites (late June-early July). Species richness was determined from a single inventory and was based on those species which occurred in the microplots and on the total macroplot search. The Shannon-Weiner (Magurran 1988) and Simpson's diversity indices (Simpson 1949, Magurran 1988) were used to quantify differences in species diversity.

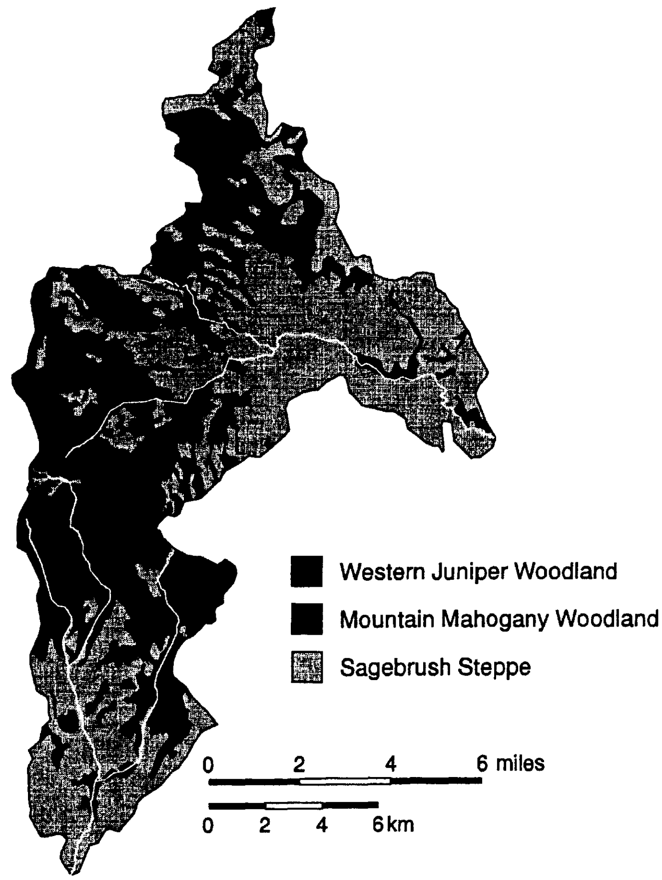

Figure 1—Potential vegetation of Red Canyon Creek (lower) and Smith Creek (upper) watersheds which are tributaries of the South Fork of the Owyhee River in southwestern Idaho. Without disturbance, most of the upper portions of the watersheds will become dominated by western juniper vegetation. (Source: ICBEMP data)

Results

Consistent with previous research (Vaitkus and Eddleman 1991, Miller and Wigand 1994, Miller and others 1995) development of western juniper woodland vegetation resulted in the reduction of shrub and herbaceous plant coverage (fig. 2). A reduction of plant species richness has been documented for sites dominated by western juniper and for other Great Basin juniper woodlands (Blackburn and Tueller 1970, West and others 1979, Koniak and Everett 1982, Miller and others 1995), however, this did not occur in the watersheds studied in the Owyhee Mountains in Idaho. While there is a major change in plant community species composition with increased juniper dominance, species richness on a macroplot basis did not change across the successional gradient (fig. 3). This was true for species richness based on species sampled with microplots and for species

Table 1—Description of structural stages used to classify vegetation within the mountain big sagebrush steppe-western juniper woodland mosaic of the Owyhee Mountains, Idaho. Structural stages used are modifications of those developed by ICBEMP.

Structural stage	Description
Herbland	Herbaceous cover <67 percent, shrub cover <5 percent
Open shrubland	Low and medium shrub cover <10 percent, tree cover <5 percent
Moderate cover shrubland	Low and medium shrub cover 10-67 percent, tree cover <5 percent
Stand initiation woodland	Tree cover (all size classes) <5 percent, seedling-sapling cover >5 percent
Stem exclusion woodland	Large tree cover < 5 percent, small and medium tree cover >5 percent, seedling-sapling cover <5 percent
Understory re-initiation woodland	Large tree cover <5 percent, seedling-sapling cover >5 percent
Young multi-story woodland	Large tree cover 0-5 percent, small and medium tree cover 5-14 percent, seedling-sapling cover 5-14 percent
Old multi-story woodland	Large tree cover 5-14 percent, other size classes 5-14 percent
Old single strata woodland	Large tree cover >5 percent, other size classes <5 percent

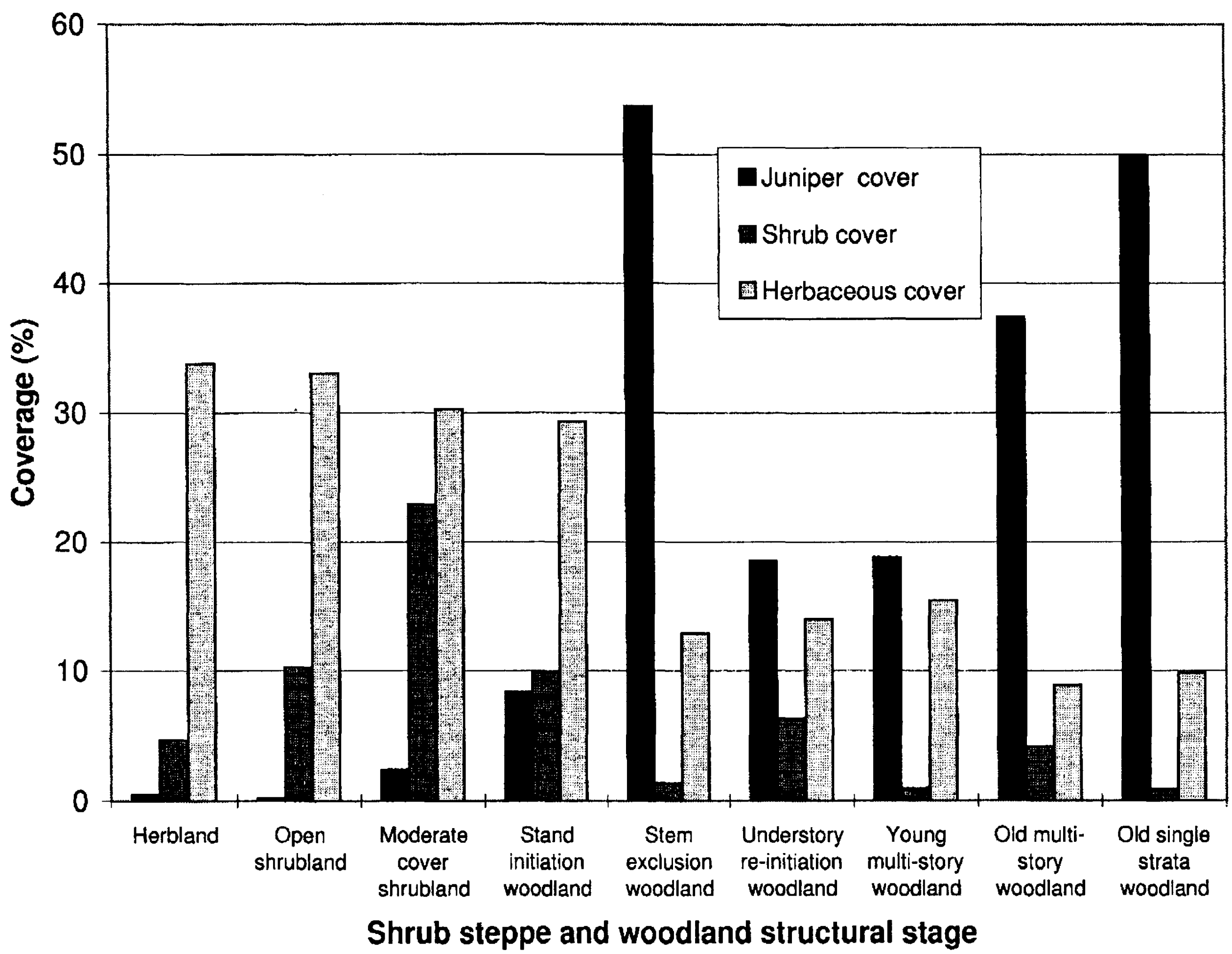

Figure 2—Data indicates that a reduction in the coverage of shrub and herbaceous species is associated with the development of western juniper woodlands. This is consistent with results from other juniper woodland studies from throughout the Great Basin and Southwest.

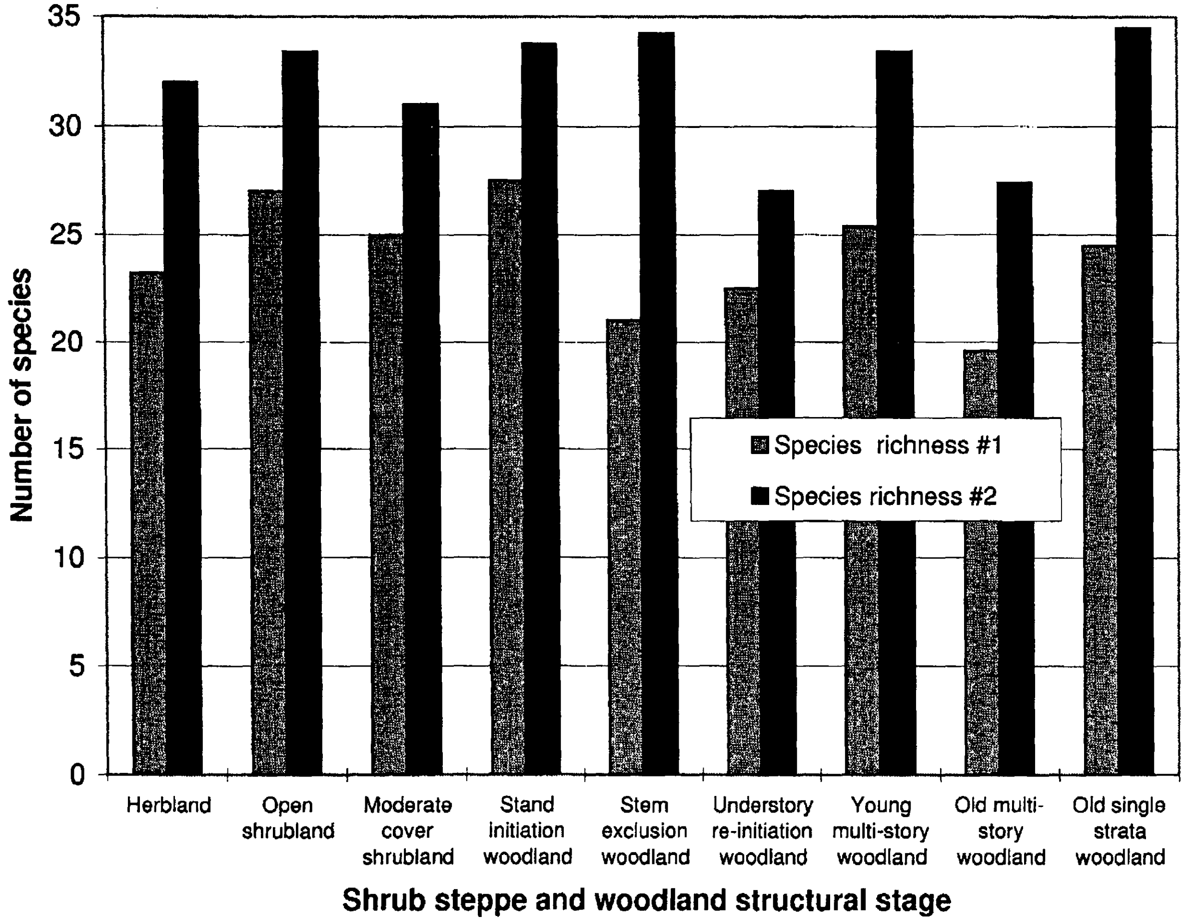

Figure 3—Species richness did not change as a result of the development of juniper woodland development. Species richness 1 is based on those species encountered when sampling the stand. Species richness 2 is based on those species resulting from a one-time macroplot inventory.

richness based on a complete macroplot inventory. Average species richness varied between 27-34 species for structural stages sampled across the successional gradient. The lowest average species richness occurred when young juniper began to dominate the site. At this stage many species found within sagebrush steppe were absent but those species associated with mature juniper woodlands had not become established.

Results indicated that many perennial herbaceous species are associated primarily with the early to mid seral communities and not found in the late seral communities (table 2). However, fewer instances of the reverse were evident. While late seral community species richness was as high as that of early and mid seral communities, the composition was comprised primarily of species that were also associated with other successional stages. In addition, due to the low perennial herbaceous plant cover, mature juniper communities contained high numbers of annual plants in the juniper interspaces. These included: cheatgrass (*Bromus tectorum*), Douglas knotweed (*Polygonum douglasii*), blue-eyed Mary (*Collinsia parviflora*), narrow-leafed collomia (*Collomia linearis*), Fremont's goosefoot (*Chenopodium fremontii*) and cryptantha (*Cryptantha* spp.). These annual species were also common in the early successional post-burn communities.

Table 2—Forb species associated with early to mid and late seral conditions within the mountain big sagebrush steppe-western juniper woodland mosaic in the Owyhee Mountains, Idaho.

Species associated primarily with grassland and sagebrush steppe communities:	Species associated primarily with old mature juniper woodland communities:
Astragalus lentiginosus	*Agastache urticifolia*
Calochortus nuttallii	*Aster chilensis*
Castilleja applegatei	*Habenaria unalascensis*
Castilleja viscidula	*Hackelia cusickii*
Eriogonum caespitosum	
Eriogonum heracleoides	
Eriogonum ovalifolium	
Eriogonum sphaerocephalum	
Eriogonun umbellatum	
Geranium viscosissimum	
Geum triflorum	
Fritillaria pudica	
Linum perenne var. *lewisii*	
Linum micranthum	
Mertensia longiflora	
Paeonia brownii	
Penstemon perpulcher	
Penstemon procerus	

Structural stages were grouped into 4 physiognomic types, grassland, sagebrush steppe, young juniper woodland and mature juniper woodland. Total species richness, those species found in at least 1 macroplot, for all physiognomic types was also similar across the successional gradient. Combined species richness for grassland, sagebrush steppe, young juniper woodland and mature juniper woodland macroplots was 65, 65, 60 and 70 species, respectively. These data indicate that highest landscape species richness (133 species) of the watersheds would occur when all structural stages were present on the landscape.

Since species richness did not change across the successional gradient, the changes in species diversity resulted primarily from differences in relative species abundance within the community. As mature juniper woodland develops, greater amounts of the community's total plant coverage and biomass is concentrated into fewer species. The number of species represented by only a few individuals in the macroplot tended to increase and species abundance becomes less equitable. This resulted in an increase in Simpson's Index and a decrease in the Shannon-Weiner Index as mature juniper woodland developed (fig. 4).

Conclusions

Although major changes in species composition and total plant coverage occurred, community species richness remained relatively constant across the successional gradient within the western juniper woodland-mountain big sagebrush steppe mosaic in southwestern Idaho. Changes in species diversity resulted as species became less equitably distributed within the communities as succession occurred. Maximum landscape species richness and species diversity occurs when all structural stages are represented within the watershed emphasizing the need to include disturbance such a fire as a process in landscape dynamics.

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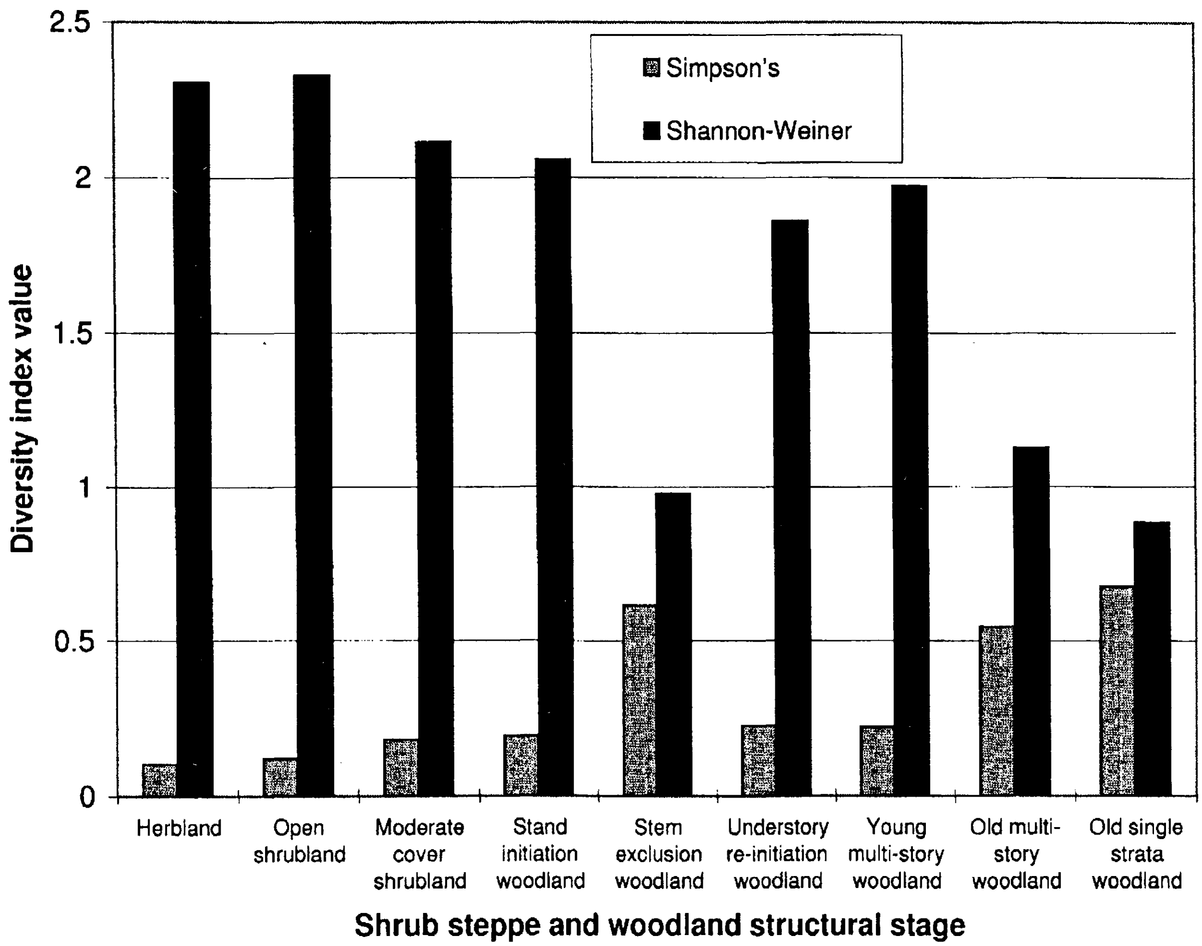

Figure 4—Changes in the Shannon-Weiner and Simpson's species diversity indices associated with western juniper woodland development in southwestern Idaho.

References

Angell, R.F., and R.L. Miller. 1994. Simulation of leaf conductance and transpiration in *Juniperus occidentalis*. Forest Science 40:5-17.

Balda, R.P., and N. Masters. 1980. Avian communities in the pinyon-juniper woodland: a descriptive analysis. In: R.M. DeGraff and N.G. Tilghman, eds. Management of western forests and grasslands for non-game birds. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-86. Pp. 146-169.

Belsky, A.J. 1996. Viewpoint: Western juniper expansion: Is it a threat to northwestern ecosystems. J. Range Manage. 49:53-59.

Blackburn, W.H., and P.T. Tueller. 1970. Pinyon and juniper invasion in blackbrush communities in east-central Nevada. Ecology 51:841-848.

Bunting, S.C., B.M. Kilgore and C.L. Bushey. 1987. Guidelines for prescribed burning sagebrush-grass rangelands in the northern Great Basin. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-231. 33p.

Burkhardt, J.W., and E.W. Tisdale. 1969. Nature and successional status of western juniper vegetation in Idaho. J. of Range Manage. 22:264-270.

Burkhardt, J.W., and E.W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57:472-484.

Canfield, H.R. 1941. Application of the line intercept in sampling range vegetation. J. Forestry 39:388-394.

Carrara, P.E. and T.R. Carroll. 1979. The determination of erosion rates from exposed tree roots in the Piance Basin, Colorado. Earth Surface Proc. 4:307-317.

Daubenmire, R. 1959. A canopy coverage method of vegetation analysis. Northwest Science 33:43-66.

Doescher, P.S., L.E. Eddleman and M.R. Vaitkus. 1987. Evaluation of soil nutrients, pH, organic matter in rangelands dominated by western juniper. Northwest Science 61:97-102.

Eddleman, L.E. 1987. Establishment and stand development of western juniper in central Oregon. In: R.L. Everett, comp. Proceedings-Pinyon-Juniper Conference; 1986 January 13-16; Reno, NV. U.S Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-215. Pp. 255-259.

Ellison, L. 1960. Influence of grazing on plant succession of rangelands. Botanical Review 26:1-78.

Everett, R.L. 1987. Plant response to fire in the pinyon-juniper zone. In: R.L. Everett, comp. Proceedings- Pinyon-Juniper Conference; 1986 January 13-16; Reno, NV. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-215. Pp.152-157.

Everett, R.L., and S. Koniak. 1981. Understory vegetation in fully stocked pinyon-juniper stands. Great Basin Naturalist 41:467-474.

Gruell, G.E. 1986. Post-1900 mule deer irruptions in the Intermountain West. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-206. 37p.

Hanley, T.A. 1978. A comparison of the line-intercept quadrat estimation methods of determining shrub canopy coverage. J. Range Manage. 26:322-325.

Klopatek, C.D. 1987. Nitrogen mineralization and nitrification in mineral soils of pinyon-juniper ecosystems. Soil Science Soc. Am. J. 51:453-457.

Koniak, S., and R.L. Everett. 1982. Seed reserves in soils of successional stages on pinyon woodlands. American Midland Naturalist 102:295-303.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, NJ. 179p.

Maser, C., and J.S. Gashwiler. 1978. Interrelationships of wildlife and western juniper. In: Western juniper ecology and management workshop. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station Gen. Tech. Rep. PNW-74. Pp.37-82.

Miller, R.L. and L.M. Schultz. 1987. Water relations and leaf morphology of *Juniperus occidentalis* in the northern Great Basin. Great Basin Naturalist 47:345-354.

Miller, R.J., and J. Rose. 1994. Historic expansion of *Juniperus occidentalis* (western juniper) expansion in southeastern Oregon. Great Basin Naturalist 55:37-45.

Miller, R.J., and P.E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioScience 44:465-474.

Miller, R.J., J. Rose, T. Svejcar, J. Bates and K. Paintner. 1995. Western juniper woodlands: 100 years of plant succession. In: D.W. Shaw, E.F. Aldon and C. LoSapio, tech. coords. Desired future conditions for piñon-juniper ecosystems. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station Gen. Tech. Rep. RM-258. Pp.5-8.

Quigley, T.M., R.W. Haynes and R.T. Graham, tech eds. 1996. An integrated scientific assessment for ecosystem management in the Interior Columbia River Basin and portions of the Klamath and Great Basins. U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station Gen. Tech. Rep. PNW-GTR-382. 303p.

Sedgwick, J.A., and R.A. Ryder. 1987. Effects of chaining pinyon-juniper on nongame wildlife. In: R.L. Everett, comp. Proceedings-Pinyon-Juniper Conference; 1986 January 13-16; Reno, NV. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-215. Pp. 541-551.

Simpson, E.H. 1949. Measurement of diversity. Nature 163:688.

Tausch, R.J., and P.T. Tueller. 1990. Foliage biomass and cover relationships between tree- and shrub-dominated communities in pinyon-juniper woodlands. Great Basin Naturalist 50:121-134.

Tiedemann, A.R., and J.O. Klemmedson. 1995. The influence of western juniper development on soil nutrient availability. Northwest Science 69:1-8.

Tisdale, E.W. 1969. The sagebrush region in Idaho. A problem in range resource management. Agr. Exp. Sta. Bull. 512. Univ. Idaho, Moscow. 15p.

Tress, J.A., and J.M. Klopatek. 1987. Successional changes in community structure of pinyon-juniper woodlands on north-central Arizona. In: R.L. Everett, comp. Proceedings- Pinyon-Juniper Conference; 1986 January 13-16; Reno, NV. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station Gen. Tech. Rep. INT-215. Pp.80-85.

Vaitkus, M.R., and L.E. Eddleman. 1991. Tree size and understory phytomass production in a western juniper woodland. Great Basin Naturalist 51:236-243.

West, N.E., R.J. Tausch, K.H. Rhea and P.T. Tueller. 1979. Phytogeographic variation within the juniper-pinyon woodlands of the Great Basin. In: K.T. Harper and J.L. Reveal, coordinators. Intermountain biogeography: a symposium. Great Basin Naturalist Memoirs No. 2. Brigham Young Univ. Press, Provo, UT. Pp.119-136.

West, N.E. 1988. Intermountain deserts, shrub steppes and woodlands. In: M.G. Barbour and W.D. Billings eds. North American Terrestrial vegetation. Cambridge Univ. Press, Cambridge. Pp. 209-230.

Wilson, J.S., and T.L. Schmidt. 1990. Controlling eastern redcedar on rangelands and pastures. Rangelands 12:156-158.

Young, J.A., and R.A. Evans. 1981. Demography and fire history of a western juniper stand. J. Range Manage. 34:501-506.

Pinyon-Juniper Woodland Classification and Description in Research Natural Areas of Southeastern Idaho

Steven K. Rust

Abstract—Pinyon-juniper and juniper woodland vegetation occurs at the northern extent of its range in Idaho. In a nationwide study Idaho-endemic woodland communities are recognized as both the most rare and most poorly understood. To assist with their identification and description, and assessment of their conservation status, pinyon- and juniper-dominated woodland communities were sampled in Bureau of Land Management and National Forest System ecological reference areas. Pinyon-juniper vegetation observed at 12 Research Natural Areas and associated sites within southeastern Idaho is classified on the basis of perceived natural potential. Four series are recognized: singleleaf pinyon (*Pinus monophylla*), Rocky Mountain juniper (*Juniperus scopulorum*), Utah juniper (*Juniperus osteosperma*), and curlleaf mountain-mahogany (*Cercocarpus ledifolius*) on the basis of potential for dominance and relative tolerance of environmental stress. Twenty-three plant associations are identified. Community composition, distribution, and environmental relations are summarized. This information on stand composition and structure provides a baseline for conservation planning and ecosystem management.

Pinyon-juniper and juniper woodland vegetation occurs at the northern extent of its range in Idaho (Cronquist and others 1972). Principle descriptive work on plant communities dominated by Utah juniper (*Juniperus osteosperma*), Rocky Mountain juniper (*Juniperus scopulorum*), and singleleaf pinyon (*Pinus monophylla*) has occurred in the southern Rocky Mountains and Great Basin (for example, Blackburn and others 1969, Baker 1984, and others). (To ease discussion, all vegetation in which singleleaf pinyon, Utah juniper, and/or Rocky Mountain juniper are constituent species will be referred to in this paper as 'pinyon-juniper woodland.') Assessment of the conservation status, and development of effective habitat conservation strategies for pinyon-juniper woodland communities in Idaho is constrained by a lack of basic ecological descriptive work. For example, in a nationwie¤ study (Grossman and others 1994), seven pinyon-juniper woodland communities are recognized as occurring exclusively in Idaho; all are ranked most rare. These Idaho-endemic pinyon-juniper woodland communities are also all considered most poorly understood.

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Research Natural Areas are established to provide a baseline reference against which the effects of intensive management may be assessed and evaluated. As well, an important objective of plant community conservation is to provide a coarse-filter by which the populations and habitats of multiple common and rare species may be captured. To effectively attain these goals and objectives information is needed on plant community composition, structure, and function.

The objectives of this project are: (1) to assist with the identification and description of reference stand conditions in pinyon-juniper woodland communities on Bureau of Land Management and National Forest System lands in the Snake River Basalts, Northwest Basin and Range, and Overthrust Mountains ecological regions of Idaho (McNab and Avers 1994) and (2) to assist in the determination of their conservation status. The purpose of this paper is to present an initial classification of the pinyon-juniper vegetation observed in Research Natural Areas and other selected sites in southeastern Idaho and to summarize composition, distribution, and environmental relations.

Methods

Pinyon-juniper woodlands were sampled at proposed and designated natural areas and other selected sites within the southern portion of the range of pinyon-juniper woodland vegetation in Idaho. To the extent possible, stands present within each sampling site were delineated based on stand environmental features (topography and elevation) and apparent structure and composition (using aerial photography interpretation). Field sampling efforts were stratified within these reference stands. Ecology plots were selected to capture the range of conditions in stand structure and composition. Plots were placed within vegetation patches that are homogeneous in structure and composition.

Basic environmental parameters (slope aspect, gradient and horizon; elevation; micro and macro topography; for example), plant cover, and the density and size distribution of live and standing dead trees were determined on a standard (fixed) one-tenth acre circular ecology plot (Bourgeron and others 1991; USDA Forest Service 1992). Plant cover data were taken by ocular estimate for all vascular plant species. Ocular estimates of the cover of tree species were differentiated by strata (height/diameter class). Tree canopy height was determined for each height/diameter class. Live and standing dead tree stems present within the fixed area plot were tallied by species and size class (using the diameter at root crown). Soils and geology were documented from maps and, where necessary, verified and qualitatively described in the field.

Multivariate classification and ordination analytical techniques were employed in the description of plant communities and assessment of environmental factors. TWINSPAN (Hill 1979b) and DECORANA (Hill 1979a) were used interactively to derive an initial classification of the plot data through progressive decomposition of the data to smaller, more similar groups. This classification was refined and environmental correlations were developed through the use of CANOCO (ter Braak 1991), again using an approach of progressive decomposition. Data analysis was aided through the use of ECOAID (Smith 1993), a data manipulation and summary package.

Results and Plant Community Characterization

Pinyon-juniper woodland sites visited during the 1995 and 1996 field seasons are listed in table 1. All formally designated natural areas on Snake River Resource Area and National Forest System lands known to encompass stands of pinyon-juniper woodland were visited. Previously unrecognized pinyon-juniper woodlands were visited at Burton Canyon RNA. Sampling also occurred at four sites which occur throughout the range of singleleaf pinyon in Idaho, including City of Rocks RNA, Jim Sage Canyon RNA, Pine Knob, and Slide Canyon. Information regarding the biological and physical characteristics and protection and stewardship status of these sites is available from Idaho Conservation Data Center upon request.

Pinyon-juniper vegetation observed in this study is classified on the basis of perceived natural potential. Four series are recognized: singleleaf pinyon, Rocky Mountain juniper, Utah juniper, and curlleaf mountain-mahogany on the basis of potential for dominance and relative tolerance of environmental stress. The 23 plant associations identified within these series are listed in table 2.

The singleleaf pinyon, Rocky Mountain juniper, Utah juniper and curlleaf mountain-mahogany series occur on an apparent environmental gradient of moisture availability and temperature. These environmental gradients are reflected in differences in elevation, substrate characteristics and parent materials, and slope aspect and exposure.

In the vegetation descriptions that follow, Federal Geographic Data Committee (1996) national vegetation classification terminology is used to the extent possible. The Federal Geographic Data Committee (1996), however, is not repeatedly cited. Tree stem size classes referred to in the discussion are defined as follows: seedling, trees <4.5 ft tall; sapling, trees <4.9 inch diameter at root crown height (and >4.5 ft tall); pole, 5.0-8.9; medium-sized tree, 9.0-20.9; large-sized tree, 21.0-32.9; and very large-sized tree, ≥33.0 inch diameter at root crown height. Plant species abundance classes referred to in the text are defined as follows: present, >0 percent cover; common, ≥1 percent cover; well represented, ≥5 percent cover; and abundant, ≥25 percent cover.

Curlleaf Mountain-mahogany Series

Curlleaf mountain-mahogany occurs over a wide range of environmental conditions within the study area. Curlleaf mountain-mahogany-dominated vegetation was sampled only in stands adjacent to singleleaf pinyon-, Rocky Mountain juniper-, or Utah juniper-dominated stands. Thus the range of variation in curlleaf mountain-mahogany-dominated vegetation discussed here is limited. Curlleaf mountain-mahogany is apparently seral to singleleaf pinyon and Rocky Mountain juniper. The successional and environmental relationships of curlleaf mountain-mahogany and Utah juniper are less clear. Utah juniper was not observed reproducing successfully in the understory of curlleaf mountain-mahogany as were singleleaf pinyon and Rocky Mountain juniper.

Data for a limited number of stands which represent late-seral curlleaf mountain-mahogany woodland were collected at Burton Canyon. These samples are classified as curlleaf mountain-mahogany/mountain snowberry/bluebunch wheatgrass (*Cercocarpus ledifolius / Symphoricarpos oreophilus / Agropyron spicatum*). This plant association is compositionally and environmentally similar to plant associations described here as singleleaf pinyon-curlleaf mountain-mahogany/bush oceanspray/basin wildrye (*Pinus monophylla-Cercocarpus ledifolius / Holodiscus dumosus / Elymus cinereus*), Rocky Mountain juniper-curlleaf mountain-mahogany/mountain snowberry/bluebunch wheatgrass (*Juniperus*

Table 1—Research Natural Areas and associated sites representing pinyon-juniper vegetation in southeast Idaho.

Site	Quadrangle	Township	Range	Sec.
Big Juniper Kipuka	Rattlesnake Butte	6S	27E	36
Burton Canyon	Grace	9S	41E	33
City of Rocks	Almo	15S	24E	19
Gibson Jack	Pocatello South	7S	34E	23
Goose Creek Mesa	Ibex Peak	16S	21E	20
Jim Sage Canyon	Jim Sage Canyon	15S	25E	15
	Elba	15S	25E	15
Pine Knob	View	12S	24E	3
Sand Kipuka	Lake Walcott East	8S	27E	10
Slide Canyon	Cache Peak	14S	23E	1
Trapper Creek	Severe Spring	15S	21E	6
Two Mile Canyon	Malad City East	14S	36E	25
W Fork Mink Creek	Clifton Creek	8S	34E	2

Table 2—Classification of pinyon-juniper woodland communities in Research Natural Areas of southeastern Idaho. Plant associations are listed by series with the abbreviated name, scientific name, and common name.

Abbreviation	Scientific Name	Common Name
	Curlleaf Mountain-mahogany Series	
CELE/SYOR/BASA/AGSP	*Cercocarpus ledifolius/Balsamorhiza sagittata/ Agropyron spicatum*	curlleaf mountain-mahogany/arrowleaf balsamroot/bluebunch wheatgrass
	Utah Juniper Series	
JUOS-CELE/SYOR/AGSP	*Juniperus osteosperma-Cercocarpus ledifolius/ Symphoricarpos oreophilus/Agropyron spicatum*	Utah juniper-curlleaf mountain-mahogany mountain snowberry/bluebunch wheatgrass
JUOS/SYOR/AGSP	*Juniperus osteosperma/Symphoricarpos oreophilus/Agropyron spicatum*	Utah juniper/mountain snowberry/bluebunch wheatgrass
JUOS/ARTRW/STCO	*Juniperus osteosperma/Artemisia tridentata wyomingensis/Stipa comata*	Utah juniper/Wyoming big sagebrush/needle-and-thread
JUOS/ARTRV/FEID	*Juniperus osteosperma/Artemisia tridentata vaseyana/Festuca idahoensis*	Utah juniper/mountain big sagebrush/Idaho fescue
JUOS/ARTRV/AGSP	*Juniperus osteosperma/Artemisia tridentata vaseyana/Agropyron spicatum*	Utah juniper/mountain big sagebrush/ bluebunch wheatgrass
JUOS/ARTRV/ORHY	*Juniperus osteosperma/Artemisia tridentata vaseyana/Oryzopsis hymenoides*	Utah juniper/mountain big sagebrush/indian ricegrass
JUOS/ARAR/FEID	*Juniperus osteosperma/Artemisia arbuscula arbuscula/Festuca idahoensis*	Utah juniper/low sagebrush Idaho fescue
JUOS/ARAR/AGSP	*Juniperus osteosperma/Artemisia arbuscula arbuscula/Agropyron spicatum*	Utah juniper/low sagebrush bluebunch wheatgrass
JUOS/ARNO/AGSP	*Juniperus osteosperma/Artemisia arbuscula nova/Agropyron spicatum*	Utah juniper/black sagebrush bluebunch wheatgrass
JUOS/ARNO/POSE	*Juniperus osteosperma/Artemisia arbuscula nova/Poa secunda*	Utah juniper/black sagebrush/Sandberg bluegrass
	Rocky Mountain Juniper Series	
JUSC-CELE/SYOR/AGSP	*Juniperus scopulorum-Cercocarpus ledifolius/ Symphoricarpos oreophilus/Agropyron spicatum*	Rocky Mountain juniper-curlleaf mountain-mahogany/mountain snowberry/bluebunch wheatgrass
JUSC/ARTRV-SYOR/ELCI	*Juniperus scopulorum/Artemisia tridentata vaseyana-Symphoricarpos oreophilus/Agropyron spicatum*	Rocky Mountain juniper/mountain big sagebrush-mountain snowberry/bluebunch wheatgrass
JUSC/ARTRW-CHMI	*Juniperus scopulorum/Artemisia tridentata wyomingensis-Chamaebatiaria millifolium*	Rocky Mountain juniper/Wyoming big sagebrush/desertsweet
JUSC/ARTRW	*Juniperus scopulorum/Artemisia tridentata wyomingensis*	Rocky Mountain juniper/Wyoming big sagebrush
JUSC/HODU	*Juniperus scopulorum/Holodiscus dumosus*	Rocky Mountain juniper/bush oceanspray
JUSC/HANA	*Juniperus scopulorum/Haplopappus nanus*	Rocky Mountain juniper/dwarf goldenweed
	Singleleaf Pinyon Series	
PIMO-CELE/HODU/ELCI	*Pinus monophylla-Cercocarpus ledifolius/ Holodiscus dumosus/Elymus cinereus*	singleleaf pinyon-curlleaf mountain-mahogany/ bush oceanspray/Great Basin wildrye
PIMO-CELE/SYOR-BERE/AGSP	*Pinus monophylla-Cercocarpus ledifolius/ Symphoricarpos oreophilus-Berberis repens/ Agropyron spicatum*	singleleaf pinyon-curlleaf mountain-mahogany/mountain snowberry Oregongrape/bluebunch wheatgrass
PIMO-CELE/POSE	*Pinus monophylla-Cercocarpus ledifolius/Poa secunda*	singleleaf pinyon-curlleaf mountain-mahogany Sandberg bluegrass
PIMO-JUOS/ ARTRV/AGSP	*Pinus monophylla-Juniperus osteosperma/Artemisia tridentata vaseyana/Agropyron spicatum*	singleleaf pinyon-Utah juniper/mountain big sagebrush/bluebunch wheatgrass
PIMO-JUOS/AGSP	*Pinus monophylla-Juniperus osteosperma/ Agropyron spicatum*	singleleaf pinyon-Utah juniper/bluebunch wheatgrass
PIMO-JUOS/ARNO/POSE	*Pinus monophylla-Juniperus osteosperma/Artemisia arbuscula nova/Poa secunda*	singleleaf pinyon-Utah juniper/black sagebrush/Sandberg bluegrass

scopulorum-Cercocarpus ledifolius/Symphoricarpos oreophilus/Agropyron spicatum), and Utah juniper-curlleaf mountain-mahogany/mountain snowberry/bluebunch wheatgrass (*Juniperus osteosperma-Cercocarpus ledifolius/Symphoricarpos oreophilus/Agropyron spicatum*). Late-seral curlleaf mountain-mahogany-dominated woodland was also observed in ridge top positions on north-facing aspects at City of Rocks. Additional work is needed in these curlleaf mountain-mahogany-dominated plant communities.

Rocky Mountain Juniper Series

Upland Rocky Mountain juniper-dominated woodlands occur on the Wapi Flow, within the Snake River Plain; south, on lower-slope positions, in the Goose Creek drainage; and east, with increasing extent, on lower- and upper-slope positions, in the Bannock, Portneuf, and Bear River ranges and on basalt flows of the Portneuf River valley of southeastern Idaho.

Rocky Mountain juniper-dominated woodlands were sampled at relatively few sites. The plant associations identified here typically have a relatively narrow distribution among the sites sampled. These data may not represent the ecological variability of Rocky Mountain juniper-dominated woodlands within the study area. Rocky Mountain juniper plant communities observed range from dense woodlands of the northern Bear River Range which posses high understory cover of mountain shrub species and are characterized by the co-dominance of curlleaf mountain-mahogany, to very open, sparsely vegetated woodlands of the Wapi Flow, on the southern end of the Great Rift system.

Rocky Mountain juniper-dominated woodlands occur with a bimodal elevational distribution. Stands were sampled at both the highest and the lowest elevations. Stands are often associated with bedrock outcrops. Bedrock may serve an ameliorative function, by reducing evaporative soil moisture loss and dampening soil temperature extremes, in an otherwise hot, dry upland rooting environment. Rock structures may also serve to funnel and catch precipitation run-off.

Rocky Mountain Juniper-Curlleaf Mountain-mahogany/Mountain Snowberry/Bluebunch Wheatgrass Plant Association

Distribution—Rocky Mountain juniper-curlleaf mountain-mahogany/mountain snowberry/bluebunch wheatgrass was sampled in stands located at one site, Burton Canyon, on the northern end of the Bear River Range. Based on cursory reconnaissance, the association is expected to be extensive in the vicinity and may occur south in the Wasatch Range in Utah and east toward the Salt River Range in Wyoming.

Vegetation—This vegetation is an open (extremely xeromorphic) evergreen woodland (Federal Geographic Data Committee 1996). Rocky Mountain juniper and curlleaf mountain-mahogany are co-dominant; the later species usually being the more abundant. Mountain snowberry is present and may be abundant. Oregongrape (*Berberis repens*) is often well represented. Mountain maple (*Acer glabrum*) and western serviceberry (*Amelanchier alnifolia*) are common, but not consistently present. The herbaceous understory is diverse. Arrowleaf balsamroot (*Balsamhoriza sagittata*) and bluebunch wheatgrass (*Agropyron spicatum*) are well represented to abundant.

Environment—This association was observed on mixed miogeosynclinal substrates. It is often associated with bedrock outcrops, but not consistently. It is located within the upper drainages of low, mountainous terrain, on mid- and lower-slope positions with southwesterly aspects. The mean elevation (± standard deviation) of sample plots was 6,907 (±234) ft.

Other Studies—Similar Rocky Mountain juniper-curlleaf mountain-mahogany-dominated vegetation is described for the eastern portion of the Beaverhead Mountains ecoregional section in Montana by Cooper and others (1995). Additional work is needed to draw conclusions about the similarities and differences in Rocky Mountain juniper-curlleaf mountain-mahogany-dominated vegetation within the region.

Rocky Mountain Juniper/Mountain Big Sagebrush-Mountain Snowberry/Basin Wildrye Plant Association

Distribution—Rocky Mountain juniper/mountain big sagebrush-mountain snowberry/basin wildrye (*Juniperus scopulorum/Artemisia tridentata vaseyana-Symphoricarpos oreophilus/Elymus cinereus*) was sampled on four plots located at one site, West Fork Mink Creek RNA, within the Bannock Range. The association is expected to occur in similar habitats in the Bannock and Portneuf ranges and may also be present farther east.

Vegetation—The vegetation is (microphyllous) evergreen shrubland. The average cover of trees is <25 percent and less then the average sum of shrub, herb, and grass cover. Mid-seral occurrences were sampled; represented by the adventitious establishment of Rocky Mountain juniper within mountain big sagebrush (*Artemisia tridentata vaseyana*), western serviceberry and mountain snowberry co-dominated shrubland. Oregongrape is often well represented, but not consistently. A rich assemblage of mesic forbs are present, characterized by giant-hyssop (*Agastache urticifolia*) and Wyeth buckwheat (*Eriogonum heracleoides*). Basin wildrye (*Elymus cinereus*) is well represented to abundant. Douglas-fir (*Pseudotsuga menziesii*) may eventually become established as a late-seral species in these stands (though this was not observed). The time period for succession to Douglas-fir occupancy may be longer, however, then the interval between fire disturbance events which would eliminate Douglas-fir establishment.

Environment—This association was sampled on mixed carbonate substrates. Rocky Mountain juniper/mountain big sagebrush-mountain snowberry/basin wildrye occurs on the upper slopes of low, mountainous terrain, within concave draws in mid- and lower-slope micro-topographical positions, often at the toe of rock outcrop or talus formations. The mean elevation (± standard deviation) of sample plots was 6,359 (±161) ft.

Other Studies—Similar vegetation is (or contained within associations) described by Cooper and others (1995), Hess and Alexander (1986), and Johnston (1987). This association incorporates stands incorrectly identified by Grossman and others (1994) as Utah juniper/bitter-brush-mountain snowberry/bluebunch wheatgrass (*Juniperus osteosperma / Purshia tridentata-Symphoricarpos oreophilus / Agropyron spicatum*). Additional work is needed to draw conclusions about the similarities and differences in this vegetation within the region.

Rocky Mountain Juniper/Wyoming Big Sagebrush-Fern-bush Plant Association

Distribution—Rocky Mountain juniper/Wyoming big sagebrush-fern-bush (*Juniperus scopulorum / Artemisia tridentata wyomingensis-Chamaebatiaria millifolium*) was only observed on the Wapi Flow. All of the data for this plant association were collected in the vicinity of Sand Kipuka RNA, on the southern end of the Wapi Flow. The community was also observed in the vicinity of Big Juniper Kipuka, on the northern end of the Wapi Flow. Similar vegetation may occur on mafic volcanic flow substrates on the Snake River Plain and in the Portneuf Valley.

Vegetation—The vegetation is characterized by an open woodland structure of (typically) large diameter, broad, limby Rocky Mountain juniper. Shrub understory is patchy and dense in association with multiple medium sized fissures to highly fractured basalt. Shrubs include fern-bush (*Chamaebatiaria millifolium*), Wyoming big sagebrush (*Artemisia tridentata wyomingensis*), bitterbrush (*Purshia tridentata*), and syringa (*Philadelphus lewisii*). Sandberg's bluegrass (*Poa secunda*) is common. Understory regeneration of Rocky Mountain juniper is usually present in a range of age and size classes.

Environment—Rocky Mountain juniper/Wyoming big sagebrush-fern-bush occurs on mafic volcanic flow substrates. The sites are highly fractured, undulating basalt basins of collapsed lava tubes. The community tends to occur on northeast and easterly aspects, adjacent to (downslope of) Rocky Mountain juniper/bush oceanspray (*Juniperus scopulorum / Holodiscus dumosus*) on lava and Rocky Mountain juniper/Wyoming big sagebrush (*Juniperus scopulorum / Artemisia tridentata wyomingensis*) at the contact of lava and kipuka sand. The mean elevation (± standard deviation) of sample plots was 4,368 (±12) ft.

Other Studies—Woodland stands on the Wapi Flow were previously described as Utah juniper-dominated. Rocky Mountain juniper/Wyoming big sagebrush-fern-bush is not described in other studies.

Rocky Mountain Juniper/Bush Oceanspray Plant Association

Distribution—Rocky Mountain juniper/bush oceanspray was only observed on the Wapi Flow. The community was sampled at both the northern and southern end of the flow. Similar vegetation may occur on mafic volcanic flow substrates on the Snake River Plain.

Vegetation—This is sparse (needle-leaved or microphyllous) evergreen dwarf-shrubland vegetation. Rocky Mountain juniper density is low and the tree canopy is very open. Many sites sampled on the northern Wapi Flow are early-seral. This vegetation is developing in the vicinity of Pillar Butte, north of Big Juniper Kipuka, through primary succession. Stands in the south are characterized by low growing, wind trained Rocky Mountain juniper. Bush oceanspray (*Holodiscus dumosus*) is typically associated with few, large fissures on these sites. Dwarf goldenweed (*Haplopappus nanus*) is often well represented and occurs with hot-rock penstemon (*Penstemon deustus*) on multiple fine crevices. Moss and lichen are usually abundant. Sandberg's bluegrass is often growing in thick moss/leaf litter mats which occur in the understory of Rocky Mountain juniper.

Environment—Rocky Mountain juniper/bush oceanspray occurs on mafic volcanic flow substrates. The sites are of convex micro-topography, dry, and well drained. The plant association is usually located on south and southeast aspects on the crest of lava pressure ridges. Few large tension fissures are present with many to numerous small crevices. The mean elevation (± standard deviation) of sample plots was 4,858 (±316) ft. Rocky Mountain juniper/dwarf goldenweed (*Juniperus scopulorum / Haplopappus nanus*) and Rocky Mountain juniper-Wyoming big sagebrush-fern-bush are adjacent, respectively, on sites with fewer large fissures and highly fractured basalt basins.

Other Studies—Woodland stands on the Wapi Flow were previously described as Utah juniper-dominated. Rocky Mountain juniper/bush oceanspray is not described in other studies.

Rocky Mountain Juniper/Dwarf Goldenweed Plant Association

Distribution—Rocky Mountain juniper/dwarf goldenweed was only observed on the Wapi Flow. The community was sampled at both the northern and southern end of the flow. Similar vegetation may occur on mafic volcanic flow substrates on the Snake River Plain.

Vegetation—This is (needle-leaved or microphyllous) evergreen dwarf-shrubland vegetation. The average cover of trees is less then the average sum of shrub, herb, and grass cover. Rocky Mountain juniper/dwarf goldenweed is structurally intermediate to Rocky Mountain juniper/bush oceanspray and Rocky Mountain juniper-Wyoming big sagebrush-fern-bush. Rocky Mountain juniper tree density is low and canopy cover is low. Dwarf goldenweed, prickly phlox (*Leptodactylon pungens*) and hot-rock penstemon are common, though typically not well represented. Mosses and lichens are usually abundant. As described for Rocky Mountain juniper/bush oceanspray, early-seral occurrences of this association are on the northern end of the Wapi Flow; late-seral occurrences, the southern.

Environment—Rocky Mountain juniper/dwarf goldenweed occurs on mafic volcanic flow substrates. The sites are variable in configuration and slope position. This plant association typically occurs on basalt surfaces with multiple medium to fine fissures; rather than with large crevices or highly fractured basalt. These relatively flat, smooth bedrock substrates occur on both pressure ridgelines and within basins formed through the collapse of lava tubes. The mean elevation (± standard deviation) of sample plots was

4,663 (±335) ft. Rocky Mountain juniper/bush oceanspray and Rocky Mountain juniper-Wyoming big sagebrush-fern-bush are adjacent communities.

Other Studies—Woodland stands on the Wapi Flow were previously described as Utah juniper-dominated. Rocky Mountain juniper/dwarf goldenweed is not described in other studies.

Rocky Mountain Juniper/Wyoming Big Sagebrush Plant Association

Distribution—Rocky Mountain juniper/Wyoming big sagebrush was sampled within Sand Kipuka on two plots. The association is common on the Wapi Flow where wind-deposited sand has the capability to support Rocky Mountain juniper. Similar vegetation likely occurs northeast of the Wapi Flow, within the Snake River Plain (The Nature Conservancy and others 1987).

Vegetation—This is (microphyllus) evergreen shrubland vegetation. The average cover of trees is less then the average sum of shrub, herb, and grass cover. Mid-seral occurrences were sampled. These stands are represented by the adventitious establishment of Rocky Mountain juniper within, otherwise, Wyoming big sagebrush-dominated shrubland. Rocky Mountain juniper density and tree canopy cover are low. Wyoming big sagebrush is well represented with green rabbitbrush (*Chrysothamnus viscidiflorus*). Pricklypear (*Opuntia polyacantha*) is common. Sand wildrye (*Elymus flavescens*) is characteristically well represented.

Environment—This plant association occurs on stabilized, windblown sand deposits within mafic volcanic flow formations on basin bottom and toe-slope positions immediately adjacent basalt bedrock.

Other Studies—Woodland stands on the Wapi Flow were previously described as Utah juniper-dominated. Rocky Mountain juniper/Wyoming big sagebrush is not described in other studies.

Singleleaf Pinyon Series

Singleleaf pinyon is known in Idaho from the Albion, Jim Sage, and Black Pine mountains. Stands were sampled at four sites within the extent of its range in Idaho. Singleleaf pinyon is co-dominant in this woodland vegetation with curlleaf mountain-mahogany and Utah juniper. Plant communities range in character from open, savanna-like woodlands with an open grassy understory to dense stands with abundant, continuous shrub cover. Singleleaf pinyon woodlands are located in upslope positions on the spur ridges of moderately high mountainous terrain.

Singleleaf Pinyon-Curlleaf Mountain-mahogany/Bush Oceanspray/Basin Wildrye Plant Association

Distribution—Singleleaf pinyon-curlleaf mountain-mahogany/bush oceanspray/basin wildrye was sampled at City of Rocks RNA, on the southern end of the Albion Range. The association is well represented at this location but has not been observed elsewhere in Idaho.

Vegetation—This plant association is (rounded crowned temperate or subpolar needle-leaved) evergreen forest. Singleleaf pinyon and curlleaf mountain-mahogany are co-dominant, the later usually being the most abundant. Rocky Mountain juniper is common, but rarely abundant. The understory is characterized by abundant cover of mountain shrub species (in order of importance): bush oceanspray, Oregongrape, and mountain snowberry. Mountain big sagebrush and squaw current (*Ribes cereum*) are often present, but not abundant. Few understory herbaceous species occur in these forest/woodlands. Basin wildrye is consistently present but only common.

Environment—Singleleaf pinyon-curlleaf mountain-mahogany/bush oceanspray/basin wildrye is only observed on granitic substrates within the Albion Mountains. The plant association occurs on lower ridge spurs of moderately high elevation mountainous terrain in upper-slope positions on relatively dry, steep, convex north- to east- to south-facing slopes. The soil surface is usually bouldery. The mean elevation (± standard deviation) of plots was 6,873 (±249) ft. Stands sampled show moderate to high woody fuel accumulations.

Other Studies—Singleleaf pinyon-curlleaf mountain-mahogany-dominated vegetation is described by Heize and others (1962) from the Steptoe watershed in Nevada. The association described here incorporates stands identified by Caicco and Wellner (1983a) as singleleaf pinyon/Utah juniper/basin wildrye (*Pinus monophylla / Juniperus osteosperma / Elymus cinereus*) and singleleaf pinyon/Utah juniper/chokecherry (*Pinus monophylla / Juniperus osteosperma / Prunus virginiana*). The more refined singleleaf pinyon-curlleaf mountain-mahogany/bush oceanspray/basin wildrye plant association has not been described elsewhere.

Singleleaf Pinyon-Curlleaf Mountain-mahogany/Mountain Snowberry-Oregongrape/Bluebunch Wheatgrass Plant Association

Distribution—Singleleaf pinyon-curlleaf mountain-mahogany/mountain snowberry-Oregongrape/bluebunch wheatgrass (*Pinus monophylla-Cercocarpus ledifolius / Symphoricarpos oreophilus-Berberis repens / Agropyron spicatum*) was observed in the west-central and southern Albion Mountains. The association is expected to have at least a moderately extensive distribution within the range of singleleaf pinyon, but this has not been determined.

Vegetation—This is (rounded-crowned temperate or subpolar needle-leaved) evergreen forest vegetation. Early- to mid-seral occurrences were sampled. In these conditions curlleaf mountain-mahogany is dominant in the overstory. Singleleaf pinyon is often present in the overstory and is consistently present in the understory. The understory shrub structure is similar to that of singleleaf pinyon-curlleaf mountain-mahogany/bush oceanspray/basin wildrye. Mountain shrub species are consistently well represented to abundant, including: Oregongrape and mountain snowberry. Mountain big sagebrush and squaw current are often present, but usually with low cover. Bush oceanspray is usually absent. A good number of herbaceous species may be present. Grass species are well represented. Bluebunch wheatgrass and spike fescue (*Leucopoa kingii*) are common and relatively constant.

Environment—The plant association is observed on both carbonate and granitic substrates. Sites are located on lower ridge spurs of moderately high elevation mountainous terrain in mid- and upper-slope positions on relatively dry, steep, convex east- to south- to west-facing slopes. Fuels are characteristically fine herbaceous materials with some dead stemwood. Singleleaf pinyon-curlleaf mountain-mahogany/ mountain snowberry-Oregongrape/bluebunch wheatgrass is adjacent singleleaf pinyon-curlleaf mountain-mahogany/ bush oceanspray/basin wildrye on more southwesterly aspects and is often upslope of singleleaf pinyon-curlleaf mountain-mahogany/Sandberg's bluegrass (*Pinus monophylla-Cercocarpus ledifolius / Poa secunda*). The mean elevation (± standard deviation) of samples was 7,090 (±298) ft.

Other Studies—Singleleaf pinyon-curlleaf mountain-mahogany-dominated vegetation is described by Heize and others (1962) from the Steptoe watershed in Nevada. The association described here incorporates stands identified by Caicco and Wellner (1983a) as singleleaf pinyon/Utah juniper/curlleaf mountain-mahogany/big mountain sagebrush/ bluebunch wheatgrass (*Pinus monophylla / Juniperus osteosperma / Cercocarpus ledifolius / Artemisia tridentata vaseyana / Agropyron spicatum*). The singleleaf pinyon-curlleaf mountain-mahogany/mountain snowberry-Oregongrape/bluebunch wheatgrass plant association has not been described elsewhere.

Singleleaf Pinyon-Curlleaf Mountain-mahogany/Sandberg's Bluegrass Plant Association

Distribution—Singleleaf pinyon-curlleaf mountain-mahogany/Sandberg's bluegrass was observed on 18 plots located in the west-central and southern Albion Mountains, at Slide Canyon, and City of Rocks, respectively. The association is expected to have at least a moderately extensive distribution within the range of singleleaf pinyon, but this has not been determined.

Vegetation—This vegetation is classified by current national standards as rounded-crowned temperate or subpolar needle-leaved evergreen woodland. In stands sampled, singleleaf pinyon and curlleaf mountain-mahogany are co-dominant in often nearly equal proportions. Mountain snowberry and mountain big sagebrush are often present and may be well represented. Sandberg's bluegrass is consistently well represented. Cheatgrass (*Bromus tectorum*) is usually abundant.

Environment—The plant association is observed on both carbonate and granitic substrates. Sites are located on lower ridge spurs of moderately high elevation mountainous terrain in mid- and upper-slope positions on relatively dry, moderately sloped, undulating south-facing slopes. The soil surface is rocky. The mean elevation (± standard deviation) of sample plots was 6,738 (±234) ft. Fuels on sites sampled were fine herbaceous materials with some dead stemwood.

Other Studies—Singleleaf pinyon-curlleaf mountain-mahogany-dominated vegetation is described by Heize and others (1962) from the Steptoe watershed in Nevada. The Singleleaf pinyon-curlleaf mountain-mahogany/Sandberg's bluegrass has not been described elsewhere.

Singleleaf Pinyon-Utah Juniper/Big Mountain Sagebrush/Bluebunch Wheatgrass Plant Association

Distribution—Singleleaf pinyon-Utah juniper/big mountain sagebrush/bluebunch wheatgrass (*Pinus monophylla-Juniperus osteosperma / Artemisia tridentata vaseyana / Agropyron spicatum*) was sampled on nine plots located in the Jim Sage Mountains and in the northwestern and west-central Albion Mountains, at Jim Sage Canyon, Pine Knob, and Slide Canyon, respectively.

Vegetation—This vegetation is rounded-crowned temperate or subpolar needle-leaved evergreen woodland (using national standards). Singleleaf pinyon and Utah juniper are co-dominant often with nearly equal cover. Stands are open, with a mix of medium to large sized mature trees and seedling, sapling and pole sized regeneration. Mountain big sagebrush is well represented in the relatively sparse shrub layer. Bluebunch wheatgrass is consistently well represented; Sandberg's bluegrass is present.

Environment—Singleleaf pinyon-Utah juniper/big mountain sagebrush/bluebunch wheatgrass occurs on carbonate, felsic pyroclastic, and sandstone substrates. The plant association is located on lower and upper ridge spurs of mountainous terrain in ridge top and upper-slope microtopographical positions. Moderately steep slopes are undulating; north to northwest and east to southeast facing. The mean elevation (± standard deviation) of plots was 6,420 (±589) ft.

Other Studies—The plant association described here may be similar in part, or contained by, the singleleaf pinyon/Utah juniper (*Pinus monophylla / Juniperus osteosperma*) association described by Blackburn and others (1968a) for the Mill Creek watershed in north-central Nevada. Their stands are early- to mid-seral and are in a disturbed ecological condition. As well, geographical floristic change makes comparison difficult. The singleleaf pinyon/Utah juniper association described by Blackburn and others (1968b) for the Duckwater watershed, however, appears less similar. The association was identified by Caicco and Wellner (1983a and b) for City of Rocks and Jim Sage Canyon, Idaho (as reported by Grossman and others 1994). This plant association does not occur at the City of Rocks site. Rather, those stands are classified here as singleleaf pinyon-curlleaf mountain-mahogany/bush oceanspray/basin wildrye, singleleaf pinyon-curlleaf mountain-mahogany/mountain snowberry-Oregongrape/bluebunch wheatgrass, and singleleaf pinyon-curlleaf mountain-mahogany/Sandberg's bluegrass. The more refined singleleaf pinyon-Utah juniper/ big mountain sagebrush/bluebunch wheatgrass plant association described here has not been described elsewhere.

Singleleaf Pinyon-Utah Juniper/Bluebunch Wheatgrass Plant Association

Distribution—Singleleaf pinyon-Utah juniper/bluebunch wheatgrass (*Pinus monophylla-Juniperus osteosperma / Agropyron spicatum*) was only observed in the Jim Sage Mountains, at Jim Sage Canyon RNA. Data was collected on seven plots.

Vegetation—The vegetation is an (rounded-crowned temperate or subpolar needle-leaved) evergreen woodland. Utah juniper is the dominant tree species in the early- to mid-seral occurrences observed. Medium to large sized trees occur with moderate density. Singleleaf pinyon and Utah juniper are present as seedling, sapling, and pole regeneration. Bluebunch wheatgrass is abundant in the open, parklike woodland.

Environment—Singleleaf pinyon-Utah juniper/ bluebunch wheatgrass was only observed on felsic pyroclastic substrates. Sites are located on upper ridge spurs in mountainous terrain, on mid- to upper-slope micro-topographical positions. Slopes are primarily south- and southwest-facing, straight and relatively gentle. The soil surface is stony with fine, porous, continuous herbaceous fuels. The mean elevation (± standard deviation) of sample plots was 7,001 (±142) ft.

Other Studies—The singleleaf pinyon/Utah juniper/black sagebrush/bluebunch wheatgrass (*Pinus monophylla / Juniperus osteosperma / Artemisia arbuscula nova / Agropyron spicatum*) association described by Blackburn and others (1968a) for the Duckwater watershed in north-central Nevada is intermediate to singleleaf pinyon-Utah juniper/ bluebunch wheatgrass and singleleaf pinyon-Utah juniper/ black sagebrush/Sandberg's bluegrass (*Pinus monophylla-Juniperus osteosperma / Artemisia arbuscula nova / Poa secunda*) as described here. The singleleaf pinyon-Utah juniper/bluebunch wheatgrass plant association described here has not been described elsewhere.

Singleleaf Pinyon-Utah Juniper/Black Sagebrush/Sandberg's Bluegrass Plant Association

Distribution—Singleleaf pinyon-Utah juniper/black sagebrush/Sandberg's bluegrass was observed in the Jim Sage Mountains and the northwestern Albion Mountains, at Jim Sage Canyon RNA and Pine Knob, respectively. Data were collected on nine plots.

Vegetation—The vegetation is classified as rounded-crowned temperate or subpolar needle-leaved evergreen woodland. Singleleaf pinyon and Utah juniper are co-dominant. Stands are open and moderately dense. Pole, sapling, and seedling sized singleleaf pinyon and Utah juniper regeneration occurs in the understory of large and medium size trees. Understory shrub cover is sparse. Low sagebrush (*Artemisia arbuscula arbuscula*) and black sagebrush (*Artemisia arbuscula nova*) may both be present; the later species is consistently more abundant. Herbaceous cover is typically well represented; herbaceous species composition is not consistent. Bluebunch wheatgrass is often present, though not abundant. Sandberg's bluegrass is consistently well represented.

Environment—Singleleaf pinyon-Utah juniper/black sagebrush/Sandberg's bluegrass was observed on carbonate and sandstone substrates. Sites are located on lower ridge spurs in mountainous terrain, on mid-slope microtopographical positions. Dry east-, southeast-, south-, and southwest-facing slopes are straight and moderately gentle. The stony soil surface is with fine, porous, continuous herbaceous fuels. The mean elevation (± standard deviation) of sample plots was 5,811 (±313) ft.

Other Studies—The singleleaf pinyon/Utah juniper/black sagebrush/bluebunch wheatgrass association described by Blackburn and others (1968a) for the Duckwater watershed in north-central Nevada is intermediate to singleleaf pinyon-Utah juniper/black sagebrush/Sandberg's bluegrass and singleleaf pinyon-Utah juniper/bluebunch wheatgrass as described here. The more refined singleleaf pinyon-Utah juniper/black sagebrush/Sandberg's bluegrass plant association described here has not been described elsewhere.

Utah Juniper Series

In Idaho, Utah juniper-dominated woodlands occur in the South Hills, east to the Malad and Bannock ranges and north across the Snake River Plain to the southern end of the Lost River and Lemhi ranges. Stands were sampled at six sites within the southern portion of this distribution. Vegetation within the series ranges from open woodland to dwarf-shrubland and shrubland (almost grassland) with dispersed trees. Utah juniper-dominated woodlands occur on upper-slope and ridge top positions in mesa and moderate elevation mountainous terrain. Ten plant associations are recognized here.

Utah Juniper-Curlleaf Mountain-mahogany/Mountain Snowberry/ Bluebunch Wheatgrass Plant Association

Distribution—Utah juniper-curlleaf mountain-mahogany/mountain snowberry/bluebunch wheatgrass was observed on the north end of the Bear River Range and in the Bannock Range. This plant association is probably more widely distributed and extensive, though it is represented here by only two plots. Sufficient data are not available to adequately describe the species composition and environmental relations of this apparently distinct plant association.

Other Studies—DeVelice and Lesica (1993) describe Utah juniper-curlleaf mountain-mahogany-dominated vegetation from the Pryor Mountains of Carbon County, Montana.

Utah Juniper/Mountain Snowberry/ Bluebunch Wheatgrass Plant Association

Distribution—Utah juniper/mountain snowberry/ bluebunch wheatgrass (*Juniperus osteosperma / Symphoricarpos oreophilus / Agropyron spicatum*) was observed in the South Hills, Jim Sage Mountains, and the Malad Range. This association may be present throughout the southern range of Utah juniper in Idaho.

Vegetation—This vegetation is rounded-crowned temperate or subpolar needle-leaved evergreen woodland. An open canopy of medium- and large-sized Utah juniper typically occurs with moderate shrub cover and abundant grass cover. Mountain big sagebrush and mountain snowberry are characteristic shrub species. Numerous herbs are observed on Utah juniper/mountain snowberry/bluebunch wheatgrass sites, few with great constancy. Lupine (*Lupinus* spp.) and prickly-pear are fairly constant. Bluebunch wheatgrass is usually abundant; Sandberg's bluegrass is often present.

Environment—The plant association occurs on carbonate, felsic pyroclastic, and sandstone substrates. Utah juniper/mountain snowberry/bluebunch wheatgrass sites are on mesa and upper ridge spurs of moderately high mountainous terrain on mid- to upper-slope micro-topographical positions. Southeast-, south-, and southwest-facing slopes are straight and gentle. The mean elevation (± standard deviation) of sample plots was 6,798 (±413) ft.

Other Studies—The Utah juniper/mountain snowberry/bluebunch wheatgrass plant association has not been described elsewhere.

Utah Juniper/Wyoming Big Sagebrush/ Needle-and-Thread Plant Association

Distribution—Utah juniper/Wyoming big sagebrush/needle-and-thread (*Juniperus osteosperma / Artemisia tridentata wyomingensis / Stipa comata*) was observed only in the Goose Creek drainage, adjacent Goose Creek Mesa RNA. It is expected that the plant association is more widely distributed; additional occurrences were not documented. The existing data essentially document a single stand; additional information is needed to describe the variability of this distinctive vegetation.

Other Studies—Blackburn and others (1971) describe a similar plant association from stands located in the Rock Springs watershed, Nevada.

Utah Juniper/Mountain Big Sagebrush/ Idaho Fescue Plant Association

Distribution—Utah juniper/mountain big sagebrush/Idaho fescue (*Juniperus osteosperma / Artemisia tridentata vaseyana / Festuca idahoensis*) was observed in the South Hills at both Trapper Creek and Goose Creek Mesa. It is expected to occur throughout the eastern portion of the South Hills, but with low areal extent.

Vegetation—This is an evergreen microphyllus shrubland. The modal abundance of trees is <25 percent cover and is less then the modal sum of shrub, herb, and grass abundance. Utah juniper/mountain big sagebrush/Idaho fescue stands are open, with an even (and relatively high) density of medium and large sized trees. Mountain big sagebrush is typically well represented. Bitterbrush is often present. Herbs are usually well represented; important species include arrowleaf balsamroot, Hood's phlox (*Phlox hoodii*), and prickly-pear. Bluebunch wheatgrass is often well represented. Idaho fescue (*Festuca idahoensis*) is usually abundant.

Environment—The plant association was observed on felsic pyroclastic and sandstone substrates. Sites are located on mesa tops and upper ridge spurs of moderately high mountainous terrain, in ridge top and upper-slope micro-topographical positions. Northeast-facing slopes are straight and gentle. The mean elevation (± standard deviation) of plots was 6,178 (±150) ft.

Other Studies—The Utah juniper/mountain big sagebrush/Idaho fescue plant association has not been described elsewhere.

Utah Juniper/Mountain Big Sagebrush/ Bluebunch Wheatgrass Plant Association

Distribution—Utah juniper/mountain big sagebrush/bluebunch wheatgrass (*Juniperus osteosperma / Artemisia tridentata vaseyana / Agropyron spicatum*) was observed in the southern South Hills, Malad Range, and Bannock Range. This plant association probably occurs at additional sites within these geographical extremes.

Vegetation—This is a rounded-crowned temperate or subpolar needle-leaved evergreen woodland. Medium- and few large-sized Utah juniper contribute to a tree canopy of 20-50 percent closure. Pole-, sapling-, and seedling-sized Utah juniper regeneration is moderately dense. Mountain big sagebrush is well represented, often with bitterbrush. Numerous herbs occur in these woodlands. Arrowleaf balsamroot is most constant, and often is abundant. Bluebunch wheatgrass is well represented to abundant.

Environment—The plant association occurs on carbonate, felsic pyroclastic, and sandstone substrates. Sites are located on upper ridge spurs of moderately high mountainous terrain, in (ridge top) upper- to lower-slope micro-topographical positions. Dry south- and west-facing slopes are moderately steep. The mean elevation (± standard deviation) of sample plots was 6,350 (±290) ft.

Other Studies—The Utah juniper/mountain big sagebrush/bluebunch wheatgrass plant association has not been described elsewhere.

Utah Juniper/Mountain Big Sagebrush/ Indian Ricegrass Plant Association

Distribution—Utah juniper/mountain big sagebrush/Indian ricegrass (*Juniperus osteosperma / Artemisia tridentata vaseyana / Oryzopsis hymenoides*) was only observed at Goose Creek Mesa. The plant association is expected to occur in similar habitats within the South Hills.

Vegetation—This is a rounded-crowned temperate or subpolar needle-leaved evergreen woodland. Utah juniper tree canopy cover ranges from 20-40 percent. Very large-, large-, and medium-sized trees contribute to a moderate stem density of 10 trees per acre. Relatively little pole- and seedling-sized regeneration is present. Mountain big sagebrush and bitterbrush are common. Relatively few herbaceous species are observed; prickly phlox and basin-butterweed (*Senecio multilobatus*) are common and constant. Bluebunch wheatgrass, Sandberg's bluegrass, and Indian ricegrass (*Oryzopsis hymenoides*) are common and characteristic species. Bluebunch wheatgrass is most abundant.

Environment—The plant association was observed on felsic pyroclastic and sandstone substrates. These sites are located in upper- and middle-slope micro-topographical positions within mesa terrain. Dry, southwest- and west-facing slopes are straight and steep. Utah juniper/mountain big sagebrush/Indian ricegrass occurs on raveling colluvium; cobbles, stones, and gravel are abundant on the soil surface. The mean elevation (± standard deviation) of samples was 6,070 (±106) ft.

Other Studies—Blackburn and others (1968b) describe Utah juniper/big sagebrush/Indian ricegrass from stands located in the Duckwater watershed, Nevada. Comparison is difficult as the authors describe early- to mid-seral stands typically in a disturbed ecological condition.

Utah Juniper/Low Sagebrush/Idaho Fescue Plant Association

Distribution—Utah juniper/low sagebrush/Idaho fescue (*Juniperus osteosperma/Artemisia arbuscula arbuscula/Festuca idahoensis*) was sampled at Goose Creek Mesa and Trapper Creek. This plant association is expected to occur throughout the South Hills in Idaho.

Vegetation—This vegetation is needle-leaved or microphyllus evergreen dwarf-shrubland with needle-leaved evergreen trees. Utah juniper/low sagebrush/Idaho fescue is open woodland/dwarf-shrubland. Tree, low shrub, and grass components often occur in equal proportions. Observed very large-, large-, and medium-sized tree density was low to moderate (12 trees per acre), relative to other Utah juniper associations. Understory regeneration was relatively low, with an average of two trees per acre pole-, sapling-, and seedling-sized Utah juniper. Low sagebrush is well represented and often abundant in the understory with bitterbrush and black sagebrush. Numerous herbaceous species are observed; few are very constant. Cushion buckwheat (*Eriogonum caespitosum*) and prickly-pear are important herbs. Idaho fescue, Sandberg's bluegrass, and bluebunch wheatgrass are important grass species. Idaho fescue is usually well represented to abundant.

Environment—The plant association was observed primarily on felsic pyroclastic substrate, but also on sandstone. Sites are located on basalt mesa tops, in ridge top and upper-slope positions. Dry, well drained north- and southeast-facing slopes are straight, and gentle (or flat). The soil surface is gravelly. The mean elevation (± standard deviation) of sample plots was 6,312 (±110) ft.

Other Studies—The Utah juniper/low sagebrush/Idaho fescue plant association has not been described elsewhere.

Utah Juniper/Low Sagebrush/Bluebunch Wheatgrass Plant Association

Distribution—Utah juniper/low sagebrush/bluebunch wheatgrass (*Juniperus osteosperma/Artemisia arbuscula arbuscula/Agropyron spicatum*) was observed in the South Hills, Jim Sage Mountains, and Bannock Range. The association may also occur in the Cotterel Mountains, Sublett Range, and Deep Creek Mountains.

Vegetation—This is rounded-crowned temperate or subpolar needle-leaved evergreen woodland vegetation. Observed very large-, large-, and medium-sized tree density was low (nine trees per acre) relative to other Utah juniper associations. Understory regeneration is moderately high, with an average of seven trees per acre pole-, sapling-, and seedling-sized Utah juniper. The understory is occupied by abundant low shrubs, herbs, and grasses. Low sagebrush is consistently well represented to abundant. Mountain snowberry is usually present but not well represented. Arrowleaf balsamroot is consistently present and usually well represented. Prickly-pear is also an important herb. Bluebunch wheatgrass and Sandberg's bluegrass are both consistently present, the former being most abundant and well represented to abundant.

Environment—The association was observed on felsic pyroclastic, mixed carbonate, and (primarily) sandstone substrates. Sites are located on mesa tops and upper ridge spurs of moderately high mountainous terrain, most frequently in upper-slope micro-topographical positions. Dry, southeast-, south-, and southwest-facing slopes are horizontally convex, vertically straight, and moderately gentle. Utah juniper/low sagebrush/bluebunch wheatgrass often occurs in association with fragmented bedrock. Large rock fragments (boulders, cobbles, and stones) occupy between 15 and 45 percent cover. The mean elevation (± standard deviation) of sample plots was 6,577 (±292) ft.

Other Studies—This association incorporates stands identified by Grossman and others (1994) as Utah juniper/bitter-brush-mountain snowberry/bluebunch wheatgrass (*Juniperus osteosperma/Purshia tridentata-Symphoricarpos oreophilus/Agropyron spicatum*). The Utah juniper/low sagebrush/bluebunch wheatgrass plant association has not been described elsewhere.

Utah Juniper/Black Sagebrush/Bluebunch Wheatgrass Plant Association

Distribution—Utah juniper/black sagebrush/bluebunch wheatgrass (*Juniperus osteosperma/Artemisia arbuscula nova/Agropyron spicatum*) was observed in the Jim Sage Mountains and Bannock Range. This plant association is probably repeated in similar ridge top habitats in the Cotterel Mountains, Sublett Range, and Deep Creek Mountains but not with large, extensive occurrences.

Vegetation—This vegetation is needle-leaved or microphyllus evergreen dwarf-shrubland with needle-leaved evergreen trees. Utah juniper large- and medium-sized trees occur with moderate density (15 trees per acre). Understory regeneration is relatively abundant (compared to other Utah juniper associations) with 15 trees per acre. The tree canopy is very open. Low shrubs, and grasses are abundant in the understory. Black sagebrush and low sagebrush are both present, the former dominant and well represented to abundant. Hood's phlox is a common and characteristic herb. Bluebunch wheatgrass and Sandberg's bluegrass are both consistently present. Bluebunch wheatgrass is well represented to abundant.

Environment—The association was sampled primarily on felsic pyroclastic substrate, but also occurs on sandstone. Sites are located on upper ridge spurs of moderately high mountainous terrain, most frequently in upper-slope micro-topographical positions. The mean elevation (± standard deviation) of sample plots was 7,120 (±211) ft. Gentle, dry, well drained, south- and west-facing slopes are horizontally convex and vertically straight. Cobbles and stones are well represented to abundant.

Other Studies—The broad juniper woodland community identified by Knight and others (1987) for Bighorn Canyon National Recreation Area, Wyoming, is similar to (or contains) the Utah juniper/black sagebrush/bluebunch wheatgrass plant association described here. Blackburn and others (1971) describe Utah juniper/black sagebrush/bluebunch wheatgrass as occurring in the Rock Springs watershed, Nevada. Utah juniper is less abundant (8.8 versus 11.5-16.4 percent cover) and black sagebrush and bluebunch wheatgrass are more abundant (20 versus 6.1-7.8 and 32 versus 3.8 percent cover, respectively) in reference area stands compared to the seral, disturbed Rock Spring stands. Caicco and Wellner (1983c) identify the association as occurring in the southern Lemhi Range. Bourgeron and Engelking (1994), however, group the southern Lemhi Range stands in the broader Utah juniper/black sagebrush (*Juniperus osteosperma / Artemisia arbuscula nova*).

Utah Juniper/Black Sagebrush/Sandberg's Bluegrass Plant Association

Distribution—Utah juniper/black sagebrush/Sandberg's bluegrass (*Juniperus osteosperma / Artemisia arbuscula nova / Poa secunda*) was observed in the South Hills. The extent of the association within the area and adjacent areas is not known.

Vegetation—This vegetation is needle-leaved or microphyllus evergreen dwarf-shrubland with needle-leaved evergreen trees. Utah juniper canopy cover ranges from 1-25 percent. Dwarf-shrub species are the dominant life form. Black sagebrush is usually abundant; low sagebrush is often present. Slenderbush buckwheat (*Eriogonum microthecum*), cushion buckwheat, and Hooker's balsamroot (*Balsamorhiza hookeri*) are common and characteristic herbs. Sandberg's bluegrass is consistently well represented.

Environment—Utah juniper/black sagebrush/Sandberg's bluegrass was only observed on felsic pyroclastic substrates. Sites are located on mesa tops, most frequently in ridge top micro-topographical positions. Gentle slopes occur with a range of aspects and micro-configurations. The mean elevation (± standard deviation) of sample plots was 6,430 (±89) ft. These sites are very rocky. Large- to medium-sized rock fragments (cobbles, stones, and gravel) may occupy 45-70 percent of the surface.

Other Studies—The Utah juniper/black sagebrush/rock (*Juniperus osteosperma / Artemisia arbuscula nova*/Rock) plant association described by Blackburn and others (1968b) for the Duckwater watershed, Nevada, is similar to Utah juniper/black sagebrush/Sandberg's bluegrass plant association described here.

Conclusions

Research Natural Areas are identified and established to provide a baseline reference for evaluation of intensive resource management affects. This paper presents an initial classification of pinyon-juniper vegetation observed in Research Natural Areas of southeastern Idaho. The composition, distribution, and environmental relations of 23 pinyon-juniper plant associations is summarized. This information provides a baseline for conservation planning and ecosystem management.

The results of this study assist with the identification and description of reference stand conditions in pinyon-juniper woodland vegetation of the northern Great Basin region. Determination of the relationships of plant associations identified here to similar vegetation within the region is (in some cases) difficult due to the availability and presentation of existing information. These questions will be resolved as more work from within the region becomes available. The data presented here, as well, need further testing within the subregional scale of the study area. These developments will make important contributions to determination of the conservation status of pinyon-juniper woodland vegetation of the northern Great Basin region.

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References

Baker, W. L. 1984. A preliminary classification of the natural vegetation of Colorado. The Great Basin Naturalist 44(4): 647-676.

Blackburn, W. H.; Tueller, P. T.; Eckert, R. E. Jr. 1968a. Vegetation and soils of the Mill Creek Watershed. Nevada Agricultural Experiment Station Bulletin R-43. Reno. 69 p.

Blackburn, W. H.; Tueller, P. T.; Eckert, R. E. Jr. 1968b. Vegetation and soils of the Duckwater Watershed. Nevada Agricultural Experiment Station Bulletin R40. Reno. 76 p.

Blackburn, W. H.; Eckert, R. E. Jr.; Tueller, P. T. 1969. Vegetation and soils of the Churchill Canyon Watershed. Nevada Agricultural Experiment Station Bulletin R-45. Reno. 157 p.

Blackburn, W. H.; Eckert, R. E. Jr.; Tueller, P. T. 1971. Vegetation and soils of the Rock Springs Watershed. Nevada Agricultural Experiment Station Bulletin R-83. Reno. 116 p.

Bourgeron, P. S.; DeVelice, R. L.; Engelking, L. D.; Jones, G.; Muldavin, E. 1991. WHTF site and community survey manual. Version 92B. Western Heritage Task Force, Boulder. 24 p.

Bourgeron, P. S.; Engelking, L. D. 1994. A preliminary vegetation classification of the Western United States. The Nature Conservancy, Western Heritage Task Force, Boulder.

Caicco, S. L.; Wellner, C. A. 1983a. Research Natural Area recommendation for City of Rocks. Unpublished report prepared for USDI, Bureau of Land Management, Burley District, Idaho by Idaho Natural Areas Coordinating Committee. On file at Idaho Conservation Data Center, Boise, Idaho. 12 p.

Caicco, S. L.; Wellner, C. A. 1983b. Research Natural Area recommendation for Jim Sage Canyon, BLM, Burley District, ID. Unpublished report prepared for USDI, Bureau of Land Management, Burley District by Idaho Natural Areas Coordinating Committee. On file at Idaho Conservation Data Center, Boise, Idaho. 12 p.

Caicco, S. L.; Wellner, C. A. 1983c. Research Natural Area recommendation for Southwest Lemhi Range. Unpublished report prepared for USDI, Bureau of Land Management, Burley District by Idaho Natural Areas Coordinating Committee. On file at Idaho Conservation Data Center, Boise, Idaho. 14 p.

Cronquist, A.; Holmgren, A. H.; Holmgren N. H.; Reveal, J. L. 1972. Intermountain flora: vascular plants of the Intermountain West, USA. Vol. 1. Hafner Publishing Company, Inc., New York. 270 p.

Cooper, S. V.; Lesica, P.; McGarvey, J. T. 1995. Classification of southwestern Montana plant communities with emphasis on those of Dillon Resource Area, Bureau of Land Management. Montana Natural Heritage Program, Helena, MT. 152 p.

DeVelice, R. L.; Lesica, P. 1993. Plant community classification for vegetation on BLM lands, Pryor Mountains, Carbon County, Montana. Montana Natural Heritage Program, Helena, MT. 78 p.

Federal Geographic Data Committee-Vegetation Subcommittee. 1996. Vegetation Classification and Information Standards. USDI, Geological Survey, Reston. 35 p.

Grossman, D. H.; Goodin, K. L.; Reuss, C. L., editors. 1994. Rare plant communities of the coterminous United States - an initial survey. Prepared for the USDI Fish and Wildlife Service. The Nature Conservancy, Arlington, VA. 620 p.

Heize, D. H.; Eckert, R. E.; Tueller, P. T. 1962. The vegetation and soils of the Steptoe Watershed. Unpublished report prepared for the USDI Bureau of Land Management. 40 p.

Hess, K.; Alexander, R. R. 1986. Forest vegetation of the Arapaho and Roosevelt National Forests in north central Colorado: A habitat type classification. USDA Forest Service Research Paper RM-266. Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. 48 p.

Hill, M. O. 1979a. DECORANA—a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ecology and Systematics, Cornell University, Ithaca. 36 p.

Hill, M. O. 1979b. TWINSPAN—a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of individuals and attributes. Ecology and Systematics, Cornell University, Ithaca. 60 p.

Johnston, B. C. 1987. Plant associations of Region Two. Edition 4. USDA Forest Service, Rocky Mountain Region. R2-Ecol-87-2. 429 p.

Knight, D. H.; Jones, G. P.; Akashi, Y.; Myers, R. W. 1987. Vegetation ecology in the Bighorn Canyon National Recreation Area. Unpublished report prepared for the USDI National Park Service and the University of Wyoming-Nat. Park Service Research Center. 114 p.

McNab, W. H.; Avers, P. E., comps. 1994. Ecological subregions of the United States: Section Descriptions. Administrative Publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

Smith, B. G. 1993. ECOAID, a users guide. Unpublished software and guide. USDA Forest Service, Pacific Northwest Region, Portland. 6 p.

ter Braak, C. J. F. 1991. CANOCO—a FORTRAN program for canonical correspondence analysis, principal components analysis, and redundancy analysis (version 3.12). IWIS-TNA, Wageningen, The Netherlands. 95 p.

The Nature Conservancy, Idaho Natural Heritage Program, and Oregon Natural Heritage Database. 1987. Final Report, Phase I, 1987 National Natural Landmark Project, Pacific Northwest Region, National Park Service; Including classification of the following ecological themes: Western Juniper, Utah and Rocky Mountain Juniper Woodlands, Lowland and Valley Grassland, Canyon Grasslands, and Montane Coastal Refugium Forest. Unpublished report prepared for the U.S. Department of the Interior, National Park Service, Pacific Northwest Region, Seattle, WA. 47 p.

USDA Forest Service. 1992. Ecosystem Inventory and Analysis Guide (7/92). Northern Region, Missoula, MT.

Tree Size and Ring Width of Three Conifers in Southern Nevada

Simon A. Lei

Abstract—The sizes and ring widths of singleleaf pinyon, ponderosa pine, and white fir were investigated along an elevational gradient in the Spring Mountain Range of southern Nevada. The mean height and stem diameter of ponderosa pine were generally taller and larger relative to singleleaf pinyon and white fir. All three conifers exhibited greater mean stem diameter on north-facing relative to south-facing slopes. Ring widths from trees on lower elevations were most variable. The widest rings were generally formed on south-facing slopes, while the narrowest rings were formed on north-facing slopes. Differences in tree sizes and ring widths were a function of variations in climate, elevations, and slope exposures in the Spring Mountain Range of southern Nevada.

The singleleaf pinyon-Utah juniper (*Pinus monophylla-Juniperus osteosperma*) woodland ranges from approximately 1,250 to 2,600 m in elevation on dry mountain slopes in southern Nevada. On south-facing slopes, the woodland is generally more open, Utah juniper predominates and the understory vegetation consists of mixed shrubs with some grasses. On north-facing slopes, the canopy is largely closed, singleleaf pinyon predominates and the understory is mostly of grasses. The montane ponderosa pine-white fir (*Pinus ponderosa-Abies concolor*) forest ranges from approximately 2,200 to 2,900 m in elevation in the Spring Mountains of southern Nevada. The pinyon-juniper woodland and ponderosa-fir forest are considered climax species because they maintain relatively stable populations without progressive replacement by other woody taxa (Luken 1990).

The greatest changes in tree characteristics of conifers growing on relatively high desert mountain slopes are related to the topographic and elevational differences in the site (Fritts 1976, 1991). The significance of topography and slope exposure is due to the influence on the moisture, air temperature, incident radiation, and orientation of prevailing wind regimes, which may become limiting to the growth of trees (Schweingruber 1989; Fritts 1965, 1991). Fritts (1969) proposed that on the dry south-facing exposures, some tree rings are absent or partially present, the pattern of ring widths is strongly correlated within and between trees, and chronologies are more variable. The environment is most limiting to ring-width growth at low elevational sites, particularly on south-facing slopes in the White Mountains of southern California (Fritts 1969). Subtle differences in relief, slope exposure, microclimate, and soil properties would lead to changes in stand density and composition.

A correlation existed between precipitation and ring widths of trees growing on arid or low elevational sites (Fritts 1976, 1991). Chronologies are not always easily dated because many rings may be small, or in extremely arid years, the cambium may fail to grow and no ring is formed (Fritts 1969). Tree-ring chronologies from lower elevations, south-facing slopes, and from areas of less snow accumulation exhibit the most chronologic variability and contain the most information regarding past climates in southern California (Fritts 1969, 1991). Drought reduces net photosynthesis, which limits the accumulation of reserved food. With less food, growth is slow and a narrow ring is formed (Fritts 1969, 1991). Dry conditions due to high air temperatures or low precipitation of late summer or autumn may also reduce the amount of accumulated food, and thus influence the width of the following season's ring (Fritts 1969, 1976). Severe drought influences tree ring characteristics, including ring widths for several years, and drought can even cause the tree mortality.

Three common conifers—singleleaf pinyon, ponderosa pine, and white fir—occupy relatively high desert mountain slopes in the Spring Mountain Range of southern Nevada. The objectives of this study were to quantitatively examine the tree size, ring width, and to correlate variations in ring width of three conifer species with variations in elevation, climatic parameters, and slope exposures in Lee Canyon of southern Nevada.

Methods

Study Area

Field studies were conducted in spring 1996 in Lee Canyon (36°05' N, 115°15' W; elevation 2,000 to 2,900 m) of the Spring Mountains, located approximately 50 km northwest of Las Vegas, Nevada (fig. 1). Lee Canyon was chosen based on the accessibility to the pinyon-juniper woodland and montane ponderosa-fir forest. The tree samples were obtained from sites representing differences in climate, elevation, and slope exposure. The pinyon-juniper woodland is found at elevations ranging from 1,250 to 2,600 m in the Spring Mountains. Vegetation is characterized by Utah juniper, singleleaf pinyon, and big sagebrush. The montane ponderosa-fir forest extends from approximately 2,150 to 2,900 m. This montane forest consists of a mixture of ponderosa pine, white fir and, to a lesser extent, limber pine (*Pinus flexilis*) and quaking aspen (*Populus tremuloides*). The narrow drainage has an eastern descent with steep slopes having north and south aspects.

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Figure 1—Map of the study area showing Lee Canyon of the Spring Mountains located in the southwestern United States. The city of Las Vegas lies to the southeast of the Spring Mountains.

The winter climate of pinyon-juniper woodland and ponderosa-fir forest is cold with frequent snowfall, while the summer climate is cool. The temperature and precipitation data in southern Nevada were acquired from the nearest long-term weather station (record of climatological observations; National Weather Service) in Kyle Canyon, located approximately 15 km from Lee Canyon. Air temperatures were frequently in the subzero range from December through early April. At 2,000 m elevation and above, summer temperatures are cool and rarely surpass 30 °C, while in the winter, snow and below-freezing temperatures are common. Minimum air temperatures on the average are above freezing from June through September, and minimum temperatures during winters are seldom below –25 °C. Occasionally, snow is present at higher elevations in midsummer. Precipitation varies considerably from year to year. Annual precipitation of the pinyon-juniper woodland is generally less than 400 mm, and montane ponderosa-fir woodland ranges from 300 to over 600 mm. This variation in precipitation is largely related to a combination of topography, elevation, and slope exposure. Most of the precipitation occurs in winter storms or in late summer thunderstorms in southern Nevada.

Field Surveys

Two (150 m * 150 m) square plots were established at each of the 10 elevations along a gradient ranging from 2,000 to 2,900 m with a fixed elevational interval of 100 m. A total of 20 plots were evenly distributed on both north- and south-facing slopes. Some pine and fir saplings were detected along this elevational gradient but were not measured. Saplings were generally more abundant on the north-facing than south-facing slopes. Living barks completely encircled the stems (full bark) in many trees. I cored through at least one-half of the stem diameters of the trees containing pith. Trees were selected from north- and south-facing exposures only for intensive study. Some partial rings were formed, especially at the lower elevational (arid) sites. For this reason, four incremental cores were extracted systematically based on four compass directions (north, south, east, and west) along the radii from each tree at breast height to reduce tree-ring error and to allow analysis of the variations within trees. Cores were extracted without major faults, such as fire scars, rotten spots, frost cracks, insect damage, and woodpecker holes. The trees were selected from a relatively small homogenous group to minimize variability arising from diverse soil types and factors. The yearly ring widths were crossdated among all radii within a stem and among different trees in sampled stands. The tree-ring widths of singleleaf pinyon, ponderosa pine, and white fir were determined with the aid of a stereoscope and a millimeter ruler after extracting cores from tree stems. One ring was assumed to equal 1 year's growth. Only rings for the past 15 years were examined. Height and stem diameter (d.b.h. or 1.5 m from the ground) of each tree were measured. Tree height was estimated by triangulation.

Statistical Analyses

One-way Analysis of Variance (ANOVA) was used to detect differences in tree characteristics (height and stem diameter) along the elevational gradient. ANOVA was also employed to detect differences in mean ring widths within a tree stem, between low and high elevational sites, and between different slope exposures. A Tukey's multiple comparison test was used to compare the mean height and stem diameter of three conifer species from the same elevation on both slope aspects, and to compare mean ring widths when significant slope and elevation effects were detected. Pearsons correlation analysis was conducted to correlate variations in ring widths of three conifer species with variations in abiotic (climate, elevation, and slope exposure) factors. Mean values in ring width were expressed with standard errors, and statistical significance was determined at $p \leq 0.05$ (Analytical Software 1994).

Results

From casual observations, both singleleaf pinyon and ponderosa pine exhibited relatively little regeneration, while white fir was the dominant understory species present within the study area. In general, ponderosa pine trees had a significantly larger stem diameter ($p < 0.001$; tables 1 and 2) than white fir and singleleaf pinyon. All three conifer species showed larger stem diameters on north-facing than on south-facing slopes. Ponderosa pine trees were significantly ($p < 0.001$) taller than white fir and singleleaf pinyon on both slope exposures. Both white fir and ponderosa pine had significantly greater mean diameter, and were significantly taller than singleleaf pinyon regardless of slope exposures ($p < 0.001$; tables 2 and 3).

The widest rings were detected in trees establishing on the south-facing slopes. Trees establishing on the south-facing slopes displayed more missing and partial rings with more

Table 1—Total abundance (number of individuals), mean stem diameter (d.b.h.), and mean height of three conifer species establishing on the north-facing slopes from elevations of 2,000 to 2,900 m in the Spring Mountains. Mean values in rows under the same category (diameter and height) followed by different letters are significantly different at $p \leq 0.05$.

Elevation	Total abundance			Stem diameter			Height		
	Pinyon	Ponderosa	Fir	Pinyon	Ponderosa	Fir	Pinyon	Ponderosa	Fir
m				--------- *cm* ---------			---------- *m* ----------		
2,000	79	—	—	46.7	—	—	20.3	—	—
2,100	66	—	—	46.1	—	—	21.4	—	—
2,200	62	12	9	48.2a	65.3b	67.2b	21.7a	37.1b	38.4b
2,300	49	20	17	57.8a	68.1b	75.6c	25.8a	42.9b	38.7b
2,400	37	15	41	55.2a	73.7b	74.9b	23.7a	46.5c	42.1b
2,500	29	10	91	50.1a	77.2c	72.8b	23.6a	48.5c	42.9b
2,600	12	19	108	47.3a	77.7c	67.6b	22.7a	45.9c	40.5b
2,700	—	17	69	—	83.9a	74.4b	—	47.4a	39.9b
2,800	—	12	32	—	81.4a	71.3b	—	45.1a	38.9b
2,900	—	8	102	—	69.1a	78.4b	—	44.2a	37.4b

Table 2—Total abundance (number of individuals), mean stem diameter (d.b.h.), and mean height of three conifer species establishing on the south-facing slopes from elevations of 2,000 to 2,900 m in the Spring Mountains. Mean values in rows under the same category (diameter and height) followed by different letters are significantly different at $p \leq 0.05$.

Elevation	Total abundance			Stem diameter			Height		
	Pinyon	Ponderosa	Fir	Pinyon	Ponderosa	Fir	Pinyon	Ponderosa	Fir
m				--------- *cm* ---------			---------- *m* ----------		
2,000	69	—	—	42.3	—	—	20.1	—	—
2,100	51	—	—	43.0	—	—	18.3	—	—
2,200	63	12	37	41.9a	73.6b	75.7b	21.5a	37.1b	38.4b
2,300	72	20	17	43.1a	68.1b	73.5c	19.8a	42.3b	40.7b
2,400	51	12	9	46.4a	65.3b	67.2b	18.2a	46.5c	42.3b
2,500	14	8	45	42.2a	78.3c	69.0b	19.4a	48.5c	43.9b
2,600	6	7	149	47.7a	74.2b	79.9c	17.7a	45.8c	39.5c
2,700	—	2	44	—	81.9a	72.0b	—	51.4a	39.4b
2,800	—	7	14	—	74.8a	77.0a	—	46.9a	38.6b
2,900	—	2	5	—	72.5a	65.8b	—	45.4a	38.9b

Table 3—Relative ring widths (mean ± SE) of singleleaf pinyon, ponderosa pine, and white fir in the Spring Mountains. Low elevational sites included 2,000 to 2,300 m in the pinyon-juniper woodland, while 2,200 and 2,500 m in the montane ponderosa-fir forest. Mean values in columns followed by different letters are significantly different at $p \leq 0.05$.

Sample	Ring width (mm)		
	Singleleaf pinyon	Ponderosa pine	White fir
	-------------------- *mm* --------------------		
North-facing slope			
Low elevation	0.78 ± 0.05 a	0.80 ± 0.07 a	1.19 ± 0.09 a
High elevation	0.66 ± 0.04 b	0.54 ± 0.05 b	0.97 ± 0.05 b
South-facing slope			
Low elevation	0.86 ± 0.08 a	0.87 ± 0.06 a	1.35 ± 0.11 a
High elevation	0.72 ± 0.07 b	0.64 ± 0.05 b	1.04 ± 0.06 b

variations in ring widths regardless of species (data not shown). On the contrary, the narrowest rings were generally detected in trees on north-facing slopes (table 3). In this study, 2,000 to 2,300 m were regarded as low elevational sites in the pinyon-juniper woodland, while 2,200 to 2,500 m represented low elevational sites in the montane ponderosa-fir forest. Within the same slope aspect, ring width from trees existing on low elevational sites was wider and more variable compared to trees existing on high elevational sites (table 3). Among the three conifers, white fir showed the greatest ring width. Variations in ring widths reflected differences in elevation, climatic variables, and slope aspects (table 3).

No significant differences ($p > 0.05$) were detected in ring widths within the tree stem in all three conifer species although some trees exhibited slight ring-width variations. A sharp boundary occurred between rings on stems, and the ring boundary represented the abrupt change in cell size between two growing seasons. Moreover, ring widths of three conifer species exhibited a significant positive correlation with mean annual air temperature, but exhibited a significant negative correlation with elevation, mean annual precipitation, and slope exposure (table 4). Narrow rings were significantly correlated with low air temperatures and high precipitation.

Table 4—Results of Pearsons correlation analysis by matching the ring widths of singleleaf pinyon, ponderosa pine, and white fir to abiotic factors. Air temperature and precipitation were averaged over an interval of 1 year. r is the coefficient of linear correlation. Significance levels: *:$p < 0.05$, **: $p < 0.01$, ***:$p < 0.001$, and NS: non-significant.

Factor	r
Singleleaf pinyon	
Elevation	–0.91***
Annual Temperature	0.88***
Annual Precipitation	–0.85***
Slope exposure	
Ponderosa pine	
Elevation	–0.93***
Annual temperature	0.90***
Annual precipitation	–0.89***
Slope exposure	–0.83***
White fir	
Elevation	–0.92***
Annual temperature	0.87***
Annual precipitation	–0.86***
Slope exposure	–0.74***

Discussion

Sizes and ring widths of singleleaf pinyon, ponderosa pine, and white fir trees on relatively high desert mountain slopes were examined at Lee Canyon in Spring Mountains of southern Nevada. White fir dominated on both slope aspects in the mixed ponderosa-fir vegetation zone. The ring widths of trees near the species' lower elevational limits would yield the most reliable climatic information. Tree-ring width and growth are chiefly dependent upon environmental factors, such as variations in elevation, topography, temperature, precipitation and slope exposure in southern Nevada.

Topography and slope exposure modify incident radiation, air temperature, wind pattern, and soil moisture which may indirectly limit the growth of trees. On the moist, cool north-facing slope where denser stands of pine and fir trees occur, chronologies including ring width are less variable, fewer rings are absent, and contained the least amount of information on past climates in southern California (Fritts 1969). Large differences in tree-ring characteristics associated with variation in topography and slope exposure are evident. If the sites are less extremes, the rings do not vary greatly in width, and ring-width variability is a function of site aridity (Fritts 1976, 1991), which corresponds with my study. Fritts (1976, 1991) further suggested that slope exposure, degree of slope, and orientation to prevailing wind are prime factors controlling moisture relations and ring-width patterns in bristlecone pine (*Pinus longaeva*) in the White Mountains of California.

A correlation existed between ring widths and moisture conditions of the previous summer and autumn, as well as temperature of the winter (Fritts 1991). Narrow rings were found to be correlated with climatic conditions, such as low air temperatures and high precipitation (LaMarche 1976). At low elevations and latitudes, variations in ring width often are highly and positively correlated with variations in precipitation and negatively correlated with variations in air temperature (Fritts 1976). However, at high elevations and latitudes, correlation between ring width with precipitation becomes weak and negative, while correlation between ring width and air temperature becomes strong and positive (Fritts 1976).

Moreover, crossdating, including examining yearly ring widths among all radii within a stem and matching of ring-width patterns among trees, is necessary because the same or similar environmental conditions have limited the ring widths in large number of trees. The year-to-year fluctuations in limiting environmental factors that are similar throughout an area appears to produce synchronous variations in ring structure (Fritts 1976). The fact that crossdating can be obtained is evidence that some climatic or environmental information were common to the sampled trees from a particular stand (Fritts 1976).

Precipitation in the pinyon-juniper and montane ponderosa-fir vegetation zones is usually in the form of snow, and freezing air temperatures in winters are frequent as elevation ascends. When spring arrives, the melting snow pack seeps into the ground and serves as moisture for plants (Lei 1994). The precise ages of pine and fir trees were difficult to determine because they exhibited little or no net growth during extremely arid spring seasons with more missing and partial rings and more chronologic variation. Nevertheless, two fairly abundant seasonal rainfalls may lead to two distinct tree-ring growth within a single year. In order to accurately determine the absolute ages of pine and fir trees, distinct annual rings must be present from an active growing season. For these reasons, the absolute ages of pine and fir trees were not determined in this study. Furthermore, extreme drought during the most active growing period in May and June would limit photosynthesis and would highly correlate with narrow rings of trees

(McGinnies 1963). On the contrary, drought in late summer and autumn appear to have less correlation with narrow rings of trees (McGinnies 1963). The influence of a favorable or unfavorable year may be observed in not only the current tree-ring width, but also in the ring widths for the following 3 years in northern Arizona (Fritts and others 1965; Ballie 1982; Stokes 1974).

Schulman (1956) suggested that rates of photosynthesis is a function of air temperature. Mean annual air temperatures decrease with ascending elevation in southern Nevada (Lei 1994, 1995). The severity of winter air temperatures may influence photosynthesis in trees growing at high elevations. Cold winters may result in a prolonged inactive period and in a depletion of food reserves (Schulman 1941, 1956). While air temperatures during the winter may limit growth, air temperatures at other seasons interact with the moisture regime to produce differences in net photosynthesis, food reserves, and ring-width growth (Fritts 1969). On the more mesic, north-facing slopes, the physiological processes, such as photosynthesis, respiration, and cambial activity, are not as frequently limited by climate, and therefore the tree-ring widths are less variable in northern Arizona (Fritts and others 1965). Trees on the moist sites formed denser stands and were generally taller since moisture stress was less directly related to tree-growth responses.

Implications and Future Directions

The results of this study reveal that tree size and ring width can be utilized to examine the growth response of various tree species to their environment. Ring widths from trees are positively correlated with air temperature, while negatively correlated with elevation, precipitation, and slope exposure. Ring width variability is indicative of environmental stress of the tree site. Subtle or significant climatic change at the local and regional scales in the future would influence the density and abundance of both pine and fir trees. Once ring width chronologies in the pinyon-juniper and ponderosa-fir vegetation zones are developed from progressively drier sites and properly dated, one can provide an accurate, long-term record of climatic patterns. When the climatically "sensitive" arid-site trees with some partial rings are appropriately dated, their ring-width chronology may be used to analyze, characterize, and reconstruct the climatic fluctuations of the past in southern Nevada.

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References

Analytical Software. 1994. Statistix 4.1, an interactive statistical program for microcomputers. Analytical Software, Minnesota. 329 p.

Ballie, M. G. L. 1982. Tree-ring dating and archaeology. University of Chicago Press, Chicago, Illinois. 274 p.

Conkle, T. M. 1970. Growth data for 29 years from the California elevational transect study of ponderosa pine. Forest Science. 19: 31-39.

Fritts, H. C., D. G. Smith, J. W. Cardis, and C. A. Budelsky. 1965. Tree-ring characteristics along a vegetational gradient in northern Arizona. Ecology. 46: 393-401.

Fritts, H. C. 1969. Bristlecone pine in the White Mountains of California. The University of Arizona Press, Tucson, Arizona. 44 p.

Fritts, H. C. 1976. Tree Rings and Climate. Academic Press, New York. 567 p.

Fritts, H. C. 1991. Reconstructing Large-scale Climatic Pattern from Tree-Ring Data. The University of Arizona Press, Tucson, Arizona. 286. p.

LaMarche, V. C. 1974. Paleoclimatic inferences from long tree-ring records. Science. 183: 1043-1048.

Lei, S. A. 1994. Plants of the North American deserts. Unpublished research report, University of Nevada, Las Vegas, Nevada. 64 p.

Lei, S. A. 1995. A gradient analysis of *Coleogyne* communities in southern Nevada. Unpublished masters thesis, University of Nevada, Las Vegas, Nevada. 117 p.

Lewis, T. E. 1995. Tree rings as indicators of ecosystem health. CRC Press, Boca Raton, Florida. 210 p.

Luken, J. 1990. Directional Ecological Succession. Chapman and Hall, London, United Kingdom. 251 p.

McGinnies, W. G. 1963. Dendrochronology. Journal of Forestry. 61: 5-11.

Schulman, E. 1941. Some propositions in tree-ring analyses. Ecology. 22: 193-195.

Schulman, E. 1956. Dendroclimatic changes in semiarid America. University of Arizona Press, Tucson, Arizona. 142 p.

Schweingruber, F. H. 1989. Tree Rings. Kluwer Academic Publishers, Boston, Massachusetts. 276 p.

Host-Parasite Relationship Between Utah Juniper and Juniper Mistletoe in the Spring Mountains of Southern Nevada

Simon A. Lei

Abstract—The infection of Utah juniper by parasitic juniper mistletoe was quantitatively investigated at a blackbrush-Utah juniper ecotone in Pine Creek of southern Nevada. Juniper mistletoes significantly reduced the vigor, viability, and reproductive success of their host. The abundance of juniper mistletoe was significantly and positively correlated with the height of Utah juniper. Diurnal and seasonal leaf water potentials of juniper mistletoe were significantly lower than leaf water potentials of adjacent, uninfected juniper trees. Heavy mistletoe infestation significantly increased host-plant water stress, and low host-plant water potentials might limit long-term mistletoe infection success. Infestation was beneficial for juniper mistletoe but harmful to Utah juniper.

Mistletoes (*Phoradendron* spp.) are dwarf hemiparasites which once established, rely entirely upon their hosts for the supply of water and mineral nutrients (Hollinger 1983). Juniper mistletoe (*Phoradendron juniperinum*) is a native plant that grows on Utah juniper (*Juniperus osteosperma*) and other gymnosperm hosts. Its range includes southern Nevada, southwestern Utah, southeastern California, southwestern Arizona, northern Baja California, Sonora, and Sinaloa (Haigh 1996; Benson and Darrow 1981). Previous studies of host-mistletoe relationships include Blumer (1910), Shreve and Wiggins (1964), Walters (1976), Daniel and Butterwick (1992), and Haigh (1996). *Phoradendron villosum*, a closely related species to juniper mistletoe, revealed a clumped dispersion pattern on several oak (*Quercus* spp.) hosts in California (Hollinger 1983). In general, juniper mistletoe shows significantly more negative leaf water potentials than its Utah juniper host, and infected host trees experience lower leaf potentials than uninfected trees through a growing season under a range of environmental conditions (Ehleringer and others 1986; Fisher 1983). In the Mojave Desert, water potentials of host plants can become extremely negative during summer months. California mistletoe (*Phoradendron californicum*) reveals lower water potential values, averaging 1.4 MPa below its catclaw (*Acacia greggii*) and creosote bush (*Larrea tridentata*) hosts during the 1996 drought in the Granite Cove of southern California (Dean Jordan, personal communication).

Although juniper mistletoe is not common throughout southern Nevada, it commonly parasitizes Utah juniper in Pine Creek. The objectives of this article were four-fold: (1) to address the spatial pattern of juniper mistletoe infection of Utah juniper trees; (2) to compare the height, vigor, viability, and reproductive success of the parasitized and unparasitized Utah juniper trees; (3) to examine the water relations of mistletoe and its host; and (4) to investigate mistletoe infection success between slightly and heavily parasitized trees during a severe drought in Pine Creek of southern Nevada.

Methods

Study Area

The field study was conducted from spring to fall of 1996 in the Pine Creek portion of the Red Rock National Conservation Area (36°05' N, 115°40'W; elevation 1,400 m), located approximately 50 km west of Las Vegas, Nevada. Pine Creek was selected on the basis of mistletoe infection success and various infection stages (early, middle, and late) on Utah juniper trees. The vegetation is transitional between blackbrush (*Coleogyne ramosissima*) shrubland and Utah juniper woodland, with Utah juniper being considerably more abundant along an intermittent stream with water running only during parts of the year. This surface stream is often dry during the peak of summer season from June through August, unless it is recharged by moderate to heavy rainfalls. The precipitation in southern Nevada includes summer storms and winter rains, averaging 250 mm annually. Summer rain typically occurs in July and August, and can be locally intense. Winter rain is widespread and may last several days (Rowlands and others 1977). Much of the 1996 year was extremely dry with a total amount of precipitation falling well below the annual average. Relative humidity of 20 percent or less is common with high evaporation in the summer months.

Blackbrush and Utah juniper share a relatively broad ecotone in southern Nevada (Lei 1994, 1995). Singleleaf pinyon-Utah juniper (*Pinus monophylla-Juniperus osteosperma*) woodland is often established on high desert mountain slopes above the blackbrush shrubland in southern Nevada. Utah juniper is typically more abundant at the lower elevations, with a homogeneous mixing of singleleaf pinyon and Utah juniper at the middle elevations of the pinyon-juniper vegetation zone (West and others 1975).

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Dispersion of Juniper Mistletoe

The study site covered approximately 3.5 ha., and all 85 Utah juniper trees within this area were surveyed for the presence and distribution of juniper mistletoes. The evergreen juniper mistletoe was easily visible among the bare and nearly bare branches of its juniper host, appearing as a slightly lighter green or brownish-green patch on Utah juniper trees. I counted and recorded the number of juniper mistletoes and measured the height on juniper trees for an analysis of the spatial dispersion pattern. The dimensions of juniper mistletoe were not measured, and sex could not be accurately determined.

The Utah juniper trees sampled ranging in height from 0.75 to 7 m, and included individuals without any visible juniper mistletoes (control) and individuals with mistletoes (infected trees). Within the infected trees, uninfected stems were segregated from infected stems. Uninfected stems did not show any visible mistletoes on the stem all the way back to the main trunk. Infected stems had mistletoes on the secondary branches.

Vigor, Viability, and Reproductive Success of Utah Juniper

The amount of host tree branches covered with green leaves was visually estimated in ten percentage point increments. The viability of parasitized and unparasitized Utah juniper trees was determined by coring through at least one-half of the stem diameter containing pith. Incremental cores were extracted from main trunks at 1.0 m above ground and from five Utah juniper individuals that were randomly selected in each of the three height categories (0-2, 2-4, and 4-7 m). The size of fruits (berry diameter) between parasitized and unparasitized trees was measured. The number of fruits (berries) produced by Utah juniper was visually estimated.

Water Potential Measurements

A total of 20 Utah juniper trees and a juniper mistletoe on each parasitized (light and heavy infections) tree were randomly selected and tagged with yarn before water potential measurements to facilitate repeated sampling throughout the day. Five replicates were made in each of four treatments (mistletoe, uninfected Utah juniper, infected and uninfected stems on mistletoe-infected juniper tree). Water potentials of juniper mistletoe and its Utah juniper host were obtained using a portable pressure chamber and nitrogen gas. Once the leaves were incised, they were immediately placed in zip-loc plastic bags and housed on ice in the dark until pressurization, which was rapidly conducted at the field site. Water potentials were measured on 10-15 cm long terminal leaves at predawn and then at 3-hour intervals throughout the day. Diurnal water potential data were collected twice, once in March and once in July 1996. Routine analysis of predawn and midday water potentials of mistletoes and juniper trees was conducted at 8-week intervals from April through October of 1996.

Statistical Analyses

The Poisson distribution was used to determine the type of spatial dispersion pattern (random, uniform, or clumped) that populations of juniper mistletoe exhibited on Utah juniper. One-way analysis of variance (ANOVA) was employed to detect differences in diurnal and seasonal water potentials among the four treatments. Students t-tests were performed to compare the height, vigor, viability, and reproductive success between the parasitized and unparasitized Utah juniper trees. Statistical significance was determined at $p \leq 0.05$.

Results and Discussion

Eighty-five Utah juniper trees were sampled in Pine Creek for an analysis of the spatial dispersion. The occurrence of juniper mistletoes was on Utah juniper trees only. Juniper mistletoes did not infect blackbrush or other common shrubs nearby, such as banana yucca (*Yucca baccata*), big sagebrush (*Artemisia tridentata*), cheesebush (*Hymenoclea salsola*), and yerba santa (*Eriodictyon angustifolium*), at the blackbrush-Utah juniper ecotone. A majority of juniper trees had either no juniper mistletoe growth (35.3 percent or 30 of 85 trees) or had more than five mistletoe individuals (48.2 percent or 41 of 85 trees; fig. 1). Only 16.5 percent (14 of 85) of trees fell between these two classes (fig. 1). The distribution of individual mistletoes was clumped ($p < 0.05$), which corresponds with Hollinger's (1983) study. Mistletoe fruits are fleshy, producing a single seed with sticky viscous layer (Calder and Bernhardt 1983). Mistletoe seeds tend to

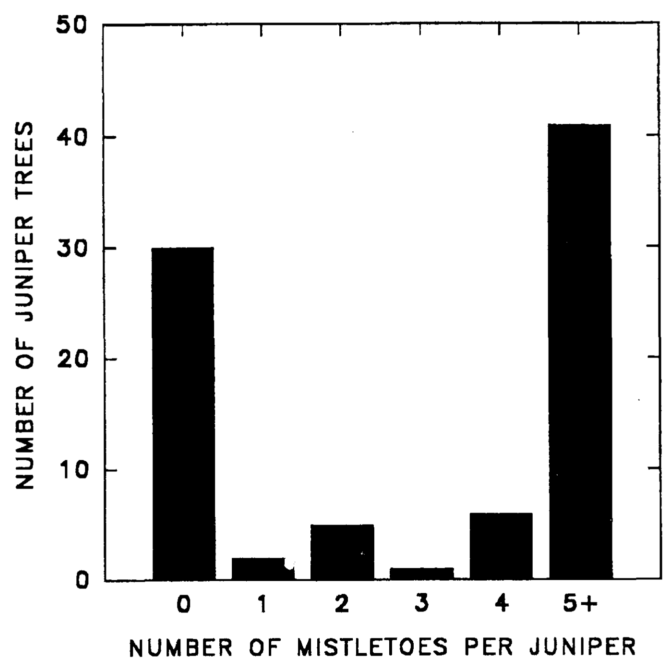

Figure 1—Distribution of juniper mistletoes on 85 Utah juniper individuals in Pine Creek of the Red Rock Canyon National Conservation Area in southern Nevada.

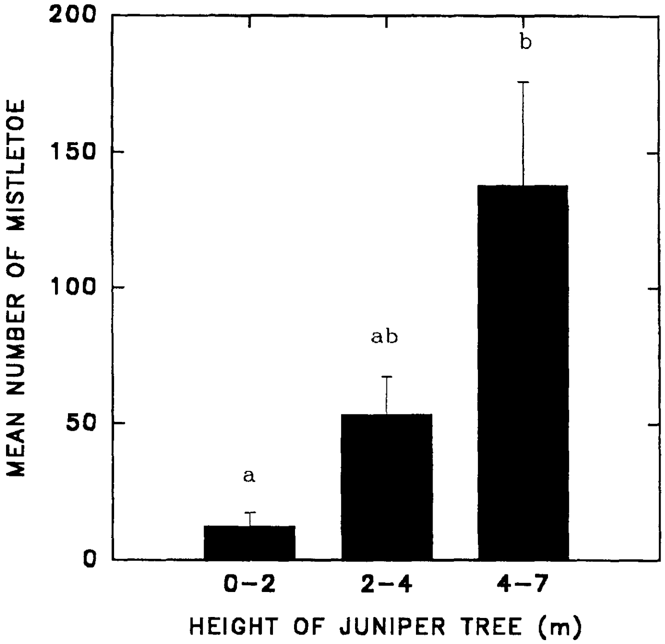

Figure 2—Number of juniper mistletoe (mean ± S.E.) growing on Utah juniper trees with variable heights in Pine Creek of the Red Rock Canyon National Conservation Area in southern Nevada. Height of Utah juniper trees was divided into three categories: 0-2 (n = 6), 2-4 (n = 25), and 4-7 m (n = 24). Different letters at the top of columns represent statistical significant at $p \leq 0.05$.

stick to birds, and mistletoe is usually spread from host to host by birds, which ingest the seeds and later defecate them onto a branch (Haigh 1996). Birds, including northern mockingbird (*Minus polyglottos*), appear to roost in specific areas which would clump mistletoes in these areas where they roost and subsequently defecate. The distribution of many species, including parasitic organisms, is generally contagious, but is seldom regular in nature (Postlethwait and Hopson 1995).

Juniper mistletoes grew on Utah juniper trees ranging from a height of 0.75 to 7.0 m (fig. 2). The abundance of juniper mistletoe was significantly and positively correlated ($p < 0.001$; $r = 0.81$) with the heights of Utah juniper hosts. Juniper mistletoe was most numerous on taller host trees, although two of the hosts that were approximately 6.0 m tall were not infested by mistletoes. Mistletoe-infested juniper trees were significantly taller ($p < 0.01$; table 1) than adjacent, uninfested trees. In general, the taller trees were older than the shorter trees (data not shown). Yet, the precise ages of host trees were difficult to determine due to the possibility of partial, missing, and double annual rings. Biseasonal rainfalls may produce double annual rings, while severe droughts during the growth periods may show a partial or missing ring within a single year.

Various stages of juniper mistletoe infections on Utah juniper trees were evident in Pine Creek. The high levels of mistletoe infestation of greatly influenced the vigor, viability, and reproductive success of juniper trees regardless of their size. The amount of berry production and green leaves on branches in the infested juniper trees were significantly ($p < 0.001$; table 1) reduced. Conversely, no significant ($p > 0.05$; table 1) differences were detected in berry size (diameter) between the parasitized and unparasitized juniper trees, although the berry size was smaller in parasitized trees. Within the infected juniper trees, hosts with heavy infections (>25 mistletoes per tree) typically showed the smallest berry size, and showed the least amount of green leaves and berry production than juniper hosts with light infections. Low host vigor can lead to rapid mortality following severe drought and pest outbreak (Calder and Bernhardt 1983).

There are several potential explanations for the higher levels of juniper mistletoe infestation exhibiting a clumped distribution in taller and larger host trees. First, large tree size would provide a greater surface area (more secondary branches) available for mistletoe colonization. Increasing in tree size, along with a greater surface area, may increase the host susceptibility of mistletoe colonization and infestation. Second, many taller trees were older with a greater stem diameter than shorter trees. This phenomenon may indicate a time dependent mistletoe colonization rate. The number of mistletoe may increase with increasing tree age. Third, some birds may prefer taller and larger trees by visiting infested trees to feed on the mistletoe's fruits, and then remain on the infested trees long enough to deposit the seeds on the same trees. Dispersal of mistletoes may also be influenced by arboreal mammals and by gravity, but these are likely to be minor mechanisms (Calder and Bernhardt 1983).

Both juniper mistletoe and Utah juniper plants were significantly ($p < 0.001$; fig. 3) more water stressed in July than in March. Water potentials of mistletoes and its juniper hosts were significantly ($p < 0.001$; fig. 4) more negative during midday than predawn hours through the growing season. Conversely, no significant differences ($p > 0.05$; fig. 3 and 4) were detected in juniper leaf water potentials between the infected and uninfected stems on the mistletoe-infected trees in both diurnal and seasonal measurements.

Table 1—A comparison of height, vigor, and reproductive success (berry size and production) between mistletoe-infested and adjacent, uninfested (control) Utah juniper trees (mean ± S.E., n = 85). The amount of host tree branches covered with green leaves (vigor) is expressed in percentage. Mean values in columns followed by different letters are significantly different at $p \leq 0.05$.

Tree group	Height	Percent green leaves	Berry diameter	Berry number
	m			
Infested tree	4.8 ± 0.7 a	47.2 ± 19.7 a	7.8 ± 0.2 a	217.9 ± 69.2 a
Uninfested tree	3.2 ± 0.4 b	86.5 ± 9.8 b	8.4 ± 0.1 a	355.4 ± 50.5 b

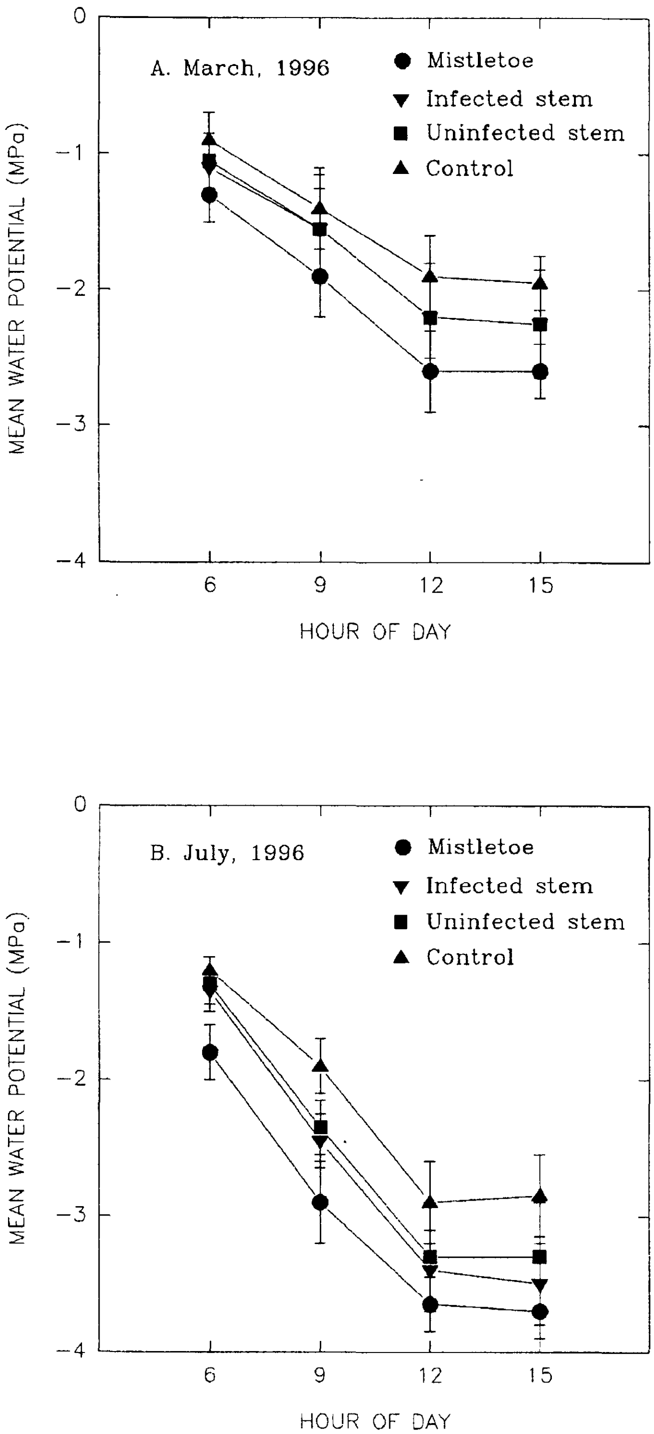

Figure 3—Diurnal water potentials (mean ± S.E.) of juniper mistletoes, leaf tissues from infected stems and uninfected stems of the Utah juniper hosts, and from an adjacent, uninfected (control) juniper hosts in March (A) and July (B), 1996. Measurements (n = 5 per treatment in each hour) were made at 3-hour intervals starting from early morning through mid-afternoon.

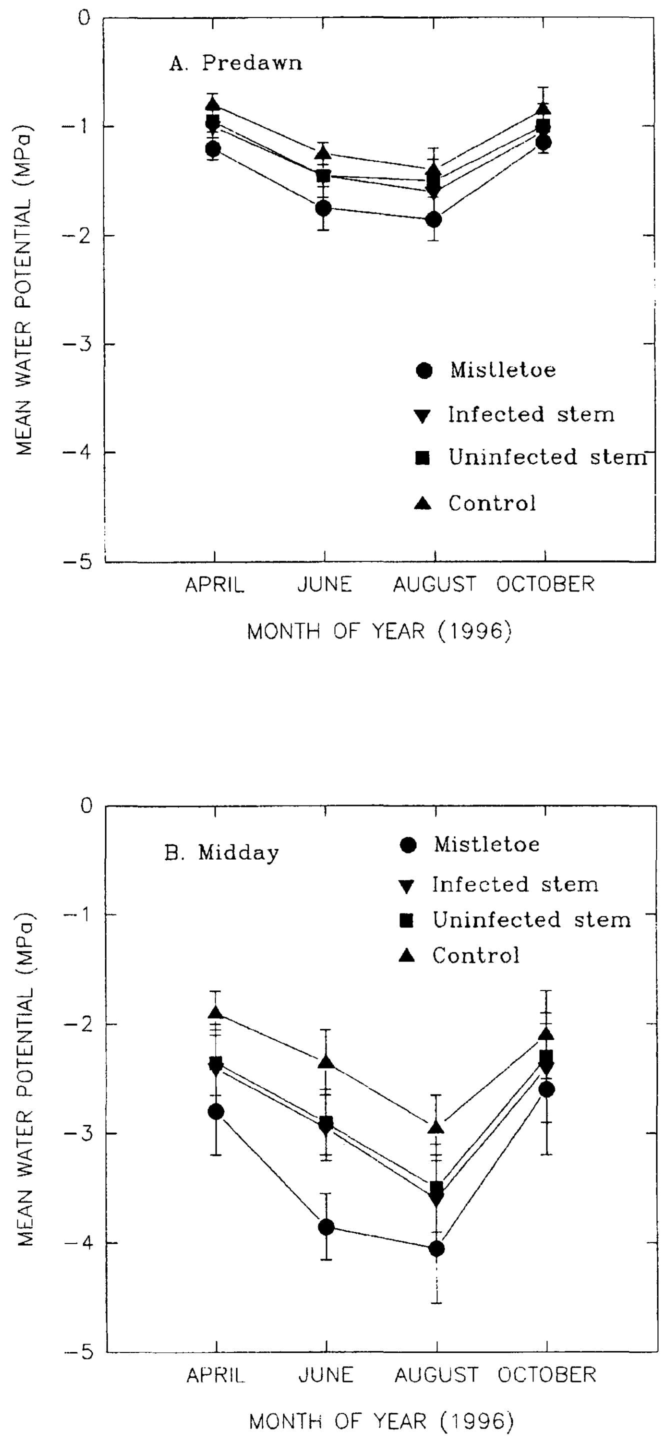

Figure 4—Seasonal water potentials (mean ± S.E.) of juniper mistletoe, leaf tissues from infected stems and uninfected stems of the Utah juniper hosts, and from an adjacent, uninfected (control) juniper hosts. Measurements (n = 5 per treatment in each month) were made during predawn (A) and midday (B) hours through the growing season from April to October, 1996.

Leaf water potentials of juniper mistletoe tissues were considerably more negative than Utah juniper tissues of either infected stems or uninfected stems (fig. 3 and 4). Leaf water potentials of mistletoe tissues were significantly ($p < 0.001$) lower than leaf water potentials of adjacent, uninfected juniper trees (fig. 3 and 4). Mistletoes are characterized by extremely low water use efficiencies and must maintain more negative water potentials than their hosts in order to obtain water (Dean Jordan, personal communication). My results generally concur with Ehleringer and others' (1986) study, indicating that mistletoe-infected trees consistently have leaf water potentials lower than adjacent, uninfected trees, and that juniper mistletoe was imposing a significant water stress on Utah juniper.

Because of the higher rates of water loss associated with mistletoe parasitism, infected Utah juniper trees experience significantly lower leaf water potentials than do uninfected juniper trees (Ehleringer and others 1986). In leafy mistletoes, the inability of stomata to respond to environmental stress may largely account for considerable water loss in massive infections (Fisher 1983). During stress, stomata of mistletoe remain open and transpiration rates of mistletoe remain higher than its Utah juniper host. Photosynthesis is curtailed in Utah juniper trees because of stomatal closure in response to environmental stress (Fisher 1983). Several aspects of Utah juniper water relations (leaf conductance, leaf water potential, and water use efficiency) are worsened by the presence of juniper mistletoe (Ehleringer and others 1986). Host with heavy infections generally revealed lower leaf water potential than hosts with light infections in this study. Increased infestation can aggravate this water stress situation, but since whole plant water balances were not measured in this study, the magnitude of this effect on host productivity cannot be accurately determined (Ehleringer and others 1986).

From casual observations, Utah juniper hosts with light to moderate infections may benefit juniper mistletoes, as evidenced by a slightly larger berry size and by a greater foliage, flower, and fruit production (biomass). As infection intensifies over time, however, the mortality of established juniper mistletoes became evident when a portion of host tree branches was dead. Within a single host, the live secondary branches supported abundant mistletoes, while the dead secondary branches revealed dead mistletoes regardless of tree size. Hence, juniper mistletoes may not be a successful parasite because, after several years of colonization and infestation, mistletoes can kill their hosts, leading to their own death.

Southern Nevada in recent years experienced severe droughts, resulting in widespread plant water stress and in an increased mortality of established juniper mistletoe infections. Substantial juniper mistletoe mortality on its Utah juniper host was observed during the 1996 drought. More mistletoes died from hosts with heavy infections than with light infections, partially due to an increase in water stress of host plants during the drought. Mistletoes showing heavy infections generally have leaf water potentials 0.2-0.7 MPa lower than mistletoes showing light infections (data not shown), presumably due to an intense resource competition among mistletoe individuals. Low host-plant water potentials with massive infections during severe droughts may limit long-term mistletoe infection success (Dean Jordan, personal communication) irrespective to host tree size.

Parasitic mistletoes live in close physical association with host to obtain nourishment and may weaken or kill its host (Postlethwait and Hopson 1995). The final outcome is a net gain in mistletoe foliage, which occupies more and more of the host canopy as the infection intensifies (Fisher 1983). In juvenile trees, infection greatly reduces root growth and the ability to survive drought and insect outbreak (Fisher 1983). All mistletoes show some degree of parasitism or dependence on a host plant, and all use the xylem sap of the host to provide water and mineral nutrients (Fisher 1983). In this study, mistletoes can be considered a water parasite because mistletoe-infected juniper trees, irrespective to their size, consistently exhibited greater water stress (lower water potentials) than adjacent, uninfected trees.

Conclusions

Results of this study indicated that many Utah juniper individuals exhibited no or severe infestation by parasitic juniper mistletoes, and that populations of juniper mistletoes revealed a clumped dispersion pattern among Utah juniper trees. Taller juniper trees were significantly more likely to be parasitized than shorter trees. The higher colonization rate and infection level of mistletoes in taller and larger host trees appeared to be a combination of tree size, age, and seed dispersal by some bird species. Heavy mistletoe infestation severely limited host's vigor, viability, and reproductive success regardless of host size. Juniper mistletoes are not likely to be a successful parasite since heavy infestation during the severe 1996 drought would lower their host-plant water potentials, which might limit mistletoe's long-term infection success. Trees without juniper mistletoes were significantly less water stressed than trees with mistletoes. However, no significant differences were detected between the infected and uninfected stems of mistletoe-infected Utah juniper trees.

Acknowledgments

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References

Analytical Software. 1994. Statistix 4.1, an interactive statistical program for microcomputers. Analytica Software, Tallahassee, Florida. 329 p.

Benson, L. and R. A. Darrow. 1981. Trees and shrubs of the southwestern deserts. Univ. of Arizona Press, Tucson, Arizona. 416 p.

Blumer, J. C. 1910. Mistletoe in the Southwest. Plant World. 13: 240-246.

Fisher, J. T. 1983. Water relations of mistletoes and their hosts. In: Calder, M. and P. Bernhardt, editors. The Biology of Mistletoes. Academic Press, New York: 146-184.

Ehleringer, J. R., C. S. Cook, and L. L. Tieszen. 1986. Comparative water use and nitrogen relationships in a mistletoe and its host. Oecologia. 68: 279-284.

Haigh, S. L. 1996. Saltcedar (*Tamarix ramosissima*), an uncommon host for desert mistletoe (*Phoradendron californicum*). Great Basin Naturalist. 56: 186-187.

Hollinger, D. Y. 1983. Photosynthesis and water relations of the mistletoe, *Phoradendron villosum*, and its host, the California valley oak, *Quercus lobata*. Oecologia. 60: 396-400.

Lei, S. A. 1994. Plants of the North American Deserts. Unpublished research report, Univ. of Nevada, Las Vegas, Nevada. 64 p.

Lei, S. A. 1995. A gradient analysis of *Coleogyne* communities in southern Nevada. Unpublished masters thesis, Univ. of Nevada, Las Vegas, Nevada. 117 p.

Odum, E. P. 1971. Fundamentals of Ecology. W.B. Sanders Company, New York, New York. 574 p.

Postlethwait, J. H. and J. L. Hopson. 1995. The Nature of Life. McGraw-Hill, Inc., New York, New York. 406 p.

Rowlands, P. G., H. Johnson, E. Ritter, and A. Endo. 1977. The Mojave Desert. In: M. Barbour and J. Major, editors, Terrestrial Vegetation of California. John Wiley and Sons, New York, New York. 1002 p.

Shreve, F. and I. L. Wiggins. 1964. Vegetation and flora of the Sonoran Desert. Volume I. Standford Univ. Press, Palo Alto, California. 840 p.

Walters, J. W. 1976. A guide to mistletoes of Arizona and New Mexico. USDA Forest. Service, Southwestern Region, Forest Insect and Disease Management. 7 p.

West, N. E., K. H. Rea, and R. J. Tausch. 1975. Basic synecological relationships in pinyon-juniper woodlands. The pinyon-juniper ecosystems: a symposium, p. 41-52. Utah State Univ., Logan, Utah.

Utah Juniper Herbaceous Understory Distribution Patterns in Response to Tree Canopy and Litter Removal

Chad S. Horman
Val Jo Anderson

Abstract—A 3-year field study was conducted to determine the effects of Utah juniper (*Juniperus osteosperma*) canopy and litter removal on native and seeded plant distribution patterns. Two zones were identified surrounding Utah juniper, one beneath the canopy and the second in the interspace. Plant abundance and seedling emergence were higher in the canopy zone. Canopy removal caused a decrease in plant abundance and seedling emergence in the canopy zone and had no effect in the interspace. Litter removal had almost no effect on plant abundance, except for annual forb abundance, which increased following litter removal. Effect of litter removal on seeded species was species dependent.

The pinyon-juniper woodland is an important ecosystem of the western United States, comprising of approximately 60 million acres throughout Nevada, Utah, Colorado, New Mexico and Arizona, with two leaf pinyon pine (*Pinus edulis*) as the principal pine species. Common juniper species include Utah juniper (*Juniperus osteosperma*), alligator juniper (*Juniperus deppeana*), one seed juniper (*Juniperus monosperma*) and Rocky Mountain juniper (*Juniperus scopulorum*) (Hurst 1987). In pre-settlement days, juniper was most abundant in southwestern U.S., but distinct populations could be found on rocky mid-elevation foothills of the Great Basin. Since the mid 1800's juniper has slowly encroached into the valleys of the Great Basin. As juniper has become the dominant species in these communities, elements of both the biotic and abiotic environments have been modified (Tausch and others 1981). This has been a serious problem for land managers, because as these trees come to dominance on a site the herbaceous understory is severely reduced (Dye and others 1995; Schott and Pieper 1985; Young and Evans 1981; Barney and Frischknecht 1974; Clary 1971). Increased precipitation runoff and soil erosion has been reported as a result of this community shift (Farmer 1995). Many ideas have been forwarded to explain the recent juniper invasion. The most commonly stated ideas are (1) lack of periodic fires which would normally kill many young trees (Hurst 1987; Young and Evans 1981; Burkhardt and Tisdale 1976), (2) spreading of seed by livestock (Burkhardt and Tisdale 1976), (3) overgrazing by livestock, which reduces grass competition with juniper seedlings (Hurst 1987) and (4) a climatic shift that favors woody species (Johnsen 1962). These postulates suggest explanations as to why junipers are able to establish themselves, but not how they are able to maintain dominance on a site.

Junipers may be able to dominate a site and maintain that dominance by way of (1) increased canopy cover which creates shading and precipitation interception (Schott and Pieper 1985; Anderson and others 1969; Skau 1964; Johnsen 1962), (2) deep litter accumulation (Horman and Anderson 1996; Schott and Pieper 1985; Everett and Koniak 1981; Jameson 1966; Johnsen 1962), (3) allelopathy (Peterson 1972; Jameson 1970a; Jameson 1961), (4) changes in the soil nutrient composition (Doescher and others 1987; Klopatek 1987; Brotherson and Osayande 1980) and (5) competition for soil moisture (Evans and Young 1985; Young and Evans 1981; Jameson 1970b; Johnsen 1962).

It has been shown that the canopy of one seed juniper (Armentrout and Pieper 1988; Schott and Pieper 1985; Arnold 1964), redberry juniper (*Juniperus pinchotii*) (Dye and others 1995; McPherson and others 1991), eastern red cedar (*Juniperus virginiana*) (Engle and others 1987), western juniper (*Juniperus occidentalis*) (Vaitkus and Eddleman 1991) and Utah juniper (Everett and Koniak 1981; Barney and Frischknecht 1974; Clary 1971) all affect understory distribution. These negative effects have been attributed to shading, rainfall interception or litter accumulation. Schott and Pieper (1985) determined that in younger stands of one seed juniper, shading, caused by the characteristically dense, low hanging canopy, was the leading cause of low understory production. Anderson and others (1969) stated that understory vegetation is more responsive to differences in throughfall precipitation than differences in light. Juniper canopy is reported to intercept about 10–20 percent of precipitation (Skau 1964). This amount of interception may explain why some species can not survive.

Litter accumulation has been studied as a deterrent of understory growth either due to its depth (Horman and Anderson 1996; Everett and Koniak 1981; Jameson 1966; Johnsen 1962) or to allelopathic properties (Peterson 1972; Jameson 1970a; Jameson 1961). Jameson (1966) stated that litter accumulation from one seed juniper was more detrimental than shading in the mature stand that he studied. He found that blue grama (*Bouteloua gracilis*) basal area and production were not affected by the roughly 40 percent shading, but that litter accumulation did adversely affect it. Horman and Anderson (1996) reported that while not affected by allelochemic properties, antelope bitterbrush

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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(*Purshia tridentata*) and bluebunch wheatgrass (*Pseudoroegnaria spicata*) emergence were negatively affected by increasing Utah juniper litter depth.

Litter not only affects plant emergence but also plant distribution. Everett and Koniak (1981) reported three litter zones under Utah juniper canopies in Nevada. The first was closest to the trunk and constituted litter cover >90 percent at a depth >0.5 cm. This zone had practically no vegetation. The second was under the majority of the canopy and had litter cover of 20-90 percent at a depth >0.5 cm. This zone had increasing amounts of vegetation. The last was near the canopy edge and contained the most vegetation. It consisted of litter cover <20 percent at a depth of <0.5 cm. They agreed with Jameson (1966) that litter depth was the leading deterrent of understory growth. This zonation pattern was similar to that found by Armentrout and Pieper (1988) around one seed juniper trees. They reported an increase in basal cover on understory vegetation from <1 percent near the trunk to 7 percent under the canopy and finally 12 percent in the interspace.

Juniper trees are also competitive due to their shallow root zones that extend out a distance that is two or three times the tree height for some species (Johnsen 1962). This allows the juniper to compete very effectively for any available moisture (Young and Evans 1981; Jameson 1970b; Johnsen 1962). It has also been suggested that junipers may have phytotoxic root exudates (Jameson 1970b).

The majority of juniper literature has focused on juniper species other than Utah juniper and little has been done in the foothill environment of central Utah. A field study was conducted in a foothill Utah juniper woodland community in central Utah that focused on the influence of Utah juniper canopy on the understory and interspace vegetation. The effects of Utah juniper canopy on six seeded species were also tested. The objectives of this study were to determine the effect of Utah juniper canopy removal and litter removal on the native plant community as well as some commonly seeded species.

Study Site and Methodology

The study site was located in a pinyon-juniper woodland between Water Hollow and Tie Fork Canyon in Spanish Fork Canyon, Utah Co., UT. Three sites with southern exposure, located at least 1.5 km apart, were chosen in this area. At each site, 10 mature juniper trees were selected that had a minimum of one meter of canopy interspace at least half way around it. Underneath each tree, four vegetational transect lines were placed with equal spacing between them. The lines ran from the trunk to the canopy edge and out into the middle of the tree interspace (not to exceed 3 m). Along each transect, three zones were identified. The trunk zone extended from the trunk to mid point of the canopy radius. The mid canopy zone extended from the mid point of canopy radius to the dripline (dripline was defined as the furthest reaching branch over the transect). The interspace zone, consisted of the area that extended beyond the dripline (Armentrout and Pieper 1988).

A 25 x 50 cm quadrat, using a modified Daubenmier method of seven cover classes (Daubenmier 1959), was placed contiguously along each line. At each placement, percent cover was recorded for total vegetation, perennial grass, annual grass, perennial forb, annual forb, shrub, litter, rock, bare ground and cryptograms. Nested frequency values were also recorded for total vegetation, perennial grass, annual grass, perennial forb, annual forb and shrub. Litter depth was also measured in the center of each quadrat. Finally, at each site, three 61 m line intercept transect were evaluated to determine canopy overstory cover.

Following the baseline vegetation inventory (August 1995), five of the ten trees at each site were randomly selected, cut down, and removed from the site with as little disturbance to the ground cover as possible. At the same time, the litter was removed from half of the area underneath both intact and removed trees. This created four treatments; (1) tree canopy with intact litter (control), (2) tree canopy with litter removal, (3) tree removal with intact litter and (4) tree removal with litter removal.

Following tree and litter removal, six species were planted in the fall of 1995. The species used were bluebunch wheatgrass (*Pseudoroegnaria spicata* (Pursh) Love 'Secar'), bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), orchardgrass (*Dactylis glomerata* L. 'Piaute'), Lewis flax (*Linum lewisii* Pursh 'Appar'), small burnet (*Sanguisorba minor* Scop. 'Delar') and antelope bitterbrush. All six species were planted on the half with intact litter and all six on the half without litter. Each half was divided into six equal areas and each area was broadcast seeded with one of the six species at a rate of 10 lb./acre pure live seed, except for antelope bitterbrush. It was planted in five caches of five seeds at equal distances (Vander Wall 1994). Seedling density was monitored for two years (summers of 1996 and 1997).

Experimental design consisted of a split-split plot design, with site being the main effect, tree and litter treatments as subplots and zone pattern as sub-subplot. Percent cover and recruitment data were arcsine transformed prior to analysis. ANOVA was performed using the Statistical Analysis System (SAS) computer program and a Fisher's protected LSD was used for mean separation (Ott 1993). Differences were deemed significant when $P < 0.05$ unless otherwise indicated.

Results

The study area had a combined Utah juniper and pinyon pine overstory cover of 31.9 percent. Utah juniper cover was 20.5 percent and pinyon pine cover was 11.4 percent. Average understory vegetation and cryptogram cover throughout the area were both very low at 8 percent and 1.5 percent, respectively. The understory composition consisted of 44.2 percent perennial grass, 1.8 percent annual grass, 31.2 percent perennial forb, 12.3 percent annual forb and 10.6 percent shrub. Litter cover was the highest at 61 percent. Bare ground and rock were 24.8 percent and 4.5 percent, respectively.

Significant differences were found among the three zones with respect to litter depth. The trunk, mid canopy and interspace zones had mean ± SD litter depths of 5.1 ± 2.5 cm, 1.0 ± 0.8 cm and 0.1 ± .08 cm, respectively. Three distinct zones were also found with respect to litter cover. Litter cover decreased significantly from 89 percent in the trunk zone to 76 percent in the mid canopy zone and finally to 26.6 percent in the interspace.

Vegetative cover was very low throughout the study and was not sensitive to the treatments or zone patterns. The observed differences due to zone and treatments were negligible, in many cases less then 1 percent. These differences were deemed insignificant from both a biological and land management stand point and were therefore not reported in this study. Nested frequency, by design, was more sensitive to the abundance of rare species and was useful in determining treatment effects.

Nested frequency values were recorded from 0 to 5 with 5 indicating the highest abundance. Zonation patterns were apparent around juniper trees (table 1). In some cases these patterns were influenced by whether or not tree or litter removal occurred. A significant (P = 0.06) tree by zone interaction was found with respect to total vegetation abundance (fig. 1). Abundance was higher beneath the canopy than in the interspace around living trees. On sites where tree removal occurred, total vegetation abundance did not differ among the three zones. Abundance of perennial and annual grasses were found to be significantly higher beneath the canopy compared to the interspace. A significant tree by zone interaction (P = 0.04) (fig. 2) and litter by zone interaction (P = 0.005) (fig. 3) occurred with respect to annual forb abundance. On the tree control sites, annual forb abundance was higher beneath the canopy than in the interspace. However, on the sites where juniper removal occurred, annual forb abundance was similar among all three zones. The litter by zone interaction indicated that annual forb abundance was similar among the three zones where the litter was left intact. Following litter removal, annual forb abundance increased in the trunk and mid canopy zones and decreased in the interspace. Perennial forb and shrub abundance did not differ among the three zones.

Tree removal had differing effects on plant abundance (table 2). The tree by zone interactions of total vegetation and annual forb abundance indicated that abundance in the canopy zones decreased sharply following tree removal, while abundance in the interspace showed a slight decline or remained unchanged. Perennial grass and forb abundance significantly decreased following tree removal, while annual grass and shrub abundance remained unchanged.

Litter removal had a limited effect on plant abundance (table 2). Abundance of total vegetation, annual grasses, perennial forbs and shrubs were not affected by litter removal. Perennial grass abundance significantly decreased where litter removal occurred. As mentioned above, a litter

Table 1—Nested frequency values for vegetation groups according to three zones surrounding individual Utah juniper trees in Spanish Fork Canyon, UT.

Zone	Total vegetation	Perennial grass	Annual grass	Perennial forb	Annual forb	Shrub
Trunk	SI	0.8 a*	0.2 a	0.7 a	SI	0.1 a
Mid canopy	SI	0.9 a	0.2 a	0.9 b	SI	0.4 a
Interspace	SI	0.5 b	0.1 b	0.7 a	SI	0.2 a

* Values in columns followed by a different letter were significantly different at P < 0.05 using a protected Fisher's LSD.
SI = A significant interaction occurred with either tree removal or litter removal, main effects not shown.

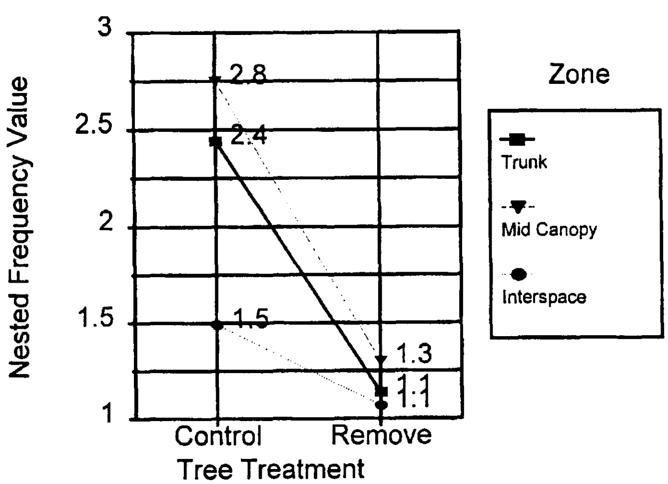

Figure 1—Influence (P = 0.06) of Utah juniper canopy removal and zonation patterns on total vegetation nested frequency values (0-5) collected in a pinyon-juniper woodland in Spanish Fork Canyon, UT.

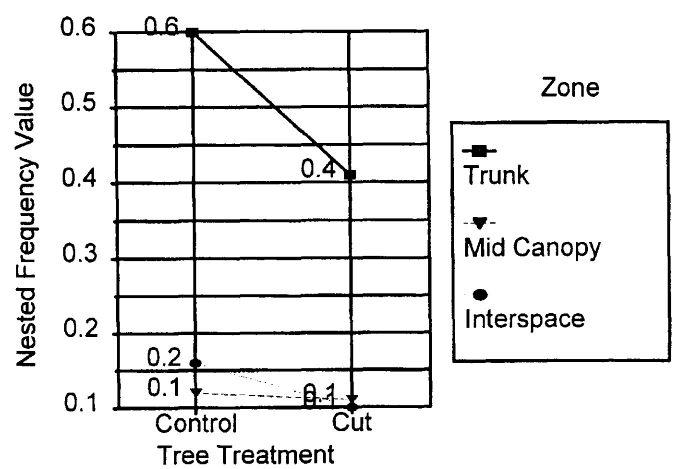

Figure 2—Influence (P = 0.04) of Utah juniper canopy removal and zonation patterns on annual forb nested frequency values (0-5) collected in a pinyon-juniper woodland in Spanish Fork Canyon, UT.

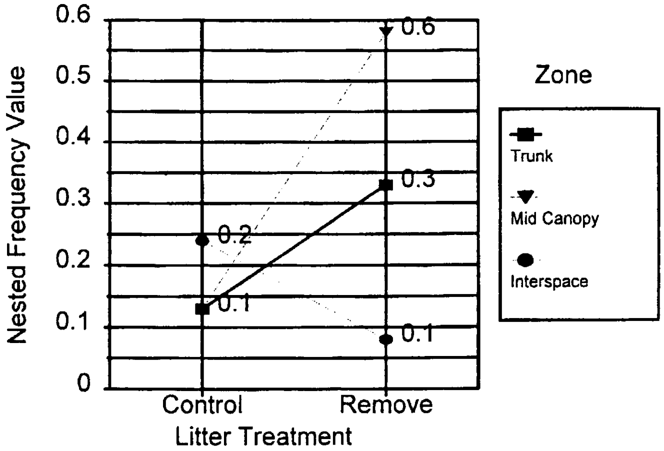

Figure 3—Influence (P = 0.005) of Utah juniper litter removal and zonation patterns on annual forb nested frequency values (0-5) collected in a pinyon-juniper woodland in Spanish Fork Canyon, UT.

Table 2—Nested frequency results for five vegetation groups in response to Utah juniper canopy and litter removal from three sites in Spanish Fork Canyon, UT.

Groups	Tree treatment Control	Tree treatment Removal	Litter treatment Control	Litter treatment Removal
Total vegetation	SI	SI	2.1 a*	1.3 a
Perennial grass	0.8 a	0.6 b	0.8 a	0.6 b
Annual grass	0.2 a	0.2 a	0.2 a	0.1 a
Perennial forb	0.9 a	0.6 b	0.8 a	0.8 a
Annual forb	0.9 a	0.6 b	0.8 a	0.8 a
Shrub	0.2 a	0.3 a	0.2 a	0.3 a

*Treatment values in rows followed by a different letter were significantly different at P < 0.05 using a protected Fisher's LSD.

SI = A significant interaction occurred with zone pattern, main effects not shown.

Table 3—Percent recruitment of seeded species according to three zones surrounding individual Utah juniper trees in Spanish Fork Canyon, UT.

Species	Zone Trunk	Zone Mid canopy	Zone Interspace
		Percent	
Bluebunch wheatgrass	SI	SI	SI
Orchardgrass	0.4 a*	0.2 a	0.0 a
Bottlebrush squirreltail	SI	SI	SI
Lewis flax	SI	SI	SI
Small burnet	0.0 a	0.0 a	0.0 a
Antelope bitterbrush	1.2 a	4.6 b	6.3 b

* Values in rows followed by a different letter were significantly different at P < 0.05 using a protected Fisher's LSD.

SI = A significant interaction occurred with either tree removal or litter removal, main effects not shown.

by zone interaction occurred with respect to annual forb abundance. Litter removal led to an increase in abundance in the trunk and mid canopy areas.

As with plant abundance, zonation patterns were found around juniper trees with respect to seedling recruitment (table 3). In some cases these patterns were again influenced by whether or not tree or litter removal occurred. Recruitment patterns of bluebunch wheatgrass and Lewis flax both exhibited similar interactions (P = 0.02 and P = 0.003, respectively) between zone and tree removal (fig. 4, 5). Underneath intact tree canopies, recruitment was higher in the trunk and mid canopy zones than in the interspace zone. In the tree removal areas, there was no difference among any of the zones.

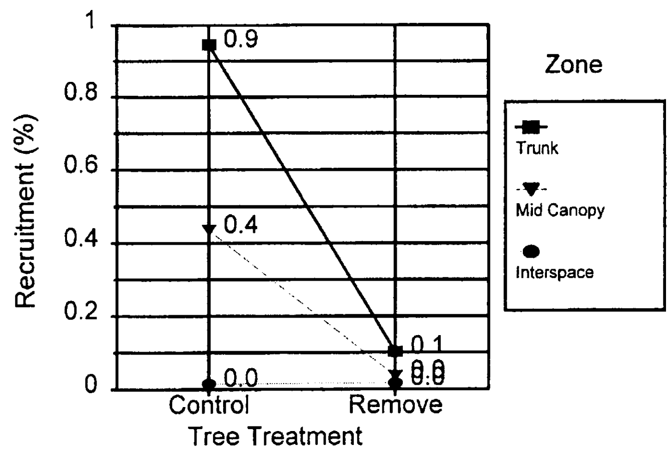

Figure 4—Influence (P = 0.02) of Utah juniper canopy removal and zonation patterns on bluebunch wheatgrass seedling recruitment (percent) seeded in a pinyon-juniper woodland in Spanish Fork Canyon, UT.

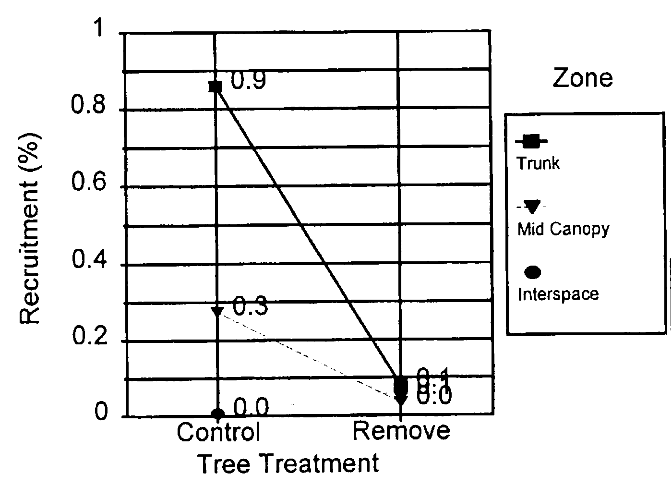

Figure 5—Influence (P = 0.003) of Utah juniper canopy removal and zonation patterns on Lewis flax seedling recruitment (percent) seeded in a pinyon-juniper woodland in Spanish Fork Canyon, UT.

A significant litter by zone interaction (P = 0.02) was found with respect to bottlebrush squirreltail recruitment (fig. 6). On areas with intact litter, seedling recruitment decreased with distance from the trunk. However, on areas where the litter was removed no difference was found among the three zones.

Antelope bitterbrush recruitment in the trunk zone was significantly lower than in the mid canopy and interspace zones (table 3). Orchardgrass and small burnet recruitment patterns were not apparent due to the lack of recruitment that occurred.

Tree removal had a more pronounced effect on seedling recruitment than it did on native vegetation abundance (table 4). Seedling recruitment of bluebunch wheatgrass, bottlebrush squirreltail, Lewis flax and antelope bitterbrush were all lower where tree removal occurred. In the case of bluebunch wheatgrass and Lewis flax, tree removal only caused a significant reduction in the area beneath the canopy. Recruitment values in the interspace were not different between control and tree removal areas. The effects of tree removal on orchardgrass and small burnet were inconclusive due to the lack of recruitment on both treatments.

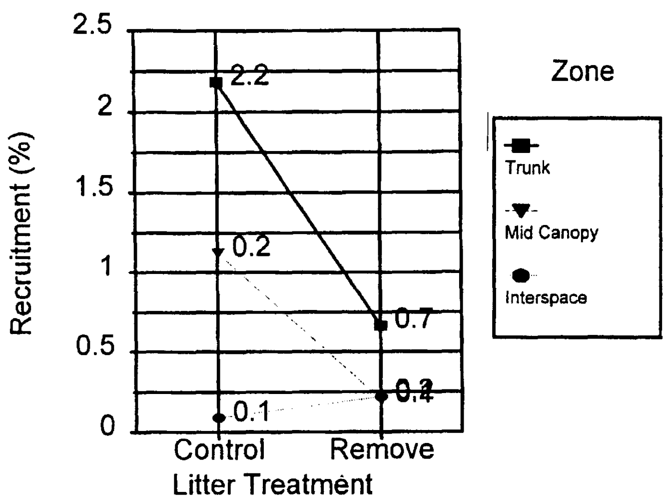

Figure 6—Influence (P = 0.02) of Utah juniper litter removal and zonation patterns on bottlebrush squirreltail seedling recruitment (percent) seeded in a pinyon-juniper woodland in Spanish Fork Canyon, UT.

Litter removal did not have a very strong effect on seedling recruitment (table 4). Bottlebrush squirreltail was the only species that demonstrated any response to litter removal (fig. 6). This response was limited to area beneath the tree canopy. Canopy areas with litter had higher recruitment than did canopy areas without litter.

Discussion

Zonation patterns around juniper trees have been reported by several authors. Armentrout and Pieper (1988) reported three zones around one seed juniper in Arizona. They found a steady increase in basal vegetative cover occurred as one moved out from the trunk into the interspace. Dye and others (1995) also reported three vegetation zones around redberry juniper trees. They found that vegetative basal cover increased with distance from the trunk. Everett and Koniak (1981) reported opposite findings in the Utah juniper stands that they studied in Nevada. They found that the trunk and mid canopy areas produced more cover than did the interspace, with the mid canopy zone being the most productive.

The findings of this study tend to support those of Everett and Koniak (1981). Zonation patterns were apparent in this area based on plant abundance, litter depth and litter cover. Significant decreases in litter depth and cover from the trunk out to the interspace supported the hypothesis of three zones around an individual tree (Dye and others 1995; Armentrout and Pieper 1988; Everett and Koniak 1981). Plant abundance results differed, because two zones were identified instead of the expected three. In most cases, the trunk and mid canopy areas formed one zone and the interspace formed the second. Greater vegetation abundance was found beneath the canopy than in the interspace.

Total vegetation abundance was significantly different between the tree canopy area and the interspace, even though among the separate vegetation classes such patterns were not consistent. Among the five vegetation groups abundance was consistently lower in the interspace compared to the canopy areas, although the differences were not always significant.

Table 4—Percent recruitment of seeded species in response to Utah juniper canopy and litter removal from three sites in Spanish Fork Canyon, UT.

Groups	Tree treatment		Litter treatment	
	Control	Removal	Control	Removal
Bluebunch wheatgrass	SI	SI	0.2 a*	0.1 a
Orchardgrass	0.0 a	0.0 a	0.0 a	0.0 a
Bottlebrush squirreltail	0.9 a	0.3 b	SI	SI
Lewis flax	SI	SI	0.1 a	0.1 a
Small burnet	0.0 a	0.0 a	0.0 a	0.0 a
Antelope bitterbrush	7.5 a	1.2 b	4.3 a	3.1 a

* Treatment values in rows followed by a different letter were significantly different at P < 0.05 using a protected Fisher's LSD.

SI = A significant interaction occurred with zone pattern, main effects not shown.

Seeding recruitment was extremely low and from a practical standpoint probably of little value. Nevertheless, the response to the treatments were significant in some cases. These results can be seen as possible indications of what may happen under more favorable circumstances. There were two potential causes for the low seeding response. The first was that the spring and summer of 1996 (growing season following the fall seeding) were unusually dry (11 ± 3.9 cm of summer precipitation was recorded in the area). This was about 40 percent of the 5 year average of 17.6 ± 4.6 cm. The drought that year not only affected the seeding response, but probably also negatively affected the existing native vegetation. The second potential cause for low response was likely poor seed to soil contact because the seed was broadcast and not covered. The reason for not artificially covering the seed was to attempt to simulate what might happen as a result of natural seed dispersal. Unfortunately, this choice resulted in three potential problems. The first being that adequate seed to soil contact probably did not occur. Even if it did, the seed was on the surface and thus subject to the greater temperature and soil moisture fluctuations which can lead to lower germination (Wilson and others 1970). The second problem with not covering the seed was that it left them exposed to movement by the wind. The final problem was that of seed predation due to insects, birds and mammals (Clements and Young 1996; Vander Wall 1994). All of these factors probably contributed to the very low recruitment.

Zonation patterns of the seeded species were apparent. Three of the six species, bluebunch wheatgrass, bottlebrush squirreltail and Lewis flax, exhibited decreasing emergence with increasing distance from the trunk. Bluebunch wheatgrass and bottlebrush squirreltail both demonstrated the two zone pattern, consisting of tree canopy and interspace. Lewis flax emergence showed three zones instead of two, with highest emergence in the trunk zone, followed by mid canopy and then the interspace. Antelope bitterbrush demonstrated an opposite trend with higher germination in the mid canopy and interspace than near the trunk. No differences were found among zones for orchardgrass or small burnet. This was most likely again due to the lack of recruitment that occurred for these two species.

The findings of this study were contrary to those of a majority of studies that have reported on the effects of juniper on understory communities (Dye and others 1995; Schott and Pieper 1985; Young and Evans 1981; Clary 1971). The differences observed in this study as compared to previous ones may be due to differences among various juniper species or differences in local environments (locales other than foothills of central Utah).

In this study, it appeared Utah juniper had a positive effect on vegetation beneath the canopy and little influence on the interspace vegetation. Similar findings were also reported by Everett and Koniak (1981) on Utah juniper stands in Nevada and by Vaitkus and Eddleman (1991) in western juniper stands.

Work done by Jackson and Caldwell (1993) with spatial patterns around bluebunch wheatgrass and mountain big sagebrush (*Artemisia tridentata* var. *vaseyana*) indicated that "islands of fertility" often occur around perennial plants. These islands are created due to increased amounts of organic matter and nutrients that occur near the plant while the interspace is left essentially barren. On the scale of an individual Utah juniper tree, in this area, it would seem that such islands occur, due to increased plant abundance and seedling recruitment beneath the canopy compared to the interspace.

The interspace, around these "islands", appeared to be a more hostile environment. Several things can occur in the interspace to make it a harsh environment. One such possibility, that has been forwarded by several researchers, is that competition for water and nutrients can occur in the interspace. Arnold (1964) believed that the low production in the interspace around one seed juniper was due to competition for water. This competition can occur due to the extensive lateral roots of juniper trees, which have been found to extend out two or three times the height of the tree (Johnsen 1962). Young and Evans (1981) working with western juniper reported that even though the aerial canopy was not closed, excavation of the interspace revealed that it was full of juniper roots which in their opinion "...effectively closed the stand." Johnsen (1962) reported similar findings around one seed junipers in Arizona. He found that lateral roots occupied much of the interspace soil. He also reported one of the highest concentrations of rootlets to be at the ends of the lateral roots in the interspace. Further evidence of this competition was reported by Evans and Young (1985). They found an increase in available soil moisture following control of western juniper.

Another important factor is the difference in temperature and humidity between the canopy and the interspace. Johnsen (1962) reported that both diurnal temperature and relative humidity fluctuations were higher in the interspace than beneath the canopy. Burkhardt and Tisdale (1976) reported that average soil surface temperatures beneath western juniper reached 26° C while average soil surface temperatures in direct sunlight in the interspace averaged 60° C.

Another difference that has been reported between the canopy and the interspace is that of water infiltration, soil nitrogen (N) content. Klopatek (1987) determined that soils beneath Utah juniper in Arizona had a coarser texture, better water retention and more available nutrients than did interspace soils. It has been reported that N, organic matter, Ca and K are all higher under the canopy than in the interspace (Doescher and others 1987; Brotherson and Osayande 1980). Thus, competition for moisture and nutrients, more extreme temperature and relative humidity fluctuations, differences in soil moisture retention and soil nutrients all combine to create a less hospitable environment for plant growth in the interspace as compared to the canopy.

Of the above possibilities, it is most likely that the effect of extreme temperature and soil moisture fluctuations were the reasons for low plant response in the interspace in this area. Higher plant abundance and seedling recruitment beneath the canopy may have been due to less extreme fluctuations there than in the interspace. The observed effects of tree removal tend to support this. Plant abundance and seedling emergence in the canopy area generally decreased to levels similar to that of the interspace following tree removal, indicating that when the canopy is removed, the understory area is subjected to the same extreme fluctuations in temperature and soil moisture that characterize the interspace zone.

Juniper litter accumulations beneath the canopy have been found to deter emergence of understory vegetation. Horman and Anderson (1996) reported that antelope bitterbrush and bluebunch wheatgrass emergence decreased as Utah juniper litter depth increased. Likewise, Jameson (1966), working with Utah juniper, and Johnsen (1962), working with one seed juniper, both reported that juniper litter reduced emergence of blue grama. It was expected that following litter removal that plant abundance and seedling recruitment would increase. As seen in the results, the response was somewhat mixed. Overall, there was little response to litter removal. Annual forb was the only exception to the generally low response. Annual forb abundance did show a significant increase in the canopy areas following litter removal, indicating that deep litter accumulations may inhibit growth of some species beneath Utah juniper.

The low response, particularly the decrease in perennial grass abundance, was probably due to the actual process of litter removal. During the raking to remove the litter enough perennial grasses may have been inadvertently removed. Koniak and Everett (1983) observed that the area underneath the canopy can act as a seed trap and was an important source of seed reserves. Even though a more favorable microsite had been developed with the litter removal there simply may have been no seeds to adequately exploit it.

Seedling recruitment either showed no response to litter removal, as was the case for bluebunch wheatgrass, or a decrease in recruitment as did bottlebrush squirreltail, Lewis flax and antelope bitterbrush. This agrees with the results of Evans and Young (1970) and Young and Evans (1977). Evans and Young (1970) found that some species, such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniantherum asperum*), had higher emergence under litter than on bare ground. Young and Evans (1977) reported that bottlebrush squirreltail emergence was poor on sites where it was not covered whether by litter or bare soil. Litter can act as a mulch which reduces temperature and moisture fluctuations (Evans and Young 1970). It appeared that in this study litter was of benefit to some of the seeded species.

Conclusions

This study classified two zonation patterns associated with Utah juniper in central Utah, namely a canopy and interspace zone. Total vegetation, perennial and annual grasses and annual forb all had greater plant abundance beneath the tree canopy than in the interspace. Perennial forb and shrub abundance did not vary among zones.

Several of the seeded species exhibited higher emergence beneath the canopy than in the interspace, these included bluebunch wheatgrass, bottlebrush squirreltail and Lewis flax. Antelope bitterbrush response differed in that higher emergence was observed in the interspace and canopy edge than near the trunk. Tree removal had no effect on annual grass and shrub abundance. Tree removal did affect abundance of total vegetation and perennial grass, perennial and annual forbs, along with seedling recruitment. These effects were tied closely to changes in zonation patterns. Following tree removal, total vegetation and annual forb abundance and seedling recruitment beneath the canopy decreased to levels found in the interspace, leading to the idea that canopy cover was of benefit to the understory vegetation. When the canopy was removed, the area was exposed to greater fluctuations in temperature and soil moisture than when the canopy was present.

Litter removal had a limited effect on plant abundance. Nested frequency values indicated that annual forb abundance increased with litter removal while perennial grass abundance decreased. Litter removal findings were somewhat inconclusive because of the actual process of removing the litter by raking. During litter removal, some perennial plants, particularly grasses, were uprooted and some of the seed reserves in the litter may have been removed.

Seeded species response to litter removal was somewhat unexpected. Recruitment of bluebunch wheatgrass, Lewis flax, and antelope bitterbrush showed no response to litter removal. Bottlebrush squirreltail seedling recruitment decreased significantly where litter removal occurred. A dry year in 1996 and the seeding method of broadcasting and not covering it contributed to an extremely low seeding response.

This study indicated that under certain conditions, such as a drought, that Utah juniper canopy cover may actually act as a nurse plant for the understory species. However, to better understand the effect of Utah juniper canopy and litter removal on understory species this study needs to be continued to observe understory response over a wide range of environmental conditions.

References

Anderson, R. C.; Loucks, O. L.; Swain, A. M. 1969. Herbaceous response to canopy cover, light intensity, and throughfall precipitation in coniferous forests. Ecology. 50:255-263.

Armentrout, S. M.; Pieper, R. D. 1988. Plant distribution surrounding Rocky Mountain pinyon pine and one seed juniper in south-central New Mexico. Journal of Range Management. 41:139-143.

Arnold, J. F. 1964. Zonation of understory vegetation around a juniper tree. Journal of Range Management. 17:41-42.

Barney, M. A.; Frischknecht, N. C. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management. 27:91-96.

Brotherson, J. D.; Osayande, S. T. 1980. Mineral concentrations in true mountain mahogany and Utah juniper in associated soils. Journal of Range Management. 33:182-185.

Burkhardt, J. W.; Tisdale, E. W. 1976. Causes of juniper invasion in southwestern Idaho. Ecology. 57:472-484.

Clary, W. P. 1971. Effects of Utah juniper removal on herbage yields from springerville soils. Journal of Range Management. 24: 373-378.

Clements, C. D.; Young, J. A. 1996. Influence of rodent predation on antelope bitterbrush seedling. Journal of Range Management. 49:31-34.

Daubenmier, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science. 33:43-64.

Doescher, P. S.; Eddleman, L. E.; Vaitkus, M. R. 1987. Evaluation of soil nutrients, pH and organic matter in rangelands dominated by western juniper. Northwest Science. 61:97-102.

Dye, K. L. II.; Ueckert, D. N.; Whisenant, S. G. 1995. Redberry juniper-herbaceous understory interactions. Journal of Range Management. 48:100-107.

Engle, D. M.; Stritzke, J. F.; Claypool, P. L. 1987. Herbage standing crop around eastern red cedar trees. Journal of Range Management. 40:237-239.

Evans, R. A.; Young, J. A. 1970. Plant litter and establishment of alien annual weed species in rangeland communities. Weed Science. 18:697-703.

Evans, R. A.; Young, J. A. 1985. Plant succession following control of western juniper (*Juniperus occidentalis*) with Picloram. Weed Science. 33:63-68.

Everett, R. L.; Koniak, S. 1981. Understory vegetation in fully stocked pinyon-juniper stands. Great Basin Naturalist. 41: 467-475.

Farmer, M. E. 1995. The effects of anchor chaining pinyon-juniper woodland on watershed values and big game animals in central Utah. Master Thesis, Brigham Young University. Provo, UT.

Horman, C. S.; Anderson, V. J. 1996. The effects of juniper litter depth and allelopathy on native species. Journal of Office of Research and Creative Activities. @www.byu.edu/tmcbucs/tt/journ95.htm

Hurst, W.D. 1987. Management strategies within the pinyon-juniper ecosystem. In Everett (compiler). Proceedings- Pinyon-juniper conference. Reno, NV. 13-16 Jan. 1986. USDA For. Serv. Gen. Tech. Rep. INT-215. Ogden, UT. pg. 391-396.

Jackson, R. B.; Caldwell, M. M. 1993. Geostatistical patterns of soil heterogeneity around individual perennial plants. Journal of Ecology. 81:683-692.

Jameson, D. A. 1961. Growth inhibitors in native plants of northern Arizona. USDA For. Serv., Rocky Mountain Forest and Exp. Sta. Res. Note 61, pg. 1-2.

Jameson, D. A. 1966. Pinyon-juniper litter reduces growth of blue grama. Journal of Range Management. 19:214-217.

Jameson, D. A. 1970a. Degradation and accumulation of inhibitory substances from *Juniperus osteosperma* (Torr.) Little. Plant and Soil. 33:213-224.

Jameson, D. A. 1970b. Juniper root competition reduces basal area of blue grama. Journal of Range Management. 23:217-218.

Johnsen, T. N. Jr. 1962. One-seed juniper invasion of northern Arizona grassland. Ecological Monographs. 32:187-207.

Klopatek, J. M. 1987. Nutrient patterns and succession in pinyon-juniper ecosystems of northern Arizona. In Everett (compiler). Proceedings- Pinyon-juniper conference. Reno, NV. 13-16 Jan. 1986. USDA For. Serv. Gen. Tech. Rep. INT-215. Ogden, UT. pg. 391-396.

Koniak, S.; Everett, R. L. 1983?. Seed reserves in soils of successional stages of pinyon woodlands. The American Midland Naturalist. 108:295-303.

McPherson, G. R.; Rasmussen, G. A.; Wester, D. B.; Masters, R. A. 1991. Vegetation and soil zonation associated with *Juniperus pinchotii* Sudw. trees. Great Basin Naturalist. 51:316-324.

Ott, R. L. 1993. An introduction to statistical methods and data analysis. Wadsorth Publishing Co. Belmont, California. Pg. 813-814.

Peterson, G. B. 1972. Determination of the presence, location and allelopathic effects of substances produced by *Juniperus scopulorum* Sarg. Dissertation Abstracts B. 32:3811-3812.

Schott, M. R.; Pieper, R. D. 1985. Influence of canopy characteristics of one-seed juniper on understory grasses. Journal of Range Management. 38:328-331.

Skau, C. M. 1964. Interception, throughfall, and stemflow in Utah and alligator juniper cover types of northern Arizona. Forest Science. 10:283-287.

Tausch, R. J.; West, N. E.; Nabi, A. A. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34:259-264.

Vaitkus, M. R.; Eddleman, L. E. 1991. Tree size and understory phytomass production in a western juniper woodland. Great Basin Naturalist. 51:236-243.

Vander Wall, S. B. 1994. Dispersal and establishment of antelope bitterbrush by seed caching rodents. Ecology. 17:1911-1926.

Wilson, A. M.; Nelson, J. R.; Goebel, C. J. 1970. Effects of environment on the metabolism and germination of crested wheatgrass seeds. Journal of Range Management. 23:283-288.

Young, J. A.; Evans, R. A. 1977. Squirreltail seed germination. Journal of Range Management. 30:33-36.

Young, J. A.; Evans, R. A. Evans. 1981. Demography and fire history of a western juniper stand. Journal of Range Management. 34:501-506.

Resurvey of the Vegetation and Soils of Fishtail Mesa: A Relict Area in Grand Canyon National Park, Arizona

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The vegetation and soils of Fishtail Mesa in Grand Canyon National Park, Arizona, were studied in May 1958 by Jameson and others (1962) to provide management information and comparison for similar, grazed areas on the mainland's Forest Service lands. Fishtail Mesa is a 1,084 acre relict site at an elevation of about 6,000 feet, located in Grand Canyon National Park. It is characterized by two major plant communities: a pinyon pine-Utah juniper woodland and a sagebrush-mutton grass shrubland or steppe. A resurvey was conducted in May 1996 to compare vegetative change after 38 years and to evaluate the site for long-term surveillance of ecological change. Seven and a half, permanent 800 foot "elbs" or line-strip transects were established in 1958; three and a half in the woodland and four in the shrubland. Vegetative methodology included line intercept, Parker loop data, tree data (including stem mapping, height, and canopy spread within a 20 foot strip centered over the transect) for all life stages, and three foot square plots located every 100 feet along the line intercept. A soil survey, landscape rephotography, comparison of historic aerial photography, estimates of mule deer population, floristic inventory, and preliminary faunal survey of the mesa were also completed. Global Positioning System coordinate data were collected to document the elb locations.

The resurvey was made with participation of Jameson, using the same methodologies. Direct comparisons with the first survey are difficult due to the loss of the original field data. Only the 1962 journal article summary is available.

Vegetation has not changed appreciably. On all elbs, a minor increase was detected for both pinyon and juniper. There is an apparent increase of pinyon seedling establishment. On the shrubland elbs, sagebrush has declined and mutton grass has increased, though the latter may reflect a difference in the minimum measurement unit from 0.1 inch in 1958 to 0.5 inch in 1996. Other species like joint-fir, prickly pear, and snakeweed have decreased. No recent evidence of wildfire was observed, though small groups of standing dead junipers suggest that fires did occur 80 to 100 years ago.

This information along with field data, photography, and herbarium samples will be archived in the Grand Canyon National Park Museum Collection. We recommend the site be established as a Federal Research Natural Area.

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Diversity with Successional Status in the Pinyon-Juniper/Mountain Mahogany/ Bluebunch Wheatgrass Community Type Near Dutch John, Utah

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Abstract—Alpha and beta diversity and vegetative cover for Colorado pinyon (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) understories of northerly exposures are compared at varying successional stages before and after disturbance. Plant diversity and species richness are highest in seral communities of alder-leaf mountain mahogany and bluebunch wheatgrass where pinyon and juniper canopy cover does not exceed 20 percent. Following disturbance at these sites, the response of native understory species was rapid and vigorous. Timely disturbance within the pinyon-juniper woodland sere appears necessary in order to maintain a responsive, productive, and diverse native understory. These studies indicate that pinyon-juniper canopy cover of about 20 percent is a critical point for the maintenance of native understory species.

In the Great Basin, Everett (1987) noted that as pinyon-juniper crown cover increases, cover, productivity, and density of understory species decrease. In the Green River corridor of Daggett County, UT, similar relationships are evident. On many northerly exposures in the area, plant diversity and species richness are highest in seral communities where alder-leaf mountain mahogany (*Cercocarpus montanus* Raf.) and bluebunch wheatgrass (*Elymus spicatus* [Pursh] Gould) are commonly associated with approximately 50 other vascular plants. Where crown cover of pinyon-juniper is less than 20 to 25 percent, response of these native understory species is rapid and vigorous following fire. When crown cover exceeds 30 percent, the understory trends toward depletion and the initial response following fire is slower and less vigorous. At 40 percent or more crown cover, many of the understory plant species have been purged from the community. Established stands of closed pinyon-juniper severely deplete understory seed reserves. Succession following fire in closed stands where crown cover of pinyon-juniper exceeds 40 percent is largely dependent on seed migration to the site, creating ideal conditions for cheatgrass (*Bromus* sps.) and other invasive exotic species. Fire intervals frequent enough to maintain alder-leaf mountain mahogany and bluebunch wheatgrass communities in the Green River corridor are indicated to maintain native plant communities of high diversity and vigor. Eventual disturbance in closed stands of pinyon-juniper where understory communities have been depleted or purged will likely result in site occupation by invasive weeds or species seeded by land managers.

Study Sites

The study sites are located within the Green River corridor in Daggett County of northeastern Utah. The corridor is within the Uinta Mountain Section defined by McNab and Avers (1994). The sites are within a land type composed of a series of ridges and ravines formed by an alternate underlay of resistant Precambrian quartzite and highly erosive shales. Within the Green River corridor, continuous and many closed stands of Colorado pinyon (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) cover approximately 20,000 acres (8,100 ha) on the Ashley National Forest, and these stands extend eastward well beyond the National Forest boundary. Historically, seral communities were maintained by wildfire. However, fire suppression since the early 1900's has maintained areas already supporting mature pinyon and juniper trees and has allowed pinyon and juniper to invade other areas dominated by herbaceous plants and shrubs. Prescribed fire has been used in the Green River corridor during the 1980's and 1990's to maintain viable and productive seral pinyon-juniper communities and to improve overall forage and habitat for big game animals. Livestock grazing was discontinued at the study sites in the mid-1960's.

The land type on which the studies are located consists of two phases that are primarily influenced by exposure. On southerly exposures, native grass-forb communities are common in the early seral stage and are later succeeded by rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.) and mountain big sagebrush (*Artemisia tridentata* var. *pauciflora* Winward and Goodrich). However, the potential for cheatgrass (*Bromus tectorum* L.) invasion and dominance on these exposures following disturbance is high, especially if pinyon-juniper crown closure existed prior to disturbance (Goodrich and Gale, these proceedings, Goodrich and Rooks, these proceedings).

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Table 1—Site information for three study sites treated with prescribed fire.

	Study site number		
	6-1	6-2	6-21
Seral status[a]	Late	Mid	Mid
Stand age (years)[a]	300	80	N/A
Year burned	1989	1993	1985

[a]Seral status and approximate stand age prior to prescribed burning.

Table 2—Site information for five study sites not treated with prescribed fire.

	Study site number				
	6-24B	6-24C	6-24E	6-24G	6-24H
Seral status	Mid	Mid	Late	Late	Mid
Stand age (yrs)	70	150	215	140	N/A

On northerly exposures, early seral native grasses and forbs are succeeded by a diverse shrub component consisting of alder-leaf mountain mahogany, low rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), snowberry (*Symphoricarpos oreophilus* Gray), serviceberry (*Amelanchier alnifolia* Nutt.), and mountain big sagebrush. Approximately 50 native vascular plants are associated with this community. Bluebunch wheatgrass is the principal understory species. Cheatgrass is also present but generally at a much lower frequency than found on southerly exposures.

This study includes eight study sites that are within 3.5 miles (north-northwest) of Dutch John, UT and are no further than 2 miles apart. All are located on northerly exposures with gradients between 20 and 35 percent. Elevations for the sites range between 6,600 and 6,800 ft (2,012 and 2,073 m). Mean annual precipitation for the Dutch John area as indicated by the Flaming Gorge Weather Station is 12.50 inches (31.75 cm), of which 63 percent is from April through September (Ashcroft and others 1992).

Three of the eight study sites were burned by helitorch and aerial seeded in a cooperative project between the Utah Division of Wildlife Resources and the Ashley National Forest. Both northerly and southerly exposures were burned. The intensity and spread of fire was sufficient to achieve essentially 100 percent mortality of pinyon and juniper within the perimeter of each burn. Ring counts of pinyon and juniper trees at most of the study sites were used to approximate stand age (tables 1 and 2).

Methods and Results

A total of one hundred 19.69 by 19.69 inch (50 by 50 cm) sample plots were established along five permanently marked 30.5 m (100 ft) beltlines at each of the study sites. Quadrat frequency was determined for all plant species at most of the study sites as outlined by the U.S. Department of Agriculture, Forest Service (1993). Alpha (number of species per quadrat) and beta (total number of species) plant diversity was determined from quadrat frequency. Four hundred point samples were read at each study site to determine ground cover. Crown cover of woody species was also measured by line intercept along each of the five beltlines. Pre-burn and post-burn data was obtained from study sites 6-1 and 6-2 (tables 3 and 4).

Data was taken from study site 6-2 before burning (1993) and 2 and 4 years after burning (1995 and 1997). Initial response of native understory species following fire at study site 6-2 was rapid and vigorous. Nearly all native species present before the burn were present after the burn. Of the shrubs, only mountain big sagebrush was absent following fire. A noticeable increase in alpha and beta was observed 4 years after burning. Some of the increase in beta, and possibly alpha, is due to the presence of seeded and annual species (table 4). All but two of the grass species increased in frequency from 1995 to 1997. Bluebunch wheatgrass was found with the highest frequency. Seeded grasses are present but are not dominant components at the site. Four years after burning, ground cover reached 85 percent of pre-burn potential and alder-leaf mountain mahogany recovered to nearly 85 percent of its pre-burn crown cover.

At study site 6-1, where crown cover of pinyon-juniper was about 60 percent before burning, the understory community had been reduced by pinyon and juniper competition. Initial response of native species after fire was sluggish at best. The increase in plant diversity is due to the presence

Table 3—Comparison of diversity, ground cover, and woody species crown cover pre-fire and post-fire at study sites 6-2 and 6-1.

Study	Diversity			Ground	Woody species crown cover[a]					
	Year	Alpha	Beta	cover	P-J	CEMO	AMAL	SYOR	ARTR	CHVI
				Percent						
6-2	1993	7.9	51	95	11.2	11.4	4.4	8.8	10.9	0.6
6-2	1995	7.6	55	48	0.0	7.5	1.6	8.4	0.0	3.4
6-2	1997	8.3	68[b]	74	0.0	9.5	2.6	10.5	0.0	2.0
6-1	1989	1.4	17	84	62.3	1.0	0.0	0.0	0.0	0.0
6-1	1993	4.7	38[c]	57	0.0	0.0	0.0	0.0	0.0	0.0

[a]P-J = pinyon-juniper, CEMO = *Cercocarpus montanus*, AMAL = *Amelanchier alnifolia*, SYOR = *Symphoricarpos oreophilus*, ARTR = *Artemisia tridentata*, CHVI = *Chrysothamnus viscidiflorus*.
[b]Sixteen of the 68 species were either seeded or were annuals.
[c]Eighteen of the 38 species were either seeded or were annuals.

Table 4—Comparison of number of species pre-fire and post-fire at study sites 6-2 and 6-1.

Study	Year	Number of species: Graminoids	Forbs	Shrubs	Seeded	Annuals
6-2	1993	10	31	8	0	5
6-2	1995	13	36	6	6	9
6-2	1997	18[a]	43[c]	7	6	10
6-1	1989	4	10	2	0	0
6-1	1993	11[b]	25[d]	3	6	12

[a]Of the 18 graminoid species, four were seeded and two were annuals.
[b]Of the 11 graminoid species, five were seeded and one was an annual.
[c]Of the 43 forbs species, two were seeded.
[d]Of the 25 forb species, one was seeded.

of seeded and annual species. Seeded grasses and annuals recorded high frequencies in 1993. Alder-leaf mountain mahogany and bluebunch wheatgrass are represented (frequency values of 2 and 1) at the study site but are minor components in the present community. Ground cover was nearly 70 percent of pre-burn potential.

Data obtained from eight study sites indicate that as crown cover of pinyon-juniper increases, alpha and beta diversity and crown cover of alder-leaf mountain mahogany decrease (table 5). Alpha and beta values were high and remained stable to 20 to 25 percent pinyon-juniper crown cover. Under these conditions, alder-leaf mountain mahogany increased in crown cover. Alpha and alder-leaf mountain mahogany crown cover showed decline at about 30 percent pinyon-juniper crown cover. At 50 percent crown cover, alpha and beta were significantly reduced, and alder-leaf mountain mahogany had been essentially purged from the community.

Discussion and Management Implications

Initial response of native understory species following fire correlates closely with the percent crown cover of pinyon and juniper trees. Our studies indicate that the understory is most productive, diverse, and responsive to disturbance when pinyon-juniper crown cover is at or below 20 percent. Initial response following fire at study site 6-2 was rapid and vigorous. The annual stage described by Barney and Frischknecht (1974) was essentially bypassed, and the perennial grass-forb stage was relatively short (approximately. 2 years). Alpha and beta had recovered to pre-burn levels. Most of the shrubs present at the site sprouted after fire, and alder-leaf mountain mahogany had nearly reached pre-burn crown cover in only 4 years.

When pinyon-juniper crown cover exceeds 20 to 30 percent, thinning of the understory seems to accelerate. The data indicate that beta remains stable but alpha begins to decline. Beyond 30 percent, there is a rapid decline in understory species and substantial decrease in alder-leaf mountain mahogany crown cover. By the time pinyon-juniper crown cover reaches 50 percent, the understory and soil seed reserves have been depleted, and many plant species have been purged from the community. Crown cover of alder-leaf mountain mahogany appears to be a positive indicator for vascular plant diversity while crown cover of pinyon and juniper appear to be negative indicators.

Our studies indicate that succession and management of pinyon-juniper woodlands of the Green River corridor can be correlated with percent crown cover of pinyon and juniper trees. Age of stand appears to be a less reliable indicator (compare stand ages and pinyon-juniper crown cover percentages for study sites 6-24C, 6-24E, 6-24G, and 6-1). Fire intervals that keep pinyon-juniper crown cover below 20 to 25 percent is indicated to maintain responsive, productive, and diverse alder-leaf mountain mahogany and bluebunch wheatgrass communities. Our findings

Table 5—Alpha and beta diversity and crown cover of shrubs and alder-leaf mountain mahogany (CEMO) in relation to crown cover of pinyon and juniper (P-J).

Study site	Year	Diversity: Alpha	Diversity: Beta	Total shrub crown cover	Crown cover: CEMO	Crown cover: P-J
				Percent		
6-2	1993	7.9	51	36.4	11.4	11.2
6-2	1995	7.6	55	21.1	7.5	0.0
6-2	1997	8.3	68	24.8	9.5	0.0
6-21	1993	9.1	49	23.0	12.1	0.0
6-24B	1997	7.2	62	38.7	29.6	18.5
6-24H	1997	N/A	N/A	27.5	22.9	27.1
6-24C	1997	4.5	50	21.6	12.7	29.2
6-24E	1997	3.2	37	0.9	0.9	53.9
6-24G	1997	2.7	30	0.2	0.0	62.1
6-1	1989	1.4	17	1.0	1.0	62.3
6-1	1993	4.7	38	0.6	0.0	0.0

concur with Doughty (1987) who reported that understory species begin to decline when trees reach one-third of their climax potential (approximately 20 percent crown cover). Where understory species have been depleted or purged from the community, invasive species such as cheatgrass can be expected to occupy these sites after disturbance if seeding is not used to control their invasion.

References

Ashcroft, G. L.; Jensen, D. T.; Brown, J. L. 1992. Utah climate. Logan, UT: Utah State University, Utah Climate Center. 125 p.

Barney, M. A.; Fischknecht, N. C. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. Journal of Range Management. 27(2): 91-96.

Doughty, J. W. 1987. The problems with custodial management of pinyon-juniper woodlands. In: Everett, R. L., comp. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 29-33.

Everett, R. L. 1987. Plant response to fire in the pinyon-juniper zone. In: Everett, R. L., comp. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 152-157.

McNab, W. H.; Avers, P. E., comps. 1994. Ecological subregions of the United States: Section descriptions. Administrative Publ. WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

U.S. Department of Agriculture, Forest Service. 1993. Rangeland ecosystem analysis and management handbook. FSH 2209-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region.

Diseases and Environmental Factors of the Pinyon-Juniper Communities

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J. N. Davis
D. L. Nelson
A. Hreha

Abstract—The pinyon-juniper woodland is the dominant ecosystem in Utah. While it is a very successful ecosystem, it is not without its disease problems. The limiting soil nutrients appear to be nitrogen, phosphorous, and potassium. Temperature and moisture gradients are limiting factors in the growth of pinyon and juniper. Juniper decline appears to be related to drought and temperature stress and increased salts. A number of pathogens occur on *Pinus edulis* and *Juniperus osteosperma*. The most frequent pathogens on junipers are the rust fungi. Mistletoe was more common on pinyon than juniper but mistletoe infection has an impact on both.

The pinyon-juniper woodland is a widespread vegetation type in the Southwestern United States that is estimated to cover from 40 to 50 million hectares (Allred 1964; Tausch and Tueller 1990). The pinyon-juniper vegetation provides a source of fuel, building materials, charcoal, pine nuts, Christmas trees, and folk medicines (Cronquist and others 1972; Gallegos 1977; Hurst 1977; Lanner 1975; Tueller and others 1979). About 80 percent of the acreage is grazed by livestock and wildlife (Bunderson and others 1986b; Clary 1975). In Utah, this ecosystem is a large component (62,705 km^2 or 28.6 percent) of the vegetation (Kuchler 1964). The pinyon-juniper woodlands are valued for their watershed, aesthetic, and recreational values (Gifford and Busby 1975). The pinyon-juniper woodlands also have a range of diseases. They range from non-pathogen types (environmental factors) to specific pathogens. Both types will be discussed in this paper. The purpose of this manuscript is to review the non-pathogenic factors and pathogens present in pinyon-juniper woodlands.

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Influence of Environmental Factors

Soil and Mineral Factors

Soil samples and foliage samples (255 trees) were collected from 17 pinyon-juniper sites throughout Utah (fig. 1, table 1). Mineral analysis of soils and leaf samples were determined. The mineral concentration was correlated with the mineral concentrations of the leaves at the different sites. Statistical and factorial analyses suggested that the primary limiting soil nutrients in the native soils were nitrogen, phosphorous, and potassium. The linear correlation coefficient of foliage mineral composition and soil mineral composition was 0.66 for nitrogen and potassium and 0.49 for sodium and phosphorous. Rotated orthogonal

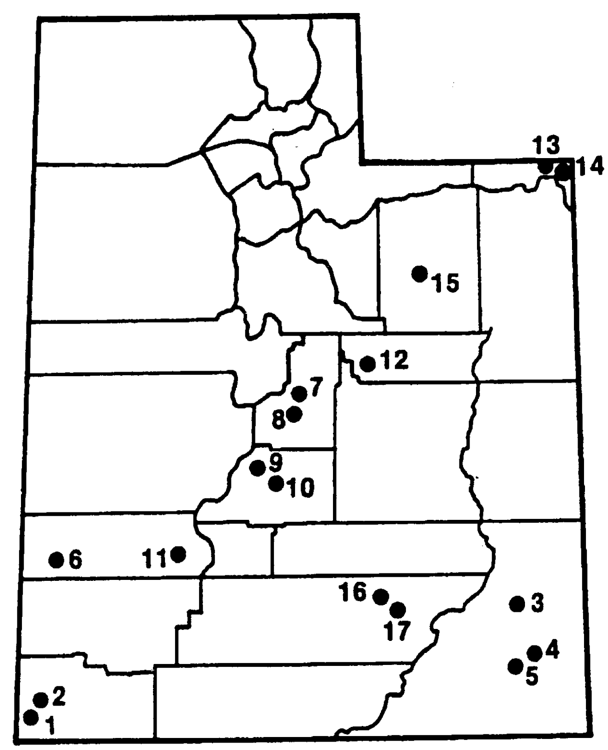

Figure 1—Location of the 17 pinyon-juniper study sites in Utah.

Table 1—Specific names of the 17 primary pinyon-juniper study sites in Utah.

Number	Site name
1	Jackson Springs
2	Tobin Bench
3	Peters Point
4	Alkali Ridge
5	Cyclone Flat
6	Indian Peak
7	Ephraim
8	Manti
9	Black Mountain
10	Triangle Mountain
11	Beaver Ridge
12	Gordon Creek
13	Dutch John
14	Taylor Flat
15	Rabbit Gulch
16	Henry Mt (Stevens Narrows)
17	Henry Mt (Airplane Flat)

factors from varimax factor analysis were 0.79 for nitrogen, 0.73 for phosphorous and 0.50 for potassium. Correlation of factors greater than an absolute value of 0.25 are significant (Bunderson and others 1986a). Increased concentration of sodium resulted in decreased growth of junipers which would indicate that *J. osteosperma* is a salt-sensitive species. Temperature and moisture gradients were also distinct growth limiting factors in this ecosystem (Bunderson and others 1985).

Juniper Decline, a Non-Pathogenic Disease

Juniper decline is common in southwestern Utah. The characteristic symptom is for the distal foliage to become chlorotic and die. Mortality progresses along twigs until whole branches or the entire tree dies. While juniper decline was observed in Natural Bridges National Monument and Needles area of Canyonland National Park, no pathogenic agent appeared to be responsible for the decline problem. There did not appear to be any high correlation between high or low amounts of minerals in the soil. It is suggested that the juniper decline is a combination of drought and temperature stress which reduces the water resources. The increased uptake of salts result in complexing of the iron, magnesium and calcium to form complex crystals in the leaves which are characteristic of the decline symptoms (Weber and others 1995).

Diseases Caused by Organisms

Diseases Reported for Pinyon Pine

The printed literature was searched by computer and manual searches of several western disease herbariums were done. The States covered by the herbarium searches were Arizona, Colorado, Idaho, Nevada, New Mexico, Oregon, Utah, Wyoming, and Washington. The reported pathogens on *Pinus edulis* were:

Acanthophysium albida (Gilbertson and others 1974)
Armillaria mellea (Plant Disease Index 1960)
Arceuthobium campylopodum (Peterson 1961)
Arceuthobium divaricatum (Hreha and Weber 1979)
Coleosporium crowellii (Christenson and Peterson 1961)
Coleosporium jonesii (Gilbertson and McHenry 1969)
Coleosporium ribicola (Peterson 1962)
Cronartium occidentale (Plant Disease Index 1960)
Dacryobolus karstenii (Gilbertson and others 1975)
Heterobasidion annosum (Tegethoff 1973)
Leptographium wageneri (Landis and Helburg 1976)
Phellinus pini (Plant Disease Index 1960)
Phoradendron juniperinum (Hreha and Weber 1979)
Tomentella chlorina (Gilbertson and others 1974)
Verticicladiella sp. (Wagener and Mielke 1961)
Verticicladiella wagenerii (Walters and Walters 1977)

Diseases Reported for Junipers

The reported pathogens on *Juniperus osteosperma* (Utah Juniper) were:

Antrodia ferox (Hawksworth 1950)
Daedalea juniperina (Gilbertson 1975)
Diplomitoporus rimosus (Hedgecock 1912)
Fomes juniperinus (Bethel 1918)
Gymnosporangium harknessianum (Plant Disease Index 1960)
Gymnosporangium inconspicuum (Bethel 1918)
Gymnosporangium juvenescens (Goodding 1919)
Gymnosporangium kernianum (Bethel 1918)
Gymnosporangium multiporum (Bethel 1918)
Gymnosporangium nelsonii (Bailey 1970)
Gymnosporangium speciosum (Bethel 1918)
Poria rimosa (Gill 1941)
Pyrofomes (Fomes) demidoffii (Gilbertson 1974)
Trametes sepium (Hawksworth 1950)
Uredo phoradendri (Hawksworth 1952)

Correlation of Diseases and Environment

Pathogens and Physiological Diseases

The diseases present on *J. osteosperma* was determined on 17 sites in Utah (fig. 1). The most frequent pathogen on the research sites was *Gymnosporangium* (rust fungi). *Gymnosporangium inconspicuum* was the most common rust fungus followed in frequency and severity by *G. nelsonii*, *G. kernianum* and *G. speciosum*. Mold-mildew type of diseases were correlated with high summer temperature and fall precipitation. Wood rot was common and correlated with low winter temperatures and low soil nitrate. Needle blight, shoot dieback, and needle cast symptoms were common and considered abiotic in origin. Needle blight was correlated with higher soil salinity. Mistletoe, *Phoradendron juniperinum* was present in seven sites (Bunderson and others 1986b).

Table 2—Percent infection comparing pinyon and juniper on rim, forest, and burned areas of the south rim of the Grand Canyon.

	Rim	Forest	Burned
Pinyon	32.3	30.6	0.02
Juniper	46.8	31.8	0.02

Mistletoe on Pinyon and Juniper

The distribution and effects of mistletoes on the pinyon-juniper vegetation along the south rim of the Grand Canyon was determined (Hreha and Weber 1979). *Arceuthobium divaricatum,* which infects *Pinus edulis,* is spread by a forced ejection mechanism of the mistletoe. *Juniperus osteosperma* is infected by *Phoradendron juniperinum,* which is spread by birds. Fire was the most effective factor in limiting the spread of the mistletoes. The trees that had regrown in the burned areas were the only areas devoid of mistletoe infection (table 2). The incident of infection increases as trunk diameter and height increases in both pinyon and juniper (Hreha and Weber 1979).

While in some cases, the non-pathogenic factors and the pathogens cause death of the trees, no control measures are used. On the other hand, the replacement seedlings appear to be more than adequate to replace lost trees.

References

Allred, B. W. 1964. Problems and opportunities on U.S. grasslands. American Hereford Journal. 54: 70-72.

Author not listed. 1960. Index of Plant Diseases in the United States. U.S. Dept. Agric. Handbook. No. 165. Washington, DC. 531 p.

Bailey, H. E. 1970. *Gymnosporangium nelsonii* Arth. on *Juniperus osteosperma* (Torr.) Little. U. Calif., Berkeley Herb. No. 1450623.

Bethel, E. 1918. *Fomes juniperinus* (Schrenk) Sacc. & Syd. in Sacc. on *Juniperus osteosperma* (Torr.) Little. Rocky Mtn. For. & Ran. (Colo.) Herb. No. 4242-G.

Bethel, E. 1918. *Gymnosporangium inconspicuum* Kern on *Juniperus osteosperma* (Torr.) Little. Rocky Mtn. For. & Ran. (Colo.) Herb. No. 4851-P.

Bethel, E. 1918. *Gymnosporangium kernianum* Bethel on *Juniperus osteosperma* (Torr.) Little. Shrub Sciences Laboratory, Provo, UT. Herb. No. 186.

Bethel, E. 1918. *Gymnosporangium multiporum* Kern on *Juniperus osteosperma* (Torr.) Little. Shrub Sciences Laboratory, Provo, UT. Herb. No. 220.

Bethel, E. 1918. *Gymnosporangium speciosum* Peck on *Juniperus osteosperma* (Torr.) Little. Rocky Mtn. For. & Ran. (Colo.) Herb. No. 4358-P.

Bunderson, E. D.; Weber, D. J. 1986a. Foliar nutrient composition of *Juniperus osteosperma* and environmental interactions. Forest Science. 32: 149-156.

Bunderson, E. D.; Weber, D. J.; Nelson, D. L. 1986b. Diseases associated with *Juniperus osteosperma* and a model for predicting their occurrence with environmental site factors. Great Basin Naturalist. 46: 427-440.

Bunderson, E. D.; Weber, D. J.; Davis, J. N. 1985. Soil mineral composition and nutrient uptake in *Juniperus osteosperma* in 17 Utah sites. Soil Science. 139: 139-148.

Christenson, J. A.; Peterson, R. S. 1961. *Coleosporium crowellii* Cummins on *Pinus edulis* Engelm. Shrub Sciences Laboratory, Provo, UT. Herb. No. 979.

Clary, W. P. 1975. Present and future multiple-use demands on the pinyon-juniper type. In: The pinyon-juniper ecosystem: A symposium. Utah Agri. Exper. Station. 194 p.

Cronquist, A.; Holmgren, A. H.; Holmgren, N. H.; Reveal, J. L. 1972. Intermountain flora. vol. 1. New York Botanical Garden, New York: Hafner Publishing.

Gallegos, R. R. 1977. Forest Practices needed for the pinyon-juniper type. In: Ecology, uses and management of pinyon-juniper woodlands. USDA Forest Service General Technical Report RM-39. 48 p.

Gifford, G. F.; Busby, F. E., eds. 1975. The pinyon-juniper ecosystem: A symposium Utah Agriculture Experiment Station. 194 p.

Gil, A. 1941. *Poria rimosa* (Murr.) on *Juniperus osteosperma* (Torr.) Little. Univ Ariz. Herb. No. 10601.

Gilbertson, R. L. 1975. *Daedalea juniperina* (Murr.) Murr. on *Juniperus osteosperma* (Torr.) Little. Univ. Ariz. Herb. No. 10604.

Gilbertson, R. L. 1974. *Fomes demidoffii* (Lev.) Cooke on *Juniperus osteosperma* (Torr.) Little. Univ. Ariz. Herb. No. RLC 7090 RLC 10107.

Gilbertson, R. L.; Burdsall, H. H., Jr.; Larsen, M. J. 1975. Notes on wood rotting hymenomycetes in New Mexico. Southwest Naturalist. 19: 359-360.

Gilbertson, R. L.; Martin, K. J.; Lindsey, J. P. 1974. Annotated check list and host index for Arizona wood-fungi. Univ. Arizona Agric. Exp. Sta. Techn. Bull. 209: 1-48.

Gilbertson, R. L.; McHenry, J. 1969. Check list and host index for Arizona rust fungi. Univ. Arizona Agric. Exp. Sta. Techn. Bull. 186: 1-40.

Goodding, L. N. 1919. *Gymnosporangium juvanescens* Kerns on *Juniperus osteosperma* (Torr.) Little. Univ. Ariz. Herb. No. 04.

Hawksworth, F. G. 1950. *Poria (Antrodia) Ferox* on *Juniperus osteosperma* (Torr.) Little. Rocky Mtn. For. & Ran. (Colo.) Herb. No. 5430-C.

Hawksworth, F. G. 1950. *Trametes sepium* Berk on *Juniperus osteosperma* (Torr.) Little. Rocky Mtn. For. & Ran. (Colo.) Herb. No. 5010-G.

Hawksworth, F. G. 1952. *Uredo phoradendri* H. Jacks on *Juniperus osteosperma* (Torr.) Little. Rocky Mtn. For & Ran. (Colo.) Herb. No. 6310-D.

Hedgecock, G. G. 1912. *Poria (Antrodia) rimosa* (Murr.) on *Juniperus osteosperma*. (Torr.) Little. Rocky Mtn. For & Ran. (Colo.) Herb. No. 4147-E.

Hreha, A. M.; Weber, D. J. 1979. Distribution of *Arceuthobium divaricatum* Engelm. and *Phoradendron juniperinum* Engelm. ex A. Grayviscaceae on the south rim of Grand Canyon Arizona USA. Southwest Naturalist. 24: 625-636.

Hurst, W. D. 1977. Managing pinyon-juniper for multiple benefits. In: Ecology, uses, and management of pinyon-juniper woodlands. USDA Forest Service General Technical Report RM-39. 48 p.

Kuchler, A. W. 1964. Manual to accompany the map potential vegetation of the coterminous United States. American Geographical Society Publication. 36: 111.

Landis, T. D.; Helburg, L. B. 1976. Black stain root disease of pinyon pine in Colorado. Pl. Dis. Reporter. 60: 713-717.

Lanner, R. M. 1975. Pinyon pines and junipers of the south-western woodlands. In: The pinyon-juniper ecosystem: A symposium. Utah Agriculture Experiment Station. 194 p.

Peterson, R. S. 1961. *Arceuthobium campylopodium* Engelm. on *Pinus edulis* Engelm. Shrub Sciences Laboratory, Provo, UT. Herb. No. S329.

Peterson, R. S. 1962. *Coleosporium ribicola* Arth on *Pinus edulis* Engelm. Shrub Sciences Laboratory, Provo, UT. Herb. No. 1001.

Peterson, R. S. 1967. Studies of juniper rusts in the West. Madrono. 19: 79-91.

Tausch, R. J.; Tueller, P. T. 1990. Foliage biomass and cover relationships between tree and shrub dominated communities in pinyon-juniper woodlands. Great Basin Naturalist. 50: 121-134.

Tegethoff, A. C. 1973. Known distribution of *Fomes annosus* (Fr.) Cooke in the intermountain region. Pl. Dis. Reporter. 57: 407-410.

Tueller, P. T.; Beeson, C. D.; Tausch, R. J.; West, N. E.; Rea, K. H. 1979. Pinyon-juniper woodlands of the Great Basin: Distribution, flora, vegetal cover. USDA Forest Service Research Paper INT-229. 22 p.

Wagener, W. W.; Mielke, J. L. 1961. A staining-fungus root disease of ponderosa, jeffrey, and pinyon pines. Pl. Dis. Rep. 45: 831-835.

Walters, J. W.; Walters, N. R. 1977. *Verticicladiella wagenerii* (Kend.) in the southwest. Pl. Dis. Reporter. 61: 419.

Weber, D. J.; Gang, D.; Halls, S.; Nelson, D. L. 1995. Juniper decline in the Natural Bridges National Monument and Canyonlands National Park. In: Roundy, Bruce A.; McArthur, E. Durant; Haley, Jennifer S.; Man, David K., comps. Proceedings: wildland shrub and arid land restoration symposium. 1993 October 19-21, Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 258-262.

Welch, L.; Weber, D. J. 1986. In vitro digestibility of *Juniperus osteosperma* Torr. Little from 17 Utah sites. Forest Science. 32: 834-840.

Methods in Historical Ecology: A Case Study of Tintic Valley, Utah

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Abstract—Through use of repeat photography, archival research, and field observation to reconstruct landscape vegetation patterns and changes across a 120 year period in the upper Tintic Valley of central Utah, researchers found significant changes in landscape vegetation pattern over time, including change in pinyon-juniper woodland area. Previously reported massive woodland harvest associated with early mining, domestic and agricultural activities elsewhere in the Intermountain West also took place in Utah. The impact on woodland area of the agricultural "bull" fence alone was significant. More recent study area woodland expansion also occurred. Because intensive industrial activity associated with development of the Tintic Mining District occurred prior to the taking of the study's 1911 photographs, those photos failed to reflect presettlement, or even early settlement, vegetation conditions. Overall, results suggest that historical ecological studies must employ a range of overlapping methodologies to accurately interpret the nature and direction of landscape vegetation change. Such information is useful for managing regional ecosystems now and into the future.

This study was undertaken to provide a historical context for proposed long-term watershed research in pinyon-juniper woodlands in Tintic Valley, Juab County, Utah. The study objective was to describe and, where possible, quantify landscape changes occurring in the study area from the time of Euroamerican settlement to the modern period. Reported here are results pertaining specifically to historic impacts on the pinyon-juniper woodlands of the study area.

Ecological histories have been widely used to characterize changes in vegetation cover over time (Bahre 1991; Hadley and Sheridan 1995; Hastings and Turner 1965). Such studies can be a useful point of departure for managers seeking guidelines for managing regional ecosystems now and into the future. Because the historical ecological record is commonly fragmented, a variety of techniques are generally employed to achieve research objectives. In this study, no single methodology was able to provide a complete picture of change in the study area. Repeat photography, archival research, oral histories, field observations and the regional ecological literature all provided clues for understanding changes in the Tintic landscape over time. The results of this study support the view that historical ecological studies must employ a range of overlapping methodologies to accurately interpret the nature and direction of landscape change.

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Materials and Methods

Archival Research

This study included an intensive survey of archival materials for references to Tintic Valley vegetation, records of ore, fuelwood and charcoal production, smelting and milling activities, and human population in the Valley in the era of biomass fuels. From this information, estimates of early settlement era (1870-1900) industrial, agricultural, and domestic fuelwood consumption were derived.

Oral Histories and Field Observations

Oral histories, maps, field measurements, and historical photographs were employed to quantify the settlement era use of juniper trees for livestock fencing ("bull fence") within the study area.

Domestic fuelwood consumption was estimated from population figures for the area (USDC 1910, USDI 1900, 1890, 1880), using an assumed fuelwood consumption rate of one cord per person, per year (Bahre 1991; Hadley and Sheridan 1995).

Quantities of cordwood and charcoal consumed in Tintic Valley mills and smelters in the biomass fuel era (1869-1880) were estimated using published figures for ore production (Butler and others 1920; Heikes 1919) and fuel consumption for the era (Raymond 1873).

Estimates of woodland area cleared for fuelwood were derived from published estimates of cordwood yields from pinyon-juniper woodlands (Young and Budy 1986, 1979). Wood used in agricultural fence construction was similarly translated to hectares cleared using woodland density estimates derived by applying a plotless density technique (Bonham 1989; Cottam and Curtis 1956) to witness tree data from the 1872-1874 General Land Office Survey of the study area (Gorlinski 1874).

Paired Photographs

1911 photographs of portions of the study area (Lindgren and Loughlin 1919), obtained through the national archives of the U.S. Geological Survey, were rephotographed in 1995, using methods outlined in Rogers (1982) and Rogers, Malde and Turner (1984).

Results

Woodland Harvest

Domestic Fuelwood—Domestic fuelwood consumption for the 1870-1900 period was estimated to have been 74,000 cords, as follows:

Decade:	1870-79	1880-89	1890-99
Cords:	12,250*	19,520*	42,230

* incomplete data

Industrial Fuels—Assuming 12 cords of wood or 33 bushels of charcoal required to process 10 tons of ore under favorable conditions (Raymond 1873), roughly one cord of wood or its charcoal equivalent was consumed per ton of ore processed. With 132,500 tons of ore processed within the District between 1870 and 1890, (Raymond 1873) a conservative estimate of cordwood consumed in processing Tintic's ores in that decade is 132,500 cords. Note that this figure is both conservative with respect to ore processing and ignores the use of wood fuels for brick making, industrial purposes other than ore processing, and the preprocessing of ores by small, independent operators.

Non-Fuel Uses—Figure 1 shows a bull fence located within or immediately adjacent to the study area at the Homansville Mill site (Seamons 1992). Field measurements of bull fence remnants in the study area yielded a mean of 3.9 trees per meter of fence. Measurements derived from this photograph yielded an estimate of 7.7 stems per meter. At least 40.65 km of McIntyre Ranch boundary fence in or near the study area are known to have been fenced in this manner (Mr. Steele McIntyre, personal communication, August 1995), resulting in an estimate of 158,500 stems used in fencing the McIntyre Ranch alone. Note that this figure does not include cross fencing with bull fence, which field observation also revealed, nor does it include posts used to support wire fence erected elsewhere in the study area. The figure also ignores other uses of the District's woodland trees; as mine timbers, or ties for narrow gauge railways associated with the District's mines. Consequently, while the figure of 158,500 stems was used as an estimate of the number of trees harvested for non-fuel uses in the Tintic area in the early settlement era, it is believed to be an extremely conservative estimate.

Total Woodland Harvest—Total woodland harvest for the 1870-1910 period is estimated to have been between 9,795 and 86,397 hectares, as follows:

Industrial fuels	4,469-53,620 ha
Domestic fuels	2,497-29,960 ha
Other uses	2,830 ha
Total	9,795-86,397 ha

The wide range in estimated harvest area is due to the range in estimated cordwood yields (1-12 cords per acre or 2.47-29.64 cords per ha) from pinyon-juniper woodlands (Young and Budy 1979).

Photographic Pairs

Figures 2 through 11 are paired photographs showing vegetation changes in the East Tintic Mountains across 84 years. Captions are based upon those of Lindgren and Loughlin (1919). Each photograph's USGS archive number follows Loughlin's name.

Figure 1—Bull fence, Homansville Mill, 1870's. (Seamons 1992).

Without exception, these photographs show an increase in the areal extent and/or density of woodland vegetation across the 84 year interval. Particularly dramatic is the increase in woodland cover in the north end of the Valley as seen in figure 2 and in the saddle of Quartzite Ridge, figure 3. Significant increase in woodland cover is also apparent on the south-facing slopes north of Ruby Hollow, above the site of Silver City (fig. 4-6).

The dynamic nature of Tintic Valley's vegetation across the 1911-1995 interval can be seen in figures 7 and 8. In both the 1911 and 1995 photographs, the west slope of Sunrise Peak is dominated by non-woodland vegetation. Rather than reflecting stasis in vegetation physiognomic type on this site, however, these apparently similar vegetation patterns bracket a period of woodland establishment, crown closure, catastrophic fire and management intervention. On this site in 1911, a young woodland stand can be seen on the lower slopes of the mountain. By 1994, the entire slope was covered with a dense stand of juniper, which burned in a fire in August of that year. By the time the photograph was retaken in 1995, the area had been chained and seeded to crested wheatgrass, at least superficially recreating vegetation conditions reflected in the 1911 photograph. Note the standing dead trees visible on the steeper upper slopes above the chaining. Thus, a complete cycle of woodland establishment and elimination by crown fire occurred within the temporal interval of this set of photographs.

These photographs cover that part of the study area in which towns and mines were concentrated and where several early smelters and mills were also located (Creque 1996). Vegetation patterns visible in the distance in figures 2 and 4, suggest, however, that the increase in woodland extent and density from approximately 1911 to 1995 has been generally the case across the Valley.

Discussion and Conclusions

In this study, an exhaustive archival survey failed to identify useful landscape photographs of the study area prior to a set of USGS photographs taken in 1911 (Loughlin 1911). While repeat photographs taken over 80 years later (Creque 1996) show a clear increase in woodland cover and tree

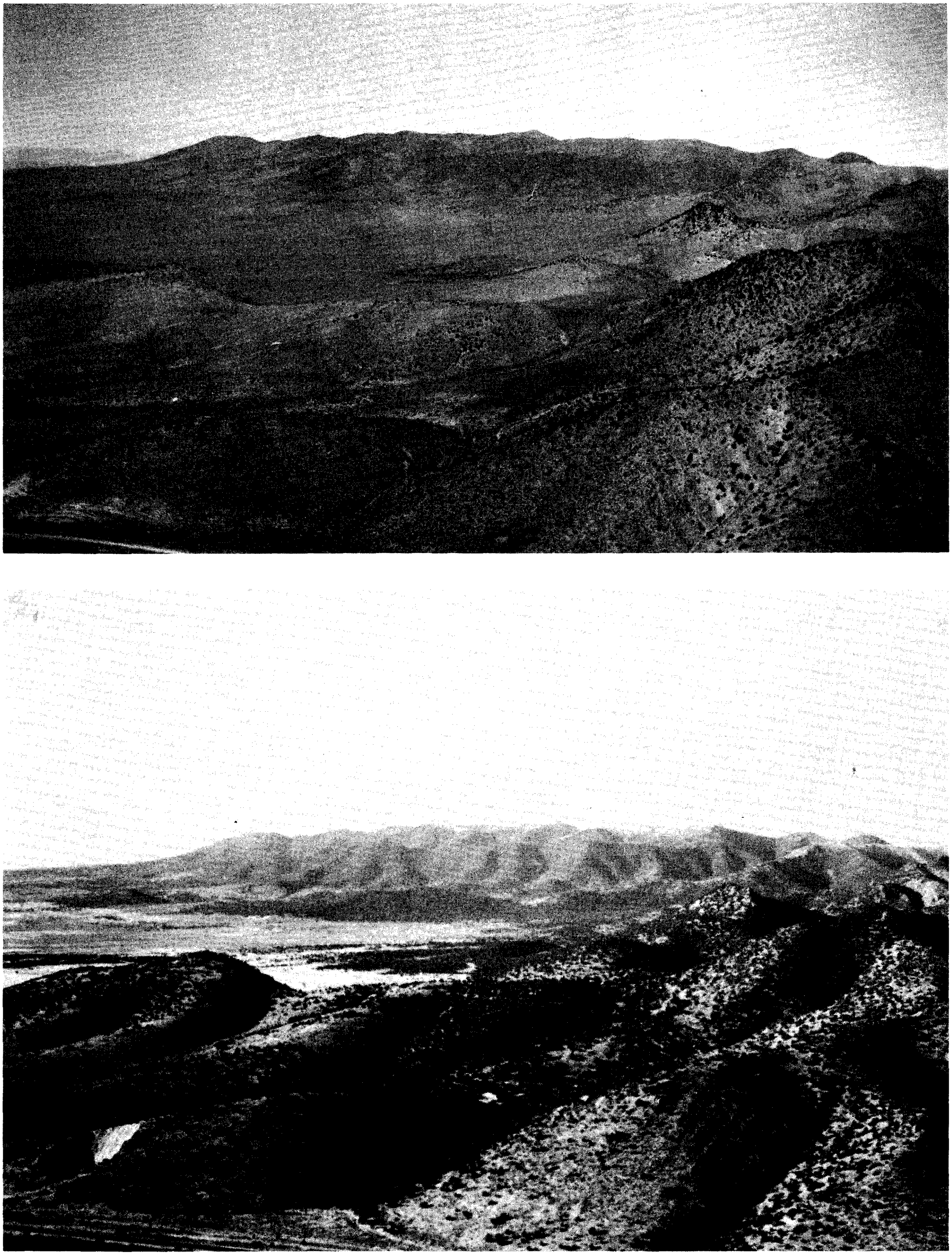

Figure 2—Foothills northwest of Eureka and head of Tintic Valley. Above: 1911 (Loughlin 18). Below: 1995.

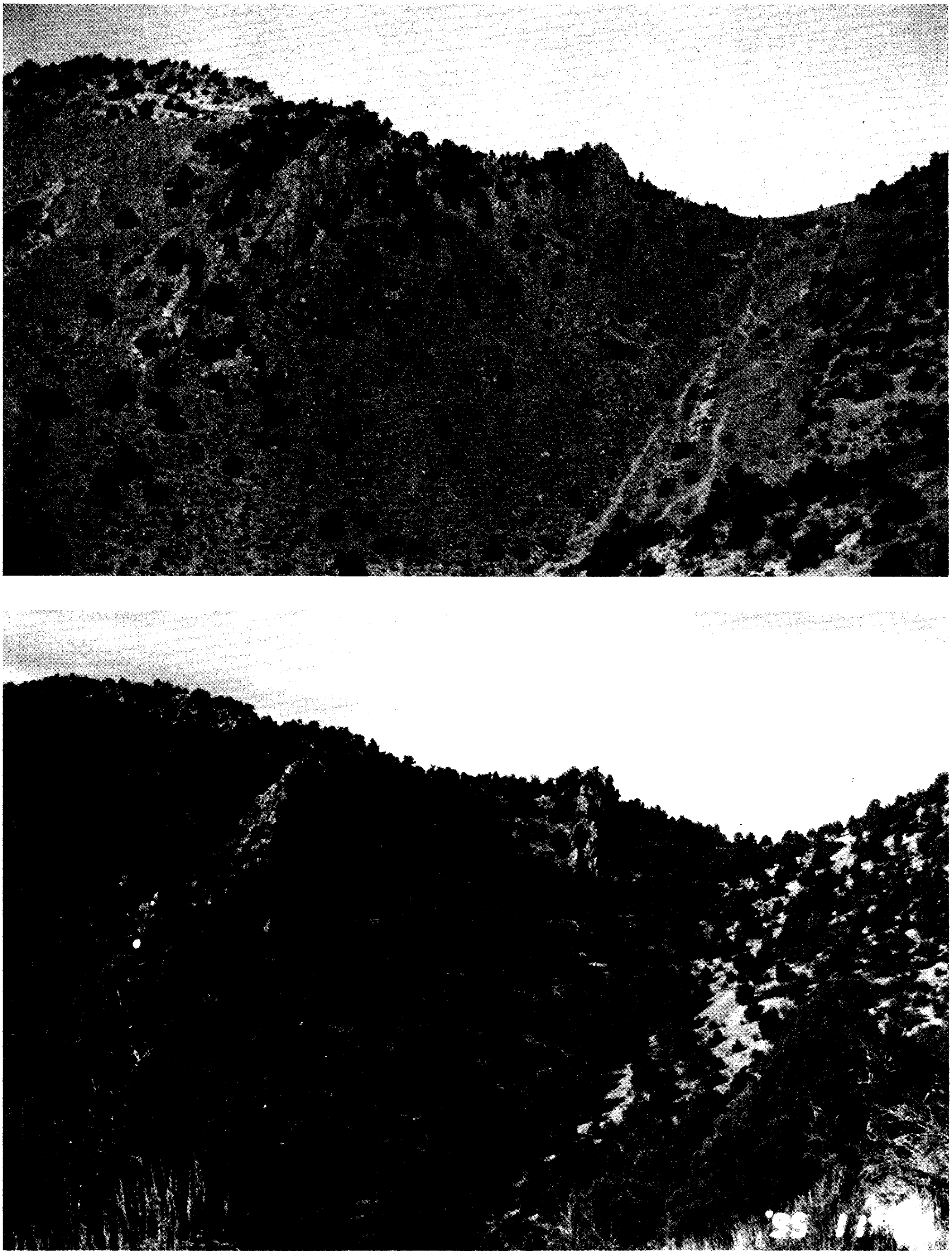

Figure 3—East-west fault south of the saddle east of Quartzite Ridge. Above: 1911 (Loughlin 19). Below: 1995.

Figure 4—East Tintic Mountains, looking north from Treasure Hill across Ruby Hollow. Above: 1911 (Loughlin 6). Below: 1995.

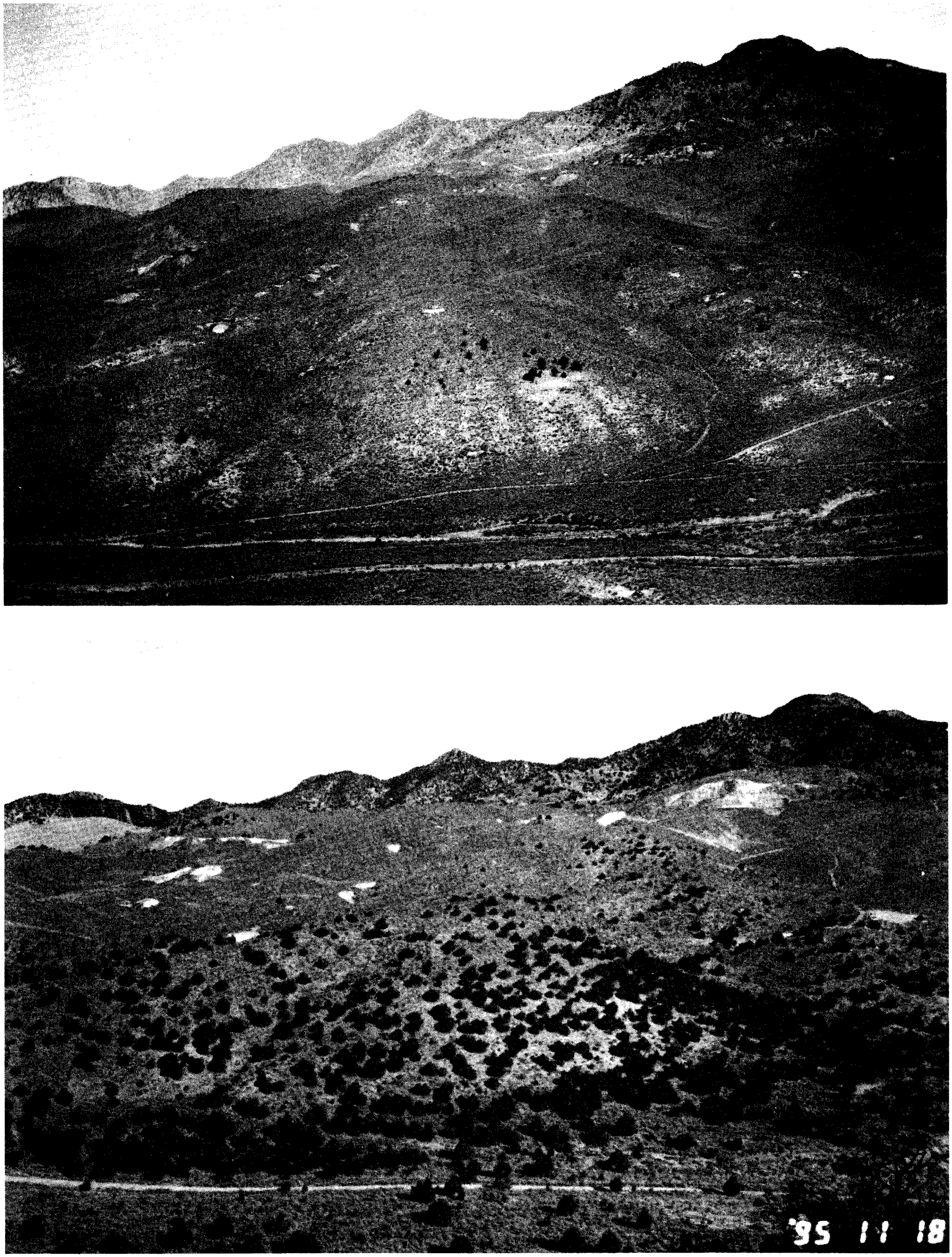

Figure 5—East Tintic Mountains, looking north from Treasure Hill across Ruby Hollow. Above: 1911 (Loughlin 5). Below: 1995.

Figure 6—East Tintic Mountains, looking north from Treasure Hill across Ruby Hollow. Above: 1911 (Loughlin 4). Below: 1995.

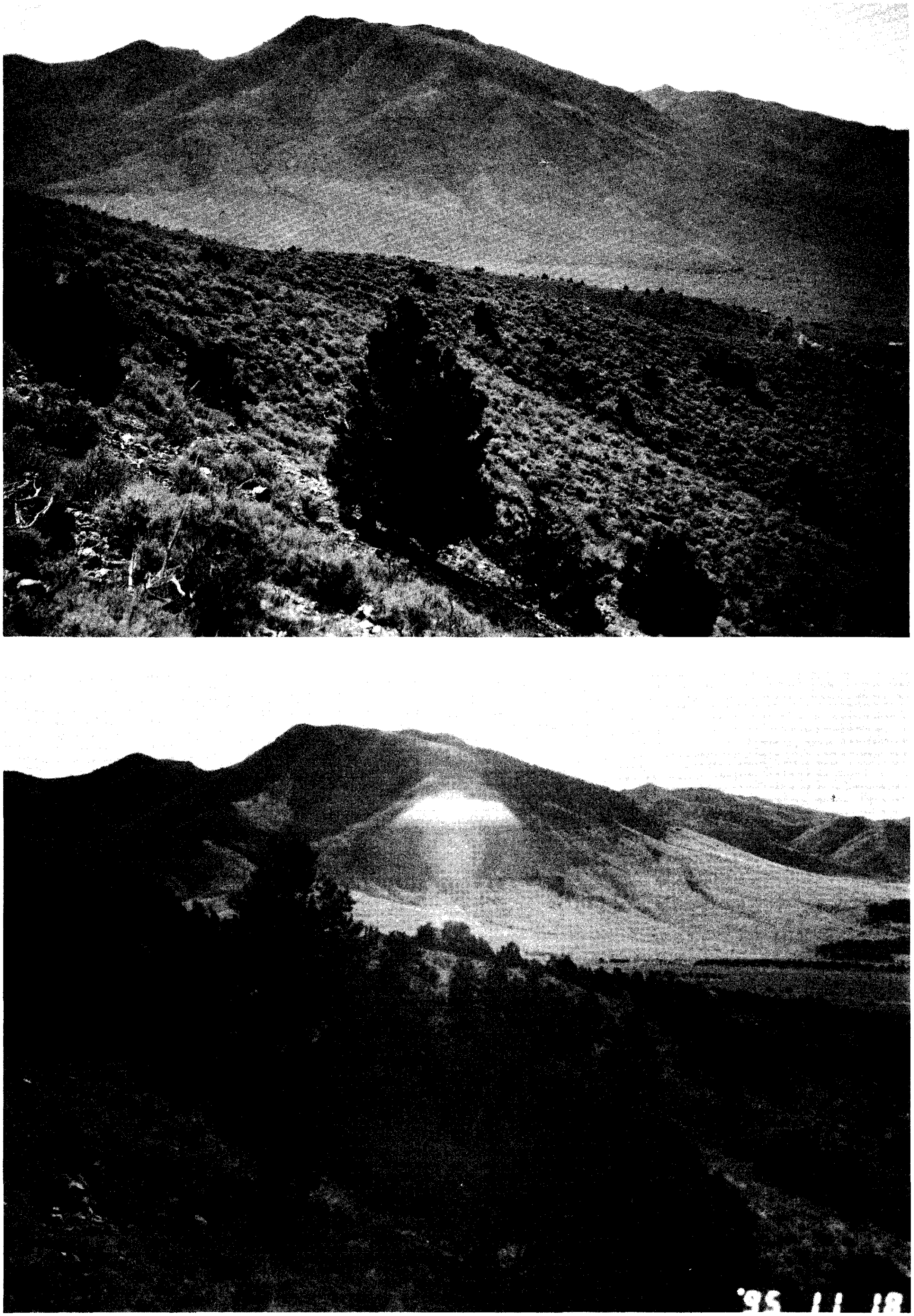

Figure 7—Sunrise Peak, looking south from Treasure Hill. Above: 1911 (Loughlin 9). Below: 1995.

Figure 8—Volcano Ridge, looking south from Treasure Hill. Above: 1911 (Loughlin 10). Below: 1995.

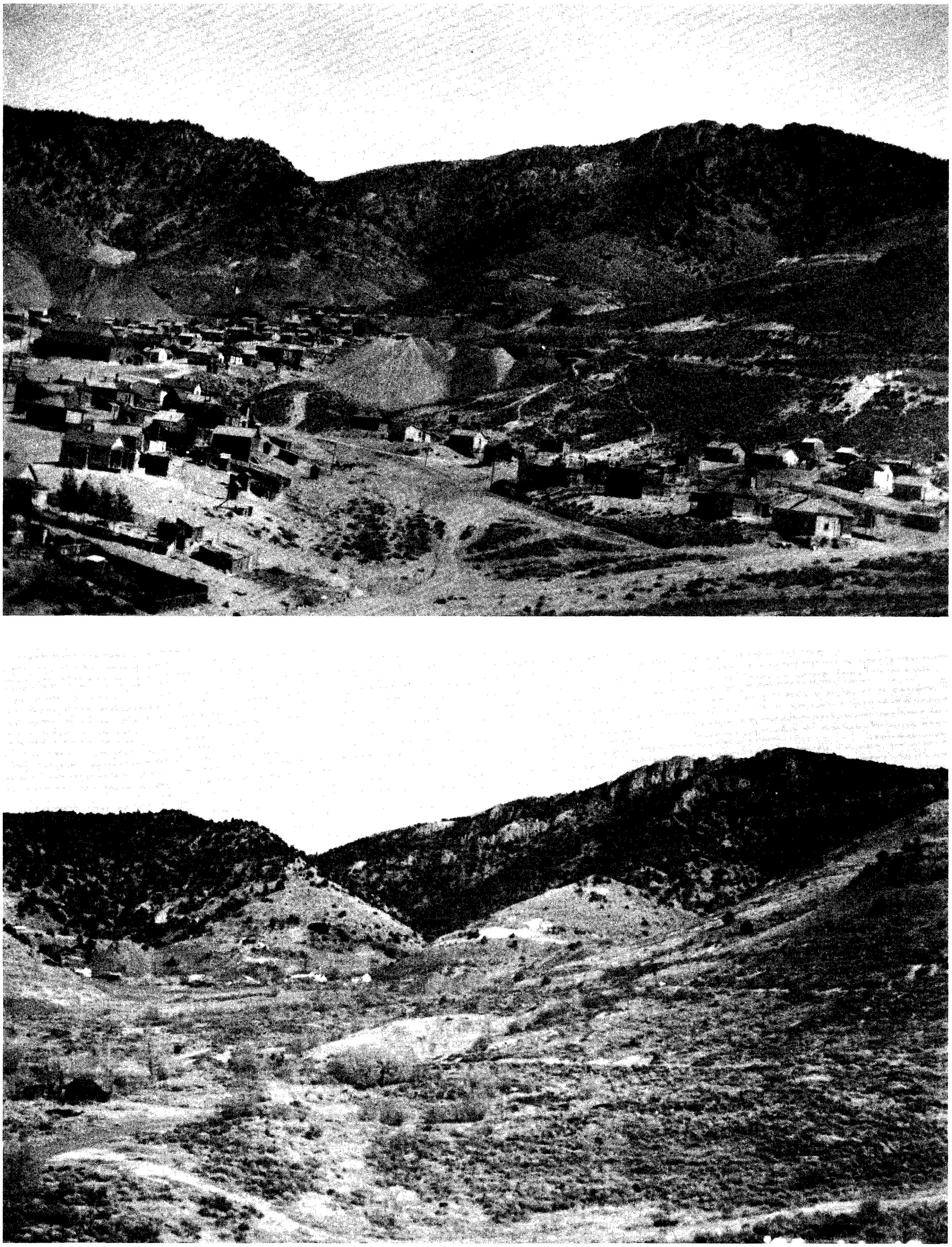

Figure 9—Mammoth and surrounding mountains. Above: 1911 (Loughlin 22). Below: 1995.

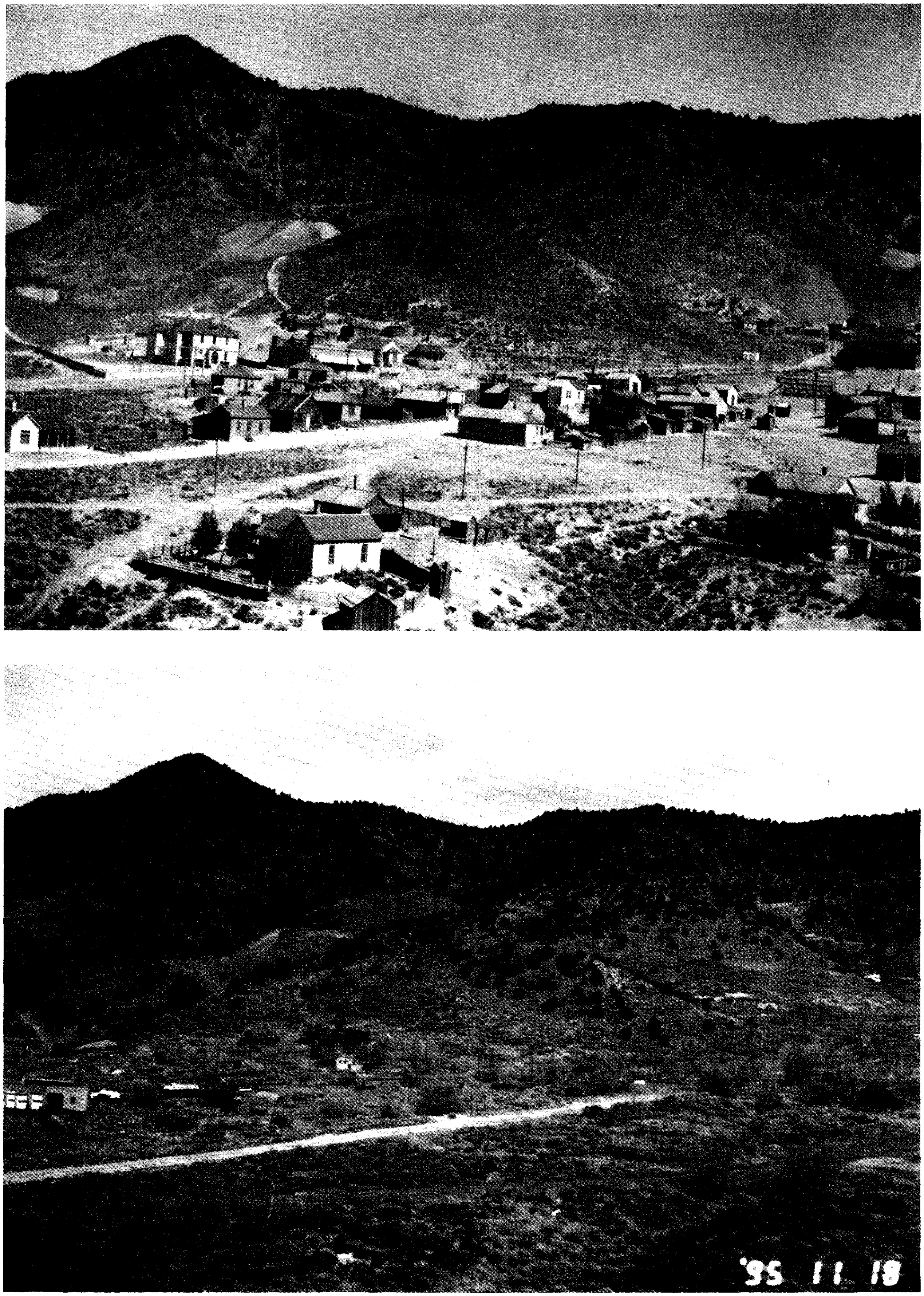

Figure 10—Mammoth and surrounding mountains. Above: 1911 (Loughlin 23). Below: 1995.

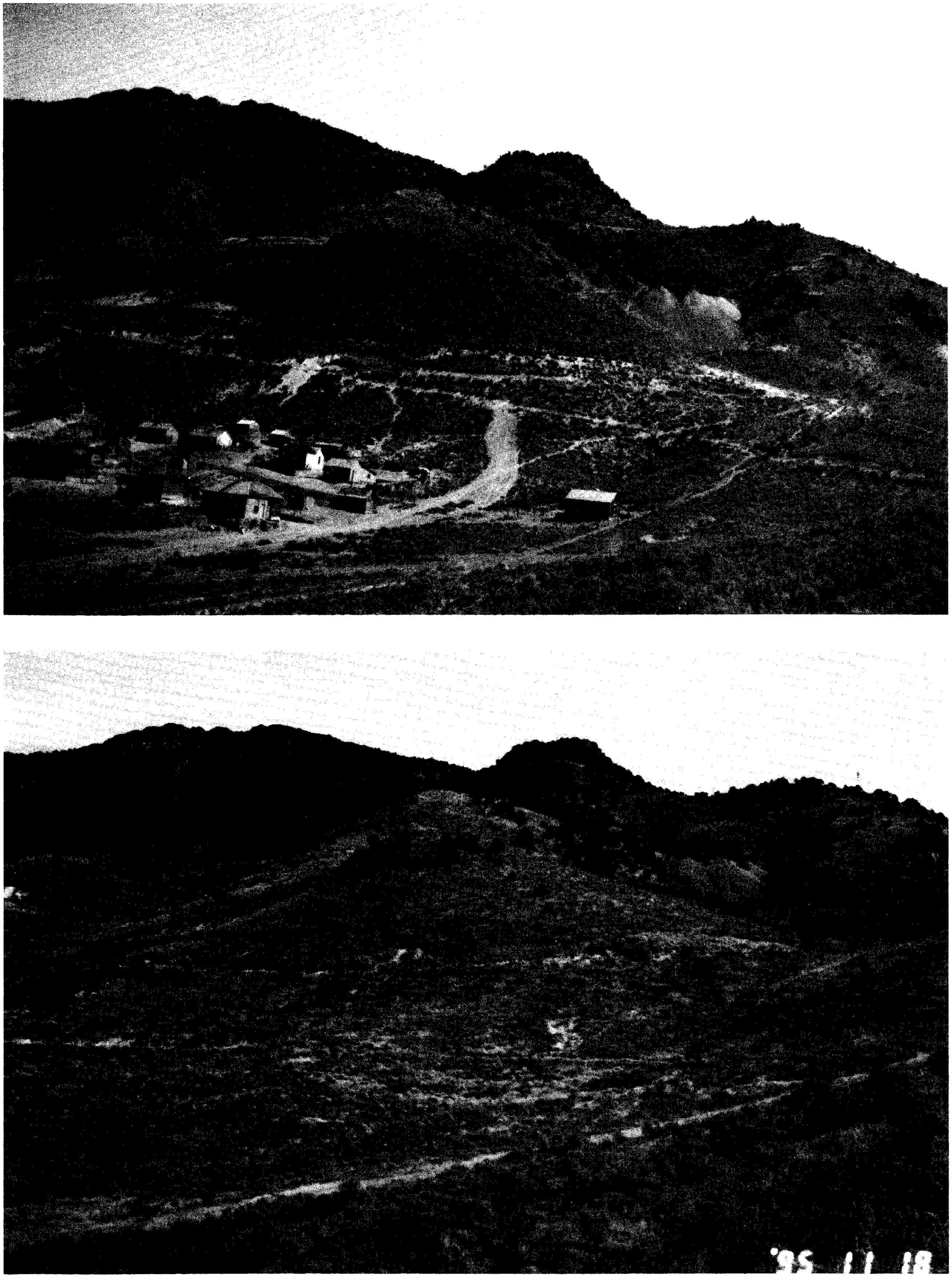

Figure 11—Mammoth and surrounding mountains. Above: 1911 (Loughlin 24). Below: 1995.

density, interpretation of pre- and post-settlement vegetation dynamics from these photographic pairs alone could easily lead to erroneous conclusions (Lanner 1977, 1981). Because intensive industrial activity associated with development of the Tintic Mining District occurred prior to the taking of the 1911 photographs employed in this study, those photographs failed to reflect presettlement, or even early settlement, vegetation conditions. Rather than revealing presettlement conditions of the study area landscape, Loughlin's photographs reflect conditions after 40 years of intensive resource exploitation associated with the early industrial development of one of the West's most productive mining Districts. For the first decade of that period, biomass constituted the only fuel available for operation of some 30 mills and smelters in the District, many of which were located on or near sites shown in Loughlin's photographs. In the same decade, a rapidly growing human population depended exclusively on biomass fuels for domestic purposes, and biomass fuels continued to meet a significant proportion of industrial and domestic fuel needs into the 20th century (Creque 1996). Livestock fencing, timbering requirements—particularly for the smaller mines and ties for the District's narrow gauge railroads—similarly drew heavily upon the District's woodlands.

While paired, multitemporal photographs provide indisputably valuable information regarding site or landscape changes across the temporal interval of the photographic pairs, a number of factors contribute to render interpretation of the ecological significance of vegetation changes documented by repeat photography alone problematic (Lanner 1977, 1981). These include the fact that early photography rarely records pre-Euroamerican settlement landscape conditions, either because such settlement and attendant land use changes predated the advent of photographic technology, or because landscape conditions did not capture the attention of the early photographer(s) of a particular region. Early photography tended to focus upon images of daily life in and around settlements, with the surrounding landscape playing an incidental role, if any, in the photographic image. Even where the landscape or plant communities were the subjects of interest, it was common for the photographer to limit his range of focus to those areas immediately adjacent to transportation corridors, such as roadsides or railroad corridors.

This study reveals the magnitude of early agriculture, domestic activities and biomass-fueled industry on the woodlands of Tintic Valley. Though not, to the knowledge of these investigators, previously reported, the impact of the bull fence, a common feature of early Intermountain ranches, was alone found to be an important factor in post-settlement reduction in tree cover. While these historical impacts on the pinyon-juniper woodlands of Tintic Valley appear extreme, they are consistent with reports from mining districts elsewhere in the region (Lanner 1981; Young and Budy 1979).

The study contributes to an improved understanding of the historic-era dynamics of the Tintic landscape and provides a point of reference for current and future management of the Valley landscape ecosystem. In a broader context, the study underscores the need for multiple lines of investigation in historical ecological research.

References

Bahre, C. J. 1991. A legacy of change: historic human impact on vegetation in the Arizona borderlands. University of Arizona Press, Tucson, Arizona, U.S.A.

Bonham, C. D. 1989. Measurements for terrestrial vegetation. John Wiley & Sons. NY, NY, U.S.A.

Butler, B. S., G. F. Loughlin, V. C. Heikes and others. 1920. The ore deposits of Utah. USDI Geological Survey 111. U.S. GPO, Washington, DC, U.S.A.

Cottam, G. and J. T. Curtis. 1956. The use of distance measures in phytosociological sampling. Ecology 37(3):451-460.

Creque, J. A. 1996. An ecological history of Tintic Valley, Juab County, Utah. Unpublished doctoral dissertation. Department of Rangeland Resources, Utah State University, Logan, Utah, U.S.A.

Gorlinski, J. 1872-1874. Field Notes. General Land Office Survey, Townships 9,10 and 11S, Ranges 2,3,4 and 5 W, Salt Lake Meridian, Utah. Microfiche USDI Bureau of Land Management, Salt Lake City, Utah, U.S.A.

Hadley, D. and T. E. Sheridan. 1995. Land use history of the San Rafael Valley, Arizona (1540-1960). USDA Forest Service. Rocky Mountain Forest and Range Experiment Station General Technical Report RM-269. Fort Collins, Colorado, U.S.A.

Hastings, J. R. and R. M. Turner. 1965. The changing mile. University of Arizona Press. Tucson, Arizona, U.S.A.

Heikes, V. C. 1919. History of mining and metallurgy in the Tintic district. Part II, pp. 105-117 in W. Lindgren and G. F. Loughlin, editors. Geology and ore deposits of the Tintic Mining District, Utah. USDI Geological Survey Professional Paper 107. U.S. GPO, Washington, DC, U.S.A.

Lanner, Ronald M. 1977. The eradication of pinyon-juniper woodland. Western Wildlands. Spring: 13-17.

Lanner, Ronald M. 1981. The Pinon Pine. University of Nevada Press, Reno, NV. 208 pp.

Lindgren, W. and G. F. Loughlin. 1919. Geology and ore deposits of the Tintic mining district. USDI Geological Survey Professional Paper 107. U.S. GPO, Washington, DC, U.S.A.

Raymond, R. W. 1873. Statistics of mines and mining in the states and territories west of the Rocky Mountains. Fifth Annual Report. Forty-second Congress, Third Session. Ex. Doc No. 210. U.S. GPO, Washington, DC, U.S.A.

Rogers, G. F. 1982. Then & now. University of Utah Press. Salt Lake City, Utah.

Rogers, G. F., H. E. Malde, and R. M. Turner. 1984. Bibliography of repeat photography for evaluating landscape change. University of Utah Press, Salt Lake City, Utah, U.S.A.

Seamons, M. L. 1992. More precious than gold. Community Press, Salt Lake City, Utah, U.S.A. United States Department of the Interior. 1880. Tenth Census of the United States. U.S. GPO, Washington, DC, U.S.A.

United States Department of the Interior. 1890. Eleventh Census of the United States. U.S. GPO, Washington, DC, U.S.A.

United States Department of the Interior. 1900. Twelfth Census of the United States. U.S. GPO, Washington, DC, U.S.A.

United States Department of Commerce. 1910. Thirteenth Census of the United States. U.S. GPO, Washington, DC, U.S.A.

Young, J. A. and J. D. Budy. 1979. Historical use of Nevada's pinyon-juniper woodlands. Journal of Forest History (23):112-121.

Young, J. A. and J. D. Budy. 1986. Energy crisis in 19th century Great Basin woodlands. Pages 23-28 in R. L. Everett, compiler. Proceedings, Pinyon-Juniper Conference, Reno, Nevada, USDA Forest Service Intermountain Forest and Range Experiment Station General Technical Report INT-215. U.S. GPO, Washington, DC, U.S.A. Ogden, Utah, U.S.A.

Calorimetric Study of the Effects of Water and Temperature on the Respiration and Growth of Small Burnet and Alfalfa

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Stephen B. Monsen
Richard Stevens

Abstract—The relative degree of drought tolerance was studied for six populations of small burnet (*Sanguisorba minor*), and six cultivars of alfalfa (*Medicago sativa*) grown in common gardens under natural conditions and in the laboratory with different levels of moisture. Metabolic heat rate (q) and respiratory rate (R_{CO2}) were measured weekly on fresh leaf tissue from field-grown plants from early April to early August 1997. Both species grew best in early spring but remained green and active throughout the summer. Small burnet was more drought tolerant than alfalfa. Further studies may allow specific selections of populations and cultivars to be made for growth on particular sites.

Desert plants have adapted to dry climates, but differ in the degree of adaptation among species and cultivars or populations. Plants that better tolerate conditions of low water and high temperature stay green longer into a hot summer, and can be used effectively in green belts and forage projects. Small burnet (*Sanguisorba minor*) and alfalfa (*Medicago sativa*) are two such species that grow in the Great Basin. Small burnet is a perennial recently introduced from Eurasia into Utah for erosion control at altitudes between 1,525 and 2,135 m (Welsh and others 1987). Alfalfa was also introduced from the Old World, possibly into California by the Spanish, and is now one of the most important forage crops in the United States (Stechman 1986; Welsh and others 1987). Both species are tolerant of heat and drought, making them candidates for green belts and forage projects in dry areas, but each species has different cultivars or populations that differ in their degrees of tolerance to drought and heat.

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Calorimetry can be used to rapidly evaluate the tolerance limits of a cultivar, accession, or species because it can quantitate the stress response of metabolism. Hansen and others (1994) have shown that simultaneous measurements of metabolic heat rate (q) and respiratory CO_2 rate (R_{CO2}) can be used to calculate growth rate and substrate carbon conversion efficiency as a function of conditions. Predictions about relative fitness can be made by comparing the growth rates and efficiencies of different plants at specific conditions. Plants can then be selected to match environmental conditions at specific sites. Calorimetry offers advantages over traditional field studies by saving time and providing insight into the mechanism of the stress response.

In the model developed by Hansen and others (1994), the specific growth rate is defined as:

$$R_{SG} = -[q + R_{CO2}(1 - \gamma_p/4)\Delta H_{O2}]/\Delta H_B \qquad \text{(Eq. 1)}$$

where γ_p is the average oxidation state of the substrate carbon, ΔH_{O2} is a thermodynamic constant equal to –455 kJ mol^{-1} O_2 and ΔH_B is the total enthalpy change associated with the conversion of one mole of substrate carbon into one mole of biomass carbon. Assuming that γ_p is equal to 0 (that is, that carbohydrate is the substrate) and that ΔH_B is a constant, the relative specific growth rate ($R_{SG}\Delta H_B$) can be calculated from measurements of q and R_{CO2}. When q and R_{CO2} are measured as functions of environmental variables, growth rate can then be calculated as a function of the same variables.

The substrate carbon conversion efficiency (ε) can be calculated from the same parameters used to calculate the relative specific growth rate. The ratio of metabolic heat rate to respiratory CO_2 rate (q/R_{CO2}) is an indicator of substrate carbon conversion efficiency.

$$q/R_{CO2} = 455(1 - \gamma_p/4) - [(\varepsilon/(1 - \varepsilon)]\Delta H_B \qquad \text{(Eq. 2)}$$

Substrate carbon conversion efficiency (ε) ranges from 0 to <1. Values of q/R_{CO2} are typically between 300 and 450 kJ mol^{-1}. In this range a lower value of q/R_{CO2} may indicate a higher efficiency although changes in γ_p and/or ΔH_B can also affect the ratio. Under conditions where the substrate being burned in respiration is carbohydrate (γ_p = 0), and ΔH_B is endothermic, that is positive, the value of q/R_{CO2} cannot exceed 455 kJ mol^{-1}, but the value of q/R_{CO2} is often observed to exceed 455 kJ mol^{-1}. If q/R_{CO2}>455 kJ mol^{-1} either the substrate being burned is no longer carbohydrate (that is, γ_p has changed to a positive value), or the biomass being produced has changed (that is, ΔH_B has changed to a negative value), or both. Either option indicates that a change in the biochemical pathways has occurred, either the substrate being burned has changed, or the product biomass composition has changed.

Arrhenius plots of metabolic heat rate versus reciprocal absolute temperature (ln(q) vs, T^{-1}) can be used to describe the temperature dependence of q over a temperature range. The temperature coefficient, μ_q, is obtained from the slope of the Arrhenius plot. Likewise, the temperature coefficient of the respiratory CO_2 rate, μ_{CO2}, is the slope of the Arrhenius plot of the respiration rate versus reciprocal temperature ($\ln(R_{CO2})$ vs. T^{-1}). μ_q and μ_{CO2} provide physiological data on the effect of temperature on the metabolism. Differences in the temperature dependency of q and R_{CO2} can be used to predict the effects of temperature on the growth of different populations or cultivars.

The purpose of this study is to use respiratory heat and CO_2 rates to select the most drought and heat tolerant populations of small burnet and cultivars of alfalfa. Criddle and others (1997) have shown that calorimetry can be used to rapidly measure metabolic heat rate and respiration rate at different temperatures.

Methods

Field Experiment

Six populations of small burnet were grown in two common gardens maintained by the Utah Division of Natural Resources near Ephraim and Nephi, UT. The variety U13 or Delar is commercially released while the others were grown from imported seed (Moore 1995): B10 (Yugoslavia), B28 (Russia), B30 (Spain), B34 (Russia), and B51 (Iran). Five cultivars of alfalfa—Henry Mt., Nomad, Ranger, Spreader II, and Ladak 65—were grown in plots in the garden at Ephraim, UT. Plants in the common gardens grew on shallow limestone soils and were not irrigated. One cultivar of alfalfa, Magnum, was grown ½ mile from the Ephraim common garden in deep soils and was irrigated and fertilized. Magnum plants were 3 years old and were *Medicago sativa*, the others were 2 years old and were hybrids of *Medicago sativa* and *Medicago falcata*.

Young leaf tissue from small burnet was collected once a week between April 2 and August 7, 1997, and between April 29 and July 10, 1997 for alfalfa. Samples were kept in an ice chest or refrigerated until measurements were made.

Laboratory Experiment

Seeds from five of the populations of small burnet, B10, B28, B30, B34, and B51, and seven cultivars of alfalfa, Henry Mt., Nomad, Ranger, Spreader II, Ladak 65, Magnum, and Yellowhead, were planted in sandy loam on laboratory growth carts. Plants were grown with a 13/11 hour light/dark schedule at a constant 21 °C. At approximately 60 days, plants were subjected to three different watering regimes. Plants were watered to field capacity, ⅔ field capacity, and ⅓ field capacity. Metabolic heat rates and respiratory CO_2 rates were measured between 70 and 77 days. Measurements were taken on two plants from each treatment.

Calorimetry

Metabolic heat rate and respiratory CO_2 rate were measured with a Hart Scientific model 7707 Differential Scanning Calorimeter operated in isothermal mode (Criddle and others 1997). Approximately 100 mg fresh weight of young leaf tissue was used for each measurement. Respiratory CO_2 rates were determined using the method described in Criddle and others (1997). After measurement of metabolic heat rate, a small vial with 40 µl of 0.4 M NaOH was placed into the calorimeter ampule with the tissue. As the CO_2 and NaOH react in solution, heat is produced and the increase in heat rate is proportional to the rate of CO_2 evolution. The heat of reaction for carbonate formation (-108.5 kJ mol^{-1}) was used to convert the heat rate into the rate of CO_2 evolution.

Results

Small Burnet

Table 1 lists the flowering and growth data for field-grown small burnet. U13 and B34 had flowering stems and red flowers the earliest (May 13) followed by B30 and B51 which had flowering stems and red flowers on May 19, and then B10 and B28 which had flowering stems on May 19 and red flowers on May 27. U13 had the slowest growth while B10 and B34 have slow growth early in the season, but growth increases in June. B28, B30, and B51 show the greatest production, with B51 showing the greatest growth early, maintaining good growth longer.

Both small burnet and alfalfa grow well early in the spring. During the first portion of the growing season, respiration rate (R_{CO2}) and efficiency (ε) are high, that is, q/R_{CO2} is low (table 2). There were no significant differences in respiratory properties between the populations of small burnet grown in Nephi and those grown in Ephraim. Also, the q and R_{CO2} values obtained did not change with sampling date except a few days following flower maturation. Therefore all data before and after this ontological

Table 1—Field growth data on small burnet. Early flower is when flowering stems first appear, mature flowers appear red. Flowering dates on Ephraim plants, growth descriptions based on Nephi plants.

Population	Early flower	Mature flower	Growth
B51	May 19	May 19	Best growth early and late
B30	May 19	May 19	Good growth early slows down in June
B10	May 19	May 27	Poor growth early good late growth
B28	May 19	May 27	Poor growth early good late growth
B34	May 13	May 13	Poor growth early fair late growth
U13	May 13	May 13	Poorest growth early and late

Table 2—Values for q, R_{CO2}, q/R_{CO2}, and $R_{SG}\Delta H_B$ for each population of small burnet at 15 and 25 °C early in the season (before late May or early June when a drop in metabolic rates occurred) and late in the season.

Pop.	q at 15°	R_{CO2} at 15°	q/R_{CO2} at 15°	$R_{SG}\Delta H_B$ at 15°	q at 25°	R_{CO2} at 25°	q/R_{CO2} at 25°	$R_{SG}\Delta H_B$ at 25°
Early in the season								
B10	3.5	13.7	273	2.7	8.9	26.0	361	2.9
B28	3.9	14.3	292	2.6	9.8	27.1	365	2.6
B30	4.0	15.4	267	3.0	10.0	30.4	348	3.8
B34	3.7	13.3	298	2.4	9.7	26.7	377	2.4
B51	4.1	14.8	284	2.7	10.3	28.4	374	2.7
U13	3.8	12.6	313	2.0	9.4	25.6	380	2.2
Late in the season								
B10	2.2	7.8	288	1.3	5.8	14.4	376	0.7
B28	2.6	7.7	381	0.9	6.8	14.7	506	–0.1
B30	2.6	6.5	412	0.4	6.2	12.4	525	–0.5
B34	2.6	6.7	401	0.4	6.2	14.0	467	0.1
B51	2.6	7.1	381	0.6	7.1	15.2	481	–0.2
U13	1.7	3.8	510	0.0	4.5	13.5	442	1.7

event were averaged to obtain two data points, one describing heat and CO_2 rates before the maturation event and one after. A few days after flowering, in late May or early June, a decrease in metabolic rate occurs (fig. 1) and q/R_{CO2} increases (table 2). Not all populations flowered at the same time nor was the time-course of metabolism identical for the populations (table 2). The decrease in metabolic activity occurred during the week following May 27 for B51, B30, and B28, but not until the week following June 2 for B10 and B34, and the week following June 9 for U13.

While a change from 15 to 25 °C increased the respiration rate (R_{CO2}) by about a factor of 2, efficiency decreased (see q/R_{CO2} values in table 2). That is, more of the available metabolic energy was lost as heat and was thus unavailable for growth at the higher temperature.

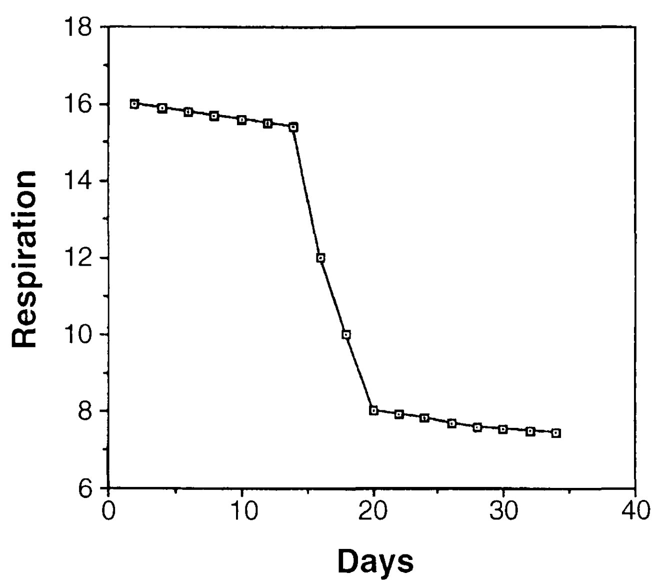

Figure 1—Schematic of the metabolic change occurring in small burnet during a few days in late May or early June 1997. Respiration or R_{CO2} in pmol mg^{-1}s^{-1} versus time in days.

Table 3—Temperature coefficient of q and R_{CO2} for different populations of small burnet.

Population	μ_q	μ_{CO2}
B10	8.0	7.2
B51	8.1	6.2
U13	8.1	5.9
B30	8.0	5.6
B34	7.8	5.5
B28	7.9	5.4

The temperature coefficient for heat rate (μ_q) was essentially the same for all populations, while the coefficient for respiration rate (μ_{CO2}) was much higher for B10 and B51 than for other populations (table 3).

In the laboratory drought experiment differences in metabolism were observed between the low, medium, and high watering treatments. As shown in table 4, heat rate, respiration rate, efficiency, and predicted growth at 15 °C are all negatively correlated with increasing levels of water. Small burnet did better at ⅓ of field capacity than at higher levels of watering.

Table 4—Laboratory drought experiment for small burnet. Data for all populations pooled. High water treatment is field capacity, medium water treatment is ⅔ field capacity, and low water treatment is ⅓ field capacity.

Water treatment	q at 15° (μW mg^{-1})	R_{CO2} at 15° (pmol mg^{-1}s^{-1})	q/R_{CO2} at 15° (kJ mol^{-1})	$R_{SG}\Delta H_B$ at 15° (μW mg^{-1})
Low	2.9	9.8	305	1.6
Med	2.4	7.0	373	0.8
High	1.9	4.9	443	0.4

Table 5—Average values for q, R_{CO2}, q/R_{CO2}, and $R_{SG}\Delta H_B$ for cultivars of alfalfa at 15 and 25 °C.

Cultivars	q at 15°	R_{CO2} at 15°	q/R_{CO2} at 15°	$R_{SG}\Delta H_B$ at 15°	q at 25°	R_{CO2} at 25°	q/R_{CO2} at 25°	$R_{SG}\Delta H_B$ at 25°
Henry Mt.	4.0	11.5	425	0.9	10.7	23.2	433	0.4
Nomad	4.4	12.0	411	0.6	11.4	26.5	435	0.7
Magnum	6.4	18.5	332	2.2	16.6	43.3	395	3.1
Ranger	4.6	12.7	363	1.2	11.5	25.5	470	0.1
Spreader II	4.8	14.9	333	2.0	12.1	29.5	395	1.5
Ladak 65	4.6	13.2	367	1.2	11.8	27.8	458	0.9

Alfalfa

All alfalfa cultivars had a Q_{10} for respiration (R_{CO2}) greater than 2 (table 5). Efficiency (q/R_{CO2}) was better at 15 than 25 °C for four of the cultivars but showed little difference with temperature for Henry Mt. and Nomad. Predicted growth ($R_{SG}\Delta H_B$) was better at 15 °C for all cultivars, except for Magnum.

The temperature coefficient for heat rate (μ_q), while more variable for alfalfa cultivars than for small burnet populations, was essentially the same for all cultivars (table 6). By contrast the temperature coefficient for respiration (μ_{CO2}) showed differences among the cultivars.

Pooled data for all cultivars of alfalfa from the laboratory drought experiment (table 7) showed no trends with watering treatment.

Discussion

The spring and summer of 1997 were unusually wet and cool. It proved to be a poor year to try to assess the effects of drought in the field. This study should be repeated over several seasons to gain a true understanding of response in the field to temperature and soil moisture of populations of small burnet and cultivars of alfalfa. However, some conclusions can be drawn from this small beginning.

While both small burnet and alfalfa remain green and active all summer, they both grow best in the cool, moist spring months. The decrease in metabolism and growth a few days after flowering (fig. 1) may signal seed set and represent a shift from active growth to partial dormancy in order to survive the usual dry, hot summer months in the Great Basin. The strategy may be to conserve energy during the harsh summer months and grow more rapidly during better, even though cooler, conditions. This can be seen best with small burnet (table 2). The Q_{10} for respiration remains the same during the shift from early to late season, but the respiration rate decreases and q/R_{CO2} increases. These changes may indicate a shift in efficiency or in biochemical pathways, either in the respiratory substrate, or the composition of the biomass being produced. In growing tissues, rates of catabolism are known to depend on rates of anabolism. The story is similar for alfalfa (table 5).

Table 6—Temperature coefficients of q and R_{CO2} for cultivars of alfalfa.

Cultivar	μ_q	μ_{CO2}
Nomad	8.1	8.1
Magnum	8.1	7.0
Ranger	8.7	7.0
Henry Mt.	8.5	6.5
Ladak 65	8.1	6.3
Spreader II	7.9	5.3

Table 7—Laboratory drought experiment for alfalfa. Data for all cultivars pooled. High water treatment is field capacity, medium water treatment is ⅔ field capacity, and low water treatment is ⅓ field capacity.

Water treatment	q at 15° ($\mu W\ mg^{-1}$)	R_{CO2} at 15° ($pmol\ mg^{-1}s^{-1}$)	q/R_{CO2} at 15° ($kJ\ mol^{-1}$)	$R_{SG}\Delta H_B$ at 15° ($\mu W\ mg^{-1}$)
Low	3.0	11.0	395	2.0
Med	2.6	6.2	453	0.3
High	3.0	9.0	357	1.1

At 15 °C the populations of small burnet (table 2) ranked from highest predicted growth rate ($R_{SG}\Delta H_B$) to lowest were:

B30>B51=B10>B28>B34>U13.

The alfalfa cultivars similarly ranked (table 5) by $R_{SG}\Delta H_B$ were:

Magnum>Spreader II>Ranger=Ladak 65>Henry Mt.>Nomad.

Conclusions

Small burnet and alfalfa have higher relative specific growth rates and higher efficiency (that is, lower values of q/R_{CO2}) at 15 than at 25 °C. Thus the rate of energy storage in structural biomass is faster at lower temperatures.

Populations of small burnet and cultivars of alfalfa that show a decrease in metabolic rate later in the season will grow slowly but remain green longer.

Small burnet seems to be more drought-resistant than alfalfa.

References

Criddle, R. S.; Smith, B. N.; Hansen, L. D. 1997. A Respiration Based Description of Plant Growth Rate Responses to Temperature. Planta. 201: 441-445.

Hansen, L. D.; Hopkin, M. S.; Rank, D. R.; Anekonda, T. S.; Breidenbach, R. W.; Criddle, R. S. 1994. The Relation Between Plant Growth and Respiration: A Thermodynamic Model. Planta. 194: 77-85.

Moore, K. D. 1995. Effects of Seed Size on Germination and Emergence of Burnet (*Sanguisorba*) Scop. (Rosaceae) and Variation in Drought Tolerance Within and Among Ecotypes of Small Burnet (*Sanguisorba minor*) Scop. (Rosaceae). Master of Science Thesis. Brigham Young University. 76 p.

Stechman, J. V. 1986. Common Western Range Plants: Their Fundamental Structure, Growth, Value and Management. 3rd ed. California Polytechnic State University Foundation.

Welsh, S. L.; Atwood, N. D.; Goodrich, S.; Higgins, L. C. 1987. A Utah Flora: Great Basin Naturalist Memoir #9. Brigham Young University Press.

Changes in Plant Composition within a Pinyon-Juniper Woodland

Dennis D. Austin

Abstract—Vegetal composition and photo comparisons were determined during 1974, 1984, and 1997 on seven permanent 50 m^2 plots within a mature pinyon-juniper community in northeastern Utah. Data and photo comparisons showed few changes over 23 years.

Within the Intermountain Region, pinyon-juniper habitat provides a major proportion of big game and livestock winter ranges. While it is clearly recognized that available forage of shrubs and other species declines as density and cover of pinyon-juniper increases, few longitudinal studies have defined the rate of change, particularly in mature woodlands. This paper presents data and supporting photographs defining the slow rate of successional change.

Methods

Data were collected in the exact methodology during 1974, 1984, and 1997 (Austin 1987), with the only exception that data collected in 1997 were taken only from selected plots with photo points.

Each plot measured 5.5 x 9.1 m and was marked by steel reinforcement rods on all corners. Plot boundaries were defined by connecting the four corners with a string or tape. All perennial plant species within the plot were counted and recorded by species. To assure that individual plants were not missed on these large plots, a separate search was made for every perennial species, previously identified in the area. Mature trees were defined with height greater than 120 cm. Annual plants were not considered in this report.

Table 1—Number of plants per seven permanent, 50 m^2 plots.

Species	Year		
Trees	**1974**	**1984**	**1997**
Juniperus osteosperma - mature	22	22	22
Juniperus osteosperma - juvenile	16	17	16
Pinus edulis - mature	6	6	6
Pinus edulis - juvenile	2	6	6
Shrubs			
Artemisia arbuscula	52	63	86
Artemisia tridentata	13	11	15
Ephedra viridis	76	74	80
Gutierrezia sarathrae	56	77	68
Other shrubs	9	10	14
Shrubs-Dead skeletons	84	67	34
Perennial Grasses			
Poa secunda	8	19	6
Sitanion hystrix	13	8	11
Perennial Forbs			
Aster arenosus	249	286	193
Cryptantha spp.	110	99	40
Erysimum spp.	88	48	81
Gilia congesta	34	19	9
Opuntia spp.	5,366	4,468	4,444
Penstemen spp.	35	99	110
Petradoria pumila	259	244	241
Physaria chambersii	14	25	8
Sisymbrium linifolium	215	154	104
Townsendia incana	14	6	4
Other Forbs	15	22	18

Results and Discussion

Changes in plant community composition were not detected during the 23 year interval (table 1). The number of mature Utah juniper (*Juniper osteosperma*) and pinyon pine (*Pinus edulis*) were unchanged. A single juvenile Utah juniper became established but later died. An additional four juvenile pinyon pines were recorded suggesting slow change towards pinyon dominance. A numerical increase in the number of low sagebrush (*Artemisia arbuscula*) was due to a number of small seedlings established within the last one to three years. The number of dead shrub skeletons declined numerically during the three periods. The number of perennial grass and forb species varied by individual species during the three measurement periods, but no distinct changes in population by species could be defined.

Photo points confirmed no measurable changes in the plant community. Figures 1-6 are representative of the woodland during 1974, 1984, and 1997. All photos were taken between June 15 and July 5. Figures 1A and 2A were taken in 1974 and compared with photos taken in 1997, figures 1B and 2B, respectively. Likewise, figures 3A, 4A, 5A, and 6A were taken in 1984 and compared with photos taken in 1997.

A few notes: After 23 years all reinforcement rods marking the plot corners, and after 13 years all reinforcement rods marking the photo positions were intact. The photo points established in 1974 were not marked by reinforcement rods. Comparing figures 1A and 1B, note the increase in size of the Ephedra (*Ephedra viridis*) in the center of the photos. Increase or decrease in size of individual Ephedra plants or clumps was variable. Comparing figures 2A and 2B, note the dead sagebrush skeleton next to the rock in the lower left corner in 1997, but absent in 1974. Establishment and death

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Figure 1A—1974 plot 19.

Figure 1B—1997 plot 19.

Figure 2A—1974 plot 20.

Figure 2B—1997 plot 20.

Figure 3A—1984 plot 21.

Figure 3B—1997 plot 21.

of individual sagebrush plants was common during the periods. Comparing figures 3A and 3B, note the consistency in density of the small perennial desert aster (*Aster arenosus*). Although found on few plots, once established this species, like most perennial forb species, persisted. Comparing figures 4A and 4B, note the fire scarred stump in the center of

Figure 4A—1984 plot 8.

Figure 4B—1997 plot 8.

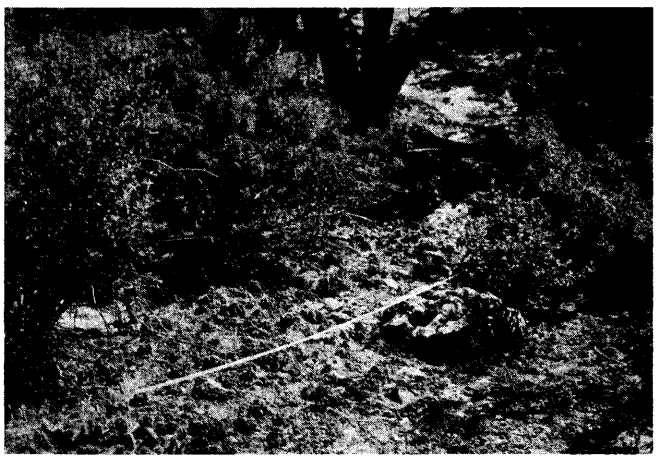

Figure 5A—1984 plot 26.

Figure 5B—1997 plot 26.

Figure 6A—1984 plot 28.

Figure 6B—1997 plot 28.

the photos. Very little change or decomposition for dead limbs of trees was found. Comparing figures 6A and 6B, note the increase in the size of diameter of the pinyon on the left. Growth rates of height and diameter for pinyon pine were about 1.0 cm/year.

Reference

Austin, D. D. 1987. Plant community changes within a mature pinyon-juniper woodland. Great Basin Naturalist. 47: 96-99.

Soil Seed Banking in Pinyon-Juniper Areas With Differing Levels of Tree Cover, Understory Density and Composition

Clare L. Poulsen
Scott C. Walker
Richard Stevens

Abstract—With removal of competitive pinyon-juniper overstory, endemic vegetation is released allowing germinating seed within the soil seed bank to establish. Density of seedlings is closely correlated with the density and composition of the understory community and tree cover. Considerable effort and costs are generally put into seeding areas following tree removal. If the amount and type of viable seed in the soil could be accurately estimated, seeding costs and effort could be adjusted. Studies were conducted on soil seed banking at two pinyon-juniper sites in central Utah. At each site, areas were studied ranging from closed pinyon-juniper stands with minimal understory to open stands with excellent understory communities. Seed density and composition within the soil varied with tree cover and understory community differences.

As pinyon-juniper stands mature, canopy cover increases, and a decrease in the understory community density and composition occurs. The correlation between decreasing understory species and increasing tree canopy cover on the soil seed bank is poorly understood. By quantifying composition and viability of seeds existing in the soil seed bank, more effective treatment of pinyon-juniper stands could occur.

Studies have looked at various influences and aspects of the soil seed bank; fire (Valbuena and Trabaud 1995); grazing (Kinucan and Smeins 1992); grasslands (Cofin and Lauenroth 1989); forest lands (Chambers and others 1991); and cultivated fields (Dessaint and others 1991). These studies show that a soil seed bank with sufficient quantity and viability of seeds can provide the needed seed reserves for community regeneration. However, it has not been identified how tree canopy cover affects the number of species and volume of viable seed in the soil seed bank. This study was established to identify the density of seeds in a soil seed bank at different percent canopy cover of pinyon-juniper.

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Methods

Two study sites were on Utah Division of Wildlife land 6 miles north of Ephraim, UT. The area is 1,800 m in elevation with Amtoft flaggy loam and Quaker silty clay loam soils. Annual precipitation for the area is 32.1 cm. The sites had an average slope of 18 percent. The southern site has a west aspect and the northern site has a north aspect. Each study site contained three areas with distinctive pinyon-juniper canopy cover classes; (1) >60 percent tree canopy cover with depleted understory community; (2) >30 percent to <60 percent tree canopy cover with moderately depleted understory community; and (3) <30 percent tree canopy cover with nondepleted understory community present. These three cover class areas were adjacent to each another with similar slope, soils, and exposure.

Within each canopy cover class area on each site one 25 x 25 m plot was identified. Within each plot five 25 m long transects were randomly established. At every meter mark along each transect one 0.25 m^2 quadrat was placed. Within each quadrat species density and cover was determined for grasses, forbs, and shrubs. Five soil samples were randomly obtained along each transect for a total of 25 samples per plot. Each soil sample consisted of the removal of all soil and material from a 7 x 7 x 2.5 cm deep area (Cabin 1996 and Garcia 1995). Soil samples were washed through a series of three sieves (4 mm, 2 mm, and 250 μm) (Gross 1990). Sieved soil samples were dried for 24 hours in a heated seed germinator. Sieved samples were ocularly inspected using a 10x microscope. Filled seed was then removed and identified to species or group and recorded. Every tree in each plot was measured for height and crown diameter. From the diameter, the area was calculated for each tree. Percent tree canopy cover per plot was calculated by total area of all trees in a plot divided by total plot area.

Understory and seed bank species were placed in groups by life form to simplify the analysis. The understory composition, vegetation life form mean density, and seed density was analyzed using a one-way analysis of variance (ANOVA). Life form groups were analyzed separately to ensure that the outcome reflected changes in composition not overall abundance. The understory composition was collected by using a modified Daubenmire (1959) cover class. The seven classes are: (1) 0.01 to 1 percent, (2) 1.1 to 5 percent, (3) 5.1 to 25 percent, (4) 25.1 to 50 percent, (5) 50.1 to 75 percent, (6) 75.1 to 95 percent, (7) 95.1 to 100 percent. Cover class midpoints of 0.5, 3, 15, 37.5, 62.5, 85, and 97.5 were used to calculate the mean cover. Results for vegetation life form per ha and seed density per m^2 were calculated and analyzed.

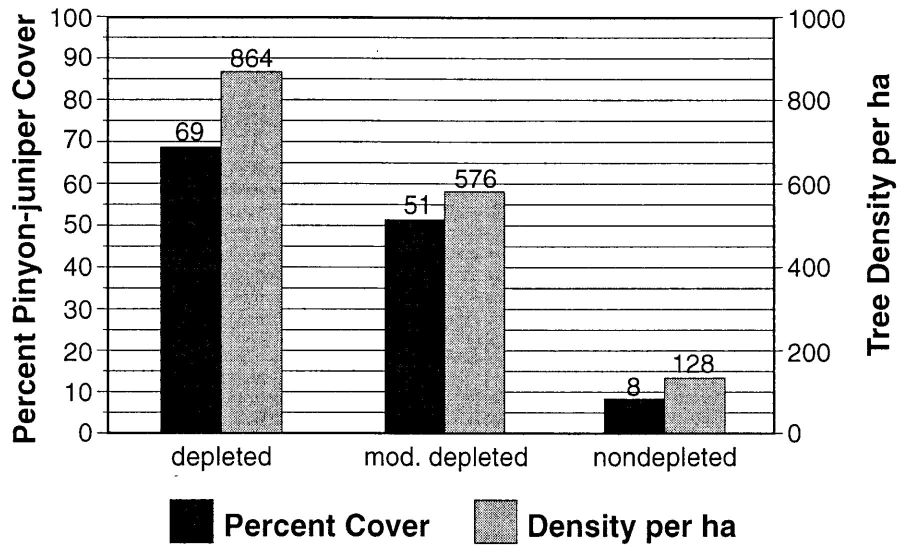

Figure 1—Percent pinyon-juniper cover and numbers of trees associated with the three understory vegetation classes.

Results

Percent tree cover and number of live trees per ha for the depleted, moderately depleted, and nondepleted understories were 69 percent cover with 864 trees per ha; 51 percent cover with 576 trees per ha; and 8 percent cover with 128 trees per ha respectively (fig. 1). The understory percent cover was significantly ($P < 0.05$) higher in the nondepleted site as compared to the depleted site (fig. 2). Litter and rock cover was lower in the areas where the canopy was open and understory vegetation was highest. Shrub, grass, and forb cover was significantly higher with fewer trees present.

In the depleted understory 31 species were present. The most common species were annual and perennial forbs. Both moderately depleted and nondepleted understory had 27 species each. The vegetation shifted from annual and perennial forbs in the depleted understory to perennial grasses and shrubs in the moderately depleted and nondepleted understories (fig. 3). The most common perennial forbs present with a high pinyon-juniper canopy were phlox (*Phlox*

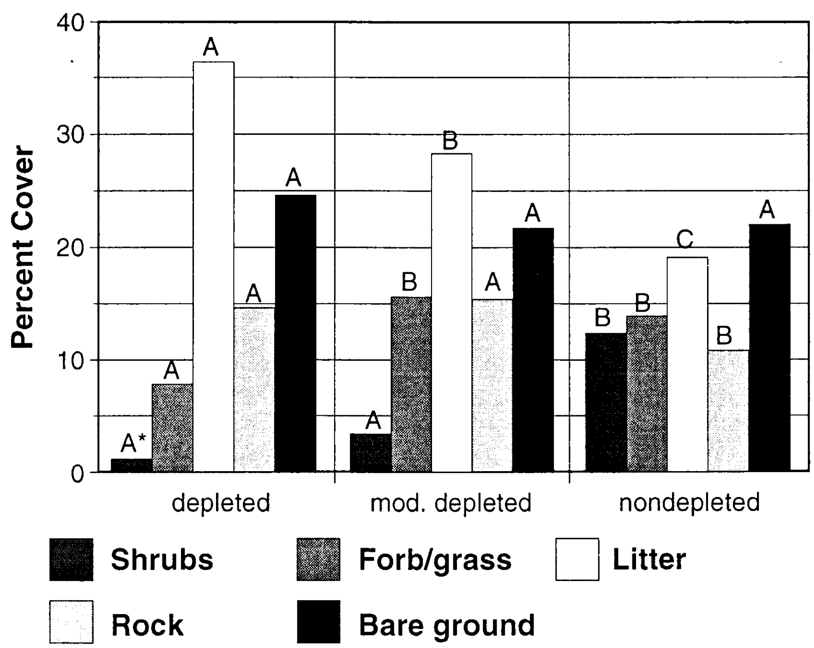

Figure 2—Percent cover of understory composition in three understory vegetation classes. *Columns for same understory component within a series with same letter are not significantly different ($P < 0.05$).

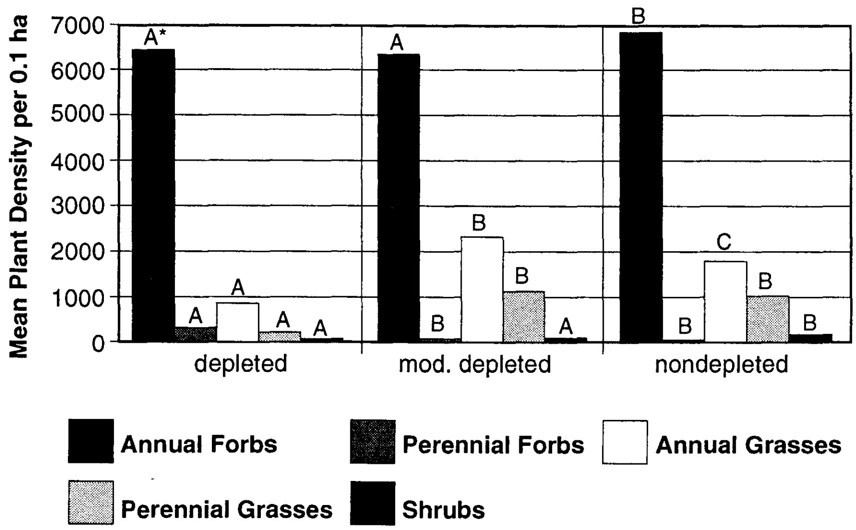

Figure 3—Mean plant density of understory species by life form per 0.1 ha. *Columns for same life form within a series with same letter are not significantly different (P < 0.05).

spp.), goldenweed (*Haplopappus* spp.), and cryptantha (*Cryptantha* spp.). With a more open tree canopy, astragalus (*Astragalus* spp.), globemallow (*Sphaeralcea coccinea*), and primrose (*Oenothera* spp.) were the prominent perennial forbs. With a closed canopy cover broom snakeweed (*Gutierrezia sarothrae*) was the common shrub. The shrub component shifted to low rabbitbrush (*Chrysothamnus viscidiflorus*), shadscale (*Atriplex confertifolia*), and big sagebrush (*Artemisia tridentata*) with a more open tree canopy.

Seed density in the soil seed bank was significantly greater in the moderately depleted and nondepleted understory compared to the depleted understory (fig. 4). The greatest density of seeds was in the moderately depleted understory with 7,240 seeds per m^2 (table 1). The depleted and nondepleted areas had 3,884 and 6,236 seeds per m^2 respectively. Seeds for 15, 12, and 14 species were found in the soil seed bank for the depleted, moderately depleted, and nondepleted communities respectively. The greatest number of grass seeds was in the nondepleted understory (fig. 4 and table 1). Perennial forbs, annual forbs, and tree seeds were the most frequent in the moderately depleted community.

Density of understory vegetation with number and seeds found in the soil was highly correlated with an $R^2 = 0.905$ (fig. 5).

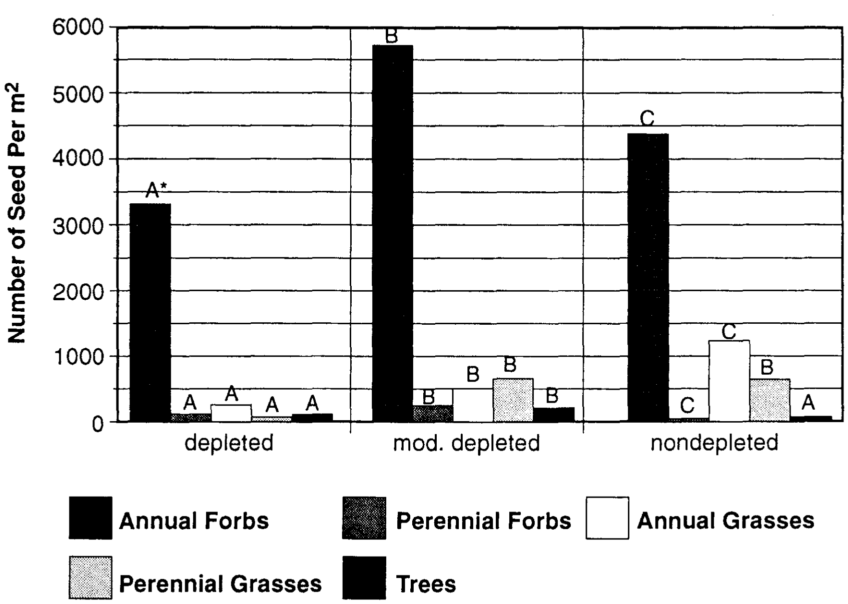

Figure 4—Extrapolated total number of seeds in the soil seed bank by life form per m^2. *Columns for same life form within a series with same letter are not significantly different (P < 0.05).

Table 1—Number of species and number of seeds per species in the soil seed bank by life form and understory vegetation class. Percent of total is included in parentheses.

	Life form	Understory vegetation class: Depleted	Mod. depleted	Nondepleted
Life form class		*Number of species (percent)*		
Annual forbs	AF	6 (40)	3 (25)	4 (29)
Perennial forbs	PF	1 (6)	2 (17)	2 (14)
Annual grasses	AG	1 (6)	1 (8)	1 (7)
Perennial grasses	PG	5 (33)	4 (33)	6 (43)
Woody	W	2 (13)	2 (17)	1 (7)
	Total	15	12	14
Individual species present		*Number of seeds (percent)*		
Bur buttercup	AF	1,892 (49)	5,352 (74)	3,364 (54)
Mustard species	AF	1,420 (37)	340 (5)	976 (16)
Composite species	PF	0	224 (3)	4 (0.1)
Cryptantha	PF	112 (3)	12 (0.2)	4 (0.1)
Cheatgrass	AG	280 (7)	496 (7)	1,212 (19)
Bluebunch wheatgrass	PG	16 (0.4)	296 (4)	352 (6)
Indian ricegrass	PG	40 (1)	20 (0.3)	68 (1)
Needle-and-thread	PG	0	0	4 (0.1)
Sanberg bluegrass	PG	4 (0.1)	308 (4)	168 (3)
Squirreltail	PG	12 (0.3)	0	4 (0.1)
Western wheatgrass	PG	0	16 (0.2)	16 (0.3)
Juniper	W	72 (2)	168 (2)	48 (0.8)
Pinyon	W	16 (0.4)	4 (0.1)	0
Other species		20 (5)	4 (0.1)	16 (0.3)
	Total	3,884	7,240	6,236

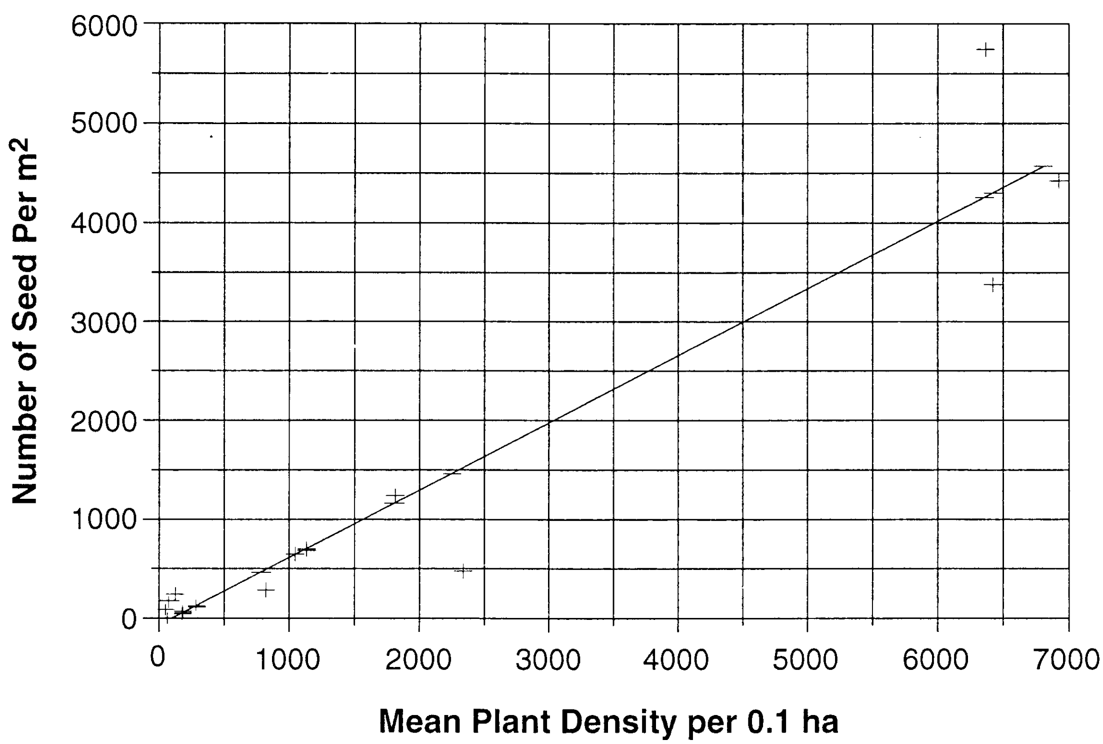

Figure 5—Understory species density per 0.1 ha and number of seeds per m^2 in the soil seed bank regression ($R^2 = 0.902$).

Conclusions

A direct correlation was found between pinyon-juniper canopy cover, density and composition of understory vegetation, and number of seeds in the soil seed bank. As tree cover increased, the understory vegetation and number of seeds in the soil seed bank decreases. Further research is needed to look more closely into the correlation between the canopy cover, understory vegetation and soil seed bank. Refinements are also needed in techniques to reduce the time requirements to separate soil and seed. As work continues in this area, the understanding of the correlation between tree canopy cover and soil seed bank will allow the use of more effective seed mixes. Seeding rates and cost of seeding should decrease with increasing abundance of seed in the soil seed bank.

Acknowledgments

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References

Cabin, R. J. 1996. Genetic comparisons of seed bank and seedling populations of a perennial desert mustard, *Lesquerella fendleri*. Evolution. 500: 1830-1842.

Chambers, J. C.; MacMahon, J. A.; Hafner, J. H. 1991. Seed entrapment in alpine ecosystem: effects of soil particle size and diaspore morphology. Ecology. 72:1668-1678.

Cofin, D. P.; Lauenroth, W. K. 1989. Spatial and temporal variation in the seed bank of semiarid grassland. American Journal of Botany. 76: 53-59.

Dessaint, F.; Chadeuf, R.; Barralis, G. 1991. Spatial pattern analysis of weed seeds in the cultivated soil seed bank. Journal of Applied Ecology. 28: 721-730.

Garcia, M. A. 1995. Relationships between weed community and soil seed bank in a tropical agroecosystem. Agri. Eco. And Envrio. 50: 139-146.

Gross, K. L. 1990. A comparison of methods for estimating seed numbers in the soil. Journal of Ecology. 78: 1079-1093.

Kinucan, R. J.; Smeins, F. E. 1992. Soil seed bank of a semiarid Texas grassland under three long-term (36-years) grazing regimes. American Midland Naturalist. 128: 11-21.

Valbuena, L.; L. Trabaud. 1995. Comparison between the soil seed banks of a burnt and unburnt *Quercus pyrenaica* Willd. Forest. Vegetatio. 119: 81-90.

Distribution of Pinyon-Juniper in the Western United States

John E. Mitchell
Thomas C. Roberts, Jr.

Abstract—The extent of pinyon-juniper woodlands in the Western United States, as determined from advanced very high resolution radiometer (AVHRR) data, has been appraised at approximately 55.6 million acres. There is presently no complete national inventory to which this total can be compared; however, Forest Service plot-based estimates and independent GAP predictions are consistent with the AVHRR acreage in Utah where adequate inventory data exist. An assessment by the Bureau of Land Management has yielded higher pinyon-juniper coverage for their own lands than that derived from AVHRR data. Spatial discrepancies remain between the AVHRR and GAP coverages, however. The importance of algorithms in classifying remotely sensed data is noted.

The Government Performance and Results Act (GPRA) of 1993 requires all Federal agencies, including USDA Forest Service and USDI Bureau of Land Management (BLM), to prepare recurring strategic plans. In order to carry out any strategic plan, agencies must have an adequate understanding of the conditions of lands under their jurisdiction. National assessments are used to provide the information needed for understanding the rangeland situation in the United States (Joyce 1989). Included in most assessments for land management agencies are estimations of the extent of and shifts in major rangeland cover types, including pinyon-juniper. In this paper, reference to pinyon-juniper includes both pinyon-juniper and juniper woodlands.

Given the relative disparities among previous appraisals of pinyon-juniper coverage in the Western United States (West and others 1975, USDA Forest Service 1989), we needed a better estimate of its distribution to support GPRA strategic plans due in the years 2000 and 2003. To do so, we used several data sources, including reports from Forest Inventory and Analysis (FIA) surveys, two different estimation methods utilizing advanced very high resolution radiometer (AVHRR) data, and GAP data to evaluate one AVHRR estimator of nationwide pinyon-juniper distribution. In addition, we compared these estimates to pinyon-juniper acreages provided by BLM for their lands.

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Methods

We used a digitized forest type map, developed from AVHRR data by the Forest Service's Southern Forest Experiment Station in 1992, as a baseline estimator to assess the extent of pinyon-juniper woodlands, by Federal ownership categories, in the Western United States (Powell and others 1994). This classification (USFS-AVHRR) differed from an earlier one produced by U.S. Geological Survey (USGS-AVHRR; Loveland and others 1991) in three ways:

- It combined AVHRR and Landsat TM classifications to create a "forest density" map that filtered out non-forest pixels.
- It used thermal Landsat bands. The USGS classification used only composite maximum greenness time-series images to separate vegetation types—a process which may not have been effective in arid environments.
- It was validated by FIA plot-based data.

Using ARC/INFO, we partitioned an Albers (equal area) projection of the USFS-AVHRR pinyon-juniper distribution map by Forest Service, BLM, other Federal, and nonfederal land ownership, and calculated the acreage in each category.

The Forest Service estimations for pinyon-juniper coverage, by state, were compared with FIA statistics for Utah and Nevada, where extensive FIA plot-based inventory data exist (O'Brien and Woudenberg, this proceedings). Although FIA state-level estimates include all land ownerships within the Intermountain region, for the most part National Forest Systems (NFS) provided the data for NFS lands. Data for forests and woodlands not on NFS lands, including most BLM lands, were collected by FIA. In 1991, FIA carried out a statewide inventory of all forest lands across all ownerships in Utah, including reserved (O'Brien 1999).

We also compared estimates of pinyon-juniper abundance on BLM lands, by state, with acreages reported by USDI Bureau of Land Management (1993).

Finally, we were interested in ascertaining how similar the USFS-AVHRR approximation for Utah was to the coverage of pinyon-juniper from the vegetation layer in the Utah GAP program (Edwards and others 1995). The Utah GAP program followed a complex vegetation classification system that used Landsat TM imagery at 30-m pixel resolution for a base map, but was modified by visual photo interpretation of aerial photography and digitizing of existing vegetation maps (Scott and others 1993). Thus, the two protocols would be based upon a substantially different pixel size, 1-km for USFS-AVHRR and 30-m for the GAP analysis.

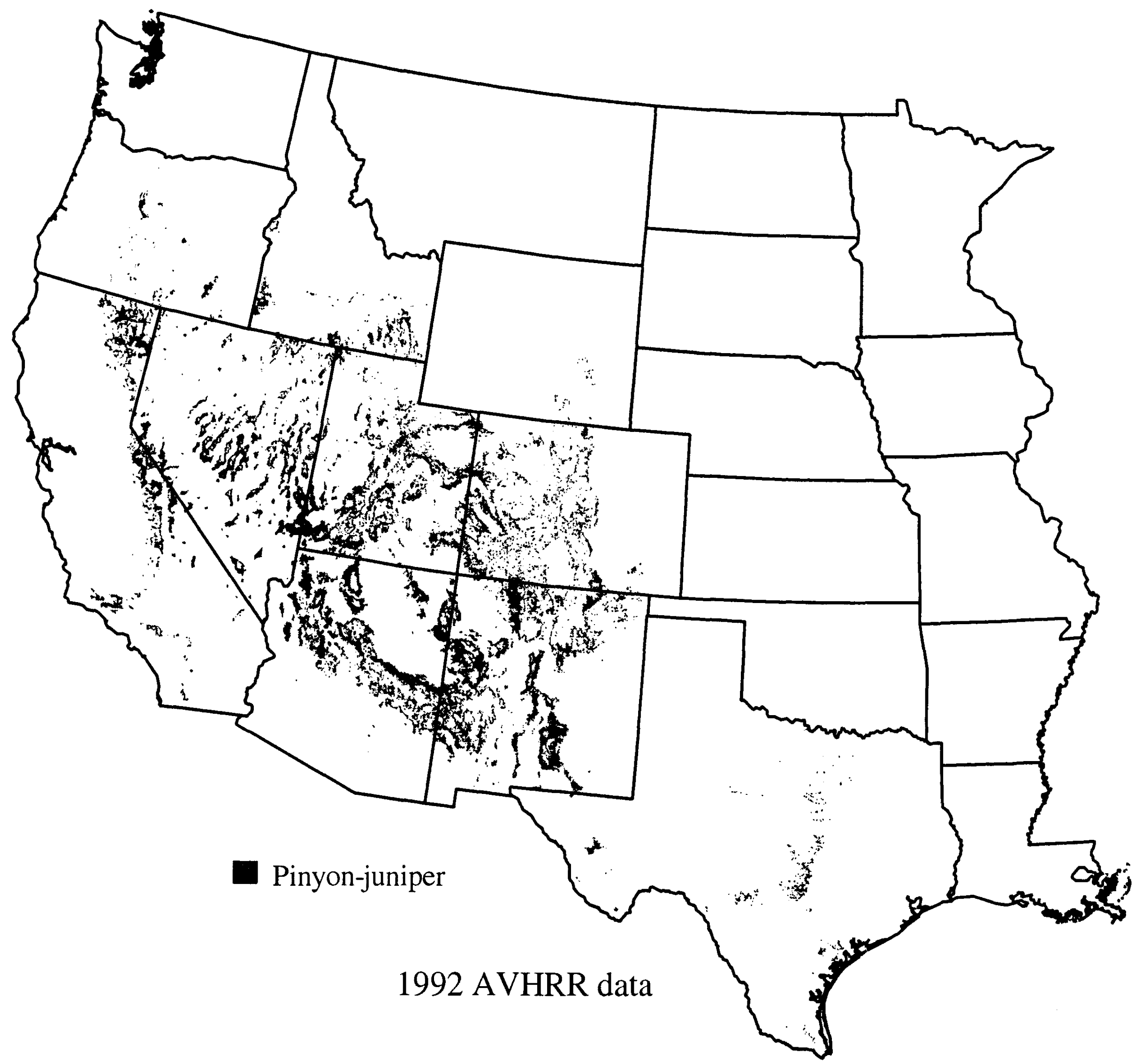


Figure 1—Distribution of pinyon-juniper woodland in the western United States (from Powell and others 1994).

Results

The Forest Service AVHRR estimate of national pinyon-juniper coverage is portrayed in figure 1 and is presented numerically in table 1 by state and land ownership. The five states of Nevada, Utah, Colorado, Arizona and New Mexico account for 46.3 million acres or about 83 percent of all U.S. lands dominated by pinyon and/or juniper. We estimate the total U.S. area occupied by pinyon-juniper to be 55.6 million acres.

Forest Inventory and Analysis plot data summarized in this document report that Nevada has 8.839 million acres of pinyon-juniper woodland with a standard error of 187,300 acres (O'Brien and Woudenberg, this proceedings). Likewise, Utah is estimated to have 9.149 million acres of pinyon-juniper woodland with a standard error of 279,500 acres. The AVHRR estimate for Utah of 9.439 million acres shown in table 1 is contained within an 80 percent confidence interval for the FIA estimate. For Nevada, the AVHRR

Table 1—Area of pinyon-juniper woodlands, by state and ownership, for 10 western states. From a Forest Service classification of AVHRR data (Powell and others 1994).

	Acres (Thousands)				
State	USFS	BLM	Other Fed	Nonfederal	All lands
Ariz.	3,634	964	3,322	1,708	9,628
Calif.	3,179	793	435	494	4,901
Colo.	2,248	1,827	500	2,021	6,596
Idaho	828	594	123	187	1,732
Nev.	2,754	4,635	414	303	8,106
N.M.	4,276	1,459	2,184	4,642	12,561
Ore.	350	134	117	186	787
Texas	0	0	85	1,562	1,647
Utah	3,696	4,064	551	1,128	9,439
Wyo.	125	12	0	66	203
Total	21,090	14,482	7,731	12,297	55,600

Table 2—Area of "woodlands" on BLM land by state for nine western states as reported by USDI Bureau of Land Management (1993).

State	Acres (Thousands)
Arizona	1,240
California	387
Colorado	3,534
Idaho	385
Nevada	6,210
New Mexico	1,721
Oregon	286
Utah	6,418
Wyoming	207
Total	~20,400

estimate of 8.106 million acres is not within the 80 percent confidence interval of 8.600 million acres to 9.079 million acres derived from FIA data (O'Brien and Woudenberg 1999) (table 1).

Table 2 portrays area of pinyon-juniper for BLM lands alone, based upon surveys from USDI Bureau of Land Management (1993). The BLM acreages greatly exceed the AVHRR estimates for lands under the jurisdiction of BLM except for California, Idaho and New Mexico (table 1). The largest dissimilarities are for Utah, Colorado and Nevada. One explanation for the somewhat high BLM estimates for Utah and Colorado would be their inclusion of oak-mountain mahogany woodlands within the woodland category (Küchler 1964).

A comparison of the two classifications of AVHRR data for the extent of pinyon-juniper in the state of Nevada is a pertinent example of how much variation can ensue from two algorithms that process the same raw data. The 1990 USGS protocol detected a total of 2.4 million acres of "western woodland" in Nevada, of which 319,000 acres was classified as pinyon-juniper woodland (fig. 2). The 1992 FS

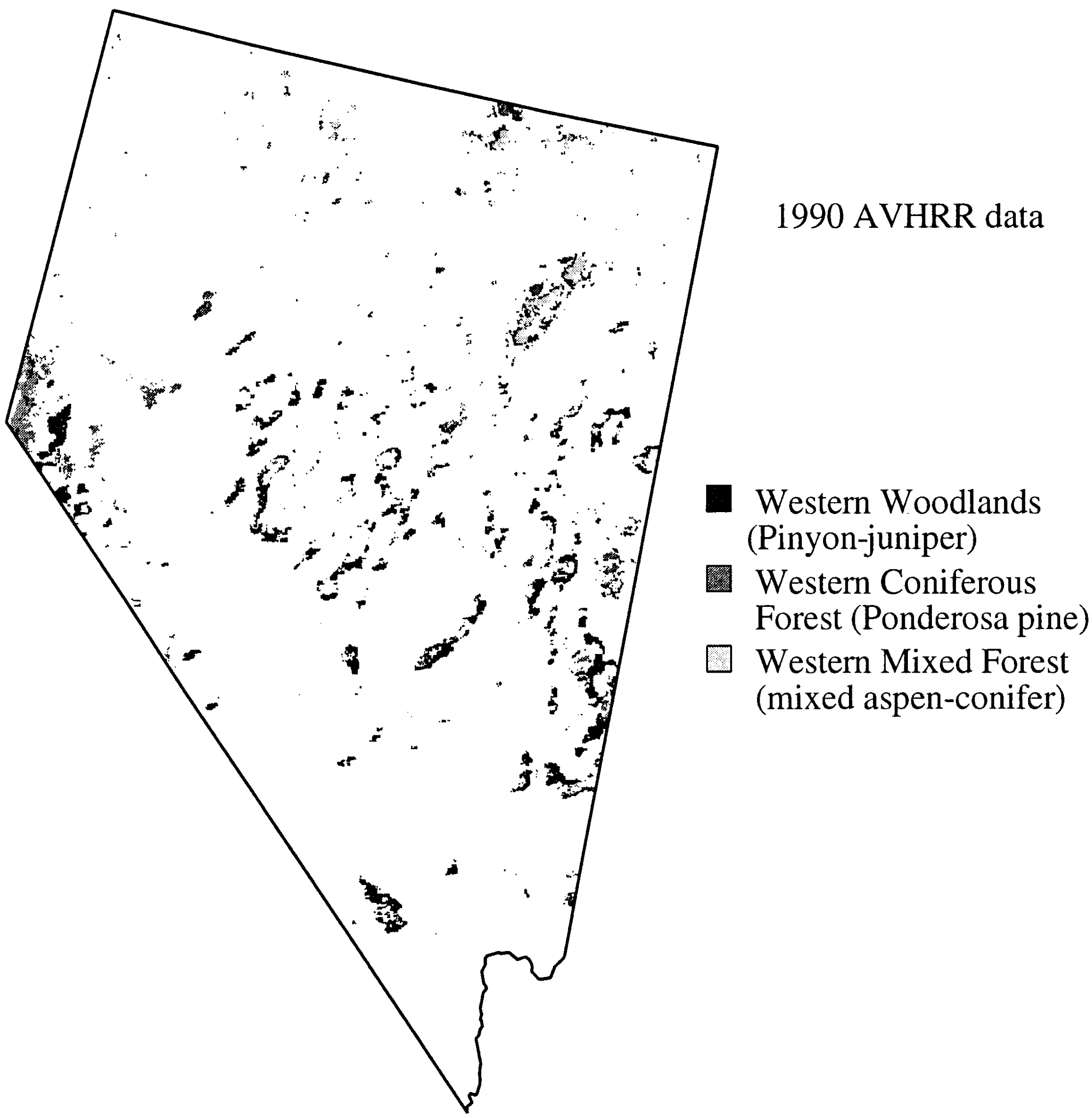


Figure 2—Distribution of pinyon-juniper woodland in Nevada, derived from a U.S. Geological Survey algorithm of AVHRR data (see Loveland and others 1991).

classification distinguished 8.1 million acres of pinyon-juniper woodland in Nevada, an estimate much closer to the 8.8 million acres obtained from FIA plot data (O'Brien and Woudenberg, this proceedings) (fig. 3).

The differences between the 1990 USGS-AVHRR and USFS-AVHRR estimates of pinyon-juniper acreages in Nevada can be visualized by examining a smaller area within the state. We arbitrarily selected an area just inside Nevada's border with Utah, primarily in White Pine and Lincoln Counties, to compare the visual effect of the two classifications. The results are obvious and profound (fig. 4 and 5).

The assessment for pinyon-juniper coverage in the state of Utah comparing USFS-AVHRR and GAP analysis is revealing. The two estimates for total cover are extremely close, 9.439 million acres to 9.596 million acres, respectively. Nonetheless, the spatial distributions are different in both locale and density (fig. 6 and 7). We had expected the larger pixel size of the USFS-AVHRR map to result in a less fragmented portrayal of pinyon-juniper, but the opposite actually occurred. The indication of differences in locale can be seen by comparing stand distributions using county lines, particularly in the south-central part of the state.

To quantify this apparent lack of consensus between the USFS-AVHRR and GAP analysis maps, we tested for overlap of the pinyon and/or juniper polygons in the ARC/INFO vector files from the two respective approaches. Only 3.92 million acres in Utah were jointly classified as pinyon-juniper, pinyon or juniper by the two methods. That means each of the methods classified approximately 5.5 million acres as pinyon-juniper woodland that the other did not. In other words, the USFS-AVHRR and GAP analysis data collectively identified a total of more than 15 million acres as being dominated by pinyon-juniper, but less than 4 million of

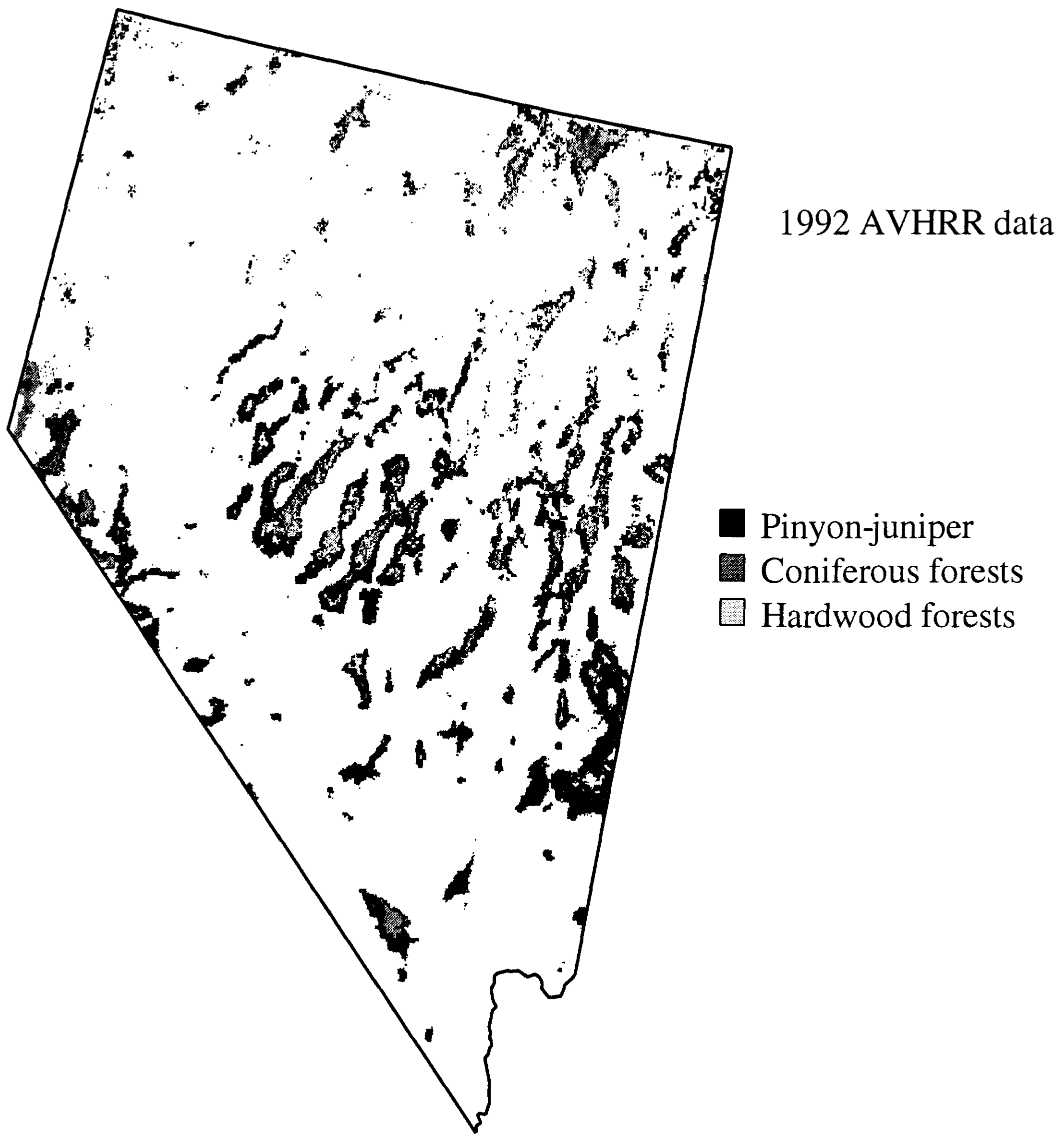


Figure 3—Distribution of pinyon-juniper woodland in Nevada, derived from a USDA Forest Service algorithm of AVHRR data (see Powell and others 1994).

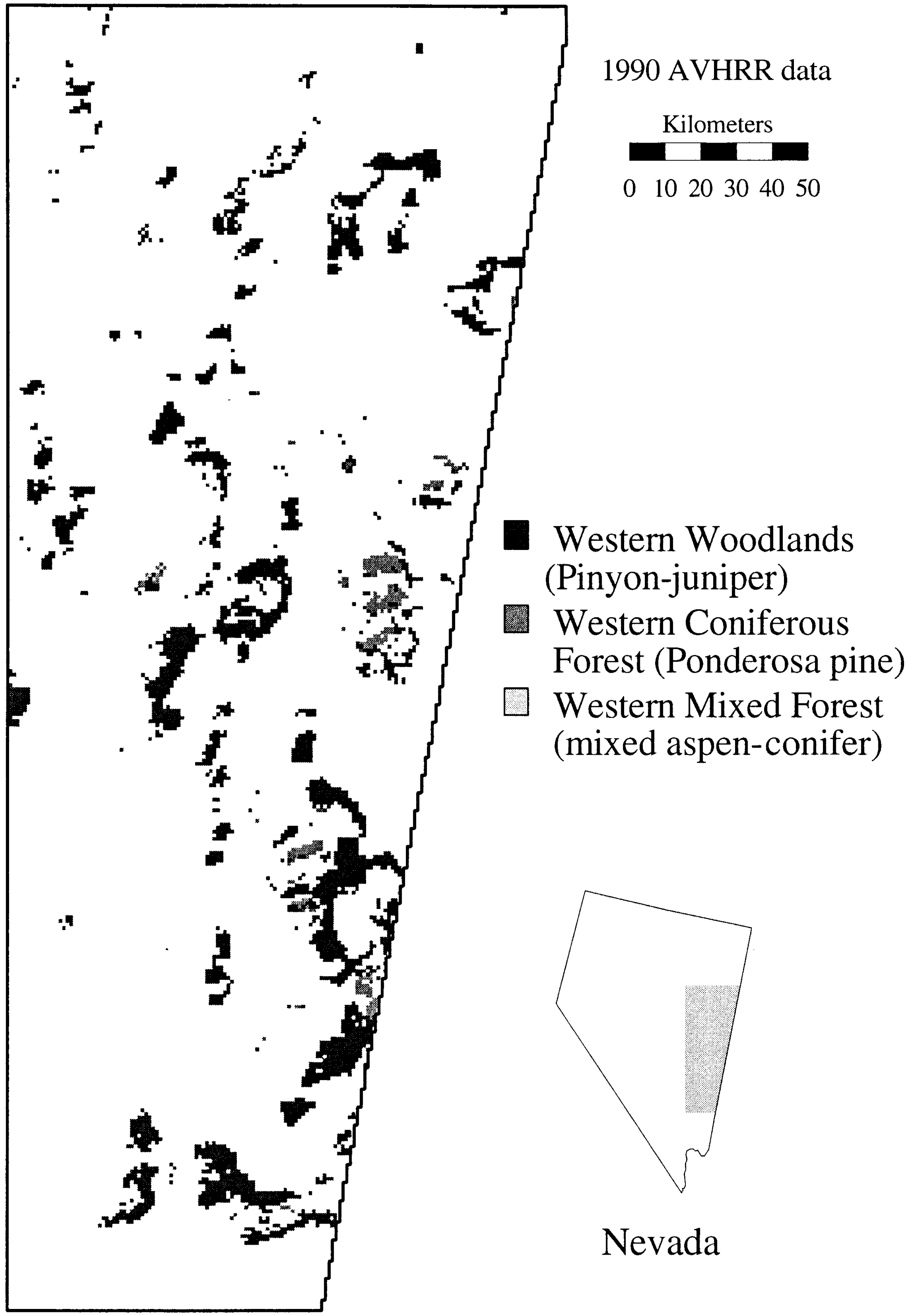


Figure 4—Distribution of various forest and woodland cover types in eastern Nevada, derived from a U.S. Geological Survey algorithm of AVHRR data (see Loveland and others 1991).

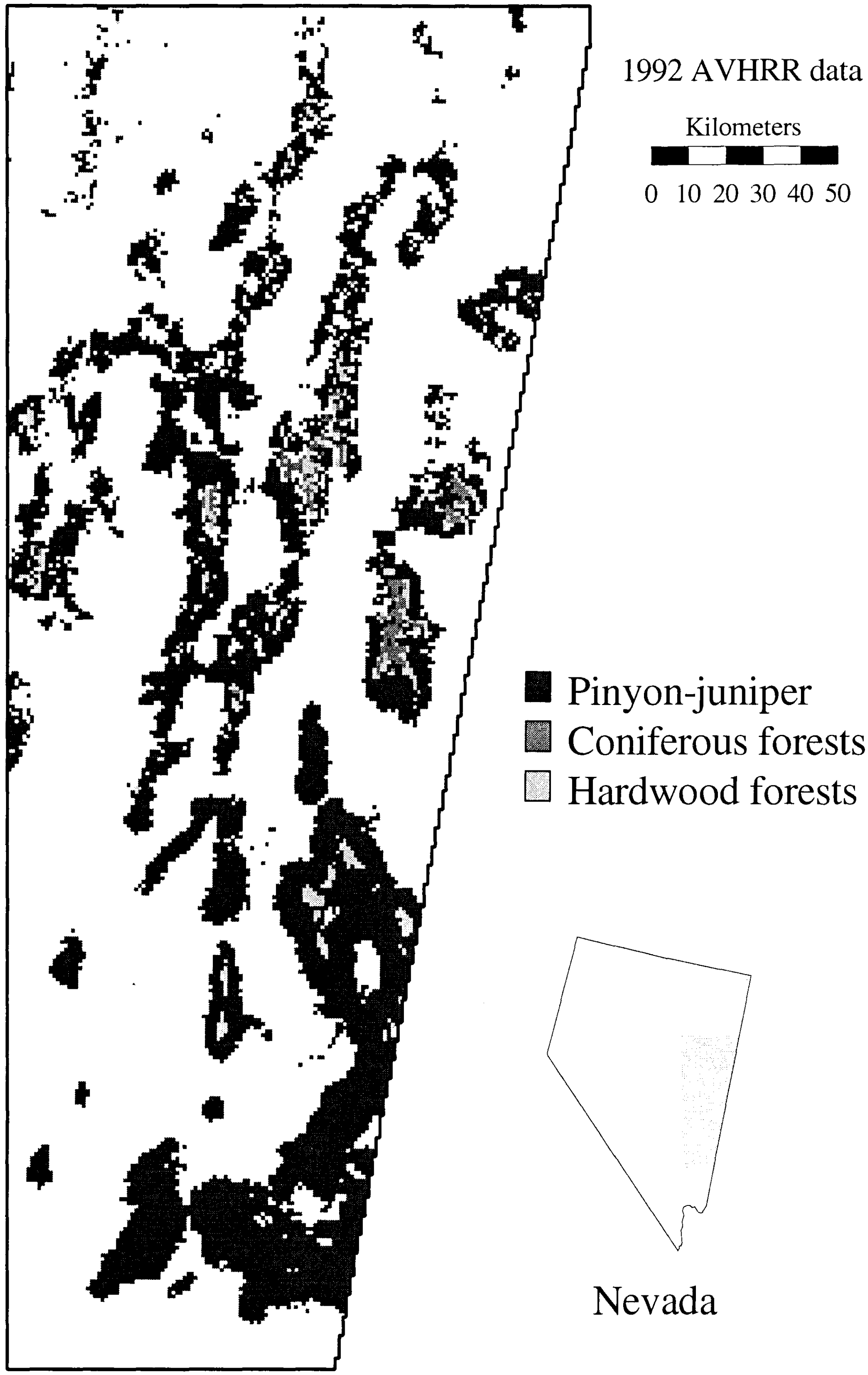
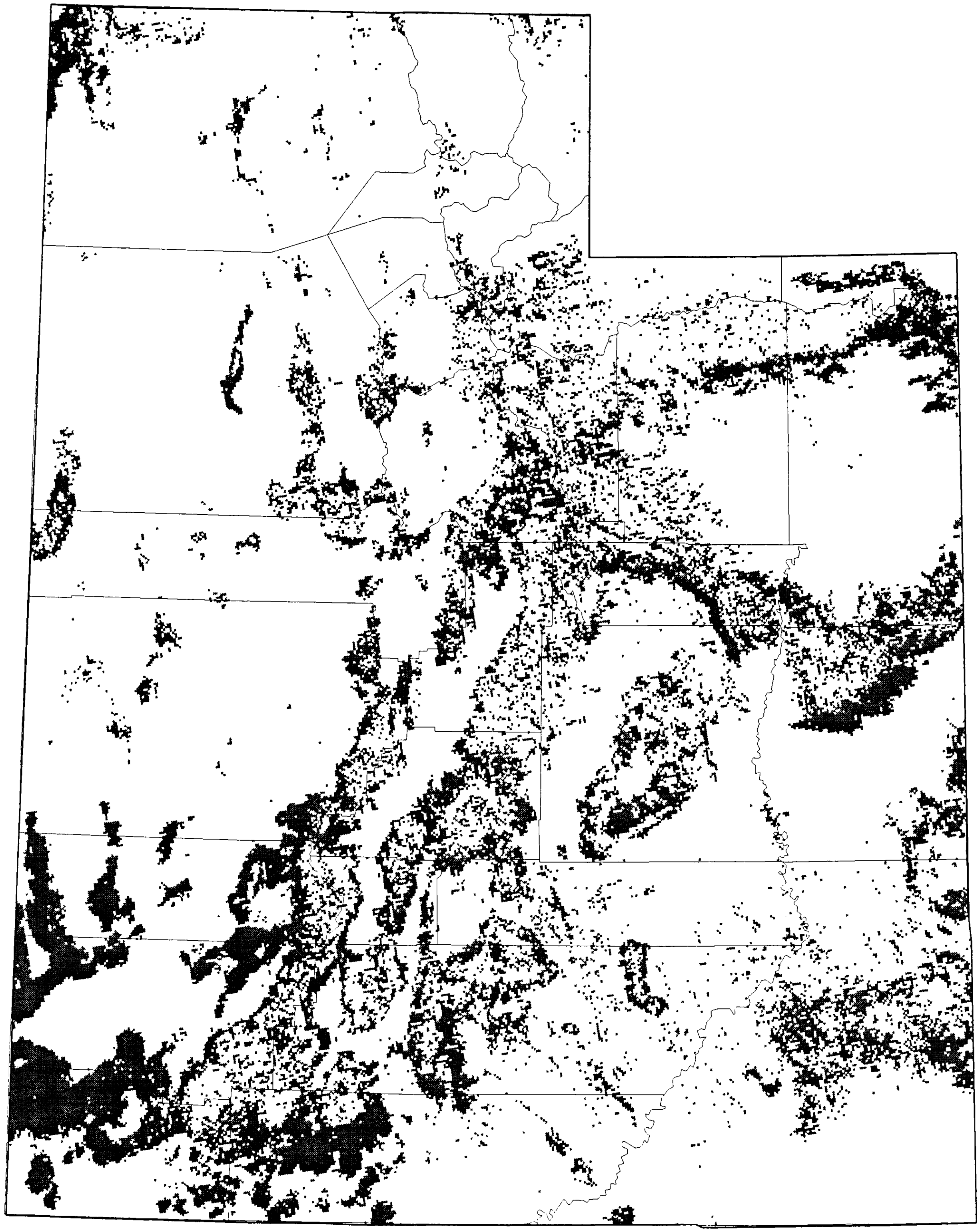


Figure 5—Distribution of various forest and woodland cover types in eastern Nevada, derived from a USDA Forest Service algorithm of AVHRR data (see Powell and others 1994).



Data Source:
1992 AVHRR data

Legend
Pinyon-Juniper County lines

Figure 6—Distribution of pinyon-juniper woodland in Utah using AVHRR data with a 1-km^2 pixel size (see Powell and others 1994).

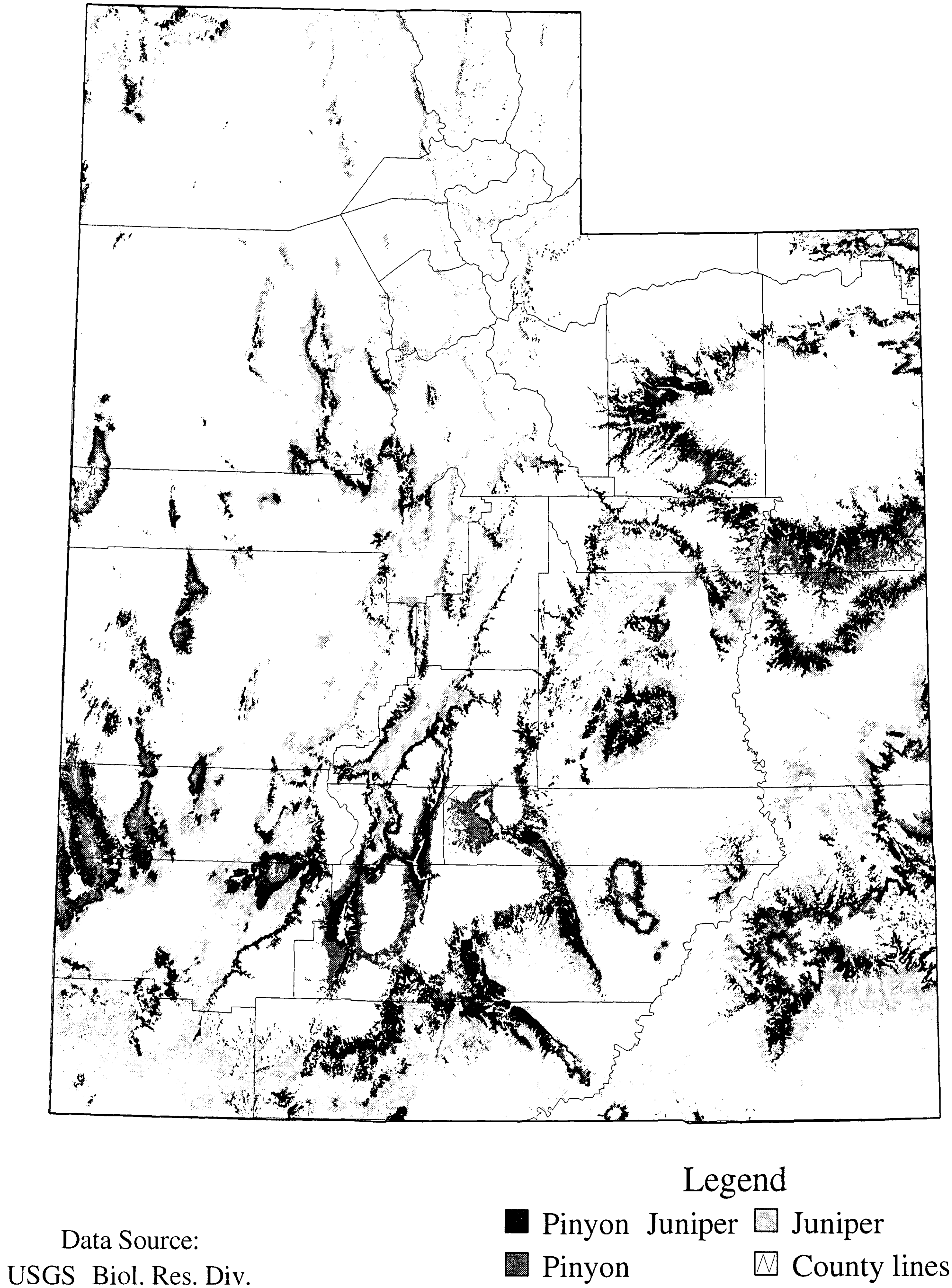


Figure 7—Distribution of pinyon-juniper woodland in Utah using GAP data with a 900-m^2 pixel size (see Edwards and others 1995).

those acres were classified in that category by both methods. Based upon the close agreement among FIA, USFS-AVHRR, and GAP predictions for the extent of pinyon-juniper woodland in Utah, we conclude that the actual coverage is about 9.5 million acres. However, its precise spatial distribution remains inconclusive.

Discussion

Broad inconsistencies exist between the various sources of land-cover data for pinyon-juniper woodlands. In general, the BLM's estimates for their own land exceed that provided by remote sensing. The difference in total woodland area on BLM lands, 20.4 million acres versus 14.5 million acres from the AVHRR estimate, cannot be totally accounted for by considering woodlands not containing juniper. Moreover, the agreement between the FIA data and USFS-AVHRR maps for Utah imply that the BLM estimates may be somewhat high. FIA estimates tend to track the USFS-AVHRR totals for pinyon-juniper for those states where comprehensive plot data are available across major landowner categories.

The relationship between the USFS-AVHRR and Utah GAP estimates for pinyon-juniper land cover demonstrate the importance of scale (pixel size) and algorithms for defining land cover types when evaluating different protocols. Research is obviously needed to develop ways for rectifying incompatible attributes of regional and national monitoring systems.

The most efficient monitoring system for making national and regional assessments may incorporate both remotely-sensed data and data from a systematic structure of ground observations. At a minimum, a multi-stage sampling procedure involving plot data could more easily validate cover type misclassification of remotely-sensed data.

Acknowledgments

We are indebted to Stella Todd and Jock Blackard for performing the ARC/INFO analyses.

References

Edwards, T.C., Jr.; Homer, C.G.; Bassett, S.D.; Falconer, A.; Ramsey, R.D.; Wight, D.W. 1995. Utah GAP Analysis: an environmental information system. Technical Report 95-1. Logan, UT: Utah State University, Utah Cooperative Fish and Wildlife Research Unit. 1189 p. + 2 CD-ROM.

Joyce, Linda A. 1989. An analysis of the range forage situation in the United States. General Technical Report RM-180. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 137 p.

Küchler, A.W. 1964. Potential natural vegetation of the conterminous United States. Special Publication 36. New York, NY: American Geographical Society. 116 p. + map.

Loveland, Thomas R.; Merchant, James W.; Ohlen, Donald O.; Brown, Jesslyn F. 1991. Development of a land-cover characteristics database for the conterminous U.S. Photogrammetric Engineering & Remote Sensing. 57:1453-1463.

O'Brien, Renee. 1999. Comprehensive inventory of Utah's forest resources, 1993. RMRS-RB-1. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 105 p.

O'Brien, Renee A.; Woudenberg, Sharon W. 1999. Description of pinyon-juniper woodlands in Utah and Nevada from an inventory perspective. In: Monsen, Steven B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick. Proceedings: ecology and management of pinyon-juniper communities in the interior West. Proc. RMRS-P-00. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Powell, Douglas S.; Faulkner, Joanne L.; Darr, David R.; Zhu, Zhiliang; MacCleery, Douglas W. 1994. Forest resources of the United States, 1992. USDA Forest Service General Technical Report RM-234 (Revised). Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 132 p. + map.

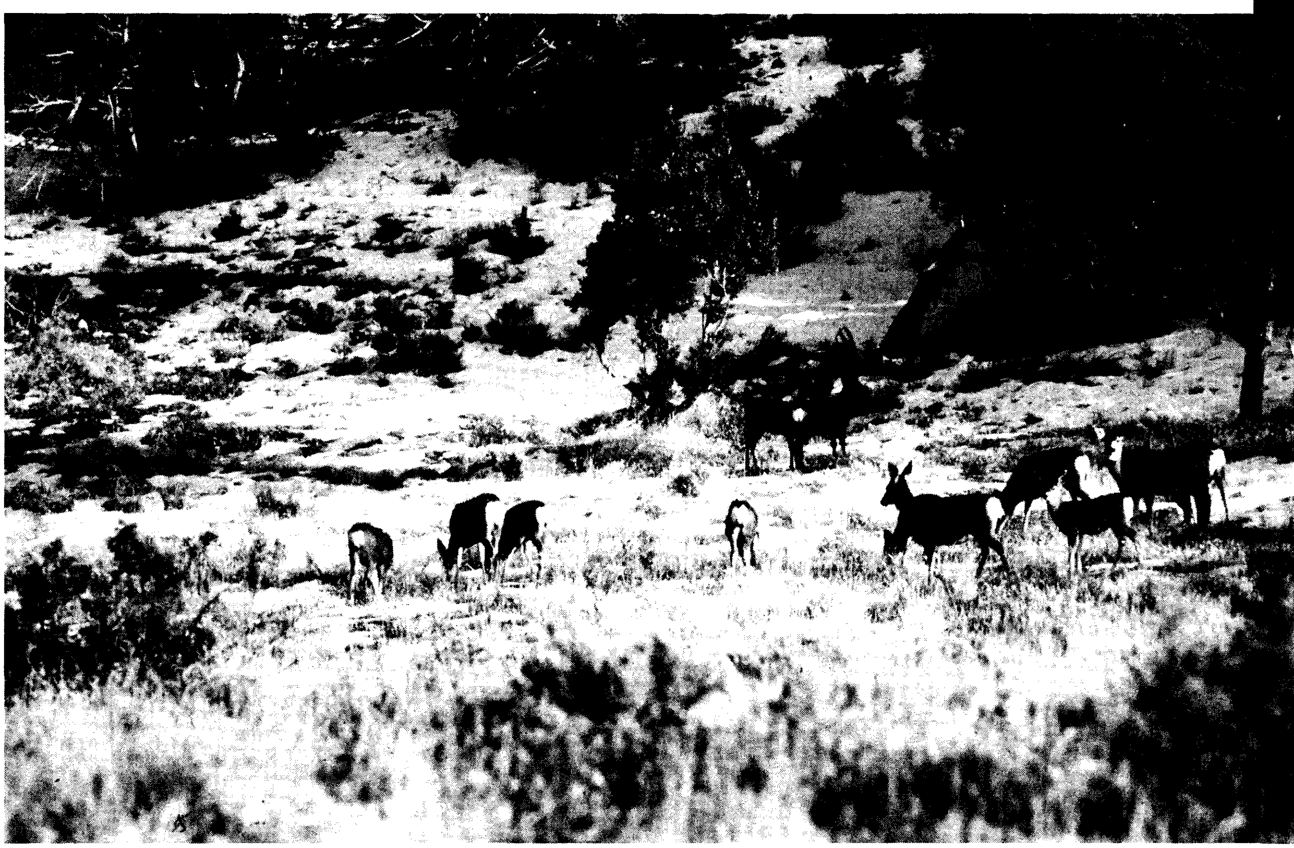
Scott, J.M.; Davis, F.; Csuti, B.; Noss, R.; Butterfield, B.; Groves, C.; Anderson, H.; Caicco, S.; D'erchia, F.; Edwards, T.C., Jr.; Ulliman, J.; Wright, R.G. 1993. GAP analysis: a geographic approach to protection of biological diversity. Wildlife Monographs. 123. 41 p.

USDA Forest Service. 1989. An analysis of the land base situation in the United States: 1989-2040. USDA Forest Service General Technical Report FM-181. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 76 p.

USDI Bureau of Land Management. 1993. Forests: our growing legacy. Washington, DC: U.S. Department of Interior, Bureau of Land Management. 19 p.

West, N.E.; Rea, K.H.; Tausch, R.J. 1975. Basic synecological relationships in juniper-pinyon woodlands. In: Gifford, G.F.; Busby, F.E. (ed.). The pinyon-juniper ecosystem: a symposium. Logan, UT: Utah State University: 41-53.

Resource Values



Ecology and Management of Pinyon-Juniper Communities Within the Interior West: Overview of the "Resource Values Session" of the Symposium

James E. Bowns

Abstract—This paper summarizes 17 excellent, detailed papers presented during the section of the symposium on the resource values of the pinyon-juniper woodlands. James E. Bowns captures the salient points of each paper, a formidable task that required that most of the detail be left out. The reader is encouraged to read the complete papers for additional details.

Past, Present, and Potential Uses of Pinyon-Juniper

Pinyon-juniper species are a sizable wood fiber resource for products that can be made from smaller, irregular stems and those that can capitalize on the unique physical and chemical characteristics of these species.

Firewood obtained from pinyon and juniper has been used longer and more extensively than any other product. This is still the main fuel in many rural areas as well as urban use in wood burning stoves and fireplaces. These species have excellent fuel wood characteristics of heat content, ignition, flaming, and fragrance.

Juniper posts have historically been used because of their easy access and natural durability. A good post can last 60 years, and the diameter of the heartwood is the determining criterion for durability. Juniper is also used for stub posts in power and telephone lines and highway guard rails. Young and intermediate aged stands provide the best posts. Pinyon is not favored for posts because they are not of suitable form or durability.

Pinyon and juniper and not widely used for sawn products because of the poor growth form and small size. Other problems include high wood density and grit in the bark that causes excess saw wear and resin build up.

Railroad ties and mine timbers are some of the usable products and are superior to those obtained from local softwoods. Furniture and novelty items (book ends, lamp bases, clocks, jewelry boxes, and small chests) capitalize on the unique fragrance, color, and grain patterns of these woods.

Particle board can be made from both pinyon and juniper. Juniper is somewhat better because of its specific gravity, texture, color, and fragrance. Markets still need to be developed for these products.

Cement board can be made with cement, wood fiber, and water. It is fire resistant, relatively unaffected by water, and can be worked like particle board.

Charcoal can be made from all species of pinyon and juniper; however, more dense woods such as gambel oak are superior. Charcoals made from pinyon and juniper were used as smelter fuel in early mining operations.

Although some species of juniper have proven satisfactory for pulp, it produces low yields. Other problems are that the pulp is too difficult to bleach for white paper, too weak for unbleached high-grade bag and wrapping paper, and too soft for corrugating board. Economic feasibility for pulping pinyon-juniper in the region is questionable.

Pinyon wood contains large quantities of oleoresin or gum. Products obtained from the resin include spirit, linseed oil, tung oil varnishes, ester gum, and zinc resinate. The Zuni Indians use the resin for an antiseptic, pottery glaze, and for burning in religious ceremonies.

Juniper woods contain large quantities of oily fragrant extractives rich in cedrol and associated essential oils. Other compounds should include terpene and sesquiterpene. Juniper foliage also contains fragrant oily extractives.

Other important products include pine nuts and Christmas trees. Nut production is highly variable from area to area and year to year, which causes problems for nut brokers and processors. Pinyon Christmas trees are favored by many residents of the Interior West. The single needle pinyon is generally favored because it is more symmetrical.

Role of Pinyon-Juniper Woodlands in Aboriginal Societies

Resources such as food, shelter, tool construction, tinder, and preferred settlement locations are available in the pinyon-juniper woodlands. These woodlands provided aboriginal peoples some of the most basic raw materials for sustaining life.

Food

Pine nuts were one of the most important foods of the early inhabitants of the Great Basin and Colorado Plateau. These nuts were gathered in large quantities and were considered the single most important food species where they occurred. The nuts are high in both protein and fats, the proportions

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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varying among species. The fat content exceeds that of chocolate and contains all 20 essential amino acids. Nuts provide tryptophan, which is deficient in diets of corn farmers.

Nut production varies from year to year, area to area, and age of the tree stand. *Pinus monophylla* is more productive and predictable than *P. edulis*. A casual relationship has been proposed between the unpredictability of pinyon pine nuts with the high residential mobility of the Great Basin people.

Nuts were harvested in the early fall at about the time of the first frost and eaten raw or toasted, hulled, winnowed, and ground into paste for making a pine nut soup or gruel. Soup was sometimes mixed with meat to add flavor and Navajos made nut butter, which was spread on corn cakes.

Nuts were stored in pits or other storage facilities that were lined with rocks, grass, or juniper bark and covered with bark, branches, dirt, and more rocks. This kind of storage ensured that the nuts would last at least all winter.

Juniper "berries" were occasionally used for food. Apaches ate them fresh or pounded them for bread or juniper tea. Utes ate the pulp fresh or dried, or used them as an ingredient in bread or stews. Great Basin people used juniper "berries" sparingly, but they were occasionally eaten in the fall and winter after they were boiled.

Medicinal Uses

The use of pinyon as medicine was limited, but the pitch and gum were boiled in water and drunk to purge worms and other parasites. Juniper leaves were used in teas for the treatment of colds and coughs.

Construction and Other Uses

Pinyon and juniper were used for house construction, hogans, sweathouses, ramadas, fences, corrals, drying racks, and storage facilities. These trees were also used for fire material or kindling wood.

Juniper bark was an integral element in roof construction, fiber for mats, diapers, menstrual pads, and cushioning and protective lining for storage pits.

Pitch was used to line basketry water jugs as a sealant, as glue for ceramic vessels, and as a mastic for attaching projectile points or stone tools.

Wildlife

Habitat values of pinyon-juniper woodlands often receive little consideration because they appear so extensive that there seems little possibility of exhausting the supply, and the aridity and lack of vegetation diversity seems inconsistent with highly productive wildlife habitat. Also, land managers may consider mature pinyon-juniper undesirable or at least less desirable than earlier seral stages because of the lack of understory vegetation.

Birds

These woodlands support rich and distinctive bird communities and make substantial contributions to landscape-level avian diversity. In northeastern Utah pinyon-juniper ranked second in percentage of obligate and semiobligate species, third in total number of individuals counted, and fourth in species richness and diversity. Only riparian areas had a higher percentage of obligate or semiobligate species. Of seven upland forest habitats studied, pinyon-juniper ranked second in total individual birds and third in species richness and diversity. In general, the number of species and individuals tended to decrease with increasing elevation.

Consideration of more than simply the number of species is important because an area that supports a few rare species can be as important as one that supports many common species.

Studies show that chaining can negatively affect the abundance of cavity nesters, timber gleaners, aerial foragers, and species that forage in or next to the foliage. Birds that nest or forage on the ground use both treated and untreated areas. Woodland treatments are not necessarily bad for birds, and creating a mosaic of seral stages provides the best balance of habitat features sought by birds. Shrub-dependent and edge-associated species benefit from well-designed treatments. Sites with high edge-to-interior ratios should be selected, and more trees should be left standing near the edge. This will add structural complexity and thus compensate for the loss of overstory.

Managers should also consider habitat values of mature woodlands when meeting watershed and forage production objectives. The best option appears to be a landscape designed to include functional patches of all seral stages.

In another study, 53 bird species, using pinyon-juniper woodlands for breeding, were observed on seven pinyon-juniper sites. Only two species, blue-gray gnatcatcher and black-throated gray warbler, occurred on all seven sites, and 77 percent were neotropical migrants. Researchers conclude that pinyon-juniper forests are important for the continued breeding success of these two species and the gray flycatcher.

Pinyon-juniper forests provide important food, cover, and nesting habitat for at least nine neotropical migrants, and the pinyon-juniper type supports a greater variety of birds than had been anticipated. However, the total number of species depending entirely on this type for breeding is low compared to other habitat types.

Sagegrouse depend upon sagebrush steppe throughout their distribution. The lack of fine fuels and more mineral soil has generally decreased fire frequency, although intensity has increased in some areas.

Sagegrouse populations have declined in much of their former range, and these declines are most notable where habitat limitations including loss, fragmentation, and degradation of sagebrush ecosystems have occurred.

Some sites have been treated with the brush beating of short (less than 1 m) pinyon and juniper trees, sagebrush, and associated deciduous shrubs. Taller trees were cut with chain saws, and some hand cutting removed trees from lek sites.

These treatments doubled sagegrouse populations, and the increase was attributed to the decreased mortality of males during the breeding season and improved survival of both males and females. Prior to the treatments raptors had hunted from the trees adjacent to the lek sites, and all documented sagegrouse mortality was attributed to predation by raptors. However, the effect of cutting trees was confounded because sagebrush beating also occurred at the lek sites, which increased the ability of the sage grouse to detect predators at greater distances. Pinyon and juniper trees were avoided from June through August, at which time sagegrouse selected treated areas that had an abundance of succulent forbs.

It seems remarkable that sagegrouse populations respond so quickly to treatments designed to solve an immediate local problem. Outside of predation, mortality of this population appeared low and no hunting was allowed. It appears that tree removal can increase usable habitat size by at least 100 percent.

Mammals

Small mammals are affected by juniper encroachment, conversion, and subsequent impacts of community structural change. An estimated 341 animal species are found in the southeastern Oregon juniper steppe.

The number of captures is usually higher on cut sites. Captures are higher on shrub sites than old-growth woodlands, and the structure provided by robust understory vegetation and overhanging juniper skeletons provides superior security and forage in the cut and dropped sites.

Leaving blocks of unchained vegetation should maintain woodland-dependent species while providing increased total numbers of small mammals in treated areas. Total captures and number of species are higher in cut sites than in uncut sites. This concurs with other studies that show that small openings can benefit a variety of wildlife.

Cut sites have preferred structure, which is provided by increased vigor (cover and height) of herbaceous species, increased seed production on cut sites, greater species richness, and juniper slash. Cut sites generally provide increased security and forage for small mammals.

Opening stands of western juniper and leaving trees or thinnings does not substantially affect small mammals. The Great Basin pocket mouse appears to be the most sensitive species to the loss of shrubs during the latter seral stages. Some species such as wood rats are favored by trees. For maximum structural diversity shrub steppe communities should be managed through early-to-mid-seral woodlands. In late and closed woodlands, structural complexity and plant diversity results in shifts in small mammal population dynamics.

Fuel wood harvesting results in immediate, drastic, and abrupt habitat changes. Small mammals have intricate roles in ecosystem function, so they are a key component of pinyon-juniper woodlands.

Slash left on the ground results in an increase of some rodent population regardless of overstory condition. This also affects microsite nutrient cycling, understory production, and regeneration of overstory species.

Overstory removal and slash accumulation seems to have more beneficial effects for deer mice specifically and other species as well. However, these two effects were detrimental to the pinyon mouse. Overstory is important to pinyon mice, and burning is of further detriment to this species.

Burning of slash is considered detrimental and may offset the beneficial effects of the slash. Small mammal populations are related to overstory adjustments or slash composition.

Mature Utah juniper "berries" are the most commonly taken food by gray fox in terms of percent relative frequency of occurrence and mean percent of volume in scats. Chemical analysis of juniper "berry" hulls indicates that they provide the basic supply of nutrients and minerals. Mature juniper "berries" are low in moisture, which concentrates more energy and nutritional content into the hulls, therefore providing more value per unit weight than immature berries with high moisture content. The hulls alone provide the minimum gross energy needed for gray fox maintenance and then some. There may also be some zoopharmacological benefits of secondary compounds in purging external parasite loads.

Mammalian prey, mostly rodents and leporids, represent the majority of the diet not consisting of juniper "berries." The addition of the mammalian prey likely supplements any nutritional deficiencies.

Gray fox contribute to community, structure, dynamics, and function of Utah juniper dominated ecosystems. Gray fox are efficient foragers that specialize in an interesting mix of vegetal and animal matter. The gray fox is the only mammal known to forage extensively on the hulls of juniper "berries." The hulls comprised a large part of their diets during all seasons studied.

Mature juniper "berries" exist in large quantities and provide a large volume of readily available nutrition throughout the year. "Berries" ripen on the tree and persist for up to 2 years. Gray fox are adept at climbing trees and use junipers for a food source, resting, and escape cover.

Juniper seeds pass through the digestive system intact, and the metabolic residue in the scat provides the seeds with a natural mulch of nitrogen and other minerals. This possibly provides a valuable benefit to juniper community dynamics in the form of seed dispersal. An alternative view may be that this seed dispersal is detrimental because it increases the spread of juniper that may be interpreted as undesirable.

Apparently gray fox do not actively feed on pinyon pine nuts and acorns, which would require the breakdown of the shell or husk before they could obtain any nutritional benefit.

Rocky Mountain Bighorn sheep show a high preference for burned areas within pinyon-juniper and ponderosa pine communities, especially those burns located within or adjacent to steep, rocky habitat within core use areas. This positive response occurs in small or large burns.

Bighorn sheep generally avoid areas with a high density of live or standing dead trees, which reduce visibility to intolerable levels. In addition to high visibility, bighorns prefer older burns dominated by grass, which constitutes 79 percent of their diet. Early seral stages are more valuable to bighorns than tree dominated areas. Therefore, maintenance of bighorn habitat is highly dependent on repeated burning or bighorn densities will be low.

Amphibians and Reptiles

The distribution, abundance, and habitat affinities of amphibians and reptiles have been documented in pinyon-juniper woodlands. Four species of amphibians and 26 species of reptiles were found. Of the reptiles, 50 percent were snakes. The speckled rattlesnake and striped whipsnake were the only snakes common throughout the zone, but the distribution of most snakes is still poorly understood. Seven species of reptiles extended into the bristlecone-limber pine zone.

Toads, frogs, skinks, and salamanders are found near springs, ponds, and seeps. This emphasizes the importance of wet areas for these species. The generally unrecognized diversity of herptofauna in these woodlands, along with specific research and management needs, have been documented.

Endemic and Endangered Plants

Nearly all plants of Utah and other Western States that are listed as threatened, endangered, or sensitive are narrow endemics, which are defined as plants restricted to one or a few counties in one or perhaps two States.

Within the pinyon-juniper thermal belt plant generalists are found on nearly all geologic strata and soil types, but pinyon-juniper and desert shrub communities also support most of the narrow endemics in Utah.

Edaphic control of vegetation by geologic formations is greatest where geologic strata are exposed, and the area must be xeric in order for the substates to be controlling. Dessication is apparently necessary for the ultimate expression of edaphic control, and this is not as common at higher precipitations. Water tends to override the influence of geology. Xeric conditions are also associated with steep slopes, cliff faces, and wind swept slopes where plant specialists are protected from the competition of generalists. Relatively few narrow endemics are found where the area is well mantled with vegetation. Therefore, Utah, with much exposed geology and xeric conditions, supports numerous, relatively narrow endemic plants.

Specific taxa have been arranged into three categories of apparent relationships to pinyon-juniper. Each taxon is named, the geology and soils are discussed, and notes are made on each species. These categories are (1) obligatory or semiobligatory to pinyon-juniper, (2) apparent associates mostly in the interspaces of trees and exposed geologic substrates, and (3) incidentals, which are found within the pinyon-juniper but extend below into the salt desert shrub or above the pinyon-juniper on wind swept slopes and ridges.

Apparently, narrow Utah endemics have evolved where geology and erosion are the primary drivers of plant community composition or dynamics, and these plants are unable to compete with generalists on well-developed soils. Narrow endemic plant population densities are often low, and survival is more a function of adaptation to harsh substrates and dry conditions than their ability to compete.

Semibarren habitats, which have low potential for vegetation manipulation, are occupied by these narrow endemics, and these species can be used as indicators of these low potential sites. Sites better suited for the high production of shrubs and herbaceous species are unsuitable for narrow endemics.

The strong relationship between highly erosive, geologic strata, and narrow endemics indicates an evolutionary situation dependent on harsh conditions and high rates of erosion. This condition predates the advent of Europeans and their livestock by thousands of years.

Most potential conflicts can be resolved where there are well-documented inventories and an understanding of the habitat requirements and biology of narrow endemics.

Old-Growth Pinyon and Juniper Woodlands

Old-growth pinyon-juniper woodlands do not fit the typical image of old-growth coniferous forests. However, some of the oldest stands throughout the Intermountain West are low statured, open, semiarid woodlands.

Old woodlands usually differ in structure and function from postsettlement woodlands, thus adding diversity at the community and landscape levels. Concern over the rapid expansion of these woodlands during the 20th century has overshadowed the presence and values of presettlement woodlands. In addition, wildlife studies have generally not separated postsettlement from presettlement stands.

Pinyon-juniper woodlands should be defined on the basis of tree age and stand structure and function. One age separation may be on the basis of tree establishment prior to European settlement. In the Great Basin rapid expansion of these woodlands coincided with settlement in the late 1860's and 1870's. Old growth can also be based on the structural characteristics of the trees. With age, canopy morphology shifts from a cone shaped to a rounded top. As trees age they may exhibit broad asymmetrical tops, deeply furrowed bark, twisted trunks or branches, dead branches and spiked tops, large lower limbs, narrow strips of bark, hollow trunks, large diameter to height ratios, and bright yellow lichens on the branches. Western and Utah juniper ages can exceed 1,000 years and pinyon 600 years.

At the community level, old-growth woodlands should be described on the basis of the presence of old trees and structural characteristics such as standing and down dead, decadent living trees, cavities, and lichen-covered branches. The pinyon-juniper type has been described as climax with woodlands shifting to grasslands or shrub steppe only following a disturbance such as fire. In the absence of a disturbance, these communities will eventually return to woodland. Old-growth woodlands occur over a wide range of parent materials, soils, aspect, slope, elevation, climate, and disturbance regimes.

Ecological provinces may provide a first separation in the classification of old-growth woodlands. A current system considers: (1) community type based on ecological province, land form, dominant shrubs and grasses, soils, and topography; (2) tree age composition and structure; and (3) understory composition. Age classes are subdivided under presettlement and postsettlement categories.

Researchers have described 13 old-growth woodland types of prehistoric and presettlement distribution and changes, extent and proportion of old growth, soils, species composition, wildlife values, and other attributes.

What should old-growth stands be managed for? These old-growth woodlands make up only a small percentage of pinyon-juniper woodlands, and they are structurally and topographically more complex than the younger, more abundant woodlands. Old-growth is esthetically pleasing and provides recreational, cultural, and spiritual opportunities.

Fire policies influencing these old stands should be evaluated for both suppression and let burn. Fuelwood cutting has been considered wasteful unless cutting is designed to remove postsettlement trees and restore presettlement stand structure.

Studies are needed to determine and describe the range of old-growth woodlands. It is also important to evaluate presettlement and postsettlement changes in community structure and composition, define desired future conditions, and develop management plans for restoring or maintaining old-growth woodlands. These old stands are an important landscape component that support many plant and animal species, and interact with adjacent community types.

Pinyon and Juniper Watersheds

Erosion and Deposition

When juniper canopies begin to mature and close, microtopographic elements become more pronounced. Coppice dunes or mounds beneath the trees are evident. These dunes are higher under the trees than in the interspaces. Within the interspaces, the soil surface can be as much as 1 m lower than at the trunk and are usually covered with gravel. Under the trees the soils are relatively fine-textured and incorporated with leaf litter. The dunes or coppices absorb the energy of flowing water and restrict the sediment delivery downslope.

One question is if sites dominated by mature juniper trees represent degraded or degrading systems. One postulation that juniper successional trajectories are currently in place and are likely to continue for centuries due to the longevity of these trees, resulting in a self-destructing system. Therefore, it is necessary to identify sediment source and sink relationships, which will help identify the need for custodial or active management.

Soil under the trees has an organic horizon that is absent in the interspaces. A petrocalcic horizon appears to restrict the downward growth of roots and impede water percolation and vertical nutrient flux. This horizon is deeper under the coppice dune and nearer the surface in the sparsely vegetated interspace. The sagebrush fluve has a weak petrocalcic layer.

Preliminary findings suggest that horizonation is different between coppice dunes, interspaces, and sagebrush fluves, which might influence the distribution of vegetation. Further studies of this problem are ongoing.

Hydrology and Spring Occurrence

Removal of junipers has altered the hydrologic regime of several small watersheds, resulting in large increases in springs and water yields. A Coordinated Resource Management Plan was developed for the purpose of increasing and maintaining the availability and duration of surface flows, enhance ground water recharge, increase and maintain plant diversity, and structure and provide quality habitat for wildlife and livestock.

Chaining and seeding, wildfires, and prescribed burning have resulted in numerous seeps, wet meadows, and perennial springs emerging. Previously dry stream channels are developing into riparian areas. However, some negative effects are slope instability and seepage erosion.

The hypothesis proposed for this phenomenon is that most springs occur at points of subsurface flow concentration where a shallow soils mantle exists over low permeability bedrock such as shale or where water may flow through a confined aquifer of fractured bedrock or bedrock containing solution cavities. Flow might also be controlled by structural features such as faults.

Preliminary results suggest that most subsurface flow is through fractured bedrock that might create discrete packets of infiltration, transfer, and discharge. Unique geology of a site may force ground water to the surface, allowing increases in water yield to be readily exploitable.

Watershed Scale Research

New research is being developed to address the problems encountered when dealing with extremely variable site conditions and protracted time scales.

The specific objectives are to (1) establish a long-term watershed-scale research site on semi-desert and upland climate zones and (2) perform mechanistic research in pinyon-juniper woodlands that will study ecosystem dynamics such as energy flow, water and nutrient cycling, organismal structure and function, and sediment source/sink relationships. At the same time, the project will address the more pragmatic concerns associated with management objectives, the effects of drastic disturbances and the results of custodial management.

The design utilizes small watersheds and spatial nesting of tributary basins and provides integration of spatial and temporal variability on a realistic scale. Potential treatments will include (1) mosaic thinning, (2) simulated wildfire, (3) mechanical manipulation (chaining), and (4) an untreated control for evaluating carbon sequestration, seed dispersal and population dynamics, and social considerations.

Watershed Values and Conditions

Pinyon-juniper woodlands are of significant economic value for spring-fall livestock grazing and big game winter range. This has led to vegetation manipulations to improve these values. Fire is a natural disturbance, and its frequency and timing are major factors in vegetation dynamics. Precipitation is often inadequate for high plant cover, but is often of sufficient intensity to produce localized runoff and erosion. Plant composition and structure is extremely important for preserving soil resources because of its basis for all other values.

The hydrology of these watersheds is a function of precipitation amount, intensity and seasonality, the geology as it relates to topography, subsurface porosity, and surface soils and understory-overstory vegetation dynamics. When trees are dominant, there is a high transpiration component and high exposure of surface soils between trees that are major sources of runoff and erosion. Geologic parent materials are mainly sedimentary rocks such as limestones, dolomites, shales and sandstones, and igneous rocks. These woodlands are found on mesas, foothills, breaks, mesa edges, escarpments, and depositional areas. Soil surveys indicate that pinyon and juniper occur on almost all textural groups, and these woodlands are not necessarily limited by texture, stoniness, or depth.

It is difficult to characterize pinyon and juniper sites hydrologically because of the great variability in soils, geological substrate, slopes, and precipitation patterns. Studies have shown that evapotranspiration is the major process of water loss, and runoff is less than 10 percent of the water budget. This usually results in little water yield in the form of runoff or ground water recharge. There are still many cases of localized runoff, erosion, down stream flooding, and deposition from pinyon-juniper dominated drainages. The combination of sufficient precipitation (usually over 450 mm per year) and an impermeable layer can create a zone of saturation, and the resulting interflow may be sufficient to feed springs and streams.

Fire occurs in pinyon-juniper when there is sufficient understory to carry it from tree to tree, or when tree canopies "close up" enough for fire to spread from crown to crown. Evergreen pinyon and juniper trees have the ability to accumulate carbon slowly and efficiently by more active year-round photosynthesis than associated herbs and shrubs. This, coupled with their tree growth form, allows the trees to build large above and below ground structures for capturing resources. Under these semiarid conditions, much of the limited precipitation is taken up by the tree's extensive root systems and transpired through their canopies. Tree-root exploitation of water and nutrients from the interspaces often results in the eventual purging of the understory plants in the absence of fire or other tree-killing disturbances.

Prior to European settlement, pinyon-juniper woodlands were open, sparse savannahs or were confined to rock, ridges, and shallow soils where fine fuels were too low to carry fires. The highest period of tree establishment beginning in the mid-1800's was downward in elevation and resulted in reduced understory fuels necessary to carry fires. The change in fire frequency came about initially with heavy understory grazing and removal of fine fuels in the late 1800's to early 1900's, and later with fire suppression following World War II.

Geologic substrate, soil, and climate interact to affect hydrologic responses and interactions. Parent materials produce soils with different infiltration, water-holding capacity, and fertility. Volcanic soils, with high fertility, support the most rapid invasion of pinyon-juniper in the absence of fire. Interspace erosion associated with the loss of nutrients, mycorrhizal fungi, cryptogams, and water-holding capacity can result in permanent loss of understory potential. Such sites may remain as degraded woodlands with little diversity and high runoff potential. This erosion may also result in the loss of archeological values.

Pinyon and juniper woodlands have been subjected to a range of environmental and human-induced disturbances over the years. During the precontact period there were natural and Native American-induced fires and climatic fluctuations. After the mid-1800's came grazing, logging, and fire control. The loss of herbaceous forage and increases in woody vegetation led to the development of brush control and revegetation technologies applied to pinyon-juniper, sagebrush, and other rangelands. It is important to remember the site and situation-specific nature of responses to vegetation manipulations. Resource management is both a science and an art and requires experience and familiarity with specific conditions and responses to specific management.

Tree control projects are usually conducted to increase forage yield, to improve watershed conditions, to increase water yield, and to improve wildlife habitat. The most critical is to improve watershed conditions. Most control projects were conducted from the 1940's through the 1960's but dropped off in the 1970's.

The traditional view is that pinyon and juniper communities, especially on invasion sites, will degrade hydrologically and ecologically unless periodic fire or other tree reductions and associated natural revegetation or seeding allow for increased herbaceous and shrub cover. Proponents of this view are concerned that continuing fire control and lack of other tree control measures are threatening the soils and associated resources. The counter position is that maturing woodlands are not eroding and degrading, and land managers may be using unfounded hydrologic or other benefits to increase forage for livestock. Others may be using similar selective interpretations and self-serving speculations to prevent tree control practices. Proponents of both views seem to agree that grazing and site-specific conditions have affected hydrologic responses and that tree dominance can deplete understory vegetation and seed banks.

There are enough pinyon-juniper woodlands (about 30 million ha or 74 million acres) that we can be selective in vegetation management to improve wildlife habitat, increase forage for livestock, and benefit hydrologic processes.

Multiple Use Management Based on Diversity and Capabilities

The determination of which uses to provide and where to provide them must be based on the land's capabilities and human and wildlife preferences.

The capacity of pinyon-juniper to dominate plant communities has been termed "super dominance" in reference to their ability to greatly oppress understory species and outlive the seed banks of these species. Successional stages of pinyon-juniper woodlands are not necessarily discreet, isolated stages but merely points along a continuum. The use of the term "stages" is used to facilitate communication. The following are stages often used to describe successional processes.

- **Fire and Skeleton Woodland**—In the first stage, live crown cover is reduced to or near zero, and the community looks totally devastated. If burning occurs before the closure of pinyon-juniper has purged the understory, the black surface persists only until sprouting species appear or seeds germinate from seed banks. If the understory has been purged and the site not seeded, the invasive species such as cheatgrass occupy the site.

- **Annual Stage**—This stage may be skipped if the burn occurred before the understory had been purged. Rapid crown cover of annuals is greatly facilitated by cheatgrass. This annual stage can be perpetuated by frequent fires that are fueled by cheatgrass. This stage can persist for 20 years and on southerly exposures up to 80 years.
- **Perennial Grass/Forb**—This community can follow directly after fire if the perennial understory had not been purged by pinyon-juniper closure. Seeding has been successful in establishing good ground cover within 5 years postfire where understory has been purged. Without seeding, cheatgrass can delay dominance of this community for 20 or more years.
- **Shrub/Grass**—This community can also follow immediately after a burn where sprouting shrubs and herbaceous species had not been purged. Where pinyon-juniper crown cover has been as high as 60 percent prior to burning, the shrub cover is often less that 2 percent 10 years postfire. In the absence of sprouting shrubs, crown cover may reach 20 percent or more in about 30 years postfire. This stage persists for about 50 years.
- **Shrub/Open Tree**—In this stage, crown cover of pinyon-juniper increases to about 20 percent. There is often a linear decrease in understory cover at about 5 to 20 percent pinyon-juniper crown cover. A prominent feature of this stage is the dense tree limbs extending to the ground level. Trees of various ages contribute to structural diversity, and this stage appears to be the most complex or diverse structural canopy in the sere. Ground cover is high for soil and watershed protection, and this stage is common for about 60 to 100 years postfire.
- **Tree/Shrub Stage**—This stage is sometimes not distinguished from the previous stages. Tree cover increases from 20 to 40 percent with a pronounced decrease in shrubs and herbaceous species. Understory species of previous stages begin to be purged. This stage is common for 100 to 200 years postfire.
- **Mature Pinyon-Juniper**—At this stage, tree crown cover is typically greater than 40 percent. The crowns are larger and more open than in previous stages, and lower branches are pruned off over time. Shrub and herbaceous layers are completely purged by this time. Cheatgrass remains at low levels, and its nearly ubiquitous distribution indicates that it will dominate the future early seres. Bare interspaces develop and persist in which rills and sheet erosion reach the highest levels except for the skeleton stage. This stage persists for about 200 years or until the next disturbance.

Capabilities and Values

Capabilities are a function of climate, geology, soils, gradient, aspect, plant taxa, variability of seral and plant communities, and other ecological features specific to the site. Values are a function of animal reaction to these features and the human perception and preference for points of a sere. Each seral stage is capable of supporting a different set of needs and desires. Each plant community has intrinsic value, and the value of each stage can vary widely within a diverse public.

Therefore, a mix of successional stages facilitates multiple use and a diversity of values. Higher resource values can be expected where the mix is taylored to the capabilities and values of specific ecological units within the landscape.

Multiple Use Management Based on Diversity of Capabilities and Values Within Pinyon-Juniper Woodlands

Sherel Goodrich

Abstract—Different wildlife species respond differently to different seral stages of pinyon-juniper ecosystems. People also have widely different preferences and uses associated with different stages of succession. Bighorn sheep prefer early seral communities, while forage values for elk and mule deer are much higher in early to mid seral stages, and mature stands provide hiding and thermal cover. Trees used as Christmas trees are more common from young, open stands. Some birds require older stands for seed. Pinyon seed crops are important commercially and for personal use. Some wildlife species are cavity nesters and require large trees in mature stands. Firewood and cedar posts come from mature stands. Watershed values can also vary with seral stage. Visual and intrinsic preferences vary greatly among individuals. To integrate such diverse values into management for multiple uses, managers use tools that include an inventory of ecological units, and studies and recorded observations for each ecological unit, to understand capabilities and values of separate units within landscapes. Application of such an inventory to multiple use management is explored.

Under the Multiple use Sustained Yield Act of 1960 and the Environmental Policy Act of 1970, management for a diversity of values is appropriate for National Forest lands. Legal, Congressional, or administrative mandates aside, providing a diversity of uses on public land seems appropriate. Determination of which uses to provide and where to provide them must be based on the land's capabilities and human and wildlife preferences for various landscape features. Within pinyon-juniper ecosystems, the sum of successional stages or the sere is a major component of capability. Capabilities of a sere vary with ecological units.

Pinyon and juniper trees themselves are obvious and meaningful indicators of values related to different seral stages. However, mature stands of these trees can obscure variability in capabilities related to other successional stages. The capacity of pinyon-juniper to dominate plant communities is so complete that West and Van Pelt (1984) used the term "super dominance" in reference to their ability to greatly oppress understory species and outlive the seed banks of these species. Thus, describing potential uses of pinyon-juniper ecosystems in terms of climax vegetation (pinyon-juniper overstory with depleted understory) is unsatisfactory because it gives little indication of what other vegetative mixes can occur in the sere (Hironaka 1987), and therefore what other values could be provided. Use of geology, geomorphology, gradient, aspect, vegetation, soils and other features as descriptors of ecological units provides a broad base for classification and inventory (Wertz and Arnold 1972) that is not dependent on climax vegetation. Such an approach to classification and inventory has been used in the Green River corridor of Daggett County, Utah, which is the focus of this paper.

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Pinyon-Juniper Successional Stages of the Green River Corridor

To facilitate a discussion of capabilities and values, I present some features of different successional stages. The successional sequence is patterned after Erdman (1970), Everett (1987), and Barney and Frischknecht (1974). This sequence appears to be highly applicable to pinyon-juniper woodlands of the Green River corridor. Successional patterns explained by Everett (1987)—including depletion of the understory with increase in pinyon-juniper cover and eventual purging of the understory when mature pinyon-juniper reach potential crown closure—are highly applicable in the Green River corridor (Huber and others, these proceedings). West and VanPelt (1987) noted that successional stages are not isolated stages but points along a continuum. However, the concept of stages can facilitate communication. Features given are those observed and measured in the Green River corridor and are not necessarily those given in the above cited works.

Fire and Skeleton Woodland

Crown cover—Live crown cover is reduced to zero or nearly so.

Structure—Pinyon-juniper are reduced to skeletons with fines less than 1 or 2 cm in diameter mostly removed. Pinyon begin to fall within the first 10 years after fire, while many juniper skeletons remain standing for three or more decades. Herbaceous species and many shrubs are consumed to near ground level or nearly so.

Plant composition—The community looks totally devastated without apparent composition.

Years—If burned before closure of mature pinyon-juniper has purged the understory, the blacked surface of the skeleton woodland persists only until precipitation and warm temperatures activate sprouting species and the seeds of seed banks. Where closure of pinyon-juniper has purged the understory and where the site is not seeded, the black and desolate appearance might persist for 1 to 2 years while invasive species, including cheatgrass (*Bromus tectorum*), respond to the open site.

Annual

This stage is essentially skipped over where stands are burned before the understory has been greatly reduced by pinyon-juniper closure.

Crown cover—Crown cover of exponentially increasing annuals including cheatgrass increases rapidly. Long-lived seed banks such as those of a few mustards (Brassicaceae) and annual chenopods (Chenopodiaceae) add to crown cover in some stands. Crown closure of 60 to 80 percent can be achieved in 5 to 10 years. This rapid crown closure of annuals is greatly facilitated by cheatgrass.

Structure—Structure is limited to the skeletons of the trees and the annual herbaceous layer.

Plant composition—Annuals dominate the community. These include cheatgrass, Japanese chess (*Bromus japonicus* Thunb.), tansy mustard (*Descurainia pinnata* [Walt.] Britt.), false flax (*Camelina microcarpa* Andrz. in DC.), Jim Hill mustard (*Sisimbrium altissimum* L), prairie pepperweed (*Lepidium densifolium* Schrad.), narrowleaf goosefoot (*Chenopodium leptophyllum* (Moq.) Wats.), wild tobacco (*Nicotiana attenuata* Torr. ex Wats.), knotweed (*Polygonum douglassii* Greene), floccose gilia (*Gilia inconspicua* [Smith] Sweet), Russian thistle (*Salsola* spp.), annual cryptanths (*Cryptantha* spp.), blue-eyed Mary (*Collensia parviflora* Lindl.), and western stick seed (*Lappula occidentalis* [Wats.] Greene). Biennials and short-lived perennials such as hoary aster (*Machaerathera canescens* [Pursh] Gray) are sometimes also a part of this early successional stage.

Of the seed bank species, wild tobacco is particularly noteworthy. Where it has not been seen prior to burning, it has expressed itself in abundance the year after fire. Within 3 years of abundant expression after fire, this plant is commonly not seen again. This indicates the production of a seed bank that is activated only by fire or perhaps other disturbance. Life of the seed bank for this species is indicated to be at least several decades and possible up to 200 years. Also, invasive species with highly mobile seeds are able to colonize these communities. Mobile seeds and aggressive colonization are features of prickly lettuce (*Lactuca serriola* L.), and introduced thistles including Canada thistle (*Cirsium arvense* [L.] Scop.) and musk thistle (*Carduus nutans* L.) which are classed as noxious weeds in several Western States.

Ground cover—Ground cover is reduced to near zero percent with fire. Were high percent crown closure of pinyon-juniper was associated with a purged understory, ground cover is comparatively slow to develop and is much a function cheatgrass and other annuals and the litter they produce. Cheatgrass can be quite effective in producing ground cover, but the quality of this cover for watershed protection is of somewhat lower value than that of perennial species.

Years—With highly competitive species such as cheatgrass, this stage can persist for 20 years and much longer where the perennial understory had been purged by closure of mature pinyon-juniper stands. On southerly exposures of the Green River corridor, cheatgrass has been found as the dominant 80 years postfire (Goodrich and Gale, these proceedings) where it appears it can persist as the dominant until pinyon and juniper return as dominants. This annual stage can also be perpetuated by frequent fires that are fueled by an abundance of cheatgrass.

Perennial Grass/Forb

This community can follow directly after fire where closure of mature pinyon-juniper has not purged perennial, understory plants.

Crown cover—This remains a function of herbaceous species.

Structure—Structure is limited to the skeletons of the trees and the herbaceous layer.

Plant composition—Bluebunch wheatgrass (*Elymus spicatus* [Pursh] Gould) with as many as 40 other herbaceous species form communities on northerly (cool) exposures. Communities with fewer species form on warm (southerly exposures). These include: Indian ricegrass (*Stipa hymenoides* R. & S.), bluebunch wheatgrass, Ross sedge (*Carex rossii* Boott), needle-and-thread grass (*Stipa comata* Trin. & Rupr.), Sandberg bluegrass (*Poa secunda* Presl.), and hairy golden aster (*Heterotheca villosa* [Pursh] Shinn.).

Ground cover—Quality and quantity (including dispersion) of ground cover rapidly improves to provide adequate soil and watershed protection where closure of preburn pinyon-juniper communities had not greatly impaired the understory. Seeding has been highly successful in establishing high percent ground cover within 5 years postfire where the understory had been purged. Quality and quantity of ground cover is a function of numerous fine-stemmed, closely spaced perennial plants and the litter they produce.

Years—Rapidity of development of perennial grass/forb communities highly depends upon closure of pinyon-juniper prior to burning and the dynamics of cheatgrass and other invasive species after burning. Heavy infestations of cheatgrass especially on warm exposures can delay the dominance of these communities for 20 or more years and much longer where they are not seeded. Many of the other annuals decrease rapidly with the development of perennial communities. Without seeding and with little or no cheatgrass competition, this community is usually well developed within 3 years postfire. With seeding this communities can be well developed within 2 years postfire even with strong presence of cheatgrass.

Shrub/Grass

Shrub/grass communities can develop immediately after fire where closure of mature pinyon-juniper have not purged the understory of sprouting shrubs and herbaceous species.

Crown cover—Crown cover rapidly increases where sprouting shrubs and herbaceous species were not purged by closure of mature pinyon-juniper stands prior to fire. Crown cover of sprouting shrubs can be near preburn levels within seven growing seasons after fire where combined crown cover of pinyon and juniper was only about 10 to 15 percent prior to fire (Huber and others, these proceedings). Where combined cover of pinyon-juniper was as high as 60 percent prior to fire, shrub crown cover is often less than 2 percent 10 years postfire. In the absence of sprouting shrubs, shrub recovery is slower with crown cover sometimes reaching 20 percent or more in about 30 years postfire.

Structure—Tree skeletons and especially those of juniper provide some structure. Shrub layers become more complex with taller shrubs such as alder-leaf mountain mahogany (*Cercocarpus montanus* Raf.) and serviceberry (*Amelanchier alnifolia* Nutt.) overtopping big sagebrush (*Artemisia tridentata* Nutt.), snowberry (*Symphoricarpos oreophilus* Gray), yellowbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.), and other lower shrubs with an understory of herbaceous species. Bitterbrush *(Purshia tridentata* [Pursh] DC.) increases in some places usually after big sagebrush.

Plant composition—Herbaceous species are the same as for the perennial grass/forb stage with shrubs including those listed above becoming more dominant.

Ground cover—Ground cover has generally reached potential prior to this stage, and it remains at or near potential through out this stage. With numerous fine-stemmed perennial plants closely spaced, quality and quantity of ground cover are of high value for soil and watershed protection.

Years—This stage persists for up to 50 or more years postfire with some minor return of trees where crown cover of these trees remains less than 3 percent.

Shrub/OpenTree

Crown cover—In this stage crown cover of pinyon-juniper increases to about 20 percent. Everett (1985) found a linear decrease in cover of understory species from about 5 to 20 percent crown cover of pinyon-juniper. However, visual appearance of crown cover of shrubs and herbaceous species remains about the same as for the shrub/grass stage until pinyon-juniper crown cover reaches about 10 percent.

Structure—Structure of the shrub and herbaceous layers remains diverse. A prominent feature of this stage is trees with dense limbs that extend to ground level. These young trees add another tall layer, and they contribute to the diversity of lower layers of structure. Return of trees is typically uneven aged, and thus trees of various ages contribute to structural diversity. This appears to be the most complex or diverse structural canopy stage in the sere. However, it does not provide large boles and soft wood of decay needed by cavity users to excavate cavities. Also, this stage does not provide tall trees with large limbs preferred by some birds including raptors.

Plant composition—Other than the addition of pinyon-juniper, composition remains similar to the previous stage. Although some understory species decrease, few are forced out of the community.

Ground cover—Ground cover remains at high value for soil and watershed protection.

Years—This stage is common from 60 to 100 years postfire.

Tree/Shrub Stage

This stage is not separated from the previous stage by Erdman (1970) or by Barney and Frischknecht (1974). It is separated in this paper for management implications. Fire or other treatment applied to the previous stage will maintain a more resilient understory than if applied to this stage.

Crown cover—Combined crown cover of pinyon and juniper increases from about 20 to 40 percent with a pronounced decrease in crown cover of shrubs and herbaceous species. Sagebrush often becomes decadent while bitterbrush, alder-leaf mahogany, serviceberry, and snowberry persist longer with greater apparent vigor, but they also show reduced numbers, crown size, and vigor.

Structure—Tree structure includes dense limbs to near ground level with larger bole and limbs than in the previous stage, but still hardly of size and sufficient decay to be selected by cavity nesting species and larger birds for nest sites. However, due to the uneven age of trees, some begin to provide this larger structure. During the latter part of this stage, pruning of lower limbs of juniper and especially pinyon is generally initiated, and some trees begin to appear mature. Structure of the shrub and herbaceous layers declines. Return of trees is typically uneven aged, and thus trees of various ages contribute to structural diversity. Skeletons of trees continue to provide some structure, but they become less conspicuous as they fall and as live trees increase.

Plant composition—Understory species present in previous stages begin to be purged from the community. Purging continues throughout this stage during which sagebrush and other species can be eliminated or nearly so.

Ground cover—As the understory is purged, quality and quantity of ground cover is decreased partly as a function of lower dispersion of ground cover. As trees mature, they draw more resources of the site into the area of their crowns. Plants in interspaces begin to thin and bare soil is exposed. Litter is increasingly confined to directly beneath the trees.

Years—This stage is common from about 100 to 200 years postfire.

Mature Pinyon-Juniper

Crown cover—Combined crown cover of pinyon-juniper is typically greater than 40 percent and can be as high as 60 percent or more.

Structure—Structure is largely a function of trees with large boles, large limbs, and more open and larger crowns than in previous stages. Also, decay within large boles increases with age, which is important to cavity using wildlife species. Some younger or smaller trees persist. However, large and small trees are usually pruned of lower branches over time. Purging of shrub and herbaceous layers is completed in this stage with sagebrush generally going first and bitterbrush and mountain brush species persisting longer.

Plant composition—Purging of the understory is carried to a high degree with relatively few individuals of comparatively few species remaining. Shrubs are often totally purged. Remaining herbaceous species include Sandberg bluegrass, Ross sedge, rock goldenrod (*Petradoria pumila* [Nutt.] Greene), and pussy toes (*Antennaria microphylla* Rydb). Cheatgrass remains in the community at low levels. The nearly ubiquitous distribution of this species indicates it will dominate the early part of future seres throughout the pinyon-juniper belt of the Green River corridor.

Ground cover—Interspaces become nearly void of plant and litter cover especially on southerly aspects. Where sites are productive enough to support dense trees with the crowns essentially continuous, a nearly continuous duff layer can develop. However, more commonly large, bare interspaces develop and persist in this stage in which rills and sheet wash reach the highest levels in the sere except for the fire and skeleton stage.

Years—This stage persists from about 200 years postfire and until the next disturbance.

Capabilities and Values

Capabilities are a function of climate, geology, soils, gradient, aspect, plant taxa, variability of seral and mature plant communities, and other ecological features particular to a specific site. Values are a function of animal reaction to these features and human perception and preference for points of a sere.

The sere is a major expression of capabilities. Each stage of succession is capable of supporting a different set of needs for wildlife and other values. Wildlife might also be used to define capabilities. However, composition and percent crown cover and structure of vegetation and forage provided by vegetation function well to define wildlife capabilities, for these are features to which wildlife species respond. Some species also respond to geologic structure such as rock outcrops. Visual values are also a function of geologic features as well as vegetation, and they should be included in an evaluation of land capabilities. With a broad spectrum of geological substrates, soils, aspects, and seral communities, pinyon-juniper woodlands present a wide array of capabilities and values.

Breeding bird surveys from the Green River corridor show a relatively high value of mature pinyon-juniper woodlands for high diversity of species, total number of birds, and for obligate and semiobligate species (Paulin and others, these proceedings). Other workers have also found similar pinyon-juniper obligates and semiobligates (Cherry 1982; Balda and Masters 1980; Fitton 1989). These include bark-gleaning, cavity-nesting insectivores such as chickadees (*Parus* spp.) and plain titmouse (*Parus inormalus*) and those dependent on seeds of pines and junipers for food. Some small mammals such as pinyon mice (*Peromyscus truei*) have been found in pinyon-juniper dominated stands and not in early seral communities (Sedgwick and Ryder 1987). Mature stands also provide hiding and thermal cover for mule deer (*Odocoileus hemionus*) and elk (*Cervis canadensis*). However, without forage openings, pinyon-juniper ecosystems are of low value for deer and elk and thus for large predators such as cougars (*Felis concolor*). Also high values for fuelwood and fenceposts are associated with mature pinyon-juniper stands. Some recreational activities (picnicking and summer camping) are greatly facilitated by shade of mature stands.

Bighorn sheep (*Ovis canadensis*) in the Green River corridor strongly favor early seral stages without visual obstructions of trees and tall shrubs (Smith 1992; Greenwood and others, these proceedings). However, these sheep also prefer steep slopes with a presence of cliffs and ledges that they use to escape predators. Thus, early seral communities in and adjacent to this essential escape habitat have high value for bighorn sheep while such communities at a distance from this essential escape terrain have low value. Pronghorn antelope (*Antilocarpa americana*) are also ungulates of open places that avoid cover of woodlands and forests. However, in contrast to bighorn sheep, pronghorn prefer low gradient plains and plateaus. Pronghorn have also responded positively to early seral communities maintained by fire within the Green River corridor. Sage grouse (*Centrocercus urophasianus*) highly favors shrub/grass/forb communities. As pinyon-juniper replace sagebrush communities, habitat value for these birds is greatly decreased. Some small mammals, such as deer mice (*Peromyscus maniculatus*), are more common in early successional communities (Sedgwick and Ryder 1987). The abundance of these animals can be important to birds of prey and other predators.

Value of yearlong and especially winter range for elk and mule deer is greatly increased by the presence of shrubs with stature that exceeds snow depths and have higher levels of protein and other nutrients than do grasses and forbs in winter. Highest value deer and elk range includes shrub/grass and shrub/open tree communities or mid seral stages intermingled with patches of mature trees that provide thermal cover. Although some birds prefer mature pinyon-juniper communities, others including hawking or foliage gleaning, cup-nesting insectivores such as the blue-gray gnatcatcher (*Polioptila caerulea*), black-throated gray warbler (*Dendroica petechia*), and gray flycatcher (*Empidonax wrightii*) (Ehrlich and others 1988) are favored by presence of shrubs. Vesper sparrow (*Pooecetes gramineus*) and Lazuli bunting (*Passering amoena*) are also associated with mountain shrub species of mid seral communities. Also birds typical of sagebrush formations are also found in stages with an abundance of sagebrush such as the sage sparrow (*Amphispiza belli*) and Brewer sparrow (*Spizella breweri*) (Behle 1981). A shrub component can increase abundance of insects used by many bird species including jays (often considered seedeaters) to feed their nestlings.

Trees most likely to be selected for Christmas trees are most likely to be found in shrub/open tree and tree/shrub communities.

Seeds of pinyon and juniper have value for a number of wildlife species including birds of the Corvidae family (Balda 1987). Pinyon nuts have value for personal and commercial use. Generally, seeds are not part of the sere until the shrub/open trees stage. They are most abundant in the tree/shrub and mature pinyon-juniper stages.

Recreation and visual values can be expected to vary with individuals and their various activities. Bird watching and study of birds are indicated to be at highest value in tree/shrub and mature stages. Viewing and hunting bighorn sheep, elk, deer, and antelope will be facilitated by maintenance of early and mid seral communities. Personal use Christmas tree harvest is a form of recreation for which shrub/open tree and tree/shrub stages are of highest value. Visual qualities can be expected to be highly variable with a diverse viewing public. Perhaps a diversity of stages across the landscape will address this value. Sometimes values expressed by humans run opposite to those favorable for some wildlife species. People often object to standing dead trees left after fire. However, these dead trees provide some cover and structure for wildlife. Also, this human view is not well supported by the ecological history of pinyon-juniper ecosystems that included standing, burnt trees. Objections are also expressed for the blackened and desolate look following fire and the broken debris following mechanical treatments. However, habitat for early and mid seral wildlife and plant species cannot be maintained without treatments that reduce trees. The debris left in place following mechanical treatments can have high value for watershed protection (Farmer 1995).

Erosion hazard is related to successional stages. In the perennial grass/forb stage and midseral stages, the ground is covered by many fine stems of vegetation that are closely spaced and by litter that has a high dispersion value. Mature pinyon-juniper stands tend to have large interspaces of high percent bare ground. This condition is especially noticeable on steep, southerly (warm) exposures in the Green River corridor (Goodrich and Reid, these proceedings). The warm aspects have potential for higher value for mule deer and elk forage in winter than cool exposures due to less depth and duration of snow cover. However, mature stands have much lower value for forage for these animals than do early and mid successional stages. Thus, both watershed and ungulate forage values for these slopes can be higher at early and midseral stages than at the mature stage.

Vigor and diversity of understory communities remains quite high thorough the shrub/open tree stage and then declines thorough the tree/shrub stage, and it is greatly reduced in the mature stage (Huber and others, these proceedings). Vigor of the understory community is critical to the resilience of native plant communities following disturbance. Recovery of native communities can be quite rapid following fire in the perennial grass/forb through the shrub/open tree stages. Recovery of native plant communities is much slower following disturbance in mature pinyon-juniper communities. This feature of pinyon-juniper woodlands has become critical with the advent of cheatgrass, musk thistle, and other highly invasive introduced species. Coupled with the nature of pinyon-juniper to greatly oppress native understory species and outlive the seed banks of these species (West and Van Pelt 1987), the explosive ability of cheatgrass to increase after disturbance (Young and Evans (1978) presents a scenario in which it is difficult to apply a concept of native plant communities. Disturbance is usually a matter of "when" more than of "if." When disturbance comes to mature and old stands of pinyon-juniper, the stands are left wide open to the invasion of cheatgrass and other invasive weeded species by the general lack of native understory species, which is a function of pinyon-juniper stand closure (Everett 1987; West and Van Pelt 1987).

Diverse plant communities develop in early and mid seral stages of succession where in dense mature stands of pinyon-juniper understory communities are often of low diversity and members of these communities are of low frequency. However, mature and old stands provide structural features not found in earlier stages.

Intrinsic values are sometimes raised as an issue. Each plant community has intrinsic value, and the value of each stage can vary widely within a diverse public. This ambiguous value is included in the other more specific values addressed above.

Ecological Units

Management for diversity of values will be well served by an understanding of capabilities. Hironaka (1987) suggests the trees themselves do not provide a bases for classification, and their suppression of understory species often prohibits classification based on the understory. Classification, inventory, and documentation of community features based on more than the end point of a sere are critical to understanding values and capabilities.

A Land Systems Inventory has been developed for part of the Green River corridor based on geology and geomorphology with gradient, aspect, soils, vegetation, and other features also used as descriptors of ecological units (Wertz and Arnold 1972). Classification is an inherent part of this inventory. The inventory also includes some information on capabilities and values of different ecological units. As more information is acquired through studies, research, observations, and experience, this is added to the inventory. Such a "living inventory" seems vital to adaptive management. This paper and other papers referenced in this paper dealing with the Green River corridor can be used as a part of the database of the Land Systems Inventory.

Managing for various values can be greatly facilitated by information about the capabilities of various land units within a landscape. Without specific examples this concept seems to remains rather empty. Thus, specific examples from the Green River corridor are used in the following discussion.

In this area, soils, vegetation, visual values, and wildlife habitat are much a function of geologic features. These features are basic to an evaluation of land capabilities. Basic to management of the pinyon-juniper belt is the consideration of how much of each successional stage is desired and where on the landscape these stages should be emphasized. A equal portion of each stage or some other mix of stages as suggested by Amundson (1996) may be satisfactorily defined in a conceptual or programmatic manner without considering where on the landscape each stage is to be emphasized. However, a random assignment of succession stages to actual parts of the landscape without regard to inherent capabilities of different ecological units within the landscape does not appear to be the most effective way to achieve a desired mix.

An evaluation of lands within the context of the Land Systems Inventory indicates different successional stages may be more appropriate for different land units. Based on a dominant feature of ridge and ravine topography as a function of differential weathering of geologic strata at the flank of the Uinta Mountain uplift, a landtype association referred to as "Structural Grain" was identified in the Land Systems Inventory. The Red Canyon gorge of the Green River was identified as "Red Canyon" Landtype Association. Nearly all of the Structural Grain Landtype Association and southerly exposures of the Red Canyon Landtype Association support pinyon-juniper communities or have the capacity to do so. Landtypes within these associations have been identified by number. This inventory is consistent with the concept of ecological units as defined within a National Hierarchical Framework of Ecological Units that has been adopted by U.S. Department of Agriculture, Forest Service as discussed by McNab and Avers (1994). They also fall within the concepts of Godfrey (1977), Godfrey and Cleaves (1991), and Wertz and Arnold (1972). A discussion of all ecological units identified for the pinyon-juniper belt of the Green River corridor is beyond page limitations for this paper. Following are three examples of these ecological units and management implications based on capabilities and values.

Structural Grain Landtype 2 Ecological Unit

Features—The landtype consists of ridge and ravine topography underlain by the Uinta Mountain Group, which includes shale and quartzitic sequences. The shale and other more easily eroded units have been eroded to produce the ravines, while the more resistent beds form ridges. The ridge/ravine sequence has a general east-west direction with northerly (cool) and southerly (warm) exposures of about 20 to 40 percent slope. The shrub/open tree stage of the cool exposures includes alder-leaf mountain mahogany/bluebunch wheatgrass communities with as high as 40 or more herbaceous plant species and often five or more shrub species (Huber and others, these proceedings). Within the Green River corridor, this diverse community is nearly unique to the Structural Grain Landtype Association. Earlier stages of succession on southerly exposures support Indian ricegrass, bluebunch wheatgrass, and a few other herbaceous species followed by mountain big sagebrush and rubber rabbitbrush. Seral communities of both cool and warm aspects can be essentially purged under mature stands of pinyon-juniper. The soil surface of cool aspects is well mantled by vegetation and litter through the shrub/tree stage and often by a layer of duff under the dense canopy of mature pinyon-juniper. The soil surface of warm aspects is moderately to highly protected by vegetation and litter in the perennial grass/forb through the shrub/open tree stage. However, as pinyon-juniper increase, the understory is depleted and ground cover decreases to the duff found under the canopies of trees with the interspaces nearly barren. Low watershed values can be associated with mature and old pinyon-juniper stands on the warm aspects (Goodrich and Reid, these proceedings).

These warm slopes can have comparatively high value for wild ungulate forage in winter because depth and duration of snow cover is less here than on cool exposures. However, the shrub stages of the cool exposures also have high value for wintering wild ungulates due to the abundance of taller shrubs including alder-leaf mountain mahogany and serviceberry. Much of the landtype is far enough removed from high value bighorn sheep escape terrain that it generally has low value for these animals. However, parts of the landtype are close enough to escape terrain to be of high value for bighorn sheep.

Management Implications—The diversity and uniqueness of shrub/grass and shrub/open tree stages indicate high value for maintaining these stages on this land type. These communities have high value for wintering mule deer and elk and for some birds and small mammals favored by shrubs. Long-term occupancy of mature pinyon-juniper stands deplete and eventually purge the understory. Where shrub/open tree communities are now present on the landscape, maintenance of the understory is indicated as high priority for management. Maintenance will require fire or other disturbance that reduces trees before shrubs, grasses, and forbs lose the ability to rapidly recover. Some stands where the understory is already purged include large boles and crowns in the structure. These serve to provide overall diversity and values associated with mature stands.

The apparent high value for winter forage for wild ungulates of early to mid successional stages of the warm, southerly exposures coupled with the erosive nature of some of these slopes under mature pinyon-juniper indicate high value for perennial grass through the shrub/open tree stages.

Capabilities and values of this ecological unit strongly indicate primary emphasis for early to mid seral communities. This emphasis should not preclude some mature stands. A fire return interval of 100 to 150 years is indicated to maintain these seral stages (Goodrich and Barber, these proceedings).

Structural Grain Landtype 7 Ecological Unit

Features—High frequency of scarp and dip slopes is typical of the landtype. The scarp slopes (of southerly exposure) often include cliff faces. The dip slopes (of northerly exposure) frequently have bed rock at or near the surface. Many pinyon-juniper trees are large and 200 to 300 years old. Some are over 400 years old. Understory vegetation is sparse. The highly diverse mountain brush communities of Structural Grain Landtype 2 are generally lacking on this landtype. However, bitterbrush is often present, and it increases with reduction in tree cover.

Currently nearly all of this ecological unit supports mature and old stands of pinyon-juniper. Ponderosa pine (*Pinus ponderosa* Laws.) is also occasionally to locally common on the landtype, which provides another layer of canopy and another dimension to woody structure. Large trees of pinyon, juniper, and ponderosa pine indicate high value for cavity nesting species. The large crowns and diverse layers of canopy provided by these trees indicate high value for many bird species and some small mammals. High percent rock at the soil surface and in the profile provide stable watershed conditions under mature stands of trees. A large unit of the landtype is adjacent to Flaming Gorge Dam. It is dissected by a National Scenic Highway (Highway 191) and by power transmission corridors. It is also near the town of

Dutch John. These features indicate difficulty for prescribed burning and other management practices.

Management Implications—Inherent and imposed features of this ecological unit strongly indicate emphasis for mature and old stands. Old trees on the landtype indicate a fire return interval of greater than 200 years to be an inherent part of the ecological history of the landtype. Increased recreation use associated with Flaming Gorge Reservoir presents a higher potential for fire than that under which these stands developed. Fire suppression could be helpful and seems appropriate in maintaining greater than a 200 year fire return interval.

Red Canyon Landtype 1 Ecological Unit

Features—The gorge of Red Canyón carved by the Green River is the prominent feature of this landtype. It includes massive cliffs of Precambrian quartzitic materials and shales of the Uinta Mountain Group. Also included are steep, rocky slopes of mostly greater than 40 percent slope. Southerly (warm) exposures dominate the landtype. Daytime temperatures well above freezing are common in midwinter on some of these slopes. Abundance of escape terrain and aspects that are warm in winter indicate high value for bighorn sheep. Smith (1992) and Greenwood and others (these proceedings) found warm aspects of Red Canyon to be highly selected by bighorn sheep. Such aspects are also conducive to abundance of cheatgrass (Goodrich and Gale, these proceedings). The winter annual habit of cheatgrass indicates high forage value of this plant for bighorn sheep. These sheep have been observed in winter on the landtype with green muzzles from feeding on wintergreen cheatgrass. However, cheatgrass does not provide nutritional needs in all seasons of the year. Maintenance of a diverse forage base will better meet the needs of these animals. Timely use of fire and seeding perennial species are important to maintain a balanced forage base. Evidence of past fire is common on the landtype. However, in many places rock cover is high and density of vegetation is sparse. In these areas fire frequency and size are expected to be low due to rock cover.

Management Implications—Pinyon and juniper have the ability to displace all other plant communities in the absence of fire or other disturbance. The high value of this landtype for bighorn sheep indicates emphasis for early seral communities with low presence of trees and tall shrubs. A fire return interval of less than 80 years is indicated for achieving and maintaining high value habitat for bighorn sheep.

References

Amundson, J.; Ogle, K.; Winward, A. H.; and others. 1996. Properly functioning condition. Draft Process—Version. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 31 p.

Balda, R. P. 1987. Avian impacts on pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 525-533.

Balda, R. P.; Masters, N. 1980. Avian communities in the pinyon-juniper woodland: A descriptive analysis. In: DeGraff, R. M. and Tilghman, N. G. comps. 1980. Workshop proceedings: management of western forests and grasslands for nongame birds; 1980 Feb. 11-14; Salt Lake City, UT. INT-GTR-86. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 146-167.

Barney, M. A.; Frischknecht, N. C. 1974. Vegetation changes following fire on the pinyon-juniper type of west-central Utah. J. Range Manage. 27: 91-96.

Behle, W. H. 1981. The birds of northeastern Utah. Occasional Publication Number 2. Salt Lake City, UT: University of Utah, Utah Museum of Natural History. 136 p.

Cherry, M. B. 1982. The effects of pinyon-juniper chaining on wildlife of the Fillmore Ranger District, Fishlake National Forest. Logan, UT: Utah State University. 114 p. Thesis.

Erdman, J. A. 1970. Pinyon-juniper succession after natural fires in residual soils of Mesa Verde, Colorado. Brigham Young University Science Bulletin Biological Series 11. Provo, UT: Brigham Young University. 24 p.

Erhlich, P. R.; Dobkin, D. S.; Whoye, D. 1988. The birder's handbook: A field guide to the natural history of N. American birds. NY: Simon and Schuster. 785 p.

Everett, R. L. 1987. Plant response to fire in the pinyon-juniper zone. In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 152-157.

Farmer, M. 1995. The influence of anchor chaining on the watershed values of a pinyon juniper woodland in central Utah. Provo, UT: Brigham Young University. 46 p. Thesis.

Fitton, S. 1989. The Utah juniper obligates. Nongame Species Accounts. Wyoming Game and Fish Department. 48 p.

Godfrey, A. E. 1977. A physiographic approach to land use planning. Environmental Geology 2:43-50.

Godfrey, A. E.; Cleaves, E. T. 1991. Landscape analysis: Theoretical considerations and practical needs. Environ. Geol. Water Sci.: 2: 141-155.

Goodrich, S.; Gale, N. These proceedings. Cheatgrass frequency at two relic sites within the pinyon-juniper belt of Red Canyon. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Goodrich, S.; Barber, B. These proceedings. Return interval for pinyon-juniper following fire in the Green River Corridor, near Dutch John, Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Goodrich, S.; Reid C. These proceedings. Soil and watershed implications of ground cover at burned and unburned pinyon-juniper sites at Rifle Canyon and Jarvies Canyon. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Greenwood, C.; Lytle J.; Goodrich, S. These proceedings. Response of bighorn sheep to burning in the Green River Corridor, Daggett County, Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Hironaka, M. 1987. Classification of the pinyon-juniper vegetation type. In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 199-201.

Huber, A.; Goodrich, S.; Anderson, K. These proceedings. Diversity with successional status in the pinyon-juniper/mountain mahogany/bluebunch wheatgrass type near Dutch John, Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

McNab, W. H.; Avers, P. E. 1994. Ecological subregions of the United States: section descriptions. Administrative Publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

Paulin, K.; Cook, J.; Dewy, S. These proceedings. Breeding bird communities in pinyon/juniper woodlands of northeastern Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sedgwick, J. A.; Ryder, R. A. 1987. Effects of chaining pinyon-juniper on nongame species. In: Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 541-551.

Smith, T. S. 1992. The bighorn sheep of Bear Mountain: ecological investigations and management recommendations. Provo, UT: Brigham Young University. 425 p.

Wertz, W. A.; Arnold, J. A. 1972. Land systems inventory. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 12 p.

West, N. E; Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

Winward, A. H. These proceedings. Using a hierarchical approach for classifying pinyon/juniper communities and sites. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Young, J. A.; Evans, R. A. 1978. Population dynamics after wildfires in sagebrush grasslands. J. Range Manage. 31: 283-289.

Watershed Values and Conditions Associated with Pinyon-Juniper Communities

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Abstract—Pinyon-juniper watersheds are important seasonal transition areas for grazing and wildlife habitat. Tree control to improve habitat and hydrologic responses have been questioned because low precipitation, high evapotranspiration, and coarse surface soils of many sites suggest that runoff, erosion, and subsurface water yield should be minimal anyway. Lack of measured data and highly variable site conditions prevent applying these generalities to all sites. Invasion sites with high soil erosion potential may quickly degrade when a small decrease in interspace vegetation cover and water storage capacity increases connectedness of runoff pathways during intense summer thunderstorms. Tree control practices which leave downed trees and debris in place and increase interspace vegetation cover may help save such sites from permanent degradation.

Pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) plant communities have been of major interest from a watershed stand point because of their extensive distribution and location in the semiarid Intermountain West. Variations of these communities are distributed on about 30 million hectares mainly across Arizona, Colorado, Nevada, New Mexico, Texas, and Utah, with lesser distributions in California, Idaho, and Oregon (West and others 1975). Their wide range elevationally from about 1,000 to 3,000 m and topographically on alluvial fans and bajadas, foothills, terraces, mesas, and mountain slopes (West and others 1975; Evans 1988) has made these communities extremely important for their resource values. Watershed concerns and values center around 1) their importance as transitional areas for livestock forage and wildlife habitat, 2) their potential for water yield, 3) the effects of their potential surface runoff and sediment on downslope, offsite values , and 4) their potential onsite erosional degradation.

These lands are transitional between lower elevational lands that are topoedaphically more arable under irrigation and higher elevational mountain shrub and coniferous forest lands with more dependable precipitation. This extent and topographic position results in significant economic value of these lands for spring-fall livestock grazing and for winter range of big game such as mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) and has led to vegetation manipulations to improve these values (Roundy 1996). There has been a major concern over the hydrologic and ecological impacts of these vegetation manipulation practices.

Droughts in the 1950's led to studies to increase water yield from pinyon-juniper woodlands and other forests (Wilcox 1994). Such potential has been strongly questioned for pinyon-juniper lands because of their low precipitation. Also, the location of these woodlands on slopes just above alluvial fans and valleys with more gentle slopes has made them sources of flooding and debris flows from summer thundershowers to some of the towns in the Intermountain area located at the base of these slopes (Stevens 1997). A major large-scale off-site concern for the hydrology of these lands is their potential contribution to salt and sediment in the Colorado River drainage (Rasley and Roberts 1991).

There is also a major concern for the onsite erosional degradation of these woodlands and especially former grass and shrublands downslope considered to be invaded by these trees in the absence of fire. These lands have a semiarid climate with 200 to 500 mm annual precipitation in the form of winter snows and light rains but also potentially-intense summer thunderstorms (West and others 1975). Therefore, the nature of the precipitation, seasonal aridity, surface hydrology, and soil moisture are the major determinants of interacting ecological and hydrological processes. As in many other seasonally dry plant communities world wide, fire occurs as a natural disturbance and its frequency and successional timing have a major affect on vegetation dynamics (Wright and Bailey 1982). The precipitation on many of these lands is inadequate to produce high plant cover, but is of sufficient intensity during summer thundershowers to produce localized runoff and erosion (Baker and others 1995). The composition and structure of these plant communities relative to hydrologic function is therefore an extremely important concern to land managers who want to preserve soil resources as the basis for all other values.

In this paper, we review the hydrology of pinyon pine and juniper lands relative to their function and ecology and discuss watershed responses to vegetation manipulations as a basis for more informed management of these lands.

Hydrologic Relationships

The hydrology of pinyon and juniper watersheds is a function of the precipitation amount, intensity and seasonality, the geology as it relates to topography, subsurface porosity, and surface soils, and understory-overstory

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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vegetation dynamics as affected by disturbance regime. Because pinyon and juniper compositional variants occur across a wide range of climatic conditions and elevations, they also vary widely in the interaction of these major factors and therefore in their hydrology (Hawkins 1987). Common to the hydrology of many of these communities when trees are dominant are a relatively high evapotranspirational component of the water budget (fig. 1) and high exposure of surface soils between trees that are potentially major sources of runoff and erosion. However, a lack of hydrologic data in general (Schmidt 1987), and lack of data for specific sites requiresthatmanagement-oriented predictions of hydrologic responses for a given site be based on a good understanding of the interaction of these major factors.

Geology and Physiography

An understanding of the geological substrate, including it's effect on surface soil and associated infiltration, it's effect on soil fertility and associated vegetation dynamics, and it's subsurface porosity and associated effects on drainage and water yield are essential in understanding pinyon-juniper site hydrology. The Basin and Range and Colorado Plateau physiographic provinces contain over 70 percent of the land area occupied by pinyon and juniper communities (West and others 1975). Geologic parent materials consist mainly of sedimentary rocks such as limestones, dolomites, shales, and sandstones, formed from Paleozoic, Mesozoic and Cenozoic sediments, and igneous rocks from Tertiary and Quaternary vulcanism (Hunt 1967; Hintze 1988).

In the Basin and Range province, pinyon and juniper grow on the shallow rocky slopes and escarpments of the mountain ranges, as well as on lower mountains, foothills, and depositional areas. In the Great Basin, these mountains were block faulted during the Tertiary and Quaternary periods and are mainly complexly deformed Paleozoic sedimentary rocks of limestone, sandstone, siltstone, and shale (Hunt 1967). Some of the mountain ranges formed from Precambrian metamorphic rocks of gneiss, schist, and quartzite, or, in some cases, Precambrian sedimentary deposits.

Tertiary vulcanism produced localized granitic intrusions in the Basin and Range Province, as well as in the Colorado Plateau. Examples of these igneous intrusions in the form of stocks and laccoliths into older sedimentary layers include the Henry, Abajo, and La Sal Mountains in southeastern Utah (Stokes 1988). Tertiary vulcanism also produced major extrusive igneous rocks in the form of basalt flows and cinders as well as rhyolite flows, ash or

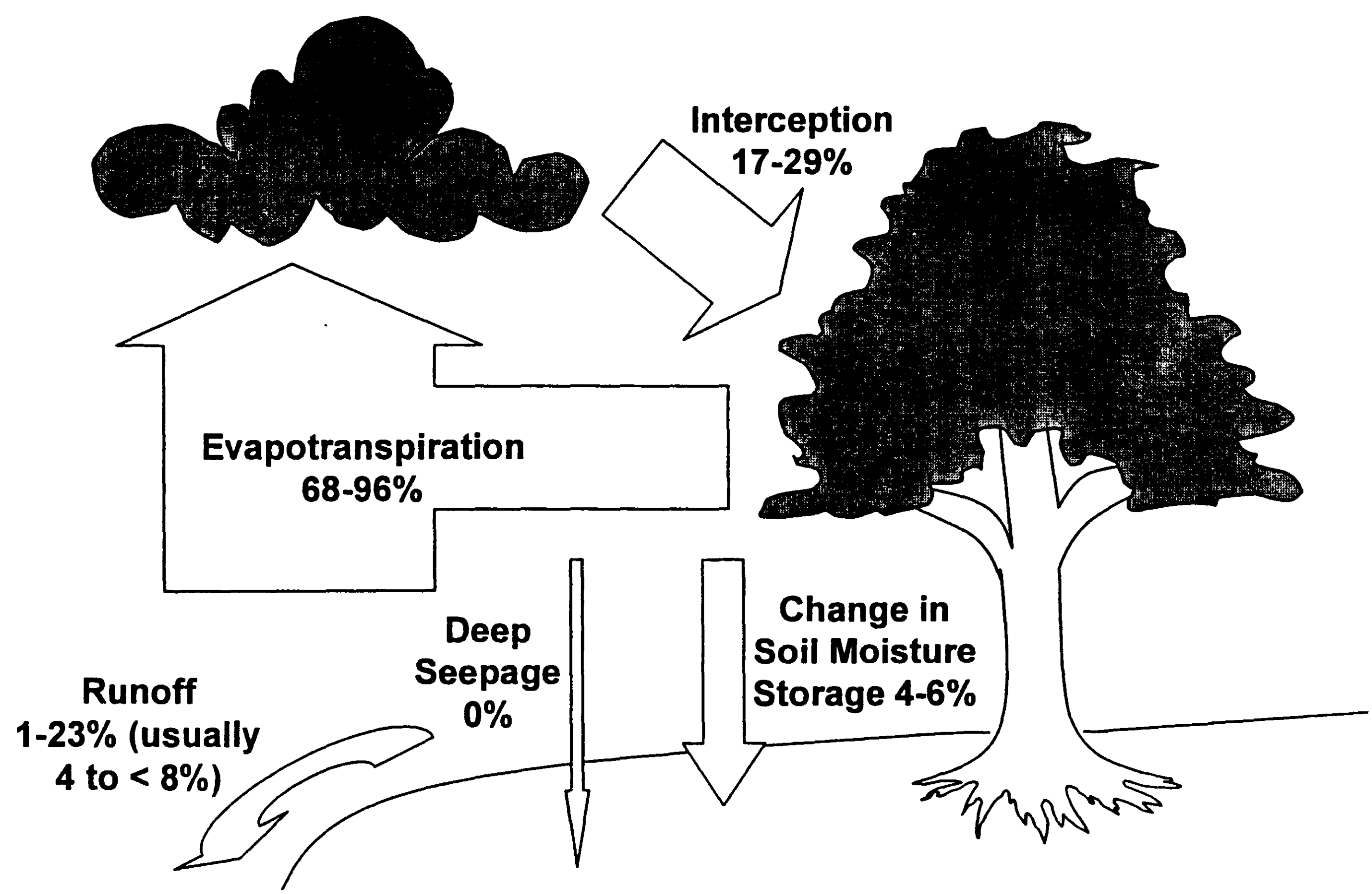

Figure 1—Hydrologic budget components of pinyon and juniper watersheds from estimates or compilations of Gifford (1975), Young and others (1984), Hawkins (1987); Lane and Barnes (1987), Eddleman and Miller (1992), and Wilcox (1994).

breccia (Stokes 1988; Hintze 1997). These volcanic materials make up many of the mountain ranges in the Basin and Range Province in south central Nevada, and include major areas where the Basin and Range and Colorado Plateau Provinces meet in Arizona and especially in south central Utah (Hintze 1997). Quaternary vulcanism associated with Basin and Range faulting has also produced localized lava flows and cinder cones (Chronic 1990).

Pinyon and juniper woodlands are found on the mesas, foothills, breaks, mesa edges, escarpments and depositional areas of the Colorado Plateau (Dortignac 1960). The predominate sedimentary rocks of the plateau formed from vast inland seas or sandy deserts during the Paleozoic and Mesozoic eras, and also from depositions in large, freshwater lakes during the early Tertiary period (Stokes 1988).

Because of highly varied geology and physiography, pinyon and juniper communities occur across a wide range of surface soils from stony, cobbly, and gravelly sandy loams to clay loams (Springfield 1976). An analysis of 100 soil surveys in Nevada, New Mexico, and Utah indicated that various species of pinyon and juniper occur on almost all textural groupings (Leonard and others 1987). The predominant textural groups in the particle size control section of the profile were coarse loamy and fine loamy and surface horizons were predominately gravelly or stony. Soil depth ranged from < 0.5 to > 1.5 m- deep but were shallower for soils described in Nevada and Utah compared to New Mexico. Leonard and others (1987) suggested that soils in New Mexico were described for all occurrences of pinyon and juniper while soils in Nevada and Utah were only described for shallow or skeletal sites with lower understory production and less fire potential. This study helps confirm that pinyon and juniper distribution is not necessarily limited by soil texture, stoniness, or depth, and suggests that a knowledge of the soils on a site is necessary for appropriate management (table 1).

Hydrologic Components

The great variability in soils, geological substrate, slopes and precipitation patterns make it difficult to uniquely characterize pinyon and juniper communities hydrologically (Hawkins 1987). Schmidt (1987) has lamented the lack of hydrologic data for pinyon and juniper watersheds and the misapplication of existing site-specific data to support general conclusions. It appears that the reverse is also true, sometimes generalizations are used to conclude or predict responses on specific sites. Wilcox (1994) summarized watershed and hillslope studies of the 1960's and 1970's, most of which were set up to evaluate the effects of vegetation manipulation on runoff and water yield. He concluded that in general, evapotranspiration is the major process of water loss; that runoff is less than 10 percent of the water budget; that streamflow is ephemeral and generated by intense summer thunderstorms, prolonged frontal storms, and melting snow; and that groundwater recharge is limited due to high evapotranspiration. The temporal and spatial variability of data in Wilcox's (1994) own study in New Mexico led him to state that hypotheses proposed for other semiarid systems are also true for pinyon and juniper woodlands. These include that runoff varies with scale and decreases as the size of the contributing area increases, that infiltration capacity is seasonally dynamic and highly dependent on soil moisture content and frost, and that erodibility follows the seasonal infiltration capacity.

Rangeland watershed research has shifted emphasis from measuring effects of management treatments to measuring processes at a range of relevant scales in order to more accurately predict hydrologic responses (Blackburn and others 1994). Research of this magnitude and intensity has been recommended for the pinyon and juniper zone (Schmidt 1987). Dobrowolski (1997) is setting up multiscale studies on juniper sites in the Clover Creek area of the Onaqui Mountains in Utah. Similar studies are under way at the Los Alamos National Laboratory's Environmental Research Park in north-central New Mexico (Wilcox 1994; Wilcox and others 1996a; Davenport and others 1998). Such studies are important, since watershed responses involving interactions among time, land, and water input, transport, and output processes do not scale up linearly (Hawkins 1987).

Because of low precipitation, Hawkins (1987) characterized pinyon and juniper hydrology as dominated by surface phenomena. He concluded that 95 percent of the precipitation becomes soil moisture, much of which is lost to evapotranspiration. Other authors have also characterized the hydrologic

Table 1—Geologic parent materials and properties of soils associated with pinyon-juniper communities in Arizona and New Mexico (Springfield 1976).

Parent material	Infiltration capacity	Moisture holding capacity	Fertility
Jurassic sandstones	High	Low	Low
Supai sandstones	Medium	Medium	Low
Coconino sandstones	High	Low	Low
Kaibab limestone	High	Low	Low
Redwall limestone	Medium	Medium	Medium
Triassic shales	Low	High	Low
Mesa Verde formation	Medium	Medium	Medium
Tertiary volcanics (basalt)	Medium	High	High
Quaternary volcanics	Medium to high	Low to high	Low to high
Granite	High	Low	Low
Sand and gravel	High	Low	Low

budget as being dominated by interception and evapotranspirational water losses, with little water left over for runoff or deep drainage (fig. 1). Newman and others (1997) found that soil water evaporation was mainly from the upper 10 cm of soil in both ponderosa pine (*Pinus ponderosa*) and pinyon-juniper communities in New Mexico. Hawkins (1987) considered storm runoff from pinyon-juniper communities to be rare and limited in volume. He expected that limited runoff, combined with the usual stony surfaces of pinyon and juniper land would produce modest erosion. He also went through a major exercise to show that some applied hydrological methods widely used by land managers were inaccurate for predicting responses under conditions of threshold runoff, especially when local data were lacking for calibration. It is important to point out that, although some studies have measured various hydrologic variables such as precipitation, interception, soil water change, and even runoff, no studies have carefully measured all components of the hydrologic cycle on a specific pinyon-juniper site. Thus estimates of high evapotranspiration, low runoff, and limited deep drainage may make sense, but are not backed up by needed measured data over a range of scales on different sites and geological substrates.

While the generalizations may apply, there are still cases of localized runoff, erosion, downstream flooding, and deposition from pinyon and juniper watersheds (Stevens in press). For example, the town of Manti, Utah historically never developed on the southern end because of frequent flooding and deposition from upslope pinyon and juniper-dominated drainages (Stevens 1997). Other towns in the Great Basin, such as Ely, Nevada have experienced similar flooding from surrounding pinyon and juniper watersheds. Pinyon and juniper landscapes are subject to high-intensity summer thunderstorms (Schmidt 1987). Even if these rarely occur, they can cause considerable damage when they do occur. In the absence of hydrologic measurements for specific sites, application of generalizations, rather than an understanding of hydrologic interactions for the specific site can lead to incorrect management predictions and decisions.

A component of the hydrologic budget that has often been overlooked for semiarid watersheds is interflow (Wilcox and Breshears 1997) . Where the combination of sufficient precipitation (usually over 450 mm/year), and an impermeable layer create a zone of saturation, the resulting interflow may be a source for streamflow (Wilcox and Breshears 1997). Downward movement of water through the soil profile was much less for a ponderosa pine site with a clayey subsurface soil horizon than it was for a nearby pinyon-juniper site with lower subsoil clay content (Newman and others 1997). Although low precipitation and high evapotranspiration of pinyon-juniper communities generally results in very little deep groundwater recharge, there may still be many sites where a shallow impermeable layer allows short seasonal saturation and sufficient interflow to feed local springs and streams.

While sophisticated models for wildland hydrology prediction are being developed, a simple conceptual model may help to explain the response of pinyon and juniper woodlands to intense thunderstorms and help to guide management decisions. This conceptual model has been used to illustrate the relationship of wind and water erosion to bare ground and vegetation cover (Branson and others 1981). Baker and others (1995) recently applied a modified form of this model (Heathcote 1983) to pinyon and juniper lands. The model shows a major potential increase in water erosion of bare surfaces compared to those with vegetation cover where annual precipitation exceeds 400 mm. The important point is that annual precipitation for the pinyon and juniper zone is insufficient to produce enough vegetation cover to prevent erosion, but is sufficient, especially with short-term thunderstorms of high intensity (Schmidt 1987) to produce water erosion. Therefore the amount and type of soil cover and the soil-holding ability of root systems are major determinants of erosion control for these areas.

Wood (1988) has explained how pattern and density, in addition to cover of vegetation in semiarid areas have a major effect on infiltration and erosion. He suggested that for a given plant cover, a greater density and perhaps dispersion of plants offers greater soil protection. Large, bare, connected interspaces between trees have much lower infiltration rates than tree mounds and can become major source areas for sediment and pathways for runoff. Wilcox and Wood (1989) also determined that vegetation cover, especially that of shrubs, was important in decreasing interrill erosion. Lack of cover and organic matter inputs, coupled with raindrop impact may result in low aggregate stability and the formation of surface crusts with low infiltration rates on semiarid interspace soils (Blackburn 1975; Roundy and others 1990). In contrast, subcanopy inputs from drip and stem flow (Young and others 1984) should be expected to infiltrate the well-aggregated, litter-covered soils beneath the trees (Blackburn 1975; Roundy and others 1978) unless stopped by an excessive unwettable layer (Scholl 1971). Davenport and others (1996) found little difference in soil morphological properties between interspace and canopy areas on a rhyolitic pinyon-juniper site in New Mexico. This suggests that runoff-erosion responses in pinyon-juniper communities are not associated with the physical effects of tree roots on soil morphology, but rather a result of biological interactions (Breshears and others 1997). Although it has been difficult to measure, determination of hydrologic source-sink relationships for canopy and interspace zones is needed to better understand pinyon and juniper runoff and soil movement at the landscape scale (Wilcox and Breshears 1995).

Wilcox and Breshears (1995) suggested a conceptual framework, scales, and functional units and hypotheses of hydrologic differences and connections for each scale for field studies of pinyon-juniper woodlands and other semiarid systems (fig.2). At the woodland, intercanopy, and herbaceous patch scales, they hypothesized that most runoff and erosion would come from interconnected, bare interspaces, but that herbaceous patches could serve as sinks for water and sediment. This framework serves well to organize future hydrologic research on semiarid lands.

Davenport and others (1998) have integrated many of the foregoing ideas into a conceptual model of soil erosion in pinyon-juniper systems. Their work in New Mexico (Wilcox and others 1996a; 1996b) suggests that soil erosion for a site is a product of the interaction of soil erosion potential (SEP, a function of climate and edaphic factors) and cover conditions. A threshold of accelerated erosion occurs when ground cover in intercanopy areas is reduced to the point

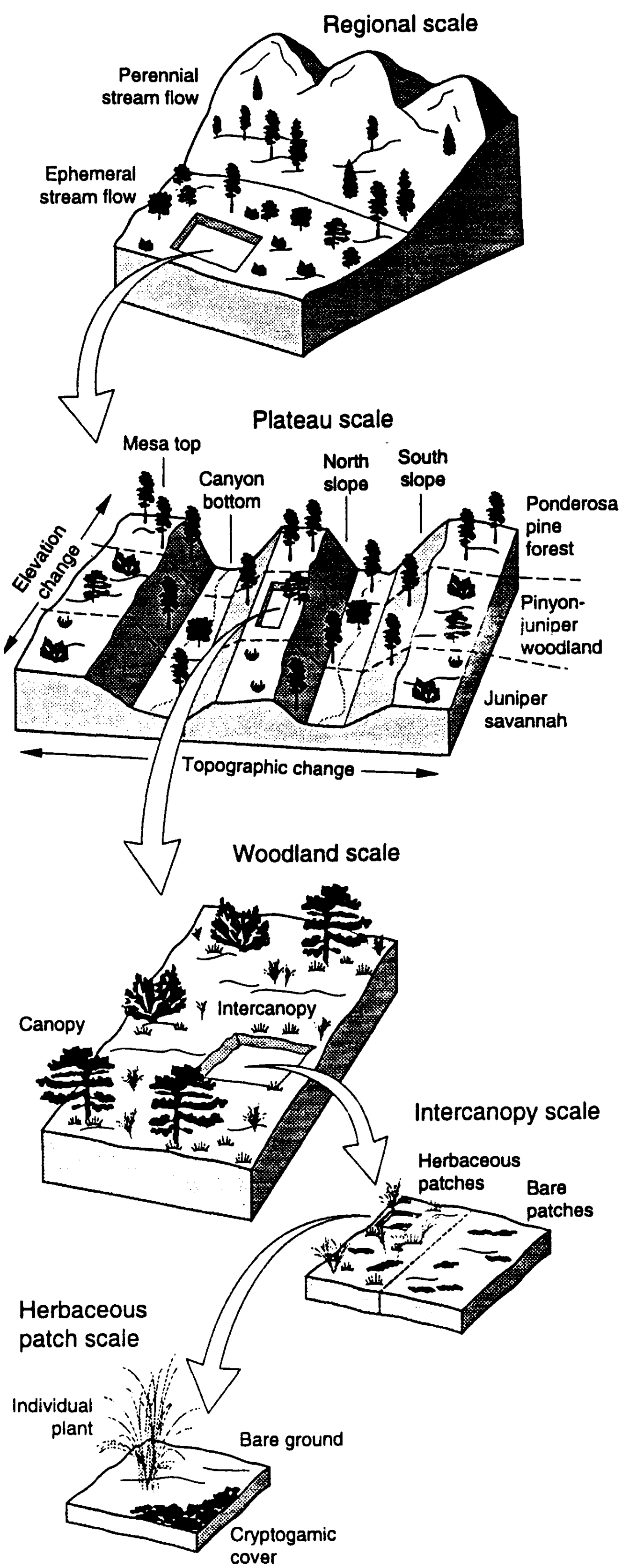

Figure 2—Conceptual model of hydrologic processes for the Pajarito Plateau showing functional units at each scale (Wilcox and Breshears 1995).

that precipitation runs off through connected interspaces when storage capacity is exceeded. For sites with high SEP due to such factors as fine soil texture, high rainfall intensity, and higher slopes, a small reduction in intercanopy ground cover can result in substantially accelerated erosion. Davenport and others (1998) suggested that the range of site conditions associated with high SEP are limited for the pinyon-juniper woodland, but that sites with these particular conditions could cover large areas.

Vegetation Dynamics

Fire occurs in pinyon and juniper communities when there is sufficient understory to carry it from tree to tree, or when tree canopies "close up" enough for fire to spread from crown to crown (Lotan and Lyon 1981). The ability of evergreen pinyon and juniper trees to slowly and efficiently accumulate carbon by more active year-round photosynthesis than associated herbs and shrubs, coupled with their tree growth form, allows them to build large above and below ground structures for resource capture (Johnsen 1962; Tausch and Tueller 1977; Evans and Ehleringer 1994; Martens and others 1997; West in press). Under semiarid conditions, much of the limited precipitation is taken up by the extensive root systems of the trees (Foxx and Tierney 1987; Evans 1988) and transpired through their canopies. Recent research of Breshears and others (1997b) has shown that shallow soil layers between tree canopies can be wetter than canopy areas when canopies receive less precipitation due to interception. Breshears and others (1997a) also determined that pinyon and especially juniper trees depleted soil moisture in intercanopy areas and that they transpire through the winter (Breshears 1993). The resulting lack of water and nutrient availability from tree-root exploitation of interspaces can result in eventual mortality of understory plants in absence of fire or other tree-killing disturbances.

Prehistorically and historically the range of pinyon and juniper dominance has been controlled by climate and fire frequency (Miller and Wigand 1994). Ranges expanded with increasing winter precipitation and contracted with drier periods. Relict woodlands, tree age-class ratios, fire scars, and historical documents generally indicate that pinyon and juniper woodlands before European settlement were open, sparse savannahs or confined to rocky ridges and shallow soils such as low sage (*Artemisia*) flats where fine fuels were too low to carry fire. In some cases, native Americans set fires which may have controlled tree expansion (West in press). Tausch and others (1981) surveyed 486 stands of pinyon and juniper in the Great Basin and found that trees were younger than 120 years in half of the stands and that the highest period of tree establishment for these stands occurred between 1870 and 1920 when settlement impacts were greatest. They also noted that expansion of trees was downward in elevation and that this expansion reduced understory fuels necessary to carry fires. This and numerous other studies and observations cited in reviews of pinyon and juniper succession (West 1984a; West and Van Pelt 1987) substantiate the role of fire in controlling pinyon and juniper expansion from upland sites with naturally low fire frequency to lower elevational sites with deeper soils, higher understory production, and potentially high fire frequency. The change in fire frequency came initially with heavy understory grazing and removal of fine fuels in the late 1800's to early 1900's, and subsequently with fire suppression after World War II (Miller and Wigand 1994). It is important to understand the fire disturbance ecology of pinyon-juniper and associated potential invasion sites downslope, because these invasion sites may behave hydrologically very different when dominated by trees than when dominated by shrubs and grasses. Also tree-invasion sites may function differently hydrologically than tree-dominated, fire-safe sites upslope.

Interactions

Geologic substrate, soils, and climate interact with pinyon and juniper vegetation dynamics, which affect hydrologic responses and subsequent interactions. Geologic parent materials produce soils with different infiltration and water-holding capacities, and fertility (Springfield 1976, table 1). Slopes of Precambrian or Cambrian quartzite have shallow soils that support limited understory and limit canopy closure of trees. These may be fire-safe sites for pinyon and juniper as are other sites with shallow, rocky, and infertile soils. Tertiary and Quaternary volcanic soils with high fertility support the most rapid invasion of pinyon and juniper in the absence of fire (Harper 1997). Tree canopies may close up enough to allow crown fires on these soils long after loss of understory fuels. On these soils and other sites with fewer rocks where trees have matured and the understory seedbank is depleted (Koniak and Everett 1982), severe crown fires could open the community to annual weed invasion and permanently degrade the site (West 1984b; Billings 1994; West in press). Wind erosion (Baker and others 1995) may also degrade former pinyon and juniper communities when vegetation structure is lost as annual weeds dominate with high fire frequency. Where pinyon and juniper have invaded coarse-textured alluvial soils which once supported sagebrush steppe, interspace erosion may remove surface soils until an armor of rocks halts additional erosion. The associated loss of nutrients (Baker and others 1995), mycorrhizal fungi, cryptogams, and water-holding capacity on these soils can result in permanent loss of understory productive potential. These sites will not close up enough for crown fires to carry and will remain as degraded woodlands with very limited diversity and high potential runoff from intense storms. On some sites subject to surface erosion, archaeological values may even be lost (Traylor and others 1990; Chong 1993). Rasley (1997) has even observed that tree-dominated sites with highly erodible soils from sandstone parent materials may erode enough to expose tree roots and endanger the persistence of the trees themselves. Tree dominance to the point of understory exclusion on finer-textured, shallow soils of sedimentary materials such as the Green River shales in central Utah, results in substantial runoff and erosion from interspaces (Farmer 1995).

The subsurface water yield of burned pinyon and juniper sites may or may not be higher than that of similar sites with much higher tree cover and evapotranspiration, depending on subsurface geology. Reduced evapotranspiration could produce increased flow from springs or streams associated with impermeable sedimentary layers below fractured or permeable sedimentary rocks (Fetter 1988). Such increased flow is a function of total and effective precipitation in relation to surface and subsurface water budgets. Greater water yield from most forests can be expected when evapotranspiration is reduced through fire, logging or other tree reductions in areas of higher precipitation, although water yields have been highly variable and situation specific (Satterlund and Adams 1992). Generally, most pinyon and juniper communities have insufficient precipitation to increase water yield by decreasing evapotranspiration (Hibbert 1979). However, where there is a subsurface impermeable layer, reduced evapotranspiration after tree control could permit a zone of saturation and interflow to feed nearby springs and streams. Also, reduced evapotranspiration from pinyon and juniper zones receiving subsurface flow from higher elevations could increase water yield locally, given suitable geology. Fires above and within the upper juniper zone of the Clover Creek watershed in the Onaqui Mountains of Utah have resulted in new stream and spring flows (Dobrowolski 1997). These mountains are composed of sandstones, shales, quartzites and mainly limestone (Hintze 1997), and the annual precipitation in the upper juniper zone is about 450 mm. Juniper management and hydrology are important locally in this area, not only because juniper control provides forage, but also because increased freshwater subsurface flow may be necessary to prevent salt water intrusion into wells in western Rush Valley.

Intrusive igneous and metamorphosed crystalline rocks, as well as some sedimentary layers, have little primary porosity and will not take in subsurface water unless fractured by faulting or other changes in crust pressure (Fetter 1988). Extrusive igneous rocks such as lava flows and cinder beds may have high porosity, while that of ash beds can be much less (Fetter 1988). Dortignac (1960) suggested that watersheds of sandstone would yield the most runoff while those of basalt would yield the least. Watersheds of deep consolidated sandstone in the Colorado Plateau take in water readily but produce little spring or stream flow. Deep deposits of volcanic ash or quartz sand produce large areas of coarse-textured soils in southwestern Utah and northwestern Arizona. Tree reductions on these deep soils and porous substrates should not be expected to increase stream or spring flows (Harper 1997). Some finer-textured deep volcanic ash and sedimentary soils in Utah readily take in water but hold most of it as surface soil moisture. Reduced tree transpiration on these soils would be expected to produce greater herbaceous or shrub growth with increased soil moisture availability, but not greater water yield (Harper 1997). Similar, but shallower soils, especially in areas of low precipitation, would be poor candidates for revegetation and should not be targeted for tree reduction programs. Where limestone substrates on gentle slopes have weathered to produce mature soil profiles with substantial clay, water-holding capacity is high and unless precipitation is higher than 500 mm, increased streamflow should not be expected with tree removal (Harper 1997).

Fractured deep rock cores of Cambrian quartzite or Tertiary volcanics have deep percolation that feed springs and streams. An example of the former are the Stansbury Mountains in Utah where such fractures produce the springs on the east side of the range and the big springs in Skull Valley on the west side. Examples of the latter are Monroe Mountain and the Fish Lake Mountains in southern Utah. These geological situations have the greatest potential to increase spring and stream flow with tree removal and reduced evapotranspiration (Harper 1997).

Pinyon and juniper associations with various understory species cover roughly 13 million hectares of the Colorado Plateau in the Colorado River drainage system (Hibbert 1979; Bentley and others 1977). Some of these soils formed in place or as alluvial depositions from sandstone, siltstone, and shale sedimentary layers and are highly erodible. As part of the Colorado River Basin Rangeland Salinity Control Project, an interagency, interdisciplinary resource team evaluated a number of basins and watersheds that ultimately drain into the Colorado River (Rasley and Roberts 1991; Rasley and others 1991a,b; Rasley and others 1996). They used a revision (Rasely 1991) of the Pacific Southwest Interagency Committee (PSIAC) system to estimate sediment yields on rangeland plant communities in the Colorado River drainage, including pinyon and juniper communities. They suggested that a typical rangeland watershed would have 7 to 15 percent of the area in a severely eroding condition due to past or present management practices (Rasely and Roberts 1991). They considered that this erosion accounted for 75 to 90 percent of the accelerated sediment loads yielded to the Colorado River. Pinyon and juniper communities with little understory and large areas of bare ground were considered to be a major source of this sediment. Although these PSIAC estimations may make sense, they have never been checked against measured data from pinyon-juniper watersheds.

Watershed Management of Pinyon and Juniper

Pinyon and juniper lands have been subjected to a range of environmental and man-induced disturbances over the years. Imposed on the natural and native American-induced fire frequency and climatic fluctuations of the precontact period, came the grazing, logging, and fire control of western settlement after the mid 1800's (West in press). Effects of heavy grazing and fire reduction on loss of herbaceous forage and increases in woody vegetation led to the development of a variety of brush control and revegetation technologies applied especially to pinyon-juniper, sagebrush, and mesquite (*Prosopis* spp.)-dominated rangelands (Vallentine 1989). Chemical control of pinyon and juniper has been primarily used in northern Arizona and New Mexico (Evans and others 1975; Johnsen 1987; Baker 1986). Mechanical methods have been used most extensively to control pinyon and juniper and, with prescribed fire, have the greatest potential effect on hydrologic variables (Blackburn 1983).

Vegetation Manipulation Effects on Hydrology

Effects of vegetation manipulation on hydrologic variables of pinyon and juniper communities have been reviewed by Clary and others (1974), Gifford (1975), Blackburn (1983), Schmidt (1987), and Wilcox (1994), and will be only briefly summarized here. It is important to remember the kind and scale of measurements taken when interpreting and applying the results of any study. Drawing conclusions of response at a higher scale than that measured is risky. For example, conclusions about infiltration capacity at the intercanopy, woodland, or plateau (watershed) scales (fig. 2) from infiltration rate measurements made at the patch scale could easily be incorrect since they do not account for the existence and interconnectedness of source-sink areas.

Another caution is to remember the site and situation-specific nature of responses to vegetation manipulations. The interactions already mentioned of geology, soils, precipitation, vegetation dynamics, and resulting hydrologic responses are also greatly affected by management history, treatment practices and posttreatment management. This is one reason why natural resource management is a science and an art in practice and requires experience and familiarity with the specific environmental conditions and responses in specific management areas to be most successful. We are still far from the point of being able to accurately model responses to changing environmental conditions for the large range of sites of interest. Most lands have been subjected to a variety of grazing pressures and treatment procedures over the years. Responses on these sites over time and with changing management may differ greatly from measurements made during the first few years after a particular treatment.

Watershed-scale studies conducted in Arizona at Beaver Creek and Corduroy Creek Basin in general found that tree removal had little effect on water yield, except in the case where runoff was increased by killing trees with herbicide and leaving them in place (Blackburn 1983, Baker 1986; Wilcox 1994). In the Beaver Creek study, juniper control by herbicide or cabling had no consistent effect on sediment yield (Blackburn 1983). Dortignac's (1960) comparison of the Beaver Creek data with that from experimental watersheds in New Mexico also concluded that little usable water yield could be expected from pinyon and juniper manipulations. He was rightly concerned that treatments to improve water yield by increasing overland flow would also accelerate erosion. Increasing water yield by increasing more controlled and reliable subsurface flows to established drainages would be much more desirable for land managers. Skau (1964) noted in initial studies of Beaver Creek that pits left from cabling juniper trees would trap overland flow.

Hill-slope scale studies summarized by Wilcox (1994) suggest that cover conditions after tree control affect runoff and erosion. Runoff was increased by tree control when slash and debris were removed or windrowed, but was lower when trees were left on site (Gifford 1973; Wood and Javed 1994). Gifford (1973) concluded that debris left in place after chaining acted as retention and detention storage and minimized runoff. In that study, areas disturbed by chaining and windrowing produced 1.6 to 6 times more sediment than untreated areas while chained areas with the debris left in place produced similar sediment as untreated areas. After burning juniper on steeper slopes in central Texas, runoff and sediment loss increased until major regrowth occurred and soil cover increased (Wright and others 1976). Intercanopy-scale plots on chained, debris -in-place, revegetated areas had 5 times less runoff and 8 times less sediment than those on nearby bare interspaces of a closed pinyon and juniper community on Green River shale sandy clay loam and clay loam soils in Utah (Farmer 1995).

Wilcox (1994) reported a hill-slope scale study of runoff and erosion from upper elevational pinyon and juniper in New Mexico. Soils were shallow from volcanic tuff with loamy or sandy clay loam surface textures and a clay to clay loam argillic horizon at 10 cm. Runoff accounted for up to 18 percent on plots with intact vegetation and up to 28 percent of precipitation on plots that had all vegetation removed 4 years previously. Runoff from the plots as a percentage of precipitation for the 2 summers and winters measured was higher than that reported in the literature, but was highly variable yearly. Large runoff events were much less frequent than small events, and occurred with summer thunderstorms. Some runoff was produced from most storms during the period of highest thunderstorm activity, probably because soil infiltration capacity was decreasing as soil moisture from previous storms was increasing. Plot runoff from winter snowmelt was not observed in drainage channels downslope, suggesting that it was redistributed among source and sink areas. Most of the erosion was from initial heavy summer thunderstorms when soils were loose from spring thawing. Runoff and erosion were highest from plots with vegetation previously cleared.

Subsequent studies of Wilcox and others (1996a,b) at the hillslope and catchment scale compared runoff and erosion from both stable and rapidly-eroding pinyon-juniper communities in New Mexico. Runoff was mainly produced by summer thunderstorms, but also occurred with snowmelt. The rapidly-eroding site produced more runoff and substantially more erosion than the stable site. This led Davenport and others (1998) to conclude that the rapidly-eroding site had crossed a threshold where intercanopy cover had been reduced enough to allow runoff through connected interspaces. In such a case where intercanopy infiltration and storage capacity are exceeded, greatly increased erosion can occur as runoff coalesces into increasingly larger channels from intercanopy to hillslope to watershed scales. Davenport and others (1998) observed that under conditions of high soil erosion potential, a small loss in interspace cover can result in a major increase in erosion.

Rainfall simulation studies have been conducted on small plots to compare infiltration and sediment production of untreated areas with areas that have been burned (Roundy and others 1978), chained (Blackburn and Skau 1974), or cabled (Williams and others 1969; Gifford and others 1970; Williams and others 1972). Although infiltration rates decreased and sediment production increased on tree and shrub mounds after burning, interspace areas with lower infiltration rates were less affected (Roundy and others 1978). Infiltration rates on these coarse-loamy and loamy-skeletal soils in Nevada were still high enough after burning to suggest that runoff and erosion would be minimal. Two sites chained and seeded to crested wheatgrass (*Agropyron desertorum*) in Nevada had similar infiltration rates and sediment production as untreated areas (Blackburn and Skau 1974). In extensive studies on numerous cabled and untreated areas of Utah, Williams and others (1969) and Gifford and others (1970) generally found no differences in infiltration rates and sediment loss between treated and untreated areas. Both infiltration rates and sediment loss were higher or lower for treated than untreated areas of certain sites. This variability led Williams and others (1972) to use site variables to try to statistically predict infiltration and soil loss. They concluded that responses were site specific and that no consistent relationships were found across all sites that would allow them to make accurate predictions among different sites. More process-oriented research using simulated rainfall methods is currently being conducted to improve infiltration and erosion prediction (Wilcox 1994; Blackburn and others 1994; Spaeth and others 1996).

A few studies have been conducted to evaluate soil loss over time in pinyon and juniper communities. Based on tree-root exposure dates, Carrara and Carroll (1979) concluded that soil loss from a northwestern Colorado site was 400 percent more in the last century than in the previous 3 centuries. Price and others (1995) estimated soil loss between pinyon and juniper trees. Assuming the soil line at the base of the trees was an accurate measurement for soil height at the time of tree invasion, they concluded that soil erosion had accelerated after invasion. Differences in soil height under and in between trees are a function of aggradation and degradation processes (West in press; Davenport and 1998) so that it is difficult to strictly attribute them to one or the other. Lack of differences in soil morphology between canopy and intercanopy patches on a site at Los Alamos, New Mexico (Davenport and others 1996) suggest that the trees do not directly increase the erodibility of a site by physical effects of roots on the soil itself.

Management Perspectives on Hydrologic Response to Tree Control

Land owners, natural resource managers, and scientists have observed hydrologic responses of pinyon and juniper woodlands. Although there may be some bias about cause and effect in these observations, they are worthy of note because they give a much wider perspective of large-scale responses than has been measured or reported in the literature. Eddleman and Miller (1992) noted that land managers in central Oregon have reported loss of spring flow when western juniper (*Juniperus occidentalis*) dominates the landscape, as well as recovery of flow on some drainages where trees were controlled. Bedell (1987) reported a specific example of this where spring and stream flow increased and erosion decreased after pushing western juniper on the Bonneville Ranch in central Oregon.

After a career of revegetating and observing pinyon and juniper lands in Utah, Stevens (in press) made a strong case for the beneficial hydrologic effects of chaining and seeding. He reported two notable cases at Ephraim and Manti, Utah which almost yearly received floods and debris flows from upslope pinyon and juniper areas until they were chained and seeded. He observed that summer thunderstorm runoff was generated from bare interspaces of unchained woodlands while chained and seeded areas nearby produced no runoff from the same storms. He also observed downslope treated areas to catch and hold runoff and debris from unchained areas upslope. He suggested that infiltration capacity across the landscape, rather than infiltration rates were most important in understanding these hydrologic responses. Chaining operations that drop trees and leave them in place greatly increase protective soil cover and create detention and retention pits and depressions immediately after treatment. Thus when soils are just disturbed after chaining and most vulnerable to erosion, cover and detention storage is increased so that off-site runoff and erosion are controlled. Subsequent revegetation response from appropriate seeding techniques produce increased vegetation cover to control erosion as downed trees decompose and depression areas fill up over the years. Stevens' (in press) observation about chained areas catching runoff and sediment from unchained areas suggests that strip and pattern chainings, favored for wildlife habitat, could be sink areas at the hill-slope scale. Effectiveness of planted strips for controlling erosion from pinyon and juniper lands has been demonstrated by Heede (1990).

Land Management Questionnaire

To get a better understanding of the perspectives of land managers relative to hydrologic responses of pinyon and juniper lands, we mailed a brief questionnaire to Bureau of Land Management, Forest Service, and Natural Resource Conservation Service personnel in Arizona, Colorado, New Mexico, Nevada, and Utah. Time constraints prevented a comprehensive survey of all personnel associated with pinyon and juniper management in these States. Basically we took the mailing list for this conference and sent questionnaires to anyone we thought might have pinyon and juniper stewardship.

The majority of the 33 respondents which reported on 83 sites, were from Colorado and Utah and were BLM and Forest Service personnel (table 2). Most of the sites reported were chained and aerial seeded, predominately with exotic grasses. Initial treatments were conducted at least 20 years ago for 53 percent of the sites. Overall, treatments were perceived as reducing on-site erosion on more sites than in reducing off-site erosion, or as increasing water yield (table 3). Overall hydrologic success of treatments was considered to be good on 67 percent of the sites, with more Forest Service than BLM sites considered good. Comments of land managers indicated that vegetation cover is the main measure used to informally assess hydrologic success. Erosion control and hydrologic success was perceived to have increased more on sites with clayey soils, than on sites with soils of loamy or coarser textures. Erosion was considered to be decreased and water yield increased by treatments on more Basin and Range and transition sites than on Colorado Plateau sites. The same trend for these variables was perceived at higher than lower precipitation sites.

Table 2—Characteristics of sites represented by respondents to a questionnaire concerning watershed conditions and treatments of pinyon-juniper communities. Unless noted otherwise, values are percent of sites reported.

Respondents (no.)	33	Soil Texture	
Total sites (no.)	83	Not reported	30
Respondent affliation		Loamy or coarser	58
Bureau of Land Management (BLM)	39	Clayey	12
US Forest Service (USFS)	29	Tree control	
State Wildlife Department	5	Not reported	5
Natural Resource Conservation Service (NRCS)	11	Chained	60
Other	17	Chained, burned	13
State		Burned	13
Arizona	14	Other	9
Colorado	30	Debris	
New Mexico	16	Not reported	70
Nevada	7	Left in place	25
Utah	31	Windrowed	5
Other	1	Revegetation	
Physiography		Not reported	6
Colorado Plateau	34	None	12
Basin and Range	41	Aerial broadcast	64
Transition	13	Drilled	8
Other	12	Dribbler	4
Slope		Combination	6
Not reported	18	Revegetation species	
5%	28	Not reported	20
10%	22	Exotic grasses	42
15-20%	22	Shrubs, forbs also reported	17
25-45%	10	Native and exotic grasses	8
Thunderstorm frequency		None	12
Not reported	1	Years since treatment	
Frequent	17	Not reported	6
Occassional	80	5	15
Rare	1	10-15	8
		20-25	20
		> 30	33

A little less than half of the sites received no comment or indication on questions asking about erosion and water yield (table 3). This suggests that respondents either were not familiar with the sites for sufficient time to make an assessment, or that changes in these variables were not obvious. The perceived watershed condition of a site after treatment is affected by the amount of tree regrowth or reinvasion. Follow-up tree control was either conducted or considered necessary on about half of the BLM and Forest Service sites. A need to increase the area of original treatment was mentioned for only a few sites. The need to control animals better was mainly considered necessary in transition areas between the Basin and Range and Colorado Plateau physiographic provinces and on steeper slopes. Slope was generally not correlated with treatment response, except that hydrologic success after treatment of sites with the highest slopes (> 20 percent) was more frequent than for sites with lesser slopes. In general, responses to the questionnaire support the observations that pinyon-juniper watershed responses to tree control vary with certain site variables, and that on-site erosion control is a more typical response than off-site erosion control or increased water yield. The majority of the sites were considered to have improved hydrologic function after treatment.

Conflicting Opinions Over Hydrologic Responses

There appears to be a major disagreement in the views of some natural resource scientists and managers relative to pinyon and juniper management alternatives and associated ecological and hydrologic responses (Belsky 1996). Ecological understanding and substantial historical evidence support both the process and occurrence of pinyon and juniper expansion and dominance with the reduced fire frequency that accompanied western settlement (West in press). What seems to be most in question is what the environmental consequences of that expansion really are, and if tree control practices will really bring proposed benefits.

Tree control projects have usually been conducted by land managers to increase forage for domestic livestock, to improve watershed conditions, to increase water yield, and to improve wildlife habitat (Hurst 1976). The most critical of these purposes is the improvement of watershed conditions. Major tree control projects were conducted from the 1940's through the 1960's, but dropped off in the 1970's as multiple-use benefits of expensive mechanical treatments were questioned (Belsky 1996; West 1984a).

The traditional view is that pinyon and juniper communities, especially on invasion sites, will degrade hydrologically and ecologically unless periodic fire or other tree

Table 3—Watershed and management responses to tree control and revegetation of pinyon-juniper sites. Values are percent of sites reported from questionnaire respondents.

A. Decreased runoff and erosion	Not reported	None	Rills, gullies decreased or sediment trapped
All sites	43	11	46
BLM	75	9	16
USFS	30	9	60
Others	15	15	69
Colorado Plateau	75	4	22
Basin and Range	31	16	53
Transition	6	11	83
Loamy or coarser soil texture	49	4	47
Clayey	22	11	66
Annual precipitation (mm)			
230-340	49	14	38
350-400	52	8	40
430-812	7	13	81
Slope (percent)			
2-5	50	9	41
6-10	44	0	56
11-20	33	17	50
21-45	22	33	44

B. Decreased off-site erosion	Not reported	None	Less erosion, flooding or gullying
All sites	46	29	18
BLM	81	16	3
USFS	13	67	20
Others	33	11	56
Colorado Plateau	75	18	7
Basin and Range	32	26	42
Transition	5	10	86
Loamy or coarser soil texture	50	29	20
Clayey	0	40	60
Annual precipitation (mm)			
230-340	49	21	23
355-400	48	36	16
430-812	29	29	42
Slope (percent)			
2-5	35	43	22
6-10	50	17	34
11-20	44	39	17
21-45	44	11	44

C. Increased water yield	Not reported	None	Increased stream or spring flow
All sites	48	26	27
BLM	63	25	12
USFS	46	38	16
Others	31	15	54
Colorado Plateau	71	29	0
Basin and Range	32	18	50
Transition	7	13	60
Loamy or coarser soil texture	46	27	28
Clayey	50	20	30
Annual precipitation (mm)			
230-340	51	24	24
350-400	56	28	16
430-812	31	25	44
Slope (percent)			
2-5	61	26	13
6-10	50	17	34
11-20	39	44	25
21-45	33	33	33

D. General hydrologic success	Not reported	Fair	Good
All sites	12	22	67
BLM	6	47	47
USFS	8	12	80
Others	22	0	77
Colorado Plateau	4	57	39
Basin and Range	15	6	80
Transition	4	46	43
Loamy or coarser soil texture	8	29	63
Clayey	0	10	90
Annual precipitation (mm)			
230-340	14	17	71
350-400	10	29	62
430-812	18	6	77
Slope (percent)			
2-5	4	26	69
6-10	6	34	62
11-20	17	28	56
21-45	0	11	89

E. Other management concerns	Not reported or none	Follow up			Incease area	Control animals
		Done	Needed	Total		
All sites	36	19	26	45	4	4
BLM	31	34	22	56	6	3
USFS	38	13	33	46	0	4
Others	41	7	19	26	4	8
Colorado Plateau	18	39	32	71	4	4
Basin and Range	44	12	21	33	3	6
Transition	9	11	8	19	19	31
Loamy or soil coarser texture	21	29	27	56	4	6
Clayey	70	10	20	30	0	0
Annual precipitation (mm)						
230-340	32	14	27	41	5	8
350-400	32	40	16	56	4	0
430-812	35	6	35	41	0	6
Slope (percent)						
2-5	30	20	30	56	4	9
6-10	39	39	17	56	0	0
11-20	22	17	28	45	6	28
21-45	34	0	33	33	11	22

reductions, and associated natural revegetation or seeding allow increased herbaceous and shrub cover (Doughty 1987; Wood 1988; West in press). Proponents of this view are concerned that continuing fire control and lack of other tree control measures are threatening the soils and associated resources of pinyon and juniper woodlands. West (1984b) suggested that most of the understory of Great Basin pinyon and juniper woodlands would be gone by the year 2000. There is a concern that bare areas on many sites are increasing as trees established over 100 years ago are now maturing and as residual or newly established trees from earlier control projects are also maturing. Over 18 years ago, Hurst (1979) noted that for the 15 percent of the pinyon and juniper type that occurs on the National Forests (3.6 million hectares in the 5 dominant States), 800,000 hectares were suitable for control treatments, and 283,000 hectares had already been treated. More recently, the Forest Service has considered that 1.4 million hectares or 35 percent of the pinyon and juniper woodland in the Southwestern Region are in unsatisfactory soil and watershed condition, prompting the development of active management guidelines and efforts directed at the woodlands (Spann 1993).

During the period of most active control work between 1960 and 1972 , the BLM chained 208,000 hectares, predominately in Utah (Aro 1975). Pinyon and juniper lands constitute approximately 17 percent or 54 million hectares of the 320 million hectares covered by BLM 's Vegetation Treatment Environmental Impact Statement (USDI 1991). BLM 's proposed area of vegetation treatments for all vegetation types and for all control methods is only 150,000 hectares per year (USDI 1991). The BLM administers 61 percent of the 2.2 million hectares of pinyon and juniper in Utah (Banner 1992). Of this, about 5 percent or 107,000 hectares have been treated to restore herbaceous and shrubby vegetation. The case could be made that, if there are large areas dominated by pinyon and juniper on public lands that are degrading, little is being done about it. West (1984a,b; West in press) has issued a number of calls to action and has helped develop guidelines for where, what, and how treatments should be imposed. Recent fires in the pinyon and juniper woodlands of Utah and Nevada have rekindled the concern about possible cheatgrass (*Bromus tectorum*) and other annual weed invasion into burned woodlands with depleted understory plants and seedbanks.

The counter position to this concern is that maturing woodlands are not eroding and degrading (Belsky 1996). Some are concerned that land managers are using unfounded hydrologic benefits to justify tree control and revegetation practices that are really meant to increase forage for livestock. Schmidt (1987) has complained that selective interpretations of the literature and self-serving speculations have been used by some to justify type conversions. Perhaps such approaches have also been used by those who want to prevent tree control practices. The real question is to what extent, if any, are woodland sites eroding. References to lack of differences in infiltration rates or sediment production between small-scale plots on untreated and treated woodlands, as well as statements about the limited precipitation and runoff of pinyon and juniper woodlands have been used to conclude that erosion and degradation are not occurring. In fact, large, bare, nonrocky soils of many sites are subject to intense thunderstorms that do have major erosion potential. That these and other potentially degrading conditions such as weed invasion are observed extensively by land managers and land owners (Goodloe 1993) familiar with their areas, as well as by scientists having a long history of extensive field work should bear considerable weight.

West (1984a) has stated that there is no definitive proof that erosion rates have increased with tree dominance since it is too late to collect before and after data from the same site. Even if we had such data for a few sites, the site and soil-specific nature of hydrologic responses would prevent extrapolation to all other sites. Proponents of both positions agree that grazing and site-specific conditions have affected measured hydrologic responses. There seems to also be agreement that tree dominance can deplete understory vegetation and seedbanks. It seems rather obvious that understory loss has and will result in accelerated erosion on certain sites. The recent contributions of watershed research in New Mexico (Wilcox and others 1996b; Breshears and others 1997b; Davenport and others 1998) have shown the importance of spatial heterogeneity in pinyon-juniper woodlands, the importance of scale in assessing hydrologic responses, and the sensitivity of erosion to intercanopy cover, connectedness, and storage conditions. Tree invasion sites with high erosion potential should be identified and treated before a major erosion threshold is crossed. Tree control practices which leave downed trees and debris in place should reduce interspace connectedness, increase hillslope infiltration, and reduce runoff and erosion on sites with high SEP.

On the other hand, land managers should not propose unreasonable hydrologic responses as justification for tree control projects. For example, on the majority of pinyon and juniper sites, the possibility and economic benefits of increased water yield are limited (Hibbert 1979; Brown 1987). Locally improved water yield is possible with suitable precipitation and geology, but should be considered a side benefit to projects which are already fully justified for erosion control and habitat improvement benefits.

Most people do not oppose tree control practices that benefit wildlife as long as they are not damaging ecologically. Techniques that benefit wildlife such as strip-clearing, also show promise for erosion control (Heede 1990; Stevens in press). Mechanical methods of tree control should always be conducted to leave debris in place for most beneficial hydrologic responses on sites with high SEP. There are enough pinyon and juniper lands that we can be selective in vegetation management. We should not be so exclusive in land management that we totally accept or reject certain approaches. Rather, we should accept the fact that the varied conditions of our environments require a knowledge of specific situations and a range of management options.

References

Aro, R. S. 1975. Pinyon-juniper woodland manipulation. In: Gifford, G. H.; Busby, F. E. eds. The pinyon-juniper ecosystem: A symposium. 1975 May; Logan, UT. Utah State University: 67-75.

Baker, M. B., Jr. 1986. Changes in streamflow in an herbicide treated pinyon-juniper watershed in Arizona. Water Resources Research 20: 1639-1642.

Baker, M. B., Jr.; DeBano, L. F.; Ffolliott, P. F. 1995. Soil loss in piñon-juniper ecosystems and its influence on site productivity and desired future condition. In: Shaw, D. W.; Aldon, E. F.; LoSapio, C. Technical coordinators. Desired future conditions of piñon-juniper ecosystems; 1994 August 8-12; Flagstaff, AZ. Gen. Tech. Rep. RM-258. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 9-15.

Banner, R. E. 1992. Vegetation types of Utah. Rangelands. 14: 109-114.

Bedell, T. E. 1987. Rehabilitation of western juniper rangeland: A case history. In: Everett, R. L. compiler. Proceedings- Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 313-315.

Belsky, A. J. 1996. Viewpoint: Western juniper expansion: Is it a threat to arid northwestern ecosystems. Journal of Range Management. 49: 53-59.

Bentley, R. G., Jr.; Eggleston, K. O. 1978. The effects of surface disturbance on the salinity of the public lands in the Upper Colorado River Basin. 1977 Status report. Denver, CO: U. S. Department of Interior, Bureau of Land Management. 180 p.

Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. In: Monsen, S. B.; Kitchen, S. G. eds. Proceedings—Ecology and management of annual rangelands: 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 22-30.

Blackburn, W. H. 1975. Factors influencing infiltration and sediment production of semiarid rangelands in Nevada. Water Resources Research. 11: 929-937.

Blackburn, W. H. 1983. Influence of brush control on hydrologic characteristics of range watersheds. In: McDaniel, K. C. ed. Proceedings brush management symposium; 1983 February 16; Albuquerque, NM. Las Cruces, NM: New Mexico State University: 73-88.

Blackburn, W. H.; Pierson, B. F., Jr.; Schuman, G. E.; Zartman, R. 1994. Variability in rangeland water erosion processes. Madison, WI: Soil Science Society of America. 106 p.

Blackburn, W. H.; Skau, C. M. 1974. Infiltration rates and sediment production of selected plant communities in Nevada. Journal of Range Management. 27: 476-480.

Branson, F. A.; Gifford, G. F.; Renard, K. G.; Hadley, R. F. 1981. Rangeland hydrology. Second edition. Dubuque, IA: Kendall/Hunt Publishing Company. 340 p.

Breshears, D. D. 1993. Spatial partitioning of water use by herbaceous and woody lifeforms in semiarid woodlands. Ph. D. Dissertation. Fort Collins, CO: Colorado State University. 78 p.

Breshears, D. D.; Myers, O. B.; Johnson, S. R.; Meyer, C. W.; Martens, S. N. 1997a. Differential use of spatially heterogeneous soil moisture by two semiarid woody species: *Pinus edulis* and *Juniperus monosperma*. Journal of Ecology. 85: 289-299.

Breshears, D. D.; Rich, P. M.; Barnes, F. J.; Campbell, K. 1997b. Overstory-imposed heterogeneity in solar radiation and soil moisture in a semiarid woodland. Ecological Applications. 7: 1201-1215.

Brown, T. C. 1987. The value of incremental water flow from pinyon-juniper lands. In: Everett, R. L. compiler. Proceedings-Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 177-182.

Carrara, P. E.; Carroll, T. R. 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. Earth Surface Processes. 4: 307-317.

Chong, G. 1993. Revegetation of piñon-juniper woodlands with native grasses. In: Aldon, E. F.; Shaw, D. W. technical coordinators. Managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30; Santa Fe, NM. Gen. Tech. Rep. RM-236. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 34-41.

Chronic, H. 1990. Roadside geology of Utah. Missoula, MT: Mountain Press Publishing Company. 326 p.

Clary, W. P.; Baker, M. B., Jr.; O'Connell, P. F.; Johnsen, T. N., Jr.; Campbell, R. E. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. Research Paper RM-128. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 28 p.

Davenport, D. W.; Wilcox, B. P.; Breshears, D. D. 1996. Soil morphology of canopy and intercanopy sites in a piñon -juniper woodland. Soil Science Society of America Journal. 60: 1881-1887.

Davenport, D. W.; Breshears, D. D.; Wilcox, B. P.; Allen, C. D. 1998. Viewpoint: Sustainability of piñon-juniper ecosystems- a unifying perspective of soil erosion thresholds. Journal of Range Management. 51: 231-240.

Dortignac, E. J. 1960. Water yield from pinyon-juniper woodland. In: Water yield in relation to environment in the southwestern United States. Committee on desert and arid zones research. Alpine, TX: American Association for the Advancement of Science Southwest and Rocky Mountain Division: 16-27.

Dobrowolski, J. 1997. [Personal communication]. Logan, UT: Utah State University.

Doughty, J. W. 1987. The problem with custodial management of pinyon-juniper woodlands. In: Everett, R. L. compiler. Proceedings: Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 29-33.

Eddleman, L. E.; Miller, P. M. 1992. Potential impacts of western juniper on the hydrologic cycle. In: Clarey, W. P.; McArthur, E. D.; Bedunah, D.; Wambolt, C. L., compilers. Proceedings- symposium on ecology and management of riparian shrub communities; 1991 May 29-31; Sun Valley, ID. Gen. Tech. Rep. INT-289. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 176-180.

Evans, R. A. 1988. Management of pinyon-juniper woodlands. Gen. Tech. Rep. INT-249. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 p.

Evans, R. D.; Ehleringer, J. R. 1994. Water and nitrogen dynamics in an arid woodland. Oecologia. 99: 233-242.

Evans, R. A.; Young, J. A. 1975. The role of herbicides in management of pinyon-juniper woodlands. In: Gifford, G. H.; Busby, F. E. eds. The pinyon-juniper ecosystem: A symposium; 1975 May; Logan, UT. Utah State University: 83-89.

Farmer, M. E. 1995. The effect of anchor chaining pinyon-juniper woodland on watershed values and big game animals in central Utah. M. S. Thesis. Provo, UT: Brigham Young University. 47 p.

Fetter, C.W. 1988. Applied hydrogeology. Columbus, OH: Merrill Publishing Company. 592 p.

Foxx, T. S.; Tierney, G. D. 1987. Rooting patterns in the pinyon-juniper woodland. In: Everett, R. L. compiler. Proceedings-Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 69-79.

Gifford, G. F. 1973. Runoff and sediment yields from runoff plots on chained pinyon-juniper sites in Utah. Journal of Range Management. 26: 440-443.

Gifford, G. F. 1975. Impacts of pinyon-juniper manipulation on watershed values. In: Gifford, G. H.; Busby, F. E. eds. The pinyon-juniper ecosystem: A symposium. 1975 May; Logan, UT. Utah State University: 127-140.

Gifford, G. F.; Williams, G.; Coltharp, G. B. 1970. Infiltration and erosion studies on pinyon-juniper conversion sites in southern Utah. Journal of Range Management. 23: 402-406.

Goodloe, S. 1993. The piñon-juniper invasion: An inevitable disaster. In: Aldon, E. F.; Shaw, D. W. technical coordinators. Managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30; Santa Fe, NM. Gen. Tech. Rep. RM-236. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 153-154.

Harper, K.T. 1997. [Personal communication]. Provo, UT: Brigham Young University.

Hawkins, R. H. 1987. Applied hydrology in the pinyon-juniper type. In: Everett, R. L. compiler. Proceedings: Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 493-504.

Heathcote, R. L. 1983. The arid lands: Their use and abuse. New York, NY: Longman. 323 p.

Heede, B. H. 1990. Vegetation strips control erosion in watershed. Research Note RM-499. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 5 p.

Hibbert, A. R. 1979. Managing vegetation to increase flow in the Colorado River basin. Gen. Tech. Rep. RM-66. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 27 p.

Hintze, L. F. 1988. Geologic history of Utah. Provo, UT: Brigham Young University Geology Studies. 202 p.

Hintze, L. F. 1997. Utah geologic highway map. Provo, UT: Department of Geology, Brigham Young University.

Hunt, C. B. 1967. Physiography of the United States. San Francisco, CA: W. H. Freeman and Company. 480 p.

Hurst, W. D. 1976. Management strategies within the pinyon-juniper ecosystem. Rangeman's Journal. 3: 5-7.

Johnsen, T. N. 1962. One seed juniper invasion of northern Arizona grasslands. Ecological Monographs. 32: 187-207.

Johnsen, T. N., Jr. 1987. Using herbicides for pinyon-juniper control in the Southwest. In: Everett, R. L. compiler. Proceedings- Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 330-334.

Koniak, S.; Everett, R. L. 1982. Seed reserves in soils of successional stages of piñon woodlands. American Midland Naturalist. 108: 295-303.

Lane, L. J.; Barnes, F. J. 1987. Water balance calculations in southwestern woodlands. In: Everett, R. L. compiler. Proceedings- Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 480-488.

Leonard, S. G.; Miles, R. L.; Summerfield, H. A. 1987. Soils of the pinyon-juniper woodlands. In: Everett, R. L. compiler. Proceedings- Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 227-230

Lotan, J. E.; Lyon, L. J. 1981. Effects of fire on flora: A state-of-the-knowledge review. Gen. Tech Rep. WO-3. U.S. Department of Agriculture, Forest Service, Washington, DC.

Martens, S. C.; Breshears, D. D.; Meyer, C. W.; Barnes, F. J. 1997. Scales of above- and below-ground competition in a semiarid woodland detected from spatial pattern. Journal of Vegetation Science. 8: 655-664.

Miller, R. F.; Wigand, P. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioScience. 44: 465-474.

Newman, B. D.; Campbell, A. R.; Wilcox, B. P. 1997. Tracer-based studies of soil water movement in semiarid forests of New Mexico. Journal of Hydrology. 196: 251-270.

Price, K. P. 1993. Detection of soil erosion within pinyon-juniper woodlands using thematic mapper (TM) data. Remote Sensing Environment. 45: 233-248.

Rasely. R.C. 1991. Proposed revision of sediment yield procedure Pacific Southwest Interagency Committee report of the Water Management Subcommittee 1968. Upper Colorado River Basin rangeland salinity control project. Salt Lake City, UT: U.S. Department of Agriculture, Natural Resources Conservation Service. 17 p.

Rasley, R.C. 1997. [Personal communication]. Salt Lake City, UT: U.S. Department of Agriculture, Natural Resources Conservation Service.

Rasely, R. C., Pyper, G., Roberts, T.C., Page, L. 1996. Resource evaluation report. Kanab Creek watershed. Upper Colorado River Basin rangeland salinity control project. Salt Lake City, UT: U.S. Department of Agriculture, Natural Resources Conservation Service. 21 p.

Rasely, R.C., Roberts, T.C., Pyper, G., Harte, J., Thompson, W. 1991a. Resource evaluation report. Sagers Wash watershed. Upper Colorado River Basin rangeland salinity control project. Salt Lake City, UT: U.S. Department of Agriculture, Natural Resources Conservation Service.

Rasely, R.C.; Roberts, T. C.; Pyper, P. 1991b. Upper Colorado River Basin rangeland salinity control project. Watershed resource condition evaluation. Phase II— Interagency Team Report. Salt Lake City, UT: U. S. Department of Agriculture, Natural Resource Conservation Service. 10 p.

Rasely, R.C., Roberts, T.C. 1991. Phase I Natural resource inventory for the Colorado River Basin rangeland salinity control project State of Utah. Salt Lake City, UT: U.S. Department of Agriculture, Natural Resources Conservation Service. 8 p.

Roundy, B. A. 1996. Revegetation of rangelands for wildlife. In: Krausman, P. R. ed. Rangeland wildlife. Denver, CO: Society for Range Management: 355-368.

Roundy, B. A.; Blackburn, W. H.; Eckert, R. E., Jr. 1978. Influence of prescribed burning on infiltration and sediment production in the pinyon-juniper woodland, Nevada. Journal of Range Management. 31: 250-253.

Roundy, B. A.; Keys, R. N.; Winkel, V. K. 1990. Soil response to cattle trampling and mechanical seedbed preparation. Arid Soil Research and Rehabilitation. 4: 233-242.

Satterlund, D.R., Adams, P.W. 1992. Wildland watershed management. New York: John Wiley and Sons, Inc. 436 p.

Schmidt, L. J. 1987. Present and future themes in pinyon-juniper hydrology. In: Everett, R. L. compiler. Proceedings- Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 474-479.

Scholl, D. G. 1971. Soil wettability in Utah juniper stands. Soil Science Society of America Proceedings 35: 344-345.

Skau, C. M. 1964. Soil water storage under natural and cleared stands of alligator and Utah juniper in northern Arizona. Research Note RM-24. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 3 p.

Spaeth, K. E.; Pierson, M. A.; Weltz, M. A.; Hendricks, R. G. eds. 1996. Grazingland hydrology issues: Perspectives for the 21st century. Denver, CO: Society for Range Management. 136 p.

Spann, C. L. 1993. Procedural guidelines for developing soil and water conservation practices in piñon-juniper ecosystems. In: Aldon, E. F.; Shaw, D. W. technical coordinators. Managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30; Santa Fe, NM. Gen. Tech. Rep. RM-236. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 159-161.

Springfield, H. W. 1976. Characteristics and management of southwestern pinyon-juniper ranges: The status of our knowledge. Research Paper RM-160. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 32 p.

Stevens, R. 1997. [Personal communication]. Ephraim, UT: Utah Division of Wildlife Resources.

Stevens, R. [In press.] Juniper-pinyon. In: Monsen, S. B.; Stevens, R. eds. Restoration of western range and wildlands. General Technical Report. Ogden, UT : U. S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Stokes, W. L. 1988. Geology of Utah. Salt Lake City, UT: Utah Museum of Natural History, University of Utah. 280 p.

Tausch, R. J.; West, N. E.; Nabi, A. A. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34: 259-262.

Traylor, D.; Wood, N.; Fielder, B. 1990. The 1977 La Mesa fire: An investigation of fire and fire suppression impact on cultural resources in Bandalier National Monument. Southwest Cultural Resources Center, Division of Anthropology Professional Paper 28. Santa Fe, NM: U. S. Department of Interior, National Park Service. 206 p.

U. S. Department of Interior, Bureau of Land Management. 1991. Final environmental impact statement. Vegetation treatment on BLM lands in thirteen western States. Casper, WY: U. S. Department of Interior, Bureau of Land Management.

Vallentine, J. F. 1989. Range development and improvements. San Diego, CA: Academic Press, Inc. 524 p.

West, N. E. 1984a. Successional patterns and productivity potentials of piñon-juniper ecosystems. In: Developing strategies in rangeland management. Boulder, CO: Westview Press: 1301-1322.

West, N. E. 1984b. Factors affecting treatment success in the pinyon-juniper type. In: Johnson, K. L. ed. Proceedings of the second Utah shrub ecology workshop; 1982 September 15-16; Fillmore, UT. Logan, UT: Utah State University: 21-33.

West, N. E. [In press.] Juniper-piñon savannahs and woodlands of western North America. In: Anderson, R.C.; ed. Vegetation of savannahs and barrens of North America. New York, NY: Oxford University Press.

West, N. E.; Rea, K. H.; Tausch, R. J. 1975. Basic synecological relationships in juniper-pinyon woodlands. In: Gifford, G. H. and Busby, F. E. eds. The pinyon-juniper ecosystem: A symposium. 1975 May; Logan, UT. Utah State University: 41-52.

West, N. E.; Van Pelt, N. A.; 1987. Successional patterns in piñon-juniper woodlands. In: Everett, R. L. compiler. Proceedings-Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT 215. Ogden,UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

West, N. E.; Young, J. A. [In press.] Vegetation of Intermountain valleys and lower mountain slopes. In: Barbour, M. G.; Billings, W. D. eds. Terrestrial vegetation of North America. Second edition. New York: NY: Cambridge University Press.

Wilcox, B. P. 1994. Runoff and erosion in intercanopy zones of pinyon-juniper woodlands. Journal of Range Management. 47: 285-295.

Wilcox, B. P.; Breshears, D. D. 1995. Hydrology and ecology of piñon-juniper woodlands: Conceptual framework and field studies. In: Shaw, D. W.; Aldon, E. F.; LoSapio, C. technical coordinators. Desired future conditions of piñon-juniper ecosystems; 1994 August 8-12; Flagstaff, AZ. Gen. Tech. Rep. RM-258. Fort Collins, CO: U. S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 109-119.

Wilcox, B. P.; Breshears, D. D. 1997. Interflow in semiarid environments: An overlooked process in risk assessment. Human and Ecological Risk Assessment. 3: 187-203.

Wilcox, B. P.; Newman, B. D.; Allen, C. D.; Reid, K. D.; Brandes, D.; Pitlick, J.; Davenport, D. W. 1996a. Runoff and erosion on the Pajarito Plateau: Observations from the field. New Mexico Geological Society Guidebook, 47th Field Conference, Jemez Mountain Region: 433-439.

Wilcox, B. P.; Pitlick, J.; Allen, C. D.; Davenport, D. W. 1996b. Runoff and erosion from a rapidly eroding pinyon-juniper hillslope. Advances in Hillslope Processes. 1: 61-77.

Wilcox, B. P.; Wood, M. K. 1989. Factors influencing interrill erosion from semiarid slopes in New Mexico. Journal of Range Management. 66:-70.

Williams, G.; Gifford, G. F.; Coltharp, G. B. 1969. Infiltrometer studies on treated vs. untreated pinyon-juniper sites in central Utah. Journal of Range Management. 22: 110-114.

Williams, G.; Gifford, G. F.; Coltharp, G. B. 1972. Factors influencing infiltration and erosion on chained pinyon-juniper sites in Utah. Journal of Range Management. 25: 201-205.

Wood, M. K. 1988. Rangeland vegetation-hydrologic interactions. In: Tueller, P. T. ed. Vegetation science applications to rangeland analysis and management. Boston, MA: Kluwer Academic Publishers: 469-491.

Wood, M. K.; Javed, N. 1994. Hydrologic responses to fuelwood harvest and slash disposal in a pinyon pine and juniper dominated grassland. Trends in Hydrology. 1: 179-190.

Wright, H. A.; Bailey, A. W. 1982. Fire ecology. New York, NY: John Wiley and Sons. 501 p.

Wright, H. A.; Churchill, F. M.; Stevens, W. C. 1976. Effect of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in Texas. Journal of Range Management. 29: 294-298.

Young, J. A.; Evans, R. A.; Easi, D. A. 1984. Stem flow on western juniper (*Juniperus occidentalis*) trees. Weed Science. 32: 320-327.

Watershed-Scale Research in a Juniper Ecosystem

James P. Dobrowolski

Abstract—Acquiring an understanding of the pinyon-juniper ecosystem challenges our current research technologies. Extremely variable site conditions and protracted time considerations result in a complex research environment. Utah State University has established a long-term watershed scale research site in the Clover Creek Management Unit near Tooele, UT. The objective is to perform mechanistic research in pinyon juniper ecosystem dynamics, for example, energy, water and nutrient cycling, organismal structure and function at relevant scales, sediment source/sink relationships, and so forth, while simultaneously addressing the more pragmatic concerns associated with management objectives, the effects of drastic disturbance and the results of custodial management. The project utilizes small watersheds and spatial nesting of tributary basins with uniform soils, slope, and aspect to provide integration of spatial and temporal variability and a more realistic scale for assessing the influence of land management activities.

Juniper Dominated Watersheds

Historically, land managers have associated canopy closure by pinyon and juniper with site degradation, measured by a reduction in desirable plant species and forage production for wildlife and livestock (Bedell 1987, Pieper 1990, West 1984). A lack of management (that is, custodial management) is often identified with accelerated soil erosion. Other researchers have found little evidence to support the idea of environmental degradation.

Once accepted as a sound rangeland rehabilitation program, the justification of pinyon-juniper type conversion is now raising concerns about disturbance of archaeological sites, conflicts with wilderness preservation, the recreational and economic importance of pinyon nuts, aesthetic values, wildlife habitat needs and the economics of brush management. Justification of active management by mechanical methods, chemical techniques and/or prescribed burning often demand answers that require a greater knowledge of the pinyon and juniper ecosystem than now exists in the available scientific literature. Soils of pinyon-juniper woodlands are typically shallow, well-drained, and have low fertility (see Lowe and Dobrowolski, this conference). As the trees mature, herbaceous cover declines. Due to little soil cover coupled with typically erodible soils, many land managers have come to the conclusion that pinyon and juniper invasion results in poor watershed condition (Bedell 1987). However, Heede (1987) found the microtopography produced by tree coppices (mounds that decrease in elevation from the trunk outward) to absorb the energy of flowing water and to restrict sediment delivery downslope.

"Improvement" of the soil hydrologic condition by pinyon-juniper clearing is considered to be a fact in land management working documents and other publications (Johnsen and Raymond 1990). However, the concept's basis is rooted in an early U.S. Forest Service paper (Arnold and Schroeder 1955) describing differences in active erosion between cleared and untreated areas. This conclusion was reached with field observations not subject to the rigors of scientific experimentation.

Typically, many published studies focussed on different technologies to improve the forage resource and they only included ancillary observations of the treatment effects on soil hydrologic condition. Clary and others (1974) found no meaningful change in sediment yield after removing pinyon-juniper by cabling or the application of herbicides at Beaver Creek, Arizona. Measured salt concentrations produced from surface soils of pinyon-juniper sites are not critical to delivery of salt within major river basins (Hessary and Gifford 1979). Gifford (1987) in Utah and Wood and Wood (1988) in New Mexico concluded that removal of pinyon-juniper by chaining does not reduce sediment production.

Many erosion plot studies (*sensu* Buckhouse and Gifford 1976, Busby and Gifford 1981) have relied on a limited number of rainfall events with the potential to produce overland flow. Standard erosion plots typically represent the spatial effects of only one tree and its associated intercanopy spaces. These plots often were installed prior to the collection of pretreatment data. When sample size is small, spatial interspersion is missing, and/or pretreatment data is lacking, the power of the statistical test can be substantially affected, risking the possibility of a Type II statistical error and the problems associated with it. An error of the second kind or Type II error is made when the experimenter accepts the null hypothesis and the alternative is true. The concept of a Type II error is particularly important in determining the sample size necessary to detect a difference of an *a priori* magnitude.

Williams and Buckhouse (1993) measured the amount of sediment exported and overland flow differences from 10 different ecosystems in eastern Oregon. Using runoff plots (1 x 5 m) treated with simulated rainfall, juniper dominated systems were found to have greater overland flow and higher potential for sediment export. However, Williams (personal communication) felt that efforts to distinguish

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In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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differences in sediment production from treated and undisturbed ponderosa pine ecosystems with the same runoff plot technology (Williams and Buckhouse 1993), was susceptible to a Type II error.

A Self-Destructive Ecosystem?

Researchers have postulated that successional trajectories currently in place and likely to carry on for future centuries due to tree longevity, result in a self-destructive system. Carrara and Carroll (1979) and others felt that a large portion of the pinyon-juniper type is exhibiting undesirable successional tree "superdominance" leading to site degradation due to loss of biodiversity, the threat of a fire holocaust, in addition to accelerated soil loss. West and Van Pelt (1987) expressed a need to know where and why this was occurring, and felt these disturbing trends to contradict the prevalent idea that succession always leads to more stable, more diverse, and more economically valuable communities. Pinyon-juniper woodlands at higher elevations tend to follow the usual concept of linear plant succession. On sites when the time between regeneration events is longer than the lifespan of established trees, alternative steady states occur (Jameson 1987). The successional trajectory of pinyon-juniper sites subjected to drastic disturbance appears to depend upon the density and size of trees before disturbance (Schott and Pieper 1987). Tausch (1977) found a steady reduction of understory cover and production beyond the fifth to eighth year after drastic disturbance, dependent upon site characteristics.

It is imperative that land managers have the knowledge to anticipate what will happen with successional change and be able to recognize problems associated with unimpeded succession (Schott and Pieper 1986).

Pinyon-Juniper Woodlands and Climatic Change: Source or Sink for Carbon?

In addition to their potential influence on water cycling, these ecosystems might influence global temperature change most directly by acting either as a sink for excess CO_2 or by giving up some of the CO_2 currently stored, that is, act as a carbon "source" (Perry and others 1991). Net primary production (NPP) can increase and thereby sequester carbon or the decay of organic matter may be greater than NPP, or fire, insects and drought may reduce NPP leading to a release of CO_2. Destruction of forests and drastic disturbance have been linked to a 30 percent increase in atmospheric CO_2 in this century. Little is known about the carbon cycling properties of a pinyon-juniper woodland.

Efforts to investigate nutrient accumulation in pinyon-juniper woodlands were traditionally restricted to the fate of plant macronutrients after application of some management technology (DeBano and others 1987). With the recent interest in global climatic change and the concentration of greenhouse gases in the atmosphere, knowledge of the temporal dynamics of carbon cycling and feedback interactions in the pinyon-juniper ecosystem is essential (Perry and others 1991). Productivity of pinyon pines and junipers as indexed by carbon gain was found to be highly correlated to some abiotic factors, particularly soil moisture (Barnes and Cunningham 1987). Klopatek (1987) found organic carbon contents of the soil beneath canopies to be statistically greater for mature pinyon-juniper canopies than stands recovering from historic fire.

Scale Considerations

Space

New plot data have sparked further debate over the relationship between soil hydrologic condition and the pinyon-juniper ecosystem. These data might have limited statistical inference simply because of small plot size (1 x 3 m). Small plots, including the standard erosion plot (3 x 10 m) often neglect the spatial mosaic of soil hydrologic conditions typical of the pinyon-juniper ecosystem. Plots may only encompass the influence of one or possibly two pinyon or juniper trees. Heede (1987) determined that spatial variability imparted to the pinyon-juniper site by litter-produced hummocks reduced the slope gradients and diverted runoff. In this case Heede's experimental areas were 5 x 8 m "microwatersheds." Heede's microwatersheds, which add 10 square meters to the standard erosion plot, likely cannot escape the same criticism for a lack of spatial representation.

A watershed-scale study integrates spatial and temporal variability and provides a more realistic scale for assessing the influence of land management activities. In addition, modelling scale-dependent problems such as a changing global climate requires the procurement of data at a variety of scales. Standard experimental watershed methodologies, such as the paired-watershed approach, often require two like watersheds and the calibration of flow from each watershed. These experimental procedures have been criticized for their high cost and for the apparent difficulty in extrapolation. Proper design, cautious planning and careful site selection can augment statistical inference from results and address the criticisms of an experimental watershed approach (Bosch and Hewlett 1982).

Time

The time scale for pinyon-juniper research is very difficult to realistically accommodate. Houghton (1969) states that it may take 30 years or more simply to determine average annual precipitation in the Great Basin. Pinyon-juniper, and other western woodlands tend to exhibit very low dynamism (Little 1987) and appear to be some of the most static of all western ecosystems (West and Van Pelt 1987). These attributes exceed the life expectancy and attention span of most research efforts. Past research was conducted over a few years period, often coinciding with the availability of graduate student assistance. The long lifespans and time to maturity of the trees means that they are subject to significant environmental fluctuations and disturbances requiring patient observation, hence the minimum requirement of a 10-year experimental horizon planned for the study proposed here. Long-term watershed studies are needed to provide a frame of reference for shorter-term plot research (Schmidt 1987).

Study Objectives

1. To establish a long-term, watershed-scale research site for applied and basic research into the dynamics of a Great Basin pinyon-juniper ecosystem. This effort will involve investigators from across the USU campus and be coordinated with other regional studies at Los Alamos National Laboratory, Oregon State University, and the University of Nevada, Reno. Utah Agricultural Experiment Station funds will be used to delineate the site and to promote the acquisition of development funding from other sources. It is hoped that a study at a watershed scale will eventually be assisted by long-term ecological reserve funding (LTER, partially funded by the National Science Foundation), representing a pinyon-juniper ecosystem in the Great Basin.

2. To perform mechanistic research of pinyon-juniper ecosystem dynamics, such as, energy, water and nutrient cycling, organismal structure and function at relevant scales, sediment source/sink relationships, and so forth, while simultaneously addressing the more pragmatic concerns associated with management by objectives, the effects of drastic disturbance, or the results of custodial management.

- Do sites that are dominated by mature, middle-aged, or young pinyon-juniper represent degraded or degrading sites?

  Sediment source / sink relationships, soil profile / organic carbon dating

- Why might pinyon-juniper dominance influence biodiversity? How will understory plants respond to partial or complete removal of the pinyon-juniper overstory? How will the abundance of mammal and bird species change with shifting successional stage?

  Mechanical manipulation under best management practices, simulated catastrophic wildfire, mosaic thinning

- How does the water balance of a pinyon-juniper ecosystem change when vegetation dominance shifts?

  Mosaic thinning, tree removal with an undisturbed understory

- Does a pinyon-juniper ecosystem act as a source or sink for carbon?

  Ecophysiological studies of drastically disturbed and / or relatively undisturbed stands at different age classes

- Why are pinyon and juniper trees considered to be invasive under some conditions? What are the dispersal mechanisms in the Great Basin?

  Pinyon-juniper population dynamics in drastically disturbed and / or relatively undisturbed environments

Pinyon-juniper research by Utah State University will attempt to define and resolve these critical ecological questions at the watershed scale.

Study Design

We propose to use an overall study design that was successfully applied to answer geomorphic and ecologic questions in Australia, Great Britain, and the U.S., a *nested-watershed approach* (*sensu* Jarvis 1976, Neary 1985). Spatial nesting of tributary basins with uniform soils, slope, and aspect is identified, and these tributary basins are instrumented as components of a larger watershed (fig. 1). Often the watershed measuring devices are located so that each drainage area monitored increases by an order of magnitude from one location to the next (Amphlett and others 1987). Nested subareas (1.2 to 98.9 km^2) of the Highland Water Catchment in Great Britain were used to analyze the difference in runoff depth and peak discharge between heath and woodland covered areas at several spatial scales (Gurnell and others 1990). Six nested watersheds provided the background for a study of the spatial and temporal variation in suspended sediment from different cropping systems in central Iowa (Hamlett and others 1987). At the variable scales common

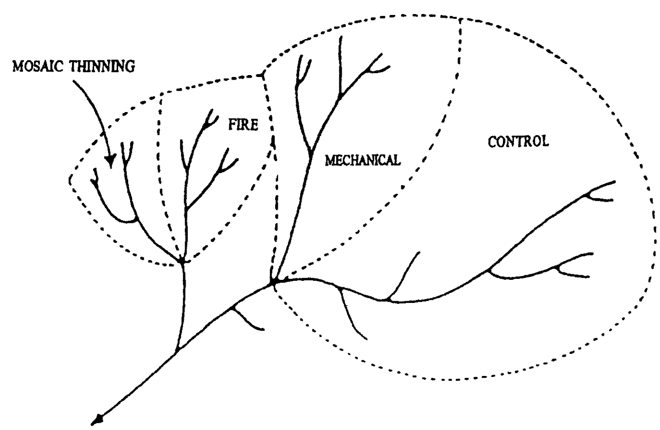

Figure 1—Nested tributaries within a larger watershed (redrawn from Jarvis 1976). Potential treatments are indicted for illustrative purposes.

to a nested watershed study, Dickinson and others (1990) were able to show dramatic variations between annual sediment yields, and suggested that the common procedure of applying sediment ratings to fill data gaps on non-instrumented watersheds is not recommended.

In our study, different land treatments will be applied to these small "nested" watersheds and the integrated effects assessed by the larger watershed (fig. 1). These studies of small watershed *process*, nested within a larger watershed require intensive efforts but can often make use of very simple techniques over short periods. A summary and review of 94 catchment experiments throughout the world revealed that paired, nested, or grouped catchment experiments produced stronger evidence than less controlled studies (Bosch and Hewlett 1982). The nested approach will provide an opportunity to confirm or extrapolate small-scale findings (Nowson 1979).

Theoretical Basis for Nested Watersheds

The attributes that set this proposed research apart from earlier efforts to establish cause and effect include:

1. Physically and biologically meaningful spatial scales that are integrated.
2. A philosophy based upon the assumption that an understanding of processes (*process-oriented research*) provides greater power to predict system response to perturbation. Additionally, using a mechanistic approach, looking for mechanisms that can be explained in terms of physics and chemistry.
3. A reasonably long time scale to obtain relevant results.
4. A study design that is flexible enough to provide for statistical analyses and the application of deterministic modelling (Deschesnes and others 1985).

Study Area

The Clover Creek Watershed is located in northeastern Tooele County approximately 32 km (20 miles) south of Tooele, Utah (St. John Quad, Sect. 35, T.6S, R.6E). The study area straddles the semidesert and upland climatic zones. Precipitation averages 32 cm (12.8 inches) each year with approximately 88 percent coming as snow and 12 percent as spring and summer thunderstorms. Temperatures can range from –7 °C to 38 °C (–19 to 101 °F) throughout the year. Soils were formed from alluvial deposits and they are presently classified as loamy-carbonatic, mesic, aridic Petrocalcic Palexerolls of the Borvant series. The vegetation type is a juniper woodland that interdigitates with a shrub steppe. The overstory is dominated by Utah juniper (*Juniperus osteosperma*) with an understory composed of microbiotic crusts and Indian ricegrass (*Oryzopsis hymenoides)*, Sandberg's bluegrass (*Poa secunda*), bluebunch wheatgrass (*Pseudorigneria spicata*), and a mix of introduced grasses and forbs. Tree interspace dominants include Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and gray rabbitbrush (*Chrysothamnus nauseosus*), understory composition is similar to the juniper understory.

Potential Treatments

Mosaic Thinning

As canopies close, herb species appear to dwindle to a fairly stable set exhibiting shade tolerance. In long-lived tree stands with shade-tolerant herbs, some researchers feel that partial removal of the canopy can negatively influence the herb biomass (Papp 1977) and their relative importance (Metzger and Shultz 1984). However, Reader and Bricker (1992) found partial canopy removal in a deciduous forest, to conserve the understory herbs. Herb species disappeared from undisturbed forest at about the same rate as partial canopy removal. These results suggest a "conserving function" that could be used to help preserve the forest understory. Manipulating the small watersheds at Clover Creek using a mosaic approach offers a unique opportunity to elucidate some of the processes producing these conflicting results. It will also add to a depauperate literature for selective removal of unmerchantable timber.

Simulated Wildfire

Canopy closure in the pinyon-juniper ecosystem appears to reduce the fine fuels available for surface fires, with the result that eventually, prescribed burning becomes an ineffective vegetation manipulation tool (Blackburn 1983). At the same time, the threat of large-scale destruction by a crown fire increases. Evaluation of the consequences of a severe wildfire through tree crowns is important to the understanding of ecosystem dynamics and risk analysis under custodial management (Tausch and West 1989).

Application of a full-scale wildfire treatment with the intensity necessary to reproduce the effects of a firestorm is not possible for obvious safety reasons. However, a portable propane plant burner, originally developed for use in evaluating the effects of fire on individual plants, can be adapted to apply specific time-temperature heat treatments to the pinyon-juniper understory. Propane burners can be constructed in a variety of sizes, depending upon the species to be treated. According to Dr. Allen Rasmussen (personal communication), a burner unit capable of moving over the soil surface could be designed and used to simulate wildfire at a small watershed scale without the threats posed by natural fire.

Mechanical Manipulation

When pinyon-juniper is uninhibited either by fire or by full-scale plant competition, the trees, with their resistance to herbivory and decay and greater physiological efficiency, permits thickening of their cover. That correlates, in most previous studies, with a further decline in understory productivity as they mature (West 1984). Dragging an anchor chain between two bulldozers or "chaining" has been used throughout the U.S. since the 1950's to remove unwanted woody vegetation. Typically, chaining was carried out in the most level portion of a pinyon-juniper dominated watershed. This heavy treatment produced an expected canopy cover shift from trees to seeded grasses, potentially lasting for at least 56 years. Disturbance levels and recovery times depend upon a myriad of factors. Disturbance levels are altered by the number of passes of the chain (for example, one-way versus two-way chaining), whether angle iron is welded to the chain, application season, and composition of the seeded mix. The permutations are numerous. Best management practices (BMP's) exist, taking slightly different forms for each management agency. These experimental studies are not intended to evaluate the efficacy of BMP's *per se*, though knowledge about the effects of this type of disturbance on pinyon-juniper at Clover Creek under the established environmental and experimental conditions will be greatly enhanced.

Untreated Control (Pre-existing and Existing Ecosystem Dynamics)

Carbon Sequestration—A recent workshop about the natural sinks of carbon dioxide (Wisniewski and Lugo 1992) proposed the hypothesis that temperate and tropical forests have the potential to sequester a part of the carbon emitted by the burning of fossil fuels not found in atmospheric and oceanic cycling. Terrestrial ecosystems supporting pinyon-juniper woodlands may be absorbing some of this misplaced carbon. As pinyon-juniper forests expand, increases in carbon storage may occur under similar circumstances as the increase in European forests since the industrial revolution. Glenn and others (1993) indicated that reversing the trend towards desertification by restoration and revegetation of degraded rangelands could, in part, result in net carbon sequestration. Annual biomass yields will need to be assessed that can produce values for net carbon uptake (*sensu* Sedjo 1989). Investigation of carbon residence times in soils supporting pinyon and juniper, likely significantly greater than forest soils, will require effort and coordination by cooperating scientists (Rick Miller, USDA-ARS, Burns, OR; David Breshears, and others, USDOE, Los Alamos).

Seed Dispersal and Population Dynamics—Koniak and Everett (1982) assert that when closed canopies of pinyon-juniper are opened artificially, few native plants tend to recover, apparently because seed banks and seed sources have been lost. The proposed experimental manipulations may be too small to gain a reasonable understanding of how large-scale treatments affect patterns of seedfall and seed predation due to the proximity and influence of the surrounding matrix. However, since treatment manipulations may differentially affect shading, water availability, and competition, experimental studies can be designed to elicit how these factors influence the incorporation of seeds into the soil, germination and successful emergence, establishment, growth and survival of seedlings (Eugene Schupp 1997, personal communication).

Historical/Ecological Relationships—See Creque, West, and Dobrowolski this proceedings.

Social Considerations—The relatively recent and vocal concern over land improvement practices in pinyon-juniper woodlands fosters a need to understand public attitudes toward such practices as chaining, prescribed burning, and seeding. The Clover Creek Study Area offers an opportunity for social science research that might link general attitudes toward rangeland improvement practices with photographs of actual sites over a period of years. Lay persons can be asked to evaluate trade-offs among alternative management scenarios after viewing computer-simulated photographs and hearing site-specific information about biodiversity, soil erosion, and other biophysical factors.

References

Amphlett, M.B., G.R. Hare, and A. Dickinson. 1987. Sediment flux monitoring in the Magat catchment, Central Luzon, the Philippines. Hydraul. Res. Ltd. Rep., Wallingford, OX, UK. 36 p.

Arnold, J.F. and W.L. Schroeder. 1955. Juniper control increases forage production on the Fort Apache Indian Reservation. Station Paper 18. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 35 p.

Bedell, T.E. 1987. Range management concerns on juniper woodlands. U.S. For. Serv. Gen. Tech. Rep. INT-215: 436-439.

Blackburn, W.H. 1983. Influence of brush control on hydrologic characteristics of range watersheds. Proc. Symp. Brush Manage., Soc. Range Manage., Denver, CO.

Blackburn, W.H. and P.T. Tueller. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecol. Late-Summer: 841-848.

Bosch, J.M. and J.D. Hewlett. 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. J. Hydrol. 55: 3-23.

Brown, T.C. 1987. The value of incremental water flow from pinyon-juniper lands. U.S. For. Serv. Gen. Tech. Rep. INT-215: 177-182.

Carrara, P.E. and T.R. Carroll. 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. Earth Surface Proc. 4: 307-317.

Clary, W.P., M.B. Baker Jr., P.F. O'Connell, T.N. Johnsen and R.E. Campbell. 1974. Effects of pinyon-juniper removal on natural resource products used in Arizona. U.S. For. Serv. Res. Pap. RM-128. 8 p.

DeBano, L.F., H.M. Perry, and S.T. Overby. 1987. Effects of fuelwood harvesting and slash burning on biomass and nutrient relationships in a pinyon-juniper stand. U.S. For. Serv. Gen. Tech. Rep. INT-215: 382-386.

Deschesnes, J., J.P. Villaneuve, E. Ledoux, and G. Girard. 1985. Modeling the hydrologic cycle: The MC model part I - principles and description. Nordic Hydrol. 16: 257-262.

Dickinson, A., M.B. Amphlett, and P. Bolton. 1990. Sediment discharge measurements from Magat catchment. Summary report: 1986-1988. Hydraul. Res. Ltd. Rep., Wallingford, OX, UK. 80 p.

Evans, R.A. 1988. Management of pinyon-juniper woodlands. U.S. For. Serv. Gen. Tech. Rep. INT-249.

Gifford, G.F. 1987. Myths and fables and the pinyon-juniper type. U.S. For. Serv. Gen. Tech. Rep. INT-215: 34-37.

Glenn, E.P., V. Squires, M. Olsen, and R. Frye. [In press]. Potential for carbon sequestration in the drylands. Water, Soil, Air Poll.

Gurnell, A.M., P.A. Hughes, and P.J. Edwards. 1990. The hydrological implications of heath vegetation composition and management in the New Forest, Hampshire. In: Thornes, J.B. Vegetation and erosion. John Wiley & Sons, Chichester, UK: 179-198.

Hamlett, J.M., J.L. Baker, H.P. Johnson. 1987. Size distribution of sediment transported within and from small agricultural watersheds. Trans. ASAE. 30: 998-1004.

Heede, B.H. 1987. The influence of pinyon-juniper on microtopography and sediment delivery of an Arizona watershed. U.S. For. Serv. Gen. Tech. Rep. RM-149: 195-198.

Hessary, I.K. and G.F. Gifford. 1979. Probable impacts of various range improvement practices on diffuse salt. J. Range Manage. 32: 189-193.

Houghton, J.C. 1969. Characteristics of rainfall in the Great Basin. Desert Res. Inst., Univ. Nevada, Reno. 205 p.

Jameson, D.A. 1987. Climax or alternative steady states in woodland ecology. U.S. For. Serv. Gen. Tech. Rep. INT-215: 9-13.

Jarvis, M.J. 1976. Classification of nested tributary basins in analysis of drainage basin shape. Water Resour. Res. 12: 1151-1164.

Johnsen, T.N. and S.D. Raymond. 1990. Managing individual juniper and pinyon infestations with pelleted tebuthiuron or picloram. J. Range Manage. 43: 249-252.

Klopatek, J.M. 1987. Nutrient patterns and succession in pinyon-juniper ecosystems of northern Arizona. U.S. For. Serv. Gen. Tech. Rep. INT-215: 391-396.

Koniak S. and R. L. Everett. 1982. Seed reserves in soils of successional stages of pinyon woodlands. Amer. Midl. Nat. 108: 295-303.

Little, E.L., Jr. 1987. Pinyon trees (*Pinus edulis*) remeasured after 47 years. U.S. Forest Serv. Gen. Tech. Rep. INT-215: 65-68.

McNichols, R.R. 1987. Management strategies in pinyon-juniper on the Hualapai Indian Reservation. U.S. Forest Serv. Gen. Tech. Rep. INT-215: 161-164.

Metzger, F. and J. Schultz. 1984. Understory response to 50 years of management of a northern hardwood forest in upper Michigan. Am. Midl. Nat. 112: 209-223.

Neary, D.G., P.B. Bush, J.E. Douglass, and R.L. Todd. 1985. Picloram movement in an Appalachian hardwood forest watershed. J. Environ. Qual. 14: 585-592.

Nowson, M.D. 1979. The results of ten years' experimental study on Plynlimon, Mid-Wales, and their importance for the water industry. J. Inst. Water Engin. and Sci. 33: 321-333.

Papp, M. 1977. Changes in phytomass and production of the herbaceous layer in the *Quercetum petraceae-cerris* forest after selecting by foresters. Acta Bot. Acad. Sci. Hung. 23: 179-192.

Perry, D.A., J.G. Borchers, D.P. Turner, S.V. Gregory, C.R. Perry, R.K. Dixon, S.C. Hart, B. Kaufmann, R.P. Neilson, and P. Sollins. 1991. Biological feedbacks to climate change: Terrestrial ecosystems as sinks and sources of carbon and nitrogen. Northwest Environ. J. 7: 202-232.

Pieper, R.D. 1990. Overstory-understory relations in pinyon-juniper woodlands in New Mexico. J. Range Manage. 43: 413-415.

Reader, R.J. and B.D. Bricker. 1992. Value of selectively cut deciduous forest for understory herb conservation: An experimental assessment. For. Ecol. Manage. 51: 317-327.

Schmidt, L.J. 1987. Present and future trends in pinyon-juniper hydrology. U.S. For. Serv. Gen. Tech. Rep. INT-215: 474-479.

Schott, M.R. and R.D. Pieper. 1986. Succession in pinyon-juniper vegetation in New Mexico. Rangelands 28: 126-128.

Schott, M.R. and R.D. Pieper. 1987. Succession of pinyon-juniper communities after mechanical disturbance in southcentral New Mexico. J. Range Manage. 40: 126-128.

Sedjo, R.A. 1989. Forests: A tool to moderate global warming? Environ. 31: 14-21.

Tausch, R.J. 1977. Plant succession following chaining of pinyon-juniper woodlands in eastern Nevada. J. Range Manage. 28: 44-49.

Tausch, R. J. and N. E. West. 1989. Differential establishment of pinyon and juniper following fire. Amer. Midl. Nat. 119: 174-184.

Williams J.D. and J.C. Buckhouse. 1993. Winter logging and erosion in a ponderosa pine forest in northeastern Oregon. West. J. Appl. For. 8: 19-23.

West, N.E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. In: Developing strategies for rangeland management. Westview Press: 1301-1332.

Hydrogeology and Spring Occurrence of a Disturbed Juniper Woodland in Rush Valley, Utah

Francis J. McCarthy III
James P. Dobrowolski

Abstract—Recent concerns over the quality of water delivered to domestic wells in Rush Valley have prompted an interest in water yields from tributary watersheds. Removal of juniper trees (*Juniperus osteosperma*) by wildfire and prescribed burning has altered the hydrologic regime of these small watersheds. The saturated areas and perennial springs that have emerged might offer direct benefits to humans, livestock and wildlife in the form of greater vegetation production later in the growing season and as more reliable water sources. We are collecting baseline hydrogeologic data and investigating the emergence of springs. Specific objectives include the determination of subsurface flow paths to selected springs and computer modeling to predict potential spring occurrence. The study area near Tooele, UT, is geologically and hydrologically complex. Most of the springs appear to occur at points of subsurface flow concentration where a shallow soil mantle exists over shale, or where fractured and solution cavities in rock are exposed and these cavities are simultaneously underlain by impermeable shale.

The removal of juniper trees (*Juniperus osteosperma*) has altered the hydrologic regime of several small watersheds in the Johnson Pass area of Rush Valley, Utah. Large increases in spring activity and water yields were observed after wildfires and prescribed burns removed junipers from tributary watersheds. Recent concern over watershed condition and the quality of water delivered to domestic wells in Rush Valley has prompted an interest in water yielded from upslope areas. Efforts to improve the watershed condition for wildlife and livestock, as well as the quantity and quality of the ground water within the valley, have led to the formation of the Clover Creek Coordinated Resource Management Plan (CRMP) (USDA 1997). The purpose of the CRMP is to increase and maintain the availability and duration of surface water flows, enhance ground water recharge, increase and maintain plant diversity and structure, and provide quality habitat for wildlife and livestock. The objectives will be met using a variety of management practices, primarily vegetation manipulation. The study area near Johnson Pass has been established by the Utah State University Department of Rangeland Resources and the Utah Agricultural Experimental Station.

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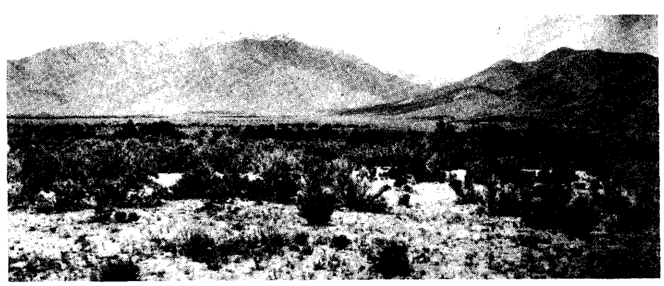
Over the past 100 years, fire suppression and overgrazing likely led to increased tree density and/or invasion of juniper trees into adjacent rangeland throughout the region (West 1989, USDA 1997). Oblique photographs from the 1880's show an area with much lower juniper tree density and aerial extent than in 1997 (fig. 1). Portions of the study area were chained and seeded with grasses in 1974 and 1975 to remove the juniper and increase forage availability. In 1991, wildfires and prescribed burning removed additional junipers, especially on the upper portions of the watershed. Following the fires, numerous seeps, wet meadows and perennial springs emerged. Riparian areas are developing within previously dry stream channels.

The purpose of this investigation is to provide baseline hydrogeological data for our study area and examine the emergence of springs. Specific objectives include the determination of subsurface flow paths to selected springs and computer modeling to predict potential spring occurrence. The Johnson Pass area is geologically and hydrologically complex (fig. 2). Several mechanisms for spring



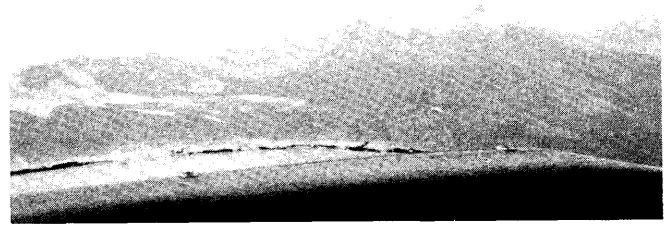


Figure 1—Top photograph was taken in the 1880's of the southern end of the Stansbury Mountains looking north into the Big Hollow area. Note small number of junipers on lower hillslopes when compared to the bottom photograph taken in November 1996 of the southern end of the Stansburys and northern Onaqui Mountains looking northwest into the Big Hollow and Johnson Pass areas.

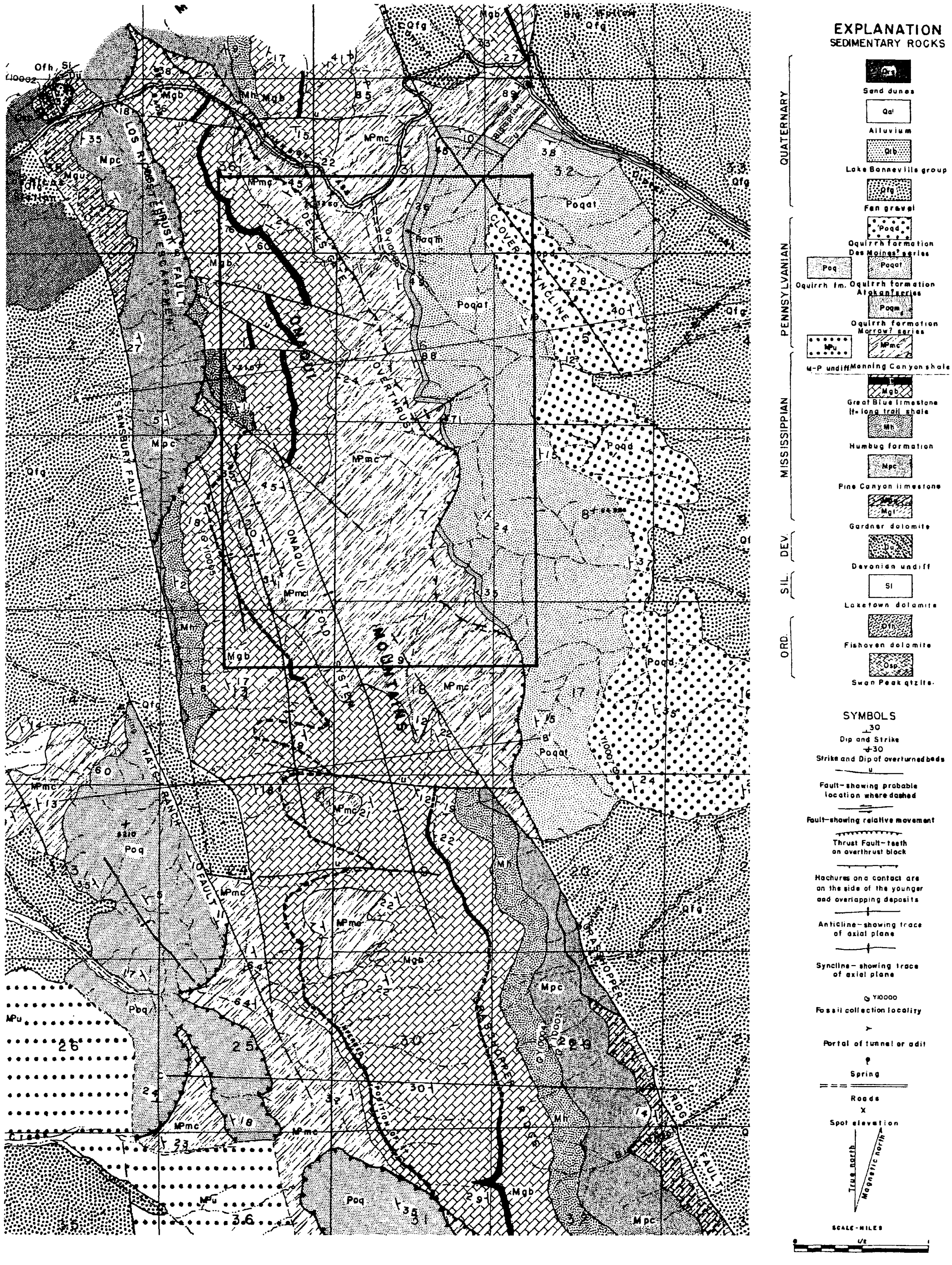


Figure 2—Geologic map with the study area outlined by a black rectangle (after Croft 1956).

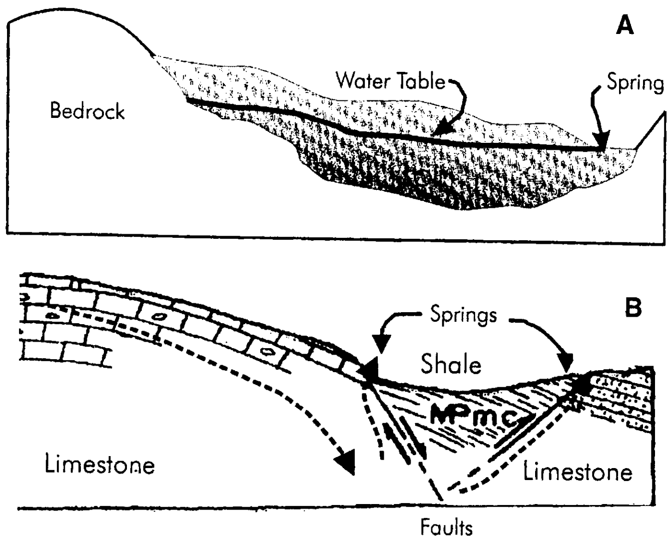


Figure 3—(A) Subsurface flow over a soil mantle resulting in a spring where the soil pinches out. (B) Possible flow paths through confined layers or along faults overlain on part of cross section (after Croft 1956).

emergence are possible. It is hypothesized that most of the springs occur at points of subsurface flow concentration where a shallow soil mantle exists over low permeability bedrock, such as shale, or other barrier to flow (fig. 3A) (Watson and Burnett 1995). Alternatively, water may flow through a confined aquifer of fractured bedrock or bedrock with solution cavities. The flow might be controlled by structural features such as faults which provide preferential flow zones or fracture the area into discrete packets of infiltration transfer and discharge across the site (fig. 3B).

Study Area

The study area is located in a high valley in the transition zone between the northern Onaqui Mountains and the southern Stansbury Mountains. Elevations within the study area range from 1,524 to 2,408 m (5,000 to 7,900 ft) above sea level. Relief is moderate compared to the surrounding terrain. Temperatures range from below zero in the winter to over 40 °C (–20 to 100+ °F) in the summer. Precipitation averages 480 mm (19 inches) per year (USDA 1988). Approximately 88 percent occurs as snowfall during the winter. Occasional monsoonal thunderstorms drop large amounts of precipitation on the area in short periods of time. Vegetation in the area consists primarily of grasses and shrubs where the junipers have been removed. Soils are thin, generally less than 50 cm (20 inches), and poorly developed (USDA 1988). Few geologic studies have been conducted in the area. Previous mapping efforts focused on larger scale structures and formations (Croft 1956). Three geologic formations are present, the Mississippian Great Blue Limestone, the Mississippian and Pennsylvanian Manning Canyon Shale and the Pennsylvanian to Permian Oquirrh Formation. The Great Blue Limestone consists of massive, thick bedded, medium to dark gray limestone. It is resistant to erosion and forms the western ridge of the study area. The majority of the study area is underlain by the Manning Canyon Shale. This is composed of three units: a lower black shale, a medial dark gray limestone unit and an upper black shale and quartzite unit (Rigby 1958). The shales are thin bedded and highly fissile. The shales are easily erodible and frequently buried. The medial quartzite outcrops very strongly across the study area and may be mapped as a marker bed. Quartzite layers are very hard and often have a scintillating appearance and visible cross bedding (Rigby 1958). The Oquirrh Formation outcrops strongly across the eastern side of the study area. It is primarily composed of hard, black to gray, well-bedded limestone with occasional clastic layers. Several strong structural features are evident across the area. The area is broadly warped into an anticline and syncline (fig. 3B) as part of a regional fold and thrust system. Numerous minor faults and folds occur within the area. Several periods of faulting have occurred. Ancient thrust faults were later dissected by strike-slip faulting and finally by Basin and Range normal faulting (Croft 1956). Much of the thrust faulting occurred within the Manning Canyon Shale making the stratigraphy hard to map due to omission or repetition of lithologic units (Rigby 1958).

The hydrology of the area focuses on two perennial spring fed streams, Chokecherry Creek and Serviceberry Creek. Annual mean flows are estimated to be less than 0.14 m^3/sec (5 ft^3/sec (cfs)) and the streams have historically dried up during the summer months (Darrell Johnson, personal communication 1997). Recent increases in water yields have resulted in the streams flowing all year with the creation and extension of riparian areas. Several wet meadows have appeared where springs occur outside of stream channels.

Methods

The investigation consists of a two-phased approach. The first phase consists of detailed Global Positioning System (GPS) assisted hydrologic and geologic mapping, including the construction of several piezometers to monitor potentiometric surface and map depth to bedrock. The second phase involves predicting the occurrence of springs and the potential for spring occurrence using a geographic information system and flow path analysis.

Phase I efforts consisted of detailed mapping of streams, roads, springs, geological contacts, geological data points, water troughs, and numerous other points of interest utilizing a handheld GPS to produce high resolution, high accuracy maps. These data are then spatially corrected and incorporated into a GIS. Earlier mapping data also will be incorporated into the GIS.

We are constructing stratigraphic and structural geologic maps to identify water bearing units and their orientation and lateral extent. Stratigraphic mapping consists of identifying and characterizing individual lithologic units and their vertical sequence. Geologic and structural mapping helps to determine the lateral extent and three dimensional orientation of each lithologic unit. Of special interest is the identification of folds and faults that might act as preferential flow paths. Field mapping will be supplemented by high resolution aerial photography. One to five thousand scale color infrared stereoscopic photographs will be acquired and used to assist surface mapping and the creation of high resolution digital terrain models (DTM's).

From these mapping efforts, several sites will be selected for construction of 5 cm (2 inches) piezometers to determine the potentiometric surface and monitor ground water levels. A 9.8 cm (3.87 inches) borehole will be drilled using a direct mud rotary technique. During drilling, information on soils, lithology, depth to bedrock, and depth to water will be collected and incorporated into the GIS. The piezometers will be completed with 5 cm PVC pipe with a screened interval of 1.5 to 3 m (5 to 10 ft). In areas with more than one water bearing unit nested piezometers will be screened to measure the potentiometric surface of each unit.

Phase II involves GIS modeling to attempt to determine what parameters promote spring occurrence and to use these parameters to predict current spring locations where springs might appear and to predict spring development if/ when the vegetation is manipulated. Preliminary efforts used standard 30 m x 30 m (98 x 98 ft) pixel size digital terrain models to examine the flow accumulation and the curvatures of the slope profile and planform to identify possible points of concentration in the topography where springs are likely to occur. Finer resolution DTM's will be created to determine drainage area, relief, aspect, slope length, curvature, and other topographic features related to each spring occurrence. These data will then be overlain with the GIS coverages of geology, potentiometric surface, depth to bedrock, and vegetation to identify the strongest influences on spring occurrence. If the model can be calibrated, it will be used to predict spring occurrence if the vegetation is manipulated.

Preliminary Results and Discussion

At present, results show that GPS based mapping is very efficient and rapidly converted to GIS coverages. Most of the data collected is still of a qualitative nature, however, several strong features can be noted. Figure 4 shows the

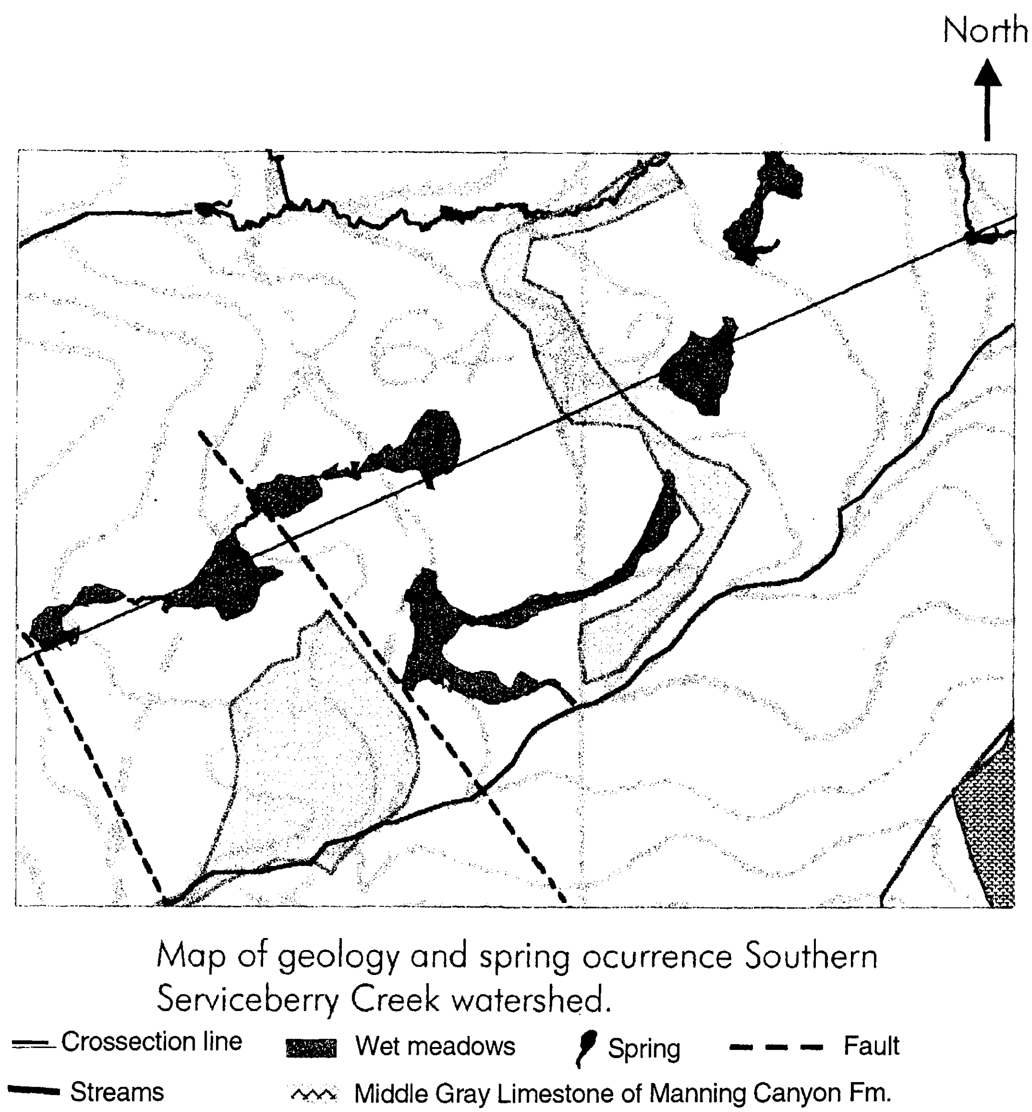


Figure 4—Geographic Information System (GIS) based map of a portion of the Chokecherry Creek tributary watershed.

locations of springs, saturated areas, streams, watershed boundaries, roads, geological contacts, and outcrop locations. Only the distinct contacts between the Manning Canyon Shale upper and lower units and the medial limestone, and the contact between the Manning Canyon Shale and the Oquirrh Formation were mapped using the GPS. Numerous strike and dip points represented by the triangles were taken to determine the orientation of the lithology. The stratigraphy is interrupted by several faults and folds within the area making stratigraphic mapping difficult. However, by focusing on the shale-limestone contacts, it is possible to get a general picture of the structure and lateral extent of lithologic units. Springs mostly appear along the contact of the shales and limestones, especially where the Manning Canyon Shale contacts the Oquirrh Formation.

The most apparent features mapped are the wet meadows and other saturated areas. Several hectares of saturated soil are apparent all year. The limited infiltration of these areas from high antecedent moisture levels, might lead to greater runoff and a concomitant increase in hydrograph storm peaks (Betson 1964, Dunne and Black 1970).

Slope instability and seepage erosion were observed in several locations across the site. Figure 5 indicates a fenced exclosure that was disturbed by failure of the slope. Strong seepage erosion appears to have undermined soil and bedrock creating spring sapping features such as streams emanating from steep semicircular slopes. Several areas across the site have similar features without flowing streams, indicating relict spring sapping features. These may provide additional insight to subsurface water flow in the area and might be incorporated into the predictive model.

Initial stratigraphic mapping shows that the Great Blue Limestone contains abundant solution cavities which might act as an aquifer, however, few spring occurrences were observed in the formation. The Manning Canyon Shale is generally impervious, although some areas are highly fractured and have open calcite lined fractures capable of moving water (Arthur 1961). The quartzite within the Manning Canyon Shale often contains open fractures that also may act as conduits for flow. Whether the medial limestone acts as an aquifer or barrier to flow has yet to be fully determined. Many of the springs appear to emanate below this unit.

Figure 5—Active seepage erosion occurring in one of the tributary watersheds.

Figure 6—Potential spring occurrence sites shown in grey-white based on slope curvature and flow accumulation. Actual springs are in black at 30 x 30 m (98 x 98 ft) pixel sizes.

Manning Canyon Shale medial limestone outcrop patterns suggest that numerous smaller folds exist across the area, as well as several unmapped faults. Detailed mapping should reveal continuation of previously mapped faults through the shale. These faults and folds might be important in controlling the behavior of many of the springs in the area. These structures might result in separate discrete zones of infiltration, transfer, and discharge with much of the transfer and discharge occurring along faults or areas where deeper soils pinch out. Movement through the soil mantle is likely, however, mapping suggests soils are too shallow and too laterally discontinuous to provide continuous flow paths. The geology of the site appears to inhibit deep penetration of ground water. Small changes in the water budget due to vegetation manipulation or climate change should be readily visible in the stream and springs.

Initial efforts to model the flow accumulation and curvature of the slopes using low resolution (30 m, 98 ft) DTM's to identify zones of flow concentration where springs might occur indicated poor results (fig. 6). Most spring features are smaller than 30 m and are obscured by the grid. Higher resolution DTM's (2 m, 6 ft) should provide enough detail to parameterize the area.

Conclusions

Preliminary results indicate that most subsurface flow is through fractured bedrock and that the structure might create discrete packets of infiltration, transfer and discharge across the site. Depth to bedrock, depth to water, and the potentiometric surface will be important to determining the flow paths to springs. The removal of juniper trees in this area increased water yields though there are a few negative side effects such as slope instability and seepage erosion. Further, the unique geology of the site forces ground water to the surface, allowing gains in water yield to be readily exploitable. Initial modeling efforts are at too coarse a scale for adequate predictive modeling. Higher resolution DTM's are required to examine spring sapping and other topographic features related to modeling at our site.

Acknowledgments

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References

Arthur, W. J. 1961. Unusual solution cavities in the Manning Canyon Shale near Fairfield, Utah Geol. Soc. Am. Bull. 72: 767-768.

Betson, R. P. 1964. What is watershed runoff? J. Geophysical Res. 69: 1541-1552.

Croft, M. 1956. The geology of the Northern Onaqui Mountains, Unpublished M.S. Thesis, Brigham Young University, Provo, UT.

Dunne, T. and R. D. Black. 1970. Partial area contribution to storm runoff in a small New England watershed. Water Resour. Res. 6: 1296-1311.

Rigby, J. K. 1958. Geology of the Stansbury Mountains, Tooele County, Utah. Guidebook to the Geology of Utah no. 13, Utah Geological Society, Salt Lake City, UT.

United States Department of Agriculture, Soil Conservation Service and Forest Service. 1988. Shambip River Basin Study, USDA, Salt Lake City, UT.

Erosion and Deposition in a Juniper Woodland: The Chicken or the Egg?

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Abstract—Mature juniper woodlands are characterized by spatial variability in hydrological conditions and microtopography. Coppice dunes (syn-hummocks or mounds) often occur beneath trees. These microtopographic features, sometimes reaching elevations of greater than one meter above the surrounding interspaces, typically are characterized by superior organic matter content and relatively fine-textured soils. This research is an attempt to identify the mechanisms involved in the production of the microtopographical differences. Differences in soil morphology and plant distribution between coppice dunes and interspaces were observed in and around backhoe trenches exposing soils in the coppice dunes and interspaces.

When juniper canopies begin to mature and close, microtopographic elements of a hillslope become more pronounced. Beneath trees, mounds or "coppice dunes" are evident. These coppice dunes appear to decrease in elevation from the tree trunk outward and they are composed of relatively fine-textured soils with incorporated leaf litter. Within interspaces, soil surfaces can be as much as one meter (3.25 ft) lower than at the tree trunk and are covered by gravel. Heede (1987) found that the microtopography produced by tree coppices absorbed the energy of flowing water and restricted the sediment delivery downslope. With the inability to effectively measure erosion, little erosion data exists to refute or substantiate the philosophical differences involving claims of site degradation and soil loss (Price and Ridd 1991). Do sites that are dominated by mature juniper trees represent degraded or degrading systems? Researchers have postulated that juniper succession trajectories are currently in place and are likely to continue for future centuries due to tree longevity, resulting in a self-destructive system (Carrara and Carroll 1979; Evans 1988; West and others, 1979).

The general objective of this study is to examine the processes occurring in a juniper ecosystem to identify sediment source or sink relationships towards answering the need for custodial or active management. It will begin with the attempt to identify the formation properties of juniper coppice dunes and how they differ or relate to the tree interspaces. The surface morphology of the juniper-covered hillslopes will be described and an attempt to model the potential flow paths will be made. The specific objectives include:

1. To describe the soil morphology beneath the juniper trees and within the interspaces and the relationship to the vegetation.
2. To survey the hillslope surfaces for small scale elevation differences between tree coppice dunes and interspaces.

Study Area

The Clover Creek Watershed is located in northeastern Tooele County approximately 32 km (20 miles) south of Tooele, Utah (St. John Quad, Sect. 35, T.6S, R.6W). Two 3.24 ha (8-acre) exclosures were established on land leased by cooperator Darrell Johnson to investigate differences in soil chemical, physical and biological characteristics beneath juniper trees and in tree interspaces. The study area straddles the semi-desert and upland climatic zones. Precipitation averages 30.98 cm (12 inches) each year with approximately 71 percent coming as snow and 29 percent as spring and summer thunderstorms. Temperatures range from –7 to 38 °C (–19 to 101 °F) throughout the year (Utah Climate Center, Johnson Pass, 1996). Soils were formed from alluvial deposits derived dominantly from limestone and were mapped as loamy-skeletal, carbonatic, mesic, shallow Petrocalcidic Palexerolls (formerly Aridic Petrocalcic Palexerolls) of the Borvant series (Soil Survey Staff, 1996; Trickler and others, in press). The vegetation type is a juniper woodland integrated with a shrub steppe. The overstory is dominated by Utah juniper (*Juniperus osteosperma*) with an understory composed of microbiotic crusts and various grasses. Tree interspace can be divided into two categories. One type had dominants that include Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) and gray rabbitbrush (*Chrysothamnus nauseosus*) with over 50 percent cover and the understory composition similar to the juniper understory. The second interspace type had sparse vegetation with various grasses, microbiotic crusts and gravel.

Analysis of Soil Morphology

Four clusters of five soil pits (twenty soil pits) were established immediately outside of the exclosures. The exclosures will have long term experiments and would have been severely disturbed by the excavation of the pits within the exclosure. In each soil pit cluster, two pits were excavated in coppice dunes after tree removal, two pits were cut into adjacent interspaces and one pit was established in a nearby sagebrush stand. Some interspaces contained living and dead sagebrush plants. Sagebrush also appeared to occur in small coppice dunes. However, coppice dunes of

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dead sagebrush were observed to be eroding apparently by wind, water or both.

Surface topography and geomorphology of the two exclosures were characterized using a GTS-3D Geodetic Total Station. Vertical resolution with this instrument was approximately 0.001 m, with spatial resolution of 0.005 m Where visible, microtopography reflecting coalescence of surface runoff was be noted on maps (fig. 1).

Soil characteristics such as depth of each horizon, depth to petrocalcic layer, petrocalcic layer thickness, pore sizes and abundance were recorded. Changes in soil color, structure and particle sizes were used to detect differences in horizons. Field and laboratory analysis of the chemical characteristics such as pH by color indicators and calcium carbonate equivalent will be conducted. Vegetation analysis will be conducted to determine percent coverage.

Results

Detailed surface mapping (fig. 1) illustrated the interfluve surfaces with juniper trees and fluvial deposits covered primarily by living and dead sagebrush. In figure 1, the sagebrush interspaces, which will be called fluves, are found in the linear depressions identified by the solid arrows. Small-scale changes in elevation and individual coppice dunes were visible. Field observations during rainfall-runoff events and the presence of litter dams suggested that visible micromorphological depressions provide paths for water flow across the landscape. The next step will be to model the overland flow on these exclosures with varying water depth.

Soils were highly variable in the study area. In general, the soil under the juniper trees had an organic horizon (table 1a) that was absent in the interspace and the fluve. There was a petrocalcic horizon that appeared to restrict the downward growth of roots and impede water percolation and vertical nutrient flux. This horizon was present in the three pedons but at different depths. The sparsely vegetated interspace had the petrocalcic horizon starting at 26 cm and extending to 149 cm (table 1c). The petrocalcic horizon under the juniper coppice dune was deeper, starting at 37.5 cm and extending to 106.5 cm (table 1a). The sagebrush fluve had a weak petrocalcic layer extending from 68 to 87 cm with roots occurring in horizontal fractures throughout the horizon (table 1b). The differences in depth indicate that water will most likely infiltrate deepest in the fluve with the best possibility of vertical distribution of nutrients, depending on the amount of rain and the intensity of the storm.

The A horizon was shallowest in the interspace (13 cm-table 1c) while the A horizon extended 14 cm and 30 cm under the juniper and in the fluve, respectively (table 1a,b). Soil color helped to distinguish between horizons and assisted in the identification of the differences in horizon properties between coppice dunes and tree interspaces. The pits in the sagebrush fluves had a deeper soil with evidence of multiple stages of deposition. The soil had a calcic or weakly developed petrocalcic horizon. Although Davenport and others (1996) concluded that pinyon and juniper trees had no significant influence on the soil morphology in New Mexico, it appears from the preliminary findings that horizonation is different between coppice dunes, interspaces and the fluves in the Great Basin. This difference might influence the distribution of vegetation. Further investigations of the linkages between soil morphology, specifically the properties of the petrocalcic layers in relation to plant establishment and erosion potential are being conducted.

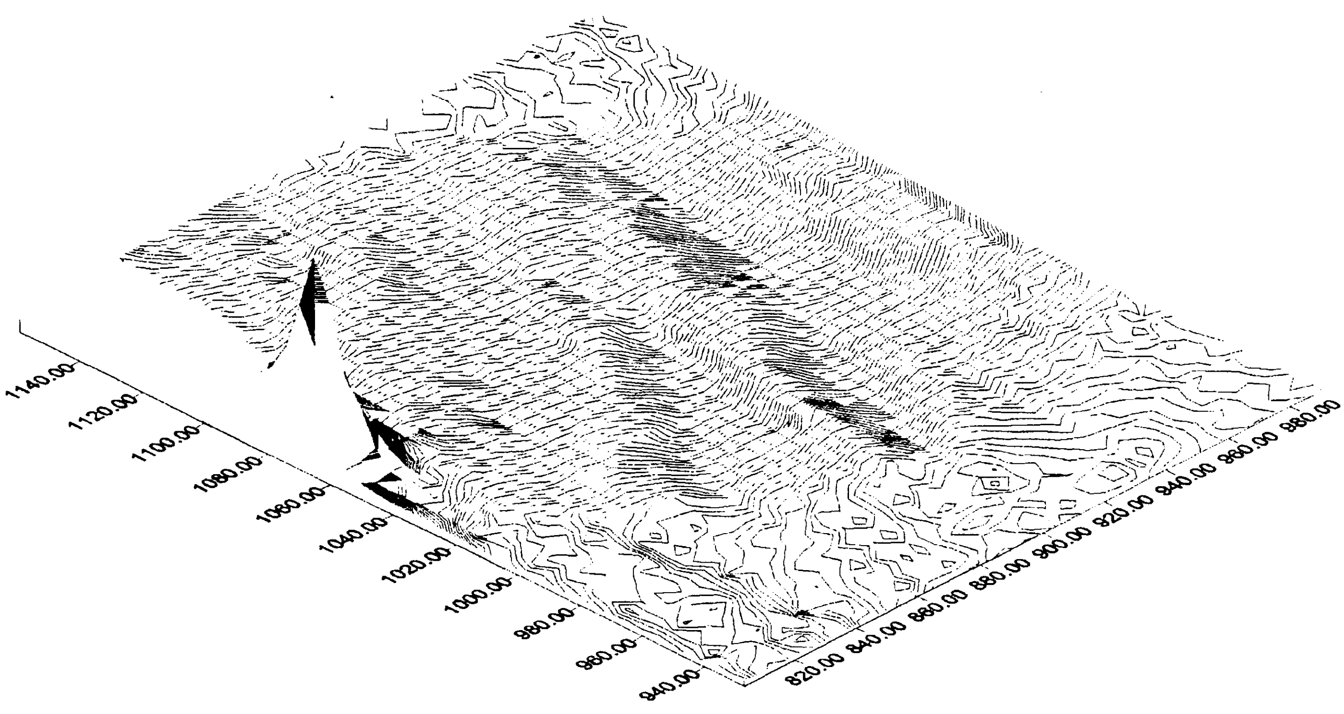

Figure 1—Three-dimensional surface plot of coppice dunes, interspaces and fluves. Arrows indicate fluves with sagebrush. Individual coppice dunes are evident in the lower right.

Table 1a—The representative soil pedon description for Plot 1-3D1 juniper coppice dune observed on 9/4/97.

The pedon for plot 1-3D1 is located under a juniper tree in St. John Quad, NE 1/4 of NE 1/4 sec. 35, T.6S, R.6W at an elevation of 5580 ft. The landform is a dissected fan composed of alluvium from limestone. There are no surface stones or rock fragments at this site. The slope is 5 percent with a northeast aspect. This pedon is well-drained with a water table that is deep. The site has a climate of aridic/mesic and supports vegetation such as: juniper and perennial grasses. Colors are for dry soil unless otherwise noted.

This soil is classified as a loamy-skeletal, carbonatic, mesic, shallow Petrocalcidic Palexeroll

Oi	3-0 centimeters; black (10YR 2/1) moist; partially decomposed root mat; loose; many fine and very fine roots; violently effervescent with a pH of 7.7; abrupt, smooth boundary.
A	0-6.5 centimeters; grayish brown (10YR 5/2) sandy loam, very dark brown (10YR 2/2) moist; moderate fine granular structure; slightly hard, very friable, slightly sticky and slightly plastic; few medium, common fine and many very fine roots; many very fine, common fine and few medium tubular pores; gravel 5 percent; violently effervescent with a pH of 8.1; clear, smooth boundary.
AB	6.5-14 centimeters; grayish brown (10YR 5/2) sandy loam, dark brown (7.5YR 3/2) moist; moderate medium subangular blocky structure; soft, friable, slightly sticky and slightly plastic; common coarse, medium, very fine and fine roots; common very fine, fine, medium and coarse tubular pores; gravel 1 percent; violently effervescent with a pH of 8.3; clear, smooth boundary.
BA	14-21 centimeters; brown (10YR 5/3) sandy loam, dark brown (10YR 3/3) moist; moderate medium subangular blocky structure; soft, friable, slightly sticky and slightly plastic; few coarse, medium, fine and very fine roots; common very fine, fine and medium tubular pores, few coarse tubular pores; gravel 10 percent with calcium carbonate seams (5 percent by vol.); violently effervescent with a pH of 8.4; clear, smooth boundary.
Bk	21-37.5 centimeters; light brownish gray (10YR 6/2) very cobbly sandy clay loam, brown (10YR 4/3) moist; moderate medium subangular blocky structure; hard, very firm, sticky and plastic; common coarse, medium, fine and many very fine roots; many very fine tubular pores, common fine, medium and coarse tubular pores; gravel 10 percent with calcium carbonate in pores and on rock faces (5 percent by vol.); violently effervescent with a pH of 8.3; clear, smooth boundary.
Bkm1	37.5-74 centimeters; white (10YR 8/1) very cobbly loamy sand, very pale brown (10YR 7/3) moist; massive; extremely hard, extremely firm, indurated; common coarse, medium, fine and many very fine roots; many very fine and fine tubular pores, common medium and coarse tubular pores; gravel 25 percent and cobbles 30 percent; violently effervescent with a pH of 8.1; clear, smooth boundary.
Bkm2	74-106.5 centimeters; white (10YR 8/1) very gravelly coarse sand, very pale brown (10YR 7/3) moist; massive; extremely hard, extremely firm, indurated; few very fine, fine and medium roots; common very fine pores; common very fine tubular pores; gravel 55 percent with calcium carbonate seams and coating rock faces (30 percent by vol.); violently effervescent with a pH of 8.8; clear, smooth boundary.
2Bkm3	106.5-121 centimeters; white (10YR 8/1) gravelly coarse sand, pale brown (10YR 6/3) moist; moderate medium platy structure; extremely hard, extremely firm, indurated; few fine roots; many very fine tubular pores; gravel 25 percent and cobbles 1 percent with calcium carbonate seams and on ped faces (25 percent by vol.); violently effervescent with a pH of 9.2; clear, smooth boundary.

The diagnostic characteristics of this pedon include: petrocalcic horizon (37.5-106.5 cm); mollic epipedon.

Table 1b—The representative soil pedon description for Plot 1-3Ew sagebrush fluve observed on 8/11/97.

The pedon for plot 1-3Ew is located in a sagebrush fluves in St. John Quad, NE 1/4 of NE 1/4 sec. 35, T.6S, R.6W at an elevation of 5580 ft. The landform is a dissected fan composed of alluvium from limestone. The surface stone and rock at this site is 10 percent gravel. The slope is 5 percent with an easterly aspect. This pedon is well-drained with a water table that is deep, >228 cm. The site has a climate of aridic/mesic and supports vegetation such as: dying big sagebrush and perennial grasses. Colors are for dry soil unless otherwise noted.

This soil is classified as a loamy-skeletal, carbonatic, mesic Xeric Petrocalcid

A	0-8 centimeters; brown (10YR 5/3) fine sandy loam, dark brown (10YR 3/3) moist; weak fine granular structure; soft, very friable, slightly sticky and nonplastic; common very fine, fine, few medium and coarse roots; many fine interstitial pores; gravel 1 percent; violently effervescent with a pH of 8.2; abrupt, smooth boundary.
BAtk	8-30 centimeters; light brownish gray (10YR 6/2) loam, dark brown (10YR 3/3) moist; weak medium to fine subangular blocky parting to granular structure; soft to slightly hard, friable, slightly sticky and slightly plastic; common very fine and fine, few medium and coarse roots; common very fine and fine tubular pores, few medium and coarse tubular pores; gravel 2 percent; violently effervescent with a pH of 8.3; clear, smooth boundary.
Bk	30-68 centimeters; light gray (10YR 7/2) loam, pale brown (10YR 6/3) moist; massive; extremely hard, friable, slightly sticky and slightly plastic; few fine, medium and coarse roots; few fine, medium and coarse tubular pores; gravel <1 percent; violently effervescent with a pH of 8.4; clear, smooth boundary.
2Bkm	68-87 centimeters; very pale brown (10YR 8/2) very gravelly; pale brown (10YR 6/3) moist; massive; indurated; common very fine, fine and few medium roots; common fine tubular pores; gravel 40 percent; roots between Bkm fractures mostly horizontal; violently effervescent with a pH of 9.3; abrupt, wavy boundary.

2Bk 87-175 centimeters; very pale brown (10YR 7/3) loamy sand, dark yellowish brown (10YR 4/4) moist; massive; hard, firm, nonsticky and nonplastic; few fine roots; many very fine and fine interstitial pores and few fine tubular pores; gravels 5 percent with thin calcium carbonate seams (1 percent by vol.); violently effervescent with a pH of 9.9; clear, smooth boundary.

3BCk1 175-183 centimeters; very pale brown (10YR 7/3) extremely cobbly loamy coarse sand, yellowish brown (10YR 5/4) moist; massive; slightly hard, friable, nonsticky and nonplastic; few fine roots; few fine tubular pores; gravels 30 percent and cobbles 40 percent with clay/silt balls (2-3 mm, <1 percent by vol.); violently effervescent with a pH of 9.7; clear, smooth boundary.

4BCk2 183-206 centimeters; very pale brown (10YR 7/3) sandy loam, yellowish brown (10YR 5/4) moist; massive; slightly hard, very friable, nonsticky and nonplastic; few fine roots; few fine tubular pores; gravel 1 percent with calcium carbonate seams (1 mm, 5 percent by vol.); violently effervescent with a pH of 9.8; abrupt, smooth boundary.

5BCk3 206-228 centimeters; pale brown (10YR 6/3) extremely cobbly loamy sand, dark yellowish brown (10YR 4/4) moist; single grain; loose, nonsticky and nonplastic; few fine roots; common fine pores; gravel 50 percent and cobbles 35 percent; violently effervescent with a pH of 9.2.

The diagnostic characteristics of the pedon include: petrocalcic horizon (68-87), ochric epipedon.

Table 1C—The representative soil pedon description for Plot 1-3l2 sparsely vegetated interspace observed on 8/11/97.

The pedon for plot 1-3l2 is located in the sparsely vegetated interspace in St. John Quad, NE 1/4 of NE 1/4 sec. 35, T.6S, R.6W at an elevation of 5,580 ft. The landform is a dissected fan composed of alluvium from limestone. The surface stone and rock at this site is 50 percent gravel. The slope is 5 percent with a northeast aspect. This pedon is well-drained with a water table that is deep, >149 cm. The site has a climate of aridic, mesic and supports vegetation such as: cryptograms, perennial grasses and sparse sagebrush. Colors are for dry soil unless otherwise noted.

This soil is Classified as a loamy-skeletal, carbonatic, mesic Xeric Petrocalcid

A 0-5 centimeters; pale brown (10YR 6/3) very gravelly loam, brown (10YR 4/3) moist; weak medium platy parting to granular structure; hard, friable, slightly sticky and slightly plastic; few very fine roots; few very fine and fine tubular pores; many very fine interstitial pores; upper 1-2 cm very few fine and very fine tubular and vesicular pores; gravel 40 percent; violently effervescent with a pH of 8.3; clear, smooth boundary.

BA 5-13 centimeters; light brownish gray (10YR 6/2) loam/silt loam, brown (10YR 4/3) moist; weak medium subangular blocky parting to very fine granular structure; hard, friable, slightly sticky and slightly plastic; common fine, medium, few coarse and very few very coarse roots; common fine and medium tubular pores, few very coarse and coarse tubular pores; gravel 1 percent; violently effervescent with a pH of 8.2; clear, smooth boundary.

Bw 13-19.5 centimeters; pale brown (10YR 6/3) loam/silt loam, brown (10YR 5/3) moist; moderate medium to fine subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common fine, few medium and coarse roots; common fine, few medium and coarse tubular pores; gravel 5 percent; petrocalcic fragments 1 percent; violently effervescent with a pH of 8.2; clear, smooth boundary.

Bw2 19.5-26 centimeters; very pale brown (10YR 7/3), loam/silt loam, brown (10YR 5/3) moist; very hard, friable, slightly sticky and slightly plastic; common fine roots, few medium and coarse roots; few fine, medium and coarse tubular pores; violently effervescent with a pH of 8.2; abrupt, smooth boundary.

Btkm 26-37.5 centimeters; white (10YR 8/1), very pale brown (10YR 7/3) moist; platy crumbling to fine subangular blocky structure; weakly cemented; very hard, firm; few fine roots; few fine tubular pores; gravel 5 percent; root layer at boundary; violently effervescent with a pH of 8.4; abrupt, smooth boundary.

Bkm1 37.5-68.5 centimeters; white (10YR 8/1), very pale brown (10YR 7/3) moist; platy crumbling to medium subangular blocky structure; weakly cemented; extremely hard, extremely firm; few fine, few medium and few coarse roots; few fine, few medium and few coarse tubular pores; roots in pores and fractures; root layer of few medium and very fine roots at boundary; gravel 10 percent; violently effervescent with a pH of 8.5; abrupt, smooth boundary.

Bkm2 68.5-77.5 centimeters; white (10YR 8/2), very pale brown (10YR 7/3) moist; massive; extremely hard, extremely firm, indurated; gravel 10 percent; root layer of few medium, coarse and many fine roots at boundary; violently effervescent with a pH of 9.0; clear, smooth boundary.

2Bkm3 77.5-92 centimeters; white (10YR 8/2), light gray (10YR 7/2) moist; massive; extremely hard, extremely firm, indurated; gravel (fine, medium and a few coarse) 40 percent; violently effervescent with a pH of 9.0; clear, smooth boundary.

2Bkm4 92-149 centimeters; white (10YR 8/1), very pale brown (10YR 7/3) moist; massive; extremely hard, extremely firm, indurated; gravel (coarse) 50 percent; violently effervescent with a pH of 9.3.

The diagnostic characteristics of this pedon include: petrocalcic horizon (26-149 cm), ochric epipedon.

References

Carrara, P. E.; Carroll, T. R. 1979. The determination of erosion rates from exposed tree roots in the Piceance Basin, Colorado. Earth Surface Processes and Landforms. 4: 307-317.

Davenport, D. W.; Wilcox, B. P.; Breshears, D. D. 1996. Soil morphology of canopy and intercanopy sites in a pinon-juniper woodland. Soil Science Society of America Journal. 60: 1881-1887.

Evans, Raymond A. 1988. Management of pinyon-juniper woodlands. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. General Technical Report, INT-249.

Heede, Burchard H. 1987. The influence of pinyon-juniper on microtopography and sediment delivery of an Arizona watershed Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. General Technical Report, RM-149: 195-198.

Price, Kevin P.; Ridd, M. K. 1991. Detection of soil erosion within pinyon-juniper woodlands using thematic mapper (TM) satellite data. ACSM/ASPRS/Auto Carto 10 Meetings. March 24-29, Baltimore MD.

Soil Survey Staff. 1996. Keys to Soil Taxonomy, Seventh edition. USDA Natural Resources Conservation Service. US Government Printing Office, Washington, D.C.

Trickler, D. and others. [In press.] Tooele County Soil Survey.

Utah Climate Center. 1996. Precipitation Data for Johnson Pass. Utah State University.

West, Neil E.; Tausch, R. J.; Rea, K. H.; Tueller, P. T. 1979. Phytogeographic variation within juniper-pinyon woodlands of the Great Basin. In: Harper, K. T.; Reveal, J. L. coordinators. Intermountain Biogeography: A Symposium. Great Basin Naturalist Memoirs No. 2. Provo, UT: Brigham Young University Press: 119-136.

Response of Bighorn Sheep to Pinyon-Juniper Burning Along the Green River Corridor, Dagget County, Utah

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Sherel Goodrich
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Abstract—Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) within the Green River Corridor have shown a high preference for burned areas within the pinyon pine (*Pinus edulis*) and juniper (*Juniperus osteosperma* and *J. scopulorum*) belt and within ponderosa pine (*Pinus ponderosa*) communities. Burns located within or adjacent to steep rocky habitat, and within core bighorn use areas, received significantly higher use than non-burned areas. Increased use of an area occurred where fire left more open areas with a reduced density of live or standing dead trees. Positive response has been found in small burns of 5 acres to large burns of 600 acres or more. Less significant use was observed on burn areas that were not within the core bighorn sheep area, or at sites with dense standing dead pinyon-juniper. Bighorn group size was significantly larger in burned areas.

Rocky Mountain bighorn sheep (*Ovis canadensis canadensis*) were reintroduced on Bare Top (also known as Bear) Mountain along the Green River Corridor in 1983-1984. Various habitat treatments have been applied to this area to improve and expand bighorn habitat. Historically, Native Americans used fire to maintain desired habitat for game species such as bighorn sheep, which they placed high value on as a resource.

Smith (1992 and 1996) studied this bighorn herd in 1986-1988, and in 1991. He found the most highly preferred habitats were burned areas dominated by grasses. He repeatedly found bighorn sheep in older burned areas and areas with sparse or intermediate cover of trees within the pinyon pine (*Pinus edulis*) and juniper (*Juniperus osteosperma utahensis* and *J. scopulorum*) belt, and at the interface of this belt with ponderosa pine (*Pinus ponderosa*) communities. Smith (1996) studied the response of Bare Top bighorns to clearcutting and prescribed burns applied to cliff-side habitat in 1989. He found that bighorns responded favorably to both habitat treatments by expanding range use and distributions into formerly unused areas, and that bighorns favored clearcuts twice as much as burned areas. Subsequent monitoring (1995-1997) by the Utah Division of Wildlife Resources (UDWR) continues to show a stronger preference for burned and open areas over those occupied by dense trees.

Smith (1992) also looked for bighorn sheep in recently burned pinyon-juniper areas with a high density of standing dead trees. He found that the bighorns generally avoided the areas that had a high density of live or standing dead trees. He considered a high density of live or standing dead trees to reduce the visibility of bighorns to intolerable levels.

Study Area

The principal area of study is on and around Bare Top Mountain which is within the Green River Corridor, Daggett County, Utah. The top of the mountain is comparatively flat with Red Canyon and Flaming Gorge Reservoir on the east, south, and west sides. Red Canyon is a deep canyon with associated side canyons. It was cut by the Green River which runs through the north flank of the Uinta Mountains. These steep rocky canyons which have been cut through Precambrian materials of the Uinta Mountain Group, Weber Sandstone, and other geologic formations, provide important habitat for bighorn sheep. Steep and cliffy canyon walls with warm exposures provide winter forage when snow is deep on the top. These steep areas are also important during the lambing season, and for escape cover (Smith 1992). Wild and prescribed fire has occurred on top of the mountain and along the canyon walls (fig. 1,2). Burns range in size from 5 acres to over 600 acres. Clearcut logging also occurred in 1989 on top of the mountain.

Pinyon and juniper are well adapted to the steep and rocky canyon walls with warm exposures. The density of pinyon-juniper is largely a function of fire history. Fire potential is dependent upon pinyon-juniper density and understory conditions. Many places along the canyon have intermediate densities of pinyon-juniper trees, where a high percent of exposed rock has reduced tree and understory densities necessary to carry fire. In other places fuel conditions have enabled fire to occur, indicating fire to be an important part of the ecology of the area.

The top of the mountain contains ponderosa pine with associated mountain brush and grass communities of sagebrush (*Artemesia tridentata wyomingensis*), bitterbrush (*Purshia tridentata*), snowberry (*Symphoricarpus* spp.), ceanothus (*Ceanothus* spp.), wheatgrasses (*Agropyron* spp.), sheep fescue (*Festuca* spp.), and needlegrass (*Stipa* spp.). Pinyon-juniper also grows on top, however, dense stands have not commonly developed there. Fuels and other conditions have effectively carried fires and reduced pinyon-juniper presence.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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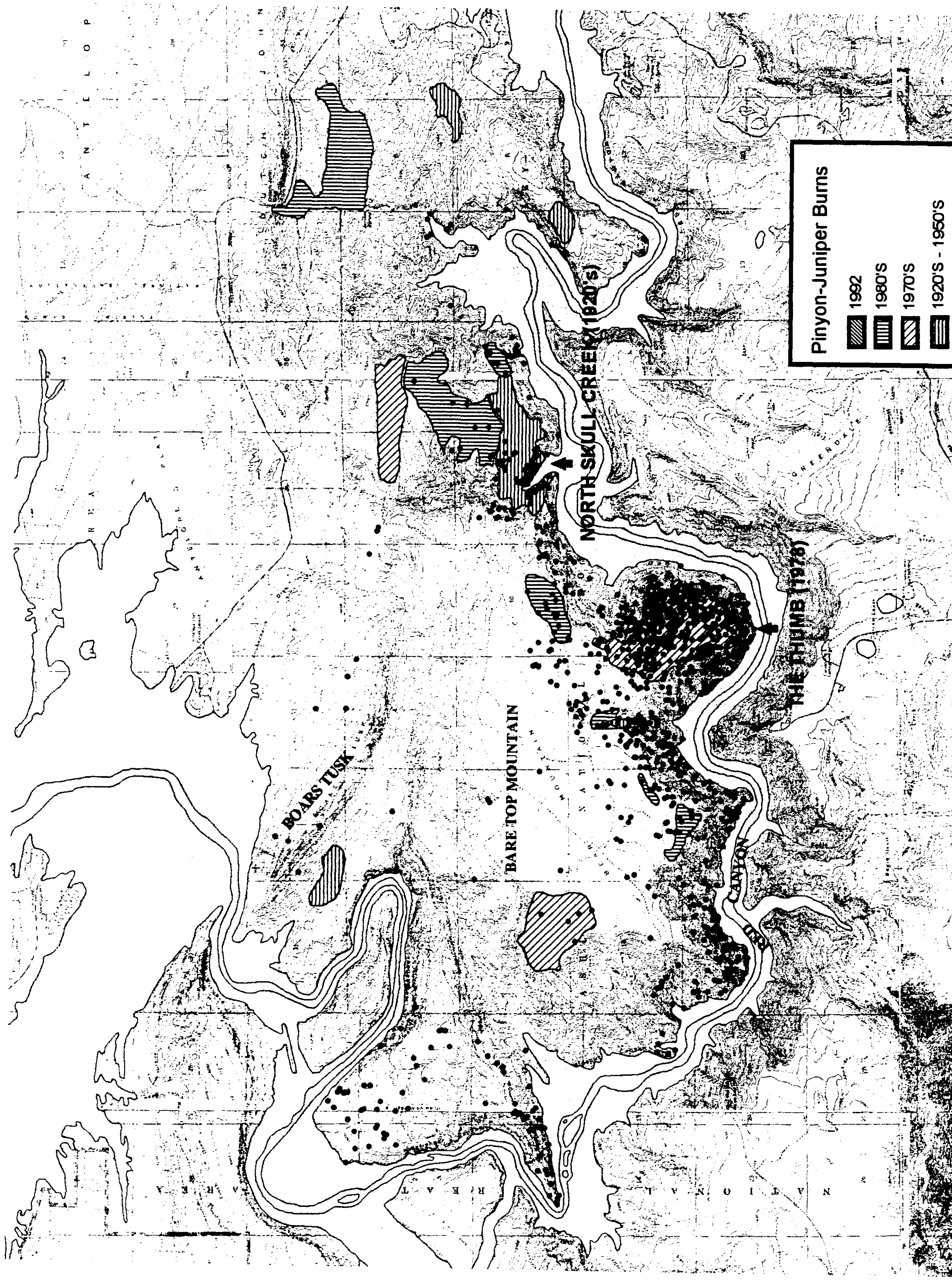

Figure 1—Bare Top bighorn sheep locations (1986-1991), in relation to pinyon-juniper burns, Daggett County, Utah (Smith 1992 and 1996).

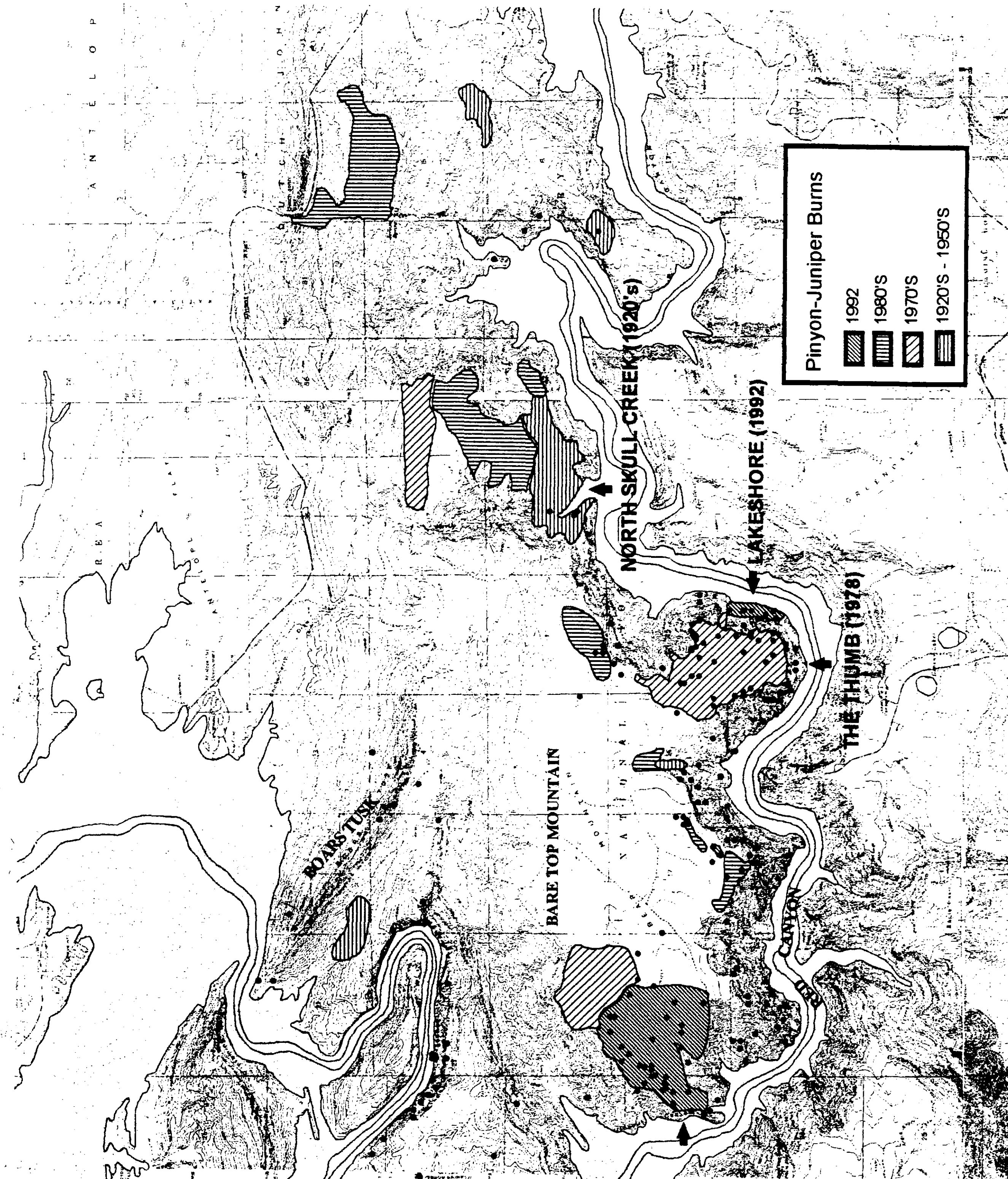

Figure 2—Bare Top bighorn sheep locations (1995-1997), in relation to pinyon-juniper burns, Daggett County, Utah.

Methods

New pinyon-juniper areas were burned in 1992 in a cooperative effort with the U.S. Forest Service and the UDWR. Both burns were located in steep rocky habitat considered to be within the core bighorn use area. The core bighorn use area was from North Skull Creek west along Red Canyon and north to the Boars Tusk (fig. 1,2). Bighorn use of the new pinyon-juniper burn areas before and after burning was compared. Comparisons were made between 1995-1997 bighorn location data, and 1986-1991 bighorn locations from Smith (1992 and 1996).

Bighorn sheep were located primarily using radio telemetry from 1995-1997. Radio-collared bighorns were located from the ground, boat, and fixed-wing aircraft. Ground surveys were performed up to 3 times per month, and fixed-wing surveys once per month. In addition, bighorn locations from helicopter trend counts and incidental observations were also used. Bighorn group size, classification (rams, ewes, and lambs), and burn category was documented for each observation. Bighorn locations and burns were digitized into a geographic information system (GIS). Smith (1992) also used radio telemetry for surveys from 1986-1988. Smith (1996) recorded visual observations of bighorns in 1991 made along an established walking transect (radio telemetry was not used during his 1991 walking transect survey).

The hypothesis, that bighorn sheep use different age burns and non-burned areas in proportion to the area of occurrence, was examined using a chi-square goodness-of-fit test. Selection or avoidance of individual burned or non-burned areas was examined using Bonferroni normal statistics (Neu and others 1974). A comparison of mean bighorn group size between burned and non-burned areas was conducted using a Student's t-test.

Results

Bighorn sheep continued to use the more open, steep and rocky habitat during 1995-1997. Forty-three percent of all bighorn locations from 1995-1997 occurred in burned areas. Twenty-two percent of the bighorn locations occurred in the new burn areas. Smith (1992 and 1996) found less than 2 percent of his bighorn locations in these areas prior to burning. The Hideout burn is 581 acres and was seeded with a mix of grasses and forbs. The Lakeshore burn is 64 acres, and was never reseeded. The core bighorn area was used to test the hypothesis that bighorns utilized burned areas of different ages, and non-burned areas, in exact proportion to their occurrence. Chi-square analysis (goodness-of-fit test) showed a significant difference between the observed and expected bighorn observations for burned and non-burned areas ($X^2 = 133.54 > X^2_{0.99\,(4)} = 13.27$). Thus the hypothesis was rejected. Next, the analysis technique developed by Neu and others (1974) was used to determine preference or avoidance of burned and non-burned areas. Comparisons of the expected proportion of bighorn observations, to the 95 percent confidence interval on the observed proportions of bighorn observations, were made (table 1). Bighorns were observed in burns, ranging in age from the 1970's to 1992, significantly more than expected (42 percent of the bighorn observations were in these more recent burns, although only 14 percent were expected). Old burns ranging in age from the 1920's to 1950's were used in proportion to their availability (1.5 percent of the bighorn groups were observed, with 2.0 percent expected). Non-burned areas were used significantly less than expected (57 percent of the bighorn observations occurred in non-burned areas, with 84 percent expected).

Bighorn group size comparisons between burned and non-burned areas found burned areas to have a mean (SE) group size of 8.3 (0.84) bighorns, and non-burned areas 5.0 (0.77) bighorns. Burned areas had a significantly higher bighorn group size than non-burned areas ($t = 2.85$, 71 df, $P < 0.01$).

Discussion

Our study shows that bighorn sheep will use new pinyon-juniper burns given the right circumstances. The Lakeshore burn is located on the east side of the Thumb area next to Flaming Gorge Reservoir in cliffside habitat. Prior to burning, trees were cut and piled to increase fire transmission. After burning, few standing dead trees remained allowing good visibility for bighorns. The Lakeshore burn was located next to the Thumb area which already received concentrated bighorn use.

The Hideout burn is located in steep rocky terrain, along Red Canyon, on the southwest side of Bare Top, within the core bighorn use area. In parts of the burn, pinyon-juniper trees were sparse enough that burned skeletons do not reduce visibility for bighorns. Most of the bighorn observations in the Hideout burn are on the west ridge which had a lower density of pinyon-juniper prior to burning.

Table 1—Observed and expected frequencies of bighorn observations in relation to pinyon-juniper burns, Bare Top Mountain, Daggett County, Utah, 1995-1997.

Burn categories	Acres	Observed N	Observed Proportion (Pi)	Expected[a] N	Expected[a] Proportion	95 percent confidence interval on Pi[b]	Selection behavior[c]
1992 Burns	650	44	0.217	13	0.065	0.143 < Pi < 0.291	Preferred
1980's Burns	190	13	0.064	4	0.019	0.020 < Pi < 0.108	Preferred
1970's Burns	578	28	0.138	12	0.058	0.076 < Pi < 0.200	Preferred
1920-50's Burns	201	3	0.015	4	0.020	– 0.007 < Pi < 0.037	Indifferent
Non-Burned	8,381	115	0.566	170	0.838	0.476 < Pi < 0.656	Avoided
Total	10,000	203	1	203	1		

[a]Derived from the acres of each burn category.
[b]From Neu and others (1974).
[c]Burn categories preferred were used significantly more than expected; burn categories indifferent used as expected; burn categories avoided used significantly less.

Bighorns tend to avoid parts of the burn where the skeletons are dense.

Smith (1992) recommended against using pinyon-juniper burns to create or enhance bighorn habitat. He found bighorn sheep had preference for areas which provide high visibility. The most highly preferred habitats were older burned areas dominated by grasses. He found bighorns avoided high and intermediate densities of pinyon-juniper stands. This avoidance included recently burned stands with high densities of standing dead trees. He observed that older burned areas with low densities of trees were preferred by bighorns. This was consistent with other studies that reported bighorns to seek burned areas. Smith (1992) also found the diets of bighorns in this area were comprised of 79.2 percent graminoids, 6.9 percent forbs, 13.0 percent shrubs, and 1 percent conifers. The rim of Red Canyon was considered by Smith (1992) to be highly important habitat for the bighorns. He found that 95 percent of all observed bighorn activity was confined to steep cliff complexes or was within 300 meters of them.

Smith (1996) found that bighorns responded favorably to both clearcut logging and prescribed burns by expanding range use and distributions into formerly unused areas. He found that bighorns favored clearcuts twice as much as burned areas.

Three criteria must be met when planning pinyon-juniper burns to enhance bighorn use and expand habitat. First, new pinyon-juniper burns must be located within the core bighorn sheep use area. Second, new burns must be within or immediately adjacent (within 300 m) to steep rocky escape terrain. Third, part of the area to be burned should have a lower density of trees, so that the burned skeletons will not reduce visibility for bighorn sheep.

Results of our study indicate that Bare Top bighorns did not significantly use new pinyon-juniper burns north and east of North Skull Creek during Smith's (1992) study primarily because these new burns were not within the core bighorn sheep area and remaining tree skeletons were dense and reduced bighorn visibility. Bighorns were not found to utilize these same burns during our study for the same reasons. It is hoped that as standing dead tree skeletons fall and decay, bighorn visibility and use will increase.

Smith (1992) observed significant bighorn use on an old burn (from the 1920's) at the mouth of North Skull Creek. The Thumb area was burned in 1978 by a wildfire and received the highest concentration of bighorn use during Smith's study (1992).

A significant shift in bighorn use to the new 1992 pinyon-juniper burned areas occurred. The Thumb continues to receive significant bighorn use. The new Hideout burn now receives comparable bighorn use to the Thumb.

Conclusions

Small burns as well as larger burns were selected during all studies. Documented observations verify high bighorn selectivity for burned areas which result in early seral, open communities. Habitat values for bighorn sheep within the pinyon-juniper belt are much higher in early seral communities than in mature pinyon-juniper stands. Visibility is indicated to be a major factor in habitat selection. Conditions that favor greater visibility are also favorable conditions for quantity and quality of forage for the bighorns. The high percentage of graminoids and low percentage of conifers in the diets of bighorns found by Smith (1992) are consistent with the concept that early seral communities are of greater value to bighorns than communities dominated by trees.

Management Implications

Valuable bighorn sheep habitat is associated with early seral plant communities in steep rocky terrain, characterized by good visibility, abundant grasses and grasslike plants, and low density of trees and tall shrubs.

As pinyon-juniper have the capacity to dominate much of the landscape, fire or other disturbances will be required to maintain valuable bighorn habitat. Disturbance intervals short enough to prevent tree dominance is essential to the maintenance of this habitat. Studies in burned sites within the pinyon-juniper belt of the Green River Corridor (Goodrich and Barber 1998, these proceedings) indicate a fire frequency of 50 or more years would likely keep tree density and stature at levels preferred by the bighorns. However, shorter intervals might be required to keep shrub density and stature within levels preferred by the bighorns. Fire intervals of 20-25 years (Houston 1973) and 10-40 years (Winward 1991) have been suggested within the inherent range of variability for montane sagebrush communities. Fire intervals of 20-25 years are indicated to keep density and stature of shrubs at levels favorable for bighorn sheep habitat.

Burning outside core bighorn use areas in mature, dense stands of pinyon-juniper should not be expected to immediately increase available bighorn habitat. Re-burning such dense stands or using additional mechanical treatments, at appropriate intervals, will create and maintain open, early seral communities, increasing its value for bighorns. Expansion of habitat for bighorn sheep in this study area will depend largely on prescribed burning or other treatments that reduce the presence of live pinyon and juniper as well as tree skeletons remaining after fire. Maintenance of bighorn habitat will be highly dependent on repeated treatments. Bighorn sheep densities will be low without such actions.

References

Goodrich, S.; Barber, B. This proceedings. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Houston, D. B. 1973. Wildfires in northern Yellowstone National Park. Ecology. 54: 1111-1117.

Neu, C. W.; Bryers, C. R.; Peek, J. M. 1974. A technique for analysis of utilization-availability data. J. Wildlife Manage. 38: 541-545.

Smith, T. S. 1992. The bighorn sheep of Bear Mountain: ecological investigations and management recommendations. Ph.D. Thesis, Brigham Young Univ., Provo, UT. 425 pp.

Smith, T. S. 1996. Draft Publication: Response of Rocky mountain bighorn sheep to clearcut logging and prescribed burning in Northeastern Utah. 22 pp.

Winward, A. H. 1991. A renewed commitment to management of sagebrush grasslands. In: Miller, R. F., editor. Management of sagebrush steppe. Special Rep. 880. Corvallis, OR: Oregon State University Agricultural Experiment Station: 2-7.

Importance of Western Juniper Communities to Small Mammals

Mitchell J. Willis
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Abstract: We investigated the composition and relative abundance of small mammals in western juniper (*Juniperus occidentalis*) woodlands of southeast Oregon in the spring of 1993 and 1995-97 by snap trapping recently cut woodlands, shrub dominated sites, and adjacent uncut (both mid-successional and old-growth) juniper sites. The number of captures were almost always higher in the cut sites than in the uncut sites, but results were mixed in the shrub/tree comparisons. The number of species captured was higher in shrub sites compared to old growth woodland sites. We believe structure provided by robust understory vegetation and the overhanging juniper skeletons provided superior security and forage for small mammals in the cut and dropped sites.

The issue of juniper (*Juniperus* sp.) encroachment, conversion, and subsequent impacts of community structural changes on small mammals has been of increasing interest by resource managers in recent years. Although research has been conducted on the direct effects of juniper on forage productivity, plant composition and structure, and impacts on big game, little has been directed toward small mammals associated with western juniper (*J. occidentalis*).

Of the estimated 341 animal species found in southeastern Oregon (Maser and others 1984), 95 have been reported to occur in juniper steppe (Puchy and Marshall 1993). Juniper steppe is defined as western juniper woodlands, typically having a sagebrush (*Artemisia* sp.) understory. The western juniper/sagebrush/bunchgrass community had the third largest number of the 341 total wildlife species from the 16 general plant communities Maser and others (1984) described in southeastern Oregon. Puchy and Marshall (1993) also reported large numbers of wildlife use juniper steppe. However, both of these reports were based on minimal data and written as guidelines. These reports lumped a broad range of transitional phases of juniper succession in shrub steppe across a wide variety of environmental variables, both of which affect plant community structure, composition, and function (Miller and others, this symposium). Juniper-shrub steppe communities described in the literature are typically shrub-steppe communities in various stages of woodland conversion. Shrubs and some perennial grasses and forbs are lost as woodlands approach full development, changing the structural characteristics of the understory (Miller and others, this symposium).

Few studies have evaluated the effects of juniper woodland development or conversion in shrub steppe communities on nongame use, and most of these have been conducted in pinyon (*Pinus* sp.)-juniper communities. Baker and Frischknecht (1973) examined small mammal changes relative to clearing and seeding in pinyon-juniper communities in Utah. They found large increases in white footed deer mice (*Peromyscus maniculatus*) and Great Basin pocket mice (*Perognathus parvus*) in cut areas for the first three years after treatment, followed by a reduction to a population level still above that before treatment. Turkowski and Reynolds (1970) found 1.2-4.0 times as many rodents on treated (cut) plots over untreated plots three years after treatment in the same type on the Kaibab Plateau in Arizona. In pinyon-juniper woodlands of northeast Nevada, Mason (1981) found rodent numbers increased while species diversity decreased on burned pinyon-juniper sites during the first two years following treatment; both bird numbers and diversity increased on burned areas in these woodlands over comparable unburned areas. O'Meara and others (1981) noted small mammal abundance in Colorado was higher in chained pinyon-juniper woodland than in control plots. They suggested adverse effects on nongame wildlife could be minimized by favoring survival of shrubs and young trees, retaining selected cavity trees, and limiting widths of clearings when chaining. O'Meara and others (1981) also found higher bird densities in unchained areas than in chained areas. Sedgwick and Ryder (1987) found small mammal species richness and total captures greater on chained versus unchained plots of pinyon-juniper in Colorado. Seven of the 16 most common bird species in the area used the control plot more, while only one species used the chained plot more. Severson (1986) found total numbers of small mammal species significantly greater on all treated areas compared to untreated pinyon-juniper woodlands 13-18 years post-treatment. Individual species and groups responded differently to the tree removal manipulations and methods of slash disposal. Grassland rodents as a group were more abundant where the overstory and slash had been removed, however, wood rats (*Neotoma* sp.) and brush mice (*Peromyscus boylii*) were greatest where the slash remained on the site. Pinyon mouse (*P. trueii*) and rock mouse (*P. difficilus*) preferred the thinned site, where slash remained on site. Austin and Urness (1976) found few differences with respect to total rodent numbers and weight in a comparison among seven pinyon-juniper types.

The apparent conflicting results of small mammal and bird responses to woodland treatment is probably largely due to the limited vegetation data collected in these studies.

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Juniper and pinyon-juniper woodlands occur across a wide variety of spatial and temporal conditions in the Intermountain west (Miller and others, this symposium; Tausch and others, this symposium). Woodland structure and composition prior to treatment, and succession following treatment will likely significantly affect small mammal and avian populations.

We investigated small mammal and bird composition and relative abundance in southeast and central Oregon, northwest Nevada, and northeast California in 1993 and 1995-97. In this paper, we compare small mammal populations between cut and uncut stands of mid-aged western juniper woodlands, old growth woodlands with adjacent shrubland, and also mid-aged stands with the old growth stands in southeast and central Oregon.

Study Areas

Page Ranch: Closed Woodland vs. Cut

The Page Ranch study area was located in Grant County, Oregon, along Warren Creek at about 4,600 ft with northwest 20 percent slopes. Treated sites were about 25 acres in size. Vegetation was a mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*)/ Idaho fescue (*Festuca idahoensis*) community. The juniper stand was fully developed, about 40 percent canopy cover, 100-130 trees/acre, with sparse understory shrubs. Perennial grasses and forbs had higher cover values in cut sites, but were common on both. Three treatment blocks were cut and the trees left in place during the fall of 1992. Sampling commenced in the spring of 1993, and was repeated in 1995-97.

Krumbo Ridge: Mid-transitional Juniper-Shrub Steppe vs. Thinned

The Krumbo Ridge study area was located at about 5,000 ft on Steens Mountain, Harney County, Oregon. Slopes were generally northerly and less than 2 percent. The three uncut sites were mid-transitional woodlands with 10-20 percent tree canopy cover and 100 trees/acre, 7-15 percent shrub cover, and 5-10 percent perennial herbaceous cover. The three cut sites were thinned to 2-3 trees/acre (1-2 percent canopy cover) in the spring of 1995. Understory vegetation was characterized by mountain big sagebrush and Idaho fescue.

Juniper Mountain: Old Growth vs. Shrub Steppe

The Juniper Mountain study area was located in Harney and Lake Counties at about 6,000 ft. All sites were on southeast aspects with 20 percent slopes. The woodland sites were old growth ranging from 400 to 1,000 years old and had 30-35 percent crown closure. Dead and down material was relatively abundant with many cavities. Shrub cover under the trees was less than 1 percent. The shrub sites had 35 percent cover of mountain big sagebrush. Abundant herbaceous plants were bluebunch wheatgrass (*Agropyron spicatum*), Thurber's needlegrass (*Stipa thurberiana*), and bottlebrush squirreltail (*Sitanian hystrix*).

Green Mountain: Old Growth Juniper Woodland vs. Shrub Steppe

The Green Mountain study area was located in Lake County Oregon at 5,000 ft. Sites were southeast aspects with <5 percent slopes. The woodland canopy was more open with slightly less dead and down woody material and fewer cavities than Juniper Mountain. Tree canopy ranged from 10-15 percent, shrub cover was <1 percent, and herbaceous cover 10 percent. The adjacent shrub sites burned about 50 years ago. Shrub cover was 15 percent and herbaceous cover was 10-15 percent.

Methods

Small mammal trapping was conducted in permanently marked grids centered within each site. Museum Special traps were set within 1 m of flags placed in a 10 x 10 array at 5 m intervals totaling 100 traps/grid. Traps were baited with peanut butter and rolled oats. At each study area, treatments and controls were repeated three times resulting in 3,000 trap-nights for each study area. Traps were set on day 1, checked in the early morning on days 2-4, and pulled after checking on day 5. Trapping was conducted May-early July. The status of each trap was recorded daily. Captured mammals other than white footed deer mice were placed in plastic bags with plot number, treatment, station, and date recorded on the outside, cooled on ice, and later identified. White footed deer mice were removed from traps and left in the area in deference to hantavirus concerns.

Museum Special snap traps were used in lieu of livetraps. While capture selectivity may exist among trap types (Fowle and Edwards 1954), snap traps have been utilized extensively and effectively (Johnson and Keller 1983). Snap traps were found more effective than pitfall traps for deer mice and chipmunks (*Tamias* sp.) (McComb and others 1991), both common to juniper woodlands (Johnson and Keller 1983). Hayward and Hayward (1995) found capture rates between pit and snap traps were generally quite similar for the most common species in their work in central Idaho. We would have used pitfall and rat-traps as well, but logistics and finances limited effort to museum specials.

Results

Fourteen species representing four orders of small mammals were captured (table 1) from the 30,000 trap-nights of study. We had 898 total captures ($\bar{x}$ = 34 trap-nights/capture, range = 16-86). The white footed deer mouse was the most often captured species (n = 614; 68.4 percent), followed by yellow pine chipmunk (n = 122; 13.6 percent, and Great Basin pocket mouse (n = 81; 9 percent).

Cut versus Uncut

Seven trapping sessions were conducted comparing cut versus uncut sites (Page Ranch and Krumbo Ridge). Although the difference was not significant (P = 0.11), between cut and uncut sites across the two study locations, in all but one instance (Krumbo Ridge 1995), there were more

Table 1—Small mammals captured at Page Ranch, Krumbo Ridge, Juniper Mountain, and Green Mountain in Eastern Oregon, 1993, 1995-97.

Location	1993		1995		1996		1997	
Page Ranch (Uncut vs. cut)								
Long-tailed meadow mouse	0	0	1	0	0	0	0	0
Montane meadow mouse	0	1	2	34[a]	0	5[b]	0	0
Bushy-tailed wood rat	0	0	1	0	0	0	0	0
Canyon mouse	0	0	1	1	0	0	0	0
White-footed deer mouse	19	23	36	86[c]	35	72[d]	9	18
Great Basin pocket mouse	1	1	2	5	1	4	0	3
Yellow pine chipmunk	0	4	1	15[e]	1[f]	11	2	3
U‡rthern pocket gopher	0	0	1	0	1	0	0	0
Western jumping mouse	0	0	0	0	0	0	0	0
Krumbo Ridge (Uncut vs. Cut)								
Long-tailed meadow mouse			0	0	0	3	0	2
Montane meadow mouse			1	1	1	1	0	1
White-footed deer mouse			15	12	25	35	25	27
Great Basin pocket mouse			2	1	8	6	6	3
Vagrant shrew			0	0	0	1	0	0
Yellow pine chipmunk			5	8	13	8	3	4
Mountain cottontail			0	0	0	0	0	3
Northern pocket gopher			1	0	2	0	0	0
Western jumping mouse			0	0	1	0	0	0
Juniper Mountain (Shrub vs. Tree)								
Long-tailed meadow mouse					0	0	3	0
Montane meadow mouse					2	0	5	0[i]
Ermine					0	0	1	0
White-footed deer mouse					59	47	26	11
Great Basin pocket mouse					9	2[g]	12	1[j]
Yellow pine chipmunk					3	4	1	16[k]
Northern pocket gopher					1	0	0	1
Green Mountain (Shrub vs. Tree)								
Ord kangaroo rat							1	0
Desert wood rat							0	1
White-footed deer mouse							10	24[l]
Great Basin pocket mouse							12	2[m]
Yellow pine chipmunk							1	19[n]

[a]Significantly different. P = 0.005
[b]Significantly different. P = 0.0132
[c]Significantly different. P = 0.0001
[d]Significantly different. P = 0.0011
[e]Significantly different. P = 0.0476
[f]Significantly different. P = 0.0047
[g]Significantly different. P = 0.0187
[h]Significantly different. P = 0.0187
[i]Significantly different. P = 0.0457
[j]Significantly different. P = 0.0059
[k]Significantly different. P = 0.0122
[l]Significantly different. P = 0.0086
[m]Significantly different. P = 0.0276
[n]Significantly different. P = 0.0005

captures in the cut blocks (uncut $\bar{x} = 31.71$, cut $\bar{x} = 57.43$). The number of species encountered (species richness) in trapping sessions was greater three times in cut sites, two times in uncut sites, and tied twice. The greatest number of species encountered (uncut treatment at Page Ranch, 1995) was eight, and two was the lowest (2 other uncut treatments at Page Ranch, 1993,1997). Mountain pocket gophers (*Thomomys talpoides*) and western jumping mice (*Zapus princeps*) were not caught in cut sites.

The lack of response of small mammals to cutting across the two areas is partially due to differences in woodland structures between the two locations. When evaluated within location, differences in small mammal abundance and diversity show up where the juniper woodland is fully developed and shrubs have been lost in the understory.

Eight different species were captured over the four years of study in the closed post-settlement juniper woodland and adjacent cut plots at Page Ranch. Montane meadow mice, white footed deer mice, and yellow pine chipmunks were significantly (P = 0.005, 0.0001, and 0.0476 respectively) more common in cut sites in 1995. This pattern held in 1996 as well (P = 0.0132, 0.0011, and 0.0047). There were consistently (but non-significant, P = 0.125) more captures in the cut blocks (uncut $\bar{x}$ = 28.5, cut $\bar{x}$ = 71.5) over the four years of study. However, in the mid-transitional juniper-shrub steppe and thinned sites at Krumbo Ridge, no distinctions or consistent patterns were noted between treatments or years. Shrub-steppe structural characteristics were present in both treatments. Nine different species were captured over the three years of study.

Shrub versus Woodland

Three trapping sessions were conducted comparing shrub dominated sites with adjacent old growth juniper woodlands. There were significantly (P = 0.032) more mammals captured in shrub sites at Juniper Mountain (shrub $\bar{x}$ = 61 captures, woodland $\bar{x}$ = 41 captures), while at Green Mountain, more were taken in woodland sites (shrub = 61 captures, woodland = 41 captures). Eight species were captured in shrub sites, and five in woodland sites.

At the Juniper Mountain area, there were significantly more Great Basin pocket mice in the shrub sites in 1996 (P = 0.0187). In 1997, there were significantly more montane meadow mice (P = 0.0457), Great Basin pocket mice (P = 0.0059), and fewer yellow pine chipmunks (P = 0.0122) in the shrub sites. Although not significant, there were more white footed deer mice in the shrub sites both years (59 vs. 47 captures in 1996, and 26 vs. 11 in 1997).

At Green Mountain, fewer white footed deer mice (P = 0.0086), more Great Basin pocket mice (P = 0.0276), and fewer yellow pine chipmunks were found in the shrub sites.

Post-settlement versus Old Growth Juniper Woodland

Five different species were captured in old growth sites and three in mid-successional sites in 1997. At old growth sites, there were significantly (P = 0.0001) more yellow pine chipmunks than in post-settlement woodlands in 1997 (n = 5 mid, 35 old growth). There were generally more Great Basin pocket mice in the mid-successional woodland sites which contained a shrub understory (n = 6) than in the old growth (n = 3). White footed deer mice were about equal between the two types (n= 34 and 35 for mid versus old respectively).

Conclusions

Our capture rates were highly variable among sites within treatments, among years, and among areas. This undoubtedly caused the lack of significance among many comparisons. With four years of sampling at Page Ranch, we hoped to find trends in composition and abundance of small mammals post-cutting. We expected some sampling "noise" but not of the magnitude encountered. Sedgwick and Ryder (1986) encountered 11-fold changes in capture rates among years in their pinyon-juniper sampling, and cited several others who had documented similar results. We hope to periodically sample at least the Page Ranch site to search for longer term trends, as those found by Severson (1986) who reported total numbers higher in manipulated sites, but a variety of individual species responses in New Mexico 18 years post-treatment. Baker and Frischknect (1973) snap-trapped a chained and seeded pinyon-juniper range, and concluded that deer mice and pocket mice populations increased through the second year post-treatment, and then dropped to levels still above uncontrolled. This pattern may have occurred at Page Ranch, but we couldn't separate population patterns from noise. O'Meara and others (1981) found higher small mammal abundance (but fewer species) in 1, 8, and 15 year old chained sites over controls. They also pointed out that leaving blocks of unchained vegetation within pinyon-juniper control areas should maintain woodland dependent species while providing increased total numbers of small mammals in treated areas.

The total captures and the number of species captured in our study were higher in the cut sites than in the uncut sites, comparable to the findings of Sedgwick and Ryder (1986) and Severson (1986), although their work was in pinyon-juniper, and the treatments were chainings.

Although we have no data on optimal size of treatment area, our findings concur with others that small openings in pinyon-juniper woodlands (Albert and others 1994), and in aspen (*Populus tremuloides*) (Christian and others 1996), can benefit a variety of wildlife. Smallwood (1994) expressed concern that habitat fragmentation might increase site invasibility by exotic birds and mammals through decreased indigenous species richness and abundance. In the case of fragmenting young and mid-aged western juniper woodlands, our work with small mammals suggests that potential site invasibility by exotics may actually be diminished because of increased abundance and richness of indigenous species.

We believe the cut sites, particularly at Page Ranch, had preferred structure to the uncut sites which was provided by increased vigor (cover and height) of herbaceous species, increased seed production in the cut sites (Bates and others in press), greater species richness, and juniper slash which has persisted five years without noticeable change in size and shape. We propose these sites generally provide increased security and forage for small mammals. The lack of differences at Krumbo Ridge was probably due to understory structure being similar between the two treatments. Woodland conversion had not progressed sufficiently to exclude shrubs. Old growth sites typically had a greater variety of species than young juniper woodlands. This may be attributable to the more structurally complex vegetation compared to closed post-settlement woodlands (Miller and others, this symposium).

In our opinion, opening stands of western juniper in southeast Oregon by cutting down and leaving trees or thinning does not substantially affect the small mammal component in the area. The Great Basin pocket mouse appears to be the most sensitive species to the loss of shrubs during the latter stages of concern from shrub steppe to juniper woodland. However, other species such as wood rats are favored by the presence of juniper trees in the stand. For the maintenance of maximum structural diversity in post-settlement stands, shrub steppe communities should be managed through early- to mid-woodland succession (Miller and others, this symposium). If conversion crosses a threshold, moving into late and closed woodlands, structural complexity and plant species diversity in the understory decline, resulting in shifts in small mammal population dynamics.

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References

Albert, S.K., N. Luna, and A.L. Chopito. 1994. Deer small mammal, and songbird use of thinned Piñon-Juniper plots: preliminary results. pp 54-64 *in* D.W. Shaw, E.F. Aldon, and C. LoSapio eds, Desired future conditions for Piñon-Juniper Ecosystems. USDA For. Ser. GTR RM-258

Austin, D. D., and Urness, P. J., 1976. Small mammal densities related to understory cover in a Colorado plateau, pinyon-juniper forest. Utah Academy of Science, Arts, and letters, 53(1): 5-12.

Baker, M.F. and N.C. Frischknecht. 1973. Small mammals increase on recently cleared and seeded juniper rangeland. J. Range Manage. 26: 101-103.

Bates, J.M., R.F. Miller, and T. Svejcar. in press. Understory vegetation patterns in western juniper woodlands (*Juniperus occidentalis* ssp. *occidentalis*). Great Basin Naturalist.

Christian, D.P., J.M. Hanowski, M. Reuvers-House, G.J. Niemi, J.G. Blake, and W.E. Berguson. 1996. Effects of mechanical strip thinning of aspen on small mammals and breeding birds in northern Minnesota, U.S.A. Can. J. For. Res. 26: 1284-1294.

Fowle, C.D. and R.Y. Edwards. The utility of break-back traps in population studies of small mammals. J. Wildl. Manage. 18: 503-508.

Hayward, G.D. and P.H. Hayward. 1995. Relative abundance and habitat associations of small mammals in Chamberlain Basin, central Idaho. Northwest Science 69: 114-124.

Johnson, W.C., and B.L. Keller. 1983. An examination of snap-trapping techniques for estimating rodent density in high desert. Northwest Science 57(3): 194-204.

Maser, C., J. W. Thomas, and R. G. Anderson. 1984. Wildlife habitats in managed rangelands-The Great Basin of Southeast Oregon: The relationship of terrestrial vertebrates to plant communities, Part 1, USDA For. Ser. Gen. Tech. Rep. PNW-172. 25pp.

Mason, R. B., 1981. Response of birds and rodents to controlled burning in pinyon-juniper woodlands. M.S. thesis. Univ. Nevada, Reno. 55pp.

McComb, W. C., R. G. Anthony, K. McGarigal, 1991. Differential vulnerability of small mammals and amphibians to two trap types and two trap baits in Pacific Northwest Forests. Northwest Science 65(3): 109-115.

O'Meara, T.E., J.B. Haufler, L.H. Stelter, and J.G. Nagy. 1981. Nongame wildlife responses to chaining of pinyon-juniper woodlands. J. Wildl. Manage. 45: 381-389.

Puchy, C. A. and D. B. Marshall. 1993. Oregon wildlife diversity plan. Oregon Department Fish and Wildlife, Portland, Oregon. 413pp.

Sedgwick, J.A. and R.A. Ryder. 1986. Effects of chaining pinyon-juniper on nongame wildlife. pp 541-551 *in* Everett, R.L. compiler, Proceedings-Pinyon-juniper conference; USDA For. Ser. Intermountain Research Station Gen. Tech. Rep INT-215. 581pp.

Severson, K.E., 1986. Small mammals in modified pinyon-juniper woodlands, New Mexico. J. Range Manage. 39:31-34.

Smallwood, K.S. 1994. Site invasibility by exotic birds and mammals. Biological Conservation 69: 251-259.

Turkowski, F.J., and H.G. Reynolds, 1970. Response of some rodent populations to pinyon-juniper reductions on the Kaibab Plateau, Arizona. Southwest Naturalist 15: 23-27.

Commercial Fuelwood Harvesting Affects on Small Mammal Habitats in Central Arizona

William H. Kruse

Abstract—In a central Arizona fuelwood harvest area, 75 percent of the overstory was cut in a commercial harvest, resulting in large quantities of residual logging debris that altered habitat for many wildlife species. Small mammals have intricate roles in ecosystem function, and current fuelwood management practices have paradoxical affects on small mammal habitats. In a small mammal study, no differences in total animals captured were detected among treatment plots. Immediately following overstory reduction or removal in 1992 and 1993, differences among species captures, specifically deer mouse, increased significantly. The increased capture rate remained significant throughout the remainder of the study. Pinyon mouse captures declined significantly immediately following treatments, but were not detectably different from pretreatment levels a year later.

Commercial fuelwood harvesting generates greater and more concentrated slash and has more affect on microsite conditions than noncommercial fuelwood cutting. This has prompted some central Arizona USDA Forest Service Ranger Districts to assess the effects of commercial fuelwood removal and slash disposal, particularly by burning. Specifically, removal of slash habitat through burning is a concern. Fortunately, commercial harvest permits, however, can provide detailed slash management directions to meet specific management objectives. Burning is usually not performed by the fuelwood permit holder but instead is included in Forest Service management plans.

Fuelwood removal and slash management also affects microsite nutrient cycling, understory production (specifically protecting forages from large ungulate grazing), and regeneration of overstory species. Small mammal populations are also affected by removal of overstory, understory composition and structure change, and slash accumulation and subsequent manipulation. Basic ecological information is needed to support current harvesting plans (Gottfried 1987). The least understood management option has been slash disposition (Severson 1986, Baker and Frischknecht 1973).

Retention or removal of slash provides or eliminates specific habitat characteristics for certain small mammals. In addition, retention or removal of slash affects the potential protective cover for emerging new plants. Slash removal by burning affects the newly formed slash habitat for small mammals and plants and also reorganizes the nutrient base stored in the slash (Harrington 1989, Covington and DeBano 1988). Natural decomposition of residual slash provides a slower and more complete return of nutrients to the system, while providing the protective effects of slash. Juniper slash, unlike pine slash, decomposes at a slower rate.

Small mammal populations are impacted by overstory disturbances (Turkowski and Reynolds 1970) while on-the-ground slash causes an increase in abundance of some rodent species regardless of overstory condition (Severson 1986). Kruse and others (1979) found that when the overstory was removed or reduced, rodents that preferred the woodland condition were fewer in number than those on the treated areas.

This small mammal research was part of an effort to study the effect of nutrient cycling, other wildlife, and wood product management on soil, water, tree, and range resources in pinyon-juniper woodlands. This paper discusses the effects of commercial fuelwood harvesting in an old-growth or late seral pinyon-juniper woodland on small mammal populations in central Arizona.

Study Area

The Heber Ranger District, Apache-Sitgreaves National Forest in central Arizona was the study-site area. Average tree basal area (diameter measured at root crown) was 23.2 ± 5.4 m^2/ha, which produced 35.3 ± 12.7 m^3/ha of fuelwood (Kruse and Perry 1995). One-seed juniper (*Juniperus monosperma*) was the dominant species (54 percent). The second most dominant tree (25 percent) was Colorado pinyon (*Pinus edulis*), followed by alligator juniper (*J. deppeana*) (13 percent). Ponderosa pine (*Pinus ponderosa*) occasionally occurred on moist sites (8 percent). Mean pretreatment canopy cover was approximately 40 percent, while the mean annual herbaceous and woody plant potential productivity was approximately 562 kg/ha.

The study area is relatively flat, dissected by several small ephemeral drainages. Elevations are between 2,000 and 2,060 m. The primary soil subgroups, derived from limestone, are Lithic Ustochrepts, Udic Haplustalfs, and Typic Eutroboralfs. The mean annual precipitation is between 34 and 46 cm.

Methods

Field Methods

The study area consisted of 33 units, 4 ha in size. Three units were treated with silvicultural prescriptions. Thirty 4 ha study units were grouped into five blocks representing

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Figure 1—Typical overstory, preharvest conditions of late seral old-growth pinyon-juniper woodland at Heber/ Mud Tank small mammal study area.

Figure 3—Type conversion. Slash accumulation but not burned following harvest of commercial fuelwood. Noncommercial stems cut and also remain.

six overstory/slash treatments. Sixteen of the 30 were randomly selected for the small mammal study. Four of the 6 overstory/slash treatments were replicated in the 16 units (Kruse 1995).

Trapping occurred on 4 overstory treatments: (1) controls, where the units were untreated (fig. 1); (2) burned, to simulate a forest fire (fig. 2); (3) type conversion, where fuelwood was harvested, the non-commercial residual trees cut, but slash was not burned (fig. 3); (4) type conversion, where fuelwood was harvested, residual trees cut, and slash burned (fig. 4). Type conversion is clearcutting to convert a woodland to grassland. The two overstory treatments not included were the silvicultural treatments and the commercial harvest where the noncommercial stems were left uncut as advanced regeneration. Small mammal trapping was conducted during July and August from 1990 through 1996. Before harvest, downed woody fuel was estimated at 3.15 mt/ha (Kruse and Perry 1995). Post harvest slash accumulation was estimated at 55.71 mt/ha (fig. 3).

Figure 2—Burned standing green woodland to simulated wildfire for type conversion (clearcutting to convert a woodland to grassland).

Treatments were assigned randomly and were not necessarily contiguous; roads or drainage channels could separate units within a given block. Harvesting began during fall/ winter of 1991 and continued for 24 months. Burning commenced when the slash was at least 2 years old. Treatment schedules are in Kruse (1995).

A 100 m^2 trapping grid was located in the center of each unit. 8 x 10 x 25 cm Sherman live trap was placed at each grid point, 10 m x 10 m apart. At alternate points, a 10 x 12 x 40 cm Sherman live trap was placed near the smaller one. The bait was a mixture of chicken scratch and rolled oats. Each unit was sampled yearly with 150 traps for 3 nights and 2 days. Physical measurements were taken and recorded for each animal, then they were toe clipped

Figure 4—Type conversion. All overstory harvested or cut, and slash burned.

Table 1—Species captured and percent of composition.

Species	Common name	Composition
		Percent
Peromyscus truei	pinyon mouse	42
Peromyscus maniculatus	common deer mouse	37
Eutamias dorsalis	cliff chipmunk	9
Neotoma albigula	white-throated woodrat	7
Neotoma mexicana	Mexican woodrat	2
Peromyscus boylei	brush mouse	2
Sylvilagus auduboni	desert cottontail	1
Spermophilus variegatus	rock squirrel	<1
Neotoma stephensi	Stephens woodrat	<1
Dipodomys ordi	Ord kangaroo rat	<1
Microtus mexicanus	Mexican vole	<1

and released. Recaptures were noted. Relative abundance and species composition of small mammals live trapped and released on the study area are in table 1.

Analysis Methods

Replicated study units among 4 blocks were selected randomly as the experimental design layout (Ludwig and Reynolds 1988). Blocks were based on similarity of pretreatment overstory conditions and characteristics. The treatment units included combinations of no burning or cutting, burning standing green, cutting and no cutting (fig. 1-4). The small mammal study replicated these 4 treatments in each of 4 blocks.

The null hypotheses was that small mammal capture rates did not differ among treatments. Capture differences among treatments were tested by analysis of variance with years used as a repeated measure. Significance of treatment effects was assessed based on temporal interaction (pre vs. post treatment) in treatment responses. Comparisons among treatments, for individual post treatment years were adjusted by Bonferoni correction to maintain Type I error at 0.05. Tests were performed on total captures, deer mouse captures, and pinyon mouse captures only. The 1992 data was also omitted from the analyses due to conflicting treatment effects and application.

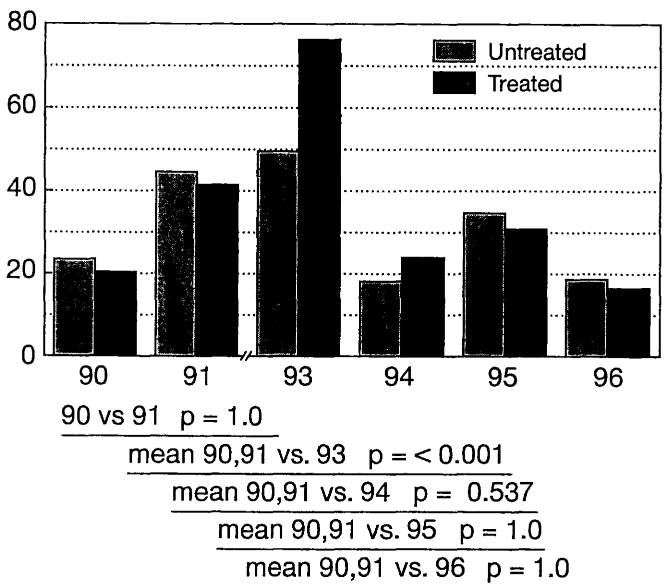

Figure 5—There were no differences in captures between unharvested and to-be- harvested units during the pre-treatment period (p > .5). Total captures of all species significantly increased immediately following treatment in 1992-1993 (p < .001), but were not detected again (p > .5).

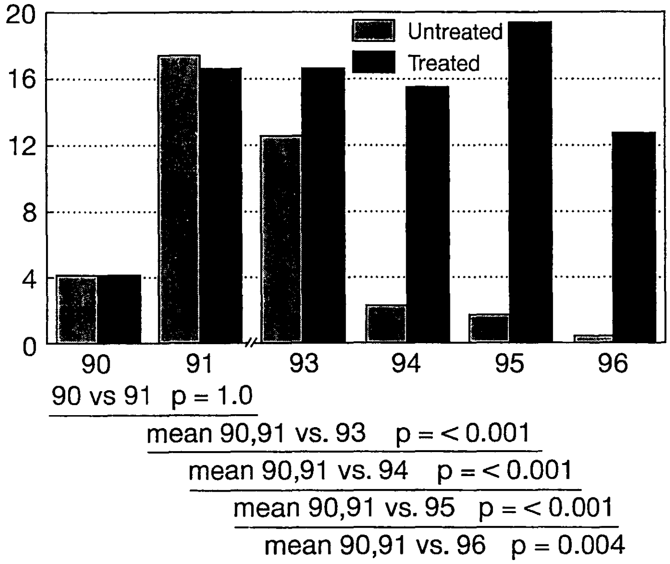

Figure 6—The deer mouse captures. Captures were significantly increased immediately following treatments in 1992-93 (p < .001), and remained higher through the remainder of the study (p < .004) while the slash habitat was on the ground aging. Some of the units were burned before the 95 and 96 trapping periods but it is unclear whether the burning impacted the deer mouse captures.

Results

Before 1992 harvest treatments, there were no differences among the unharvested and the to-be-harvested units for total captures (fig. 5). Although year-to-year differences occurred, these data demonstrated the homogeneous nature (p = 1.0) of all units in 1990 and 1991. Analysis of post treatment responses, however, indicated significant treatment effect (F= 7.17, p < 0.001). Following treatment, a significant difference among treatments in 1993 was demonstrated (F = 5.79, SE 5.47, p < 0.001). Total captures treatment effects were not significant for 1994 (p = 0.536), 1995 (p = 1.0), and 1996 (p = 1.0).

Deer mouse captures on the harvested and the unharvested units (fig. 6) also showed the similarity among all units before treatment (p = 1.0), and the significant difference between treatments in 1993 (p < 0.001). Unlike total captures, differences for deer mouse captures were significant for 1994 (p < 0.001), 1995 (p < 0.001), and 1996 (p = 0.004). Half of the harvested units were burned in 1995 and 1996.

Pretreatment tests on pinyon mouse captures among all study units were again similar (p = 1.0). Converse to the deer mouse, pinyon mouse captures (fig. 7) significantly reflected a negative effect following treatment in 1993 (p = 0.052). This negative effect for the pinyon mouse between the harvested and non-harvested units was not evident in 1994 (p = 0.322) but was evident in 1995 (p = 0.017) and 1996 (p = 0.040). The 1995 and 1996 harvest unit data included some units that were burned in 1994 and 1996; 1996 was before sampling.

Discussion

This study was designed to evaluate fuelwood harvesting affects on small mammal capture rates following the harvest of old-growth or late-seral pinyon-juniper woodland overstory. The treatments were 1) overstory removal; 2) creation of large quantities of slash that was generally lopped and scattered, although some piling was done to allow cutting, loading, and hauling, and 3) eventual slash burning. Data were insufficient to determine which treatment activity had the greater affect on the small mammal capture rates. Therefore, the "treatment" units included overstory removal, slash deposition, and some were burned. These "treatment" units were tested against the uncut units.

Although not tested, it appeared that: 1) woodrat (*Neotoma spp.*) middens burned; 2) numbers of captures of all species may have decreased following burning; and 3) captures of brush mice (*Peromyscus boylii*) appeared to be greater on unburned slash units. Initially, both *Peromyscus* species responded positively or negatively to the harvest treatment and some differences continued for the following 3 years. Half of the harvested units were burned in 1994 and 1995. Burning standing green, during a wildfire simulation, occurred in 1994 and 1996. The study suggests that overstory removal and slash accumulation probably had more beneficial effects for the deer mouse, specifically, and to other species as well. These 2 effects were detrimental to the pinyon mouse, however, particularly in the year following cutting. This study corroborates earlier work showing that overstory is important to the pinyon mouse (Severson 1986). Burning, which would not have corrected the lack of overstory condition, was of further detriment to the pinyon mouse.

Fewer captures of all species were evident in the latter 3 years that included the burning portion of the study. Tests between treated and untreated units suggest little significant difference, while treatment effects to the deer mouse still appear beneficial. Field observations suggest that unburned units still contained viable woodrat middens and higher capture numbers for other species such as the cliff chipmunk (*Eutamias dorsalis*). Baker and Frischknecht (1973) found no effect from slash on mice populations, except where it was windrowed, while Severson (1986) found that treatments leaving slash benefited woodrats and brush mice following canopy removal. Therefore, the detrimental burning effects in this study could have off-set the beneficial effects of the slash. In addition, slash provided improved site protective characteristics for plant regeneration and development.

Population densities of small mammals are related to overstory adjustments and/or slash composition in assessing site productivity and quality. This study contributes to small mammal and basic ecological information to improve guidelines for harvesting fuelwood in pinyon-juniper ecosystems in the Southwestern United States.

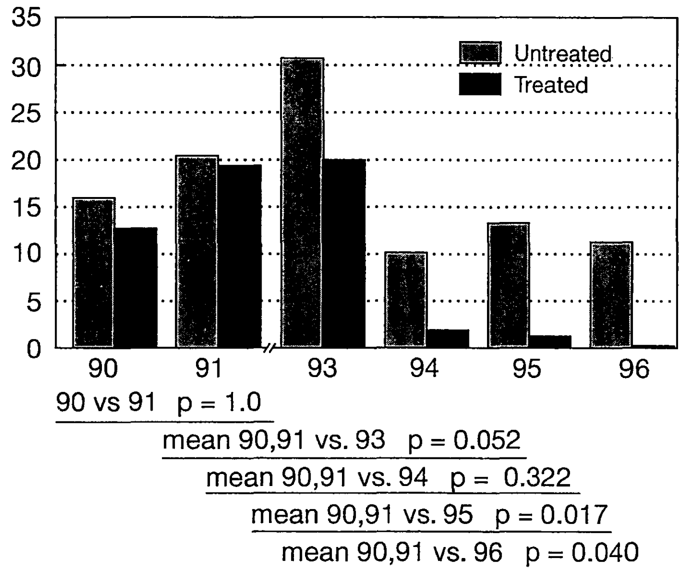

Figure 7—Pinyon mouse captures. Captures were significantly decreased immediately after treatments were implemented in 1992-93 (p = .05), but not detectably lower a year later (p = .32). Lower captures on the treated units were again apparent in 1995-96 (p < .04).

References

Baker, Maurice F. and Neil C. Frischknecht. 1973. Small mammals increase on recently cleared and seeded juniper rangeland. J. Range Manage. 26: 101-103.

Covington, W. Wallace and Leonard F. DeBano. 1988. Effects of fire on pinyon-juniper soils. pp 78-85. In Proceedings: Effects of Fire in Management of Southwestern Natural Resources. Tucson, Arizona. Nov. 14-17, 1988.

Gottfried, Gerald J. 1987. Regeneration of pinyon. In: Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 249-254.

Harrington, M.G. 1989. Soil nutrient and pinyon seedling response to fire severity, p.143-147. In: Proceedings of the 10th conference on fire and forest meteorology, Maciver, D.C., ed. and others Chalk River, Ont.: Forestry, Canada, 1989, 469 p.

Kruse, W. H. 1995. Effects of fuelwood harvesting on small mammal populations in a pinyon-juniper woodland, p91. In; Douglas W. Shaw; Earl F. Aldon; Carol LoSapio, tech. Coords. Desired future conditions for pinyon-juniper ecosystems; proceedings of the symposium; 1994 August 8-12; Flagstaff, Arizona. GTR-RM-258. Fort Collins, CO. USDA-For. Serv., Rocky Mtn. For. & Range Exp. Stn, 226 p.

Kruse, W. H. and H. M. Perry, 1995. Ecosystem management and fuelwood harvesting in an "old growth" pinyon-juniper woodland, p219.In; Douglas W. Shaw; Earl F. Aldon; Carol LoSapio, tech. Coords. Desired future conditions for pinyon-juniper ecosystems; proceedings of the symposium; 1994 August 8-12; Flagstaff, Arizona. GTR-RM-258. Fort Collins, CO. USDA-For. Serv., Rocky Mtn. For. & Range Exp. Stn, 226 p.

Kruse, W. H., R. P. Balda, M. J. Simono, A. M. Macrander, and C. D. Johnson. 1979. Community development in two adjacent pinyon-juniper eradication areas twenty-five years after treatment. J. Environ. Manage. 8: 237-247.

Ludwig, John A. and James F. Reynolds. 1988. Statistical ecology. New York: John Wiley and Sons. 337 p.

Severson, K. E. 1986. Small mammals in modified pinyon-juniper woodlands, New Mexico. Journal of Range Management. 39: 31-34.

Turkowski, F. J. and H. G. Reynolds. 1970. Response of some rodent populations to pinyon-juniper reductions on the Kiabab Plateau, Arizona. Southwest. Natur. 15:23-27.

Dietary Use of Utah Juniper Berries by Gray Fox in Eastern Utah

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Abstract—The contents of 214 gray fox (*Urocyon cinereoargenteus*) scats from the Nash Wash pinyon (*Pinus edulis*)-juniper (*Juniperus osteosperma*) zone of eastern Utah were analyzed. Analyses revealed that mature Utah juniper berries were the most commonly taken food items by mean percent relative frequency of occurrence (51.1 percent, dry weight) and mean percent of volume (51.3 percent, dry weight) for the time period of April 1994-March 1996. Utah juniper berries dominated the diet for 6 of 8 3-month seasonal periods (Spring 1994, Summer 1994, Fall 1994, Winter 1995, Fall 1995, and Winter 1996). Mammalian prey, mostly rodents and leporids, represented the majority of the diet not consisting of Utah juniper berries. Chemical analyses of the hulls of Utah juniper berries indicated that they provide a basic supply of nutrients and minerals. The diets of gray fox in eastern Utah showed that they are efficient foragers specializing on an interesting mix of vegetation and animal matter. Decided dietary selection was evident, since some available fruits were not found in diets.

The distribution of gray fox (*Urocyon cinereoargenteus*) is extensive, ranging from extreme southern Canada to northern South America, excluding eastern Central America, the Great Plains, and portions of the northwestern United States (Fritzell 1987). Seasonal diets and habitat use of gray fox have been studied broadly in the southeastern, eastern and north-central United States (Trapp and Hallberg 1975; Fritzell 1987). However, there is a paucity of research regarding the behavioral ecology of gray fox in the pinyon (*Pinus edulis*)-juniper (*Juniperus* spp.) zones of the western United States. Trapp (1978) compared the behavioral ecology of the ringtail (*Bassariscus astutus*) and gray fox in Zion National Park, Utah. Turkowski (1970) studied gray fox in the Upper and Lower Sonoran Life zone, and Harrison (1997) compared gray fox ecology between residential and undeveloped rural landscapes in New Mexico. In addition, Small (1971) tried to determine the interspecific competition for food among coyotes (*Canis latrans*), gray foxes, and bobcats (*Felis rufus*) on a ranch in Arizona.

In 1993, our study was undertaken to investigate behavioral ecology of the gray fox. In order to determine the degree, and season, of dependence of gray fox on various prey (that is, leporids, rodents, and juniper berries), the study included evaluation of its diet using scat analyses.

Study Area

The study site chosen was the Nash Wash Wildlife Management Area (NWMA) (39°4' N. 109°35'30" W.) and surrounding area in Grand County, Utah. The Nash Wash drainage and its ephemeral streams appeared to provide suitable habitat for gray fox. The habitat included pinyon-juniper (*Juniperus osteosperma*), mixed mountain brush, big sagebrush (*Artemisia tridentata*), desert saltbush and associated riparian zones intermixed with numerous cliffs and rocky outcroppings.

Elevation of the study area ranges from 1,500 to 2,250 m. The range of elevation and topography results in several microclimates with variable precipitation and temperatures. Weather data from a Bureau of Land Management (BLM) Resource Automatic Weather Station (RAWS) located at 39°07'30" N. 109°42'20" W. (elevation 2,438 m) shows the average annual precipitation per year during the study was 201 mm. Daily high and low temperatures ranged from 2 to –6 °C in January and 28 to 16 °C in July.

Objectives

Preliminary analyses of 24 gray fox scats taken in the study area led to the development of the following research hypotheses concerning gray fox diets.

1. Diets of gray fox can be accurately and quantitatively assessed through identification of plant and animal residue in scat.
2. Animal matter would be preferentially chosen over plant material during the reproductive periods of gray fox, rodents, leporids, and insects.
3. Juniper berries and fruits of other woody plants in the study area are only seasonal augmentations, rather than important nutritional components, of gray fox diets.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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4. Hulls of mature juniper berries are chemically complex but not nutritionally adequate to serve as a primary source of nutrition for the gray fox.

Methods

Diet Analysis

Gray fox scat was collected along scat deposition transects conducted by White and others (1997). Collection of scat also occurred along dry stream beds, ridges, overhangs, and sagebrush-grass flats. To insure that only gray fox scat was collected, the guidelines by Green and Flinders (1981) and Halfpenny and Biesiot (1986) were followed along with knowledge of species specific locations and use of habitat. If a scat could not be identified with confidence, it was not used in the analysis. Date, location, and other pertinent information including estimated age of each scat sample were recorded.

In the laboratory, diameter in millimeters at the largest width was recorded for each air dried scat with a caliper. Dry weight of each scat was recorded in grams. All scats were then "heated" in a drying oven at 60-70 °C for 24 hours to kill any microorganisms. Subsequently, each scat was placed in a fine mesh nylon bag (42 meshes per cm), soaked in water and laundry detergent, and then washed in a conventional washing machine to remove mucus, metabolites and dissolvable organic matter (O'Neal and others 1987; Findlay 1992). Each scat was then spread evenly on a tray, 25 x 25 cm, with a grid having 25 random points assigned. Contents of scat were identified using two methods. O'Neal and others (1987) and Findlay's (1992) procedures for determining percent frequency of occurrence and relative percent frequency of occurrence were followed with minor modifications.

To facilitate food item identification, a dissecting microscope (0.7-3 power zoom) was used with published keys for identification of hair (Adorjan and Kolenosky 1969; Moore and others 1974). A "mammal hair" collection was used as well as mammal, entomology, and herbarium collections at the Monte L. Bean Life Science Museum, Brigham Young University, to identify food items. The Martin and Barkley (1961) seed identification manual was used for seed identification. Taxonomic nomenclature was standardized using the following authorities: Wilson and Reeder (1993) (mammals), Welsh and others (1993) (flora), Robbins and others (1983) (birds), Borror and White (1970) (arthropods), and Stebbins (1985) (reptiles and amphibians).

Relative Percent Frequency of Occurrence (RPFO)—In order to determine the relative percent frequency of occurrence it was first necessary to determine the frequency of occurrence. This was done by sampling 25 random points within the 25 x 25 cm tray and noting the nearest identifiable food item. The number of occurrences for each identifiable food item was divided by the total number of points sampled (25) and multiplied by 100 to give percent frequency of occurrence for each identified food item in each scat.

When identifying food items, an effort was made to identify each item to genus and species if possible or to the next higher taxonomic level possible. If several identifiable food items were located on the same point (for example, mammalian hair and Juniper berry), then one point was assigned to each food item, making it possible to have a dot count total exceeding 25. The relative percent frequency of occurrence was determined for each scat by summing the percent frequency of occurrence values for all identified food items and dividing each individual value by the sum of frequency value.

Relative Percent of Volume (RPV)—All identifiable food items were ocularly estimated as percent of volume (PV) for each scat. Food items identified and assigned a PV value were summed and divided by the summation of PV values to obtain a RPV.

For this report, prey items were classified into seven major categories: Mammals, Birds, Arthropods, Reptiles and Amphibians (Rep. & Amph.), Utah Juniper Berries, Miscellaneous Vegetation (Misc. Vegetation) (that is, grass, woody vegetation and their seeds), and Miscellaneous Items (Misc. Items) (that is, rocks, sand, finite vegetation mixed with sand, unknown items). A Spearman's Rank Correlation test was used to evaluate similarity of RPFO and RPV values for each major temporal category. Additionally, a Kruskal-Wallis Test was applied to test for significance of differences among years or seasons for each major food category. After determining if there were significant differences among groups of factors, individual factors were tested for significance against each other using Gibbons' (1976) method. All percent data were arcsine transformed before statistical analyses.

Leporid and Rodent Availability

To determine if leporids and/or rodents in the diet of gray fox was correlated with leporid and/or rodent availability in their habitat, leporids and rodents were assessed along three permanent census transects established by White and others (1997) in NWMA. Each transect, 3.2 km (2 miles) long, was established along an existing dirt road. Scat deposition transects, operated by White and others (1997), were also located on these transects. Thus, the census transects for leporids and rodents traversed roads where most of the gray fox scat analyzed in our study was collected. Transects names listed here and locations were the same as White and others (1997) transects, with the exception that our Transect C corresponded to their Transect E. Transect's names and periods of study are:

- Transect A-July 1993 to December 1996
- Transect B-March 1994 to December 1996
- Transect C-July 1993 to November 1993; May 1995 to December 1996

Correlation tests comparing leporids and rodents in the diet of gray fox and leporids and rodents availability were based on the Spearman's Rank Correlation procedure. Kruskal-Wallis Tests were used to evaluate significances of differences among years or seasons of rodent and leporid use by gray fox. After determining if there were significant differences among a group of factors, individual factors were tested for significance against each other (Gibbons 1976). All percent data were arcsine transformed before statistical analyses.

Rodent Assessment—To obtain a relative estimate of rodent numbers along the three transects, scent stations by White and others (1997) for gray fox monitoring were also evaluated for rodent use. Although the scent stations were designed for census of gray fox, the consistency of the method provided a relative measure of rodent abundance as well.

Scent station methodology followed the procedures recommended by White and others (1997). Along each transect, 10 1.0 m^2 track stations (metal sheets) were placed 5 to 20 m perpendicular to the road. Each station was placed 0.3 km (0.2 miles) apart. The afternoon before the census was conducted, metal sheets were blackened with burnt acetylene from a welding torch. In the center of the sheet was placed a 1 inch diameter Scented Predator Survey Disk (SPSD) made of plaster of Paris. SPSDs were previously soaked in Fatty Acid Scent (FAS) which acts as an attractant (Roughton and Sweeny 1982). The scent stations were examined the following morning. Visits to stations are recorded by species and a species visit to a station is recorded as 1 no matter how many tracks of that species are left on the soot covered metal sheet. Since it was easy to identify a track as that of a rodent but difficult to identify the species of rodent, a visit was defined as ≥1 track of a rodent per station, regardless of the number of rodent tracks on a station. The index of abundance has normally been expressed as the number of stations visited by a species divided by the number of operable stations sampled that night times 1000 (Linhart and Knowlton 1975; Lindzey and others 1977; U.S.F.W.S. 1984).

$$\frac{\textit{Total Species Visits}}{\textit{Total Operable Stations}} * 1000 = \textit{Index Value}$$

"Total Species Visits" in this formula would then be equivalent to the total number of stations visited by rodents.

The sheets were re-blackened before each census and SPSDs re-saturated. Scent stations were operated only one night per month for the majority of the diet analysis period. Only data from Transect A and B were available for the first year of the diet analysis study.

Leporid Assessment—Availability of leporids was assessed by two methods. Spotlight transects were conducted each month along the three operating transects. The procedure, modified from the King method (Hayne 1949), was to have an observer stand in the back of a pickup truck (or from the cab if only one researcher was available) with a spotlight (1,000,000 candle power) while traversing each of the 3.2 km (2 mile) transects. All mammals observed were recorded by species and their perpendicular distance from the road was estimated. Binoculars (10 x 50) were often used to assist in identification of species. Only data from Transect A and B were available for the first year of the diet analysis study.

The second method involved counts of leporid fecal pellets in plots located along the three transects used in our study. For each transect, 10 circular plots (each 10 m^2) were established. They were located 0.32 km (0.20 miles) apart with 4 (0.45 m^2 each) leporid fecal pellet plots placed within each 10 m^2 circular plots. Location of the fecal pellet plots within the circular plot involved placing one leporid fecal plot at the inside edge of each of the circular plot's cardinal directions. The three transects combined had a total of 120 leporid fecal pellet plots.

Plots were monitored in the spring (May-June) and near the end of summer (August) seasons. All new pellets were counted and cleared at the end of each of these periods (Flinders and Crawford 1977). To ensure accuracy, colored nails were placed in two opposite corners of each 0.45 m^2 plot and the UTM coordinates of each 10 m^2 circular plot were obtained using a Magellan 5000 Pro global positioning (GPS) unit. To account for degradation due to weather and invertebrates Blackwell's (1991) pellet degradation rate was used to estimate loss of pellets over time. Leporid abundance was estimated along all transects for summer and fall-winter seasons of 1994, 1995, and 1996. Leporid abundance was calculated using Cochran and Stains (1961) estimated number of fecal pellets voided per cottontail per day.

Nutritional and Chemical Analyses of Utah Juniper Berries

Preliminary analyses showed large numbers of mature Utah juniper berries in gray fox scat. Literature could not adequately answer whether juniper berries constituted a satisfactory or starvation diet. Thus, Utah juniper berries were collected monthly from June 1995 to October 1996. Mature berries were identified from immature berries using the criteria of Johnsen and Alexander (1974) as cited in Young and Young (1992). Collection and analysis of immature and mature berries occurred separately. A group of 4-5 trees were sampled each month with an additional 3-7 trees being sampled as needed. All mature berries collected in a month were placed in one bag, thus making one bulk sample of matures berries per month, for analysis. Immature berries were also collected in one bulk sample per month. Berries were weighed in the field after collection and then weighed again in the laboratory after being dried in an oven at 60-70 °C for several days. Fleshy tissue (hull) for each was removed from around the seed and hulls were ground in a Wiley Mill (20 mesh screen) for dry juniper berry analyses. Mineral and nutritional analyses of dry Utah juniper berry hulls were conducted by the Soil and Plant Analyses Laboratory at Brigham Young University (BYU) (Provo, Utah) using the methods outlined by Horwitz (1980). Although analysis occurred on one bulk sample of mature berries per month, it should be noted that bulk samples were comprised of berries from several different trees. Immatures were also analyzed as one bulk sample per month and a sample was comprised of berries from several trees.

From October 1995 to October 1996 a portion of the monthly Utah juniper berries collected, by the procedure described above, were weighed in the field and immediately frozen. The berries were transported to the lab in a cooler. At the lab, berries were kept in a freezer for "wet" chemical analyses. Before wet chemical analyses, berries were removed from the freezer and approximately 10 g of fleshy tissue (hull) was separated from the seeds, ground with mortar and pestle in liquid nitrogen, and put back in the freezer within a few minutes. Further fractional analyses of chemicals in wet and dry juniper hulls were undertaken by the Plant Product Chemistry Laboratory also at BYU.

Their extraction of tannins, phenolics, and terpenes followed the procedures of Zou and Cates (1995). Gross energy (kcal) content of dry mature Utah juniper hulls was determined using a Parr Adiabatic Oxygen Bomb Calorimeter (Model 1241).

A Wilcoxon Sum Rank Test was used to test for significance of differences between the minerals, nutrients, and chemical components of mature and immature Utah juniper hulls. All percent data were arcsine transformed before statistical analyses.

Results and Discussion

Diet Analyses

It was common to find gray fox scat on small rocks, boulders, logs next to the roads, on the roads, and next to older feces of gray fox or other species. A sample of 214 gray fox scats (deposited from April 1994 to March 1996) was selected for dietary analysis. These scats had a mean diameter of 14.9 mm (SD = 1.6 mm, n = 179) with a range from 10 to 18 mm. The mean air dry weight was 7.5 g (SD = 3.5 g, n = 213) with a range from 0.9-25.7 g. The mean diameter was within 0.3 mm of Trapp's (1978) findings ($\bar{x}$ = 15.19 mm, SD = 2.50 mm, range = 9-24 mm) at Zion National Park.

A total of 25 mammalian and 1 avian food items were identified to genus. Of the mammalian food items, *Sylvilagus* (cottontail) had the highest RPFO and RPV values. *Peromyscus* (white-footed mice) had the second highest RPFO and RPV values. Three Classes (with 13 Families representing 12 Orders) of Arthropoda were recognized. The group having the highest percent RPFO and RPV was the Gryllacrididae (camel crickets and others). All fox scat that contained Gryllacrididae, except one, could be seen to contain the subfamily Stenopelmatine (Jerusalem crickets). Both suborders of reptiles (snakes and lizards) were represented. Since some food items could only be identified as either reptile or amphibian these categories were lumped together. Thirteen different genera of forbs, shrubs, or trees were represented in the diet of gray fox. Twelve different genera (including Utah juniper berries) of forb, shrub, or tree seeds (or flowering parts) were identified. Miscellaneous items were discovered but the most consistent was sand-size rock and minerals. Likely some of the Miscellaneous Vegetation and most of the Miscellaneous Items were inadvertently ingested while consuming other food items.

To visualize the annual diet these foregoing data were organized by season of use defined as follows: April-June (Spring), July-September (Summer), October-December (Fall), January-March (Winter). These seasons appeared to coincide best with shifts in diet as well as changes in meteorological seasons and vegetational phenophases. A total of eight seasons (figs. 1-5) were analyzed by RPFO and RPV methods using major prey categories. The mammalian prey items of importance are shown beneath the major prey categories in figures 1-5 and are grouped into three subcategories: Rodents, Leporids, and Other (that is, carrion and all other mammalian prey). The RPFO and RPV methods suggest similar amounts of the various dietary categories in all seasons. Thus discussion in the text will be applicable to both methods unless otherwise specified.

Spring 1994 and 1995—Gray fox relied more heavily on Utah juniper berries than mammalian prey in the Spring of 1994, however in the Spring of 1995 they relied more heavily on mammalian prey (fig. 1). Individual prey in the mammals category also switched from leporids being highest in the Spring of 1994 to a higher rodent content in the Spring of 1995. Arthropods accounted for approximately 10 percent of the diet and were the third largest category in the Spring of 1994 but accounted for less than 3 percent in the Spring of 1995 and were only the fifth largest category.

Summer 1994 and 1995—The diets of gray fox during these summers shifted from being more dependent on Utah juniper berries in 1994 to being more dependent on mammalian food in 1995 (fig. 2). Utah juniper berries and mammalian prey maintained the top two positions for dietary items in both years. Mammalian prey showed leporids and rodents were fairly even the first summer, but rodents were taken in greater amounts than leporids in 1995. Arthropods accounted for approximately 10 percent of the diet: they were the third highest item by either RPFO or RPV values. Misc. Vegetation contributed measurably to gray fox diets in both summer periods.

Fall 1994 and 1995—During both fall periods, Utah juniper berries constituted the major portion of gray fox diets (fig. 3). Leporids accounted for a lesser percent than did rodents in 1994 with the reverse being true in 1995. Diets during both fall periods consisted of little other than Utah juniper berries and mammals.

Winter 1995 and 1996—During both winters, Utah juniper berries dominated the diets of gray fox (fig. 4). Mammalian prey contributed almost twice as much in 1996 as in 1995. Leporids contributed slightly more to the mammalian prey take than did rodents in 1995 but were slightly less or equal to rodents in 1996. The mammalian prey category "Other" was higher in 1996 than in 1995 and was comprised largely of carrion (that is, deer and per or elk hair). Misc. Vegetation and Misc. Items contributed more to gray fox diets in 1996 than in 1995.

April 1994 to March 1996—Overall, Utah juniper berries contributed 50 percent or more to diets of gray fox during the two years scat was collected (fig. 5). Mammals were the next common prey item contributing just over 35 percent. Rodents were the most common mammalian prey, followed by Leporids, and then "Other" mammals. The third highest category was Misc. Vegetation, fourth was Misc. Items, and then Arthropods, Rep. & Amph., and finally Birds.

By comparison, Turkowski (1970) found that mammals by percent occurrence, overall, contributed more to gray fox diet than other items in the southwestern United States. He noted rodents were the primary mammalian prey, while plants (principally grasses and legumes) contributed the next greatest percent. Trani (1980) found that along the northern California coast gray fox existed primarily on an herbaceous diet. True fleshy fruits, by percent volume and percent frequency, were major foods. Mammals were the next most important prey selected in Trani's study and rodents as a group were the most important mammal prey. In Trapp's (1978) study of gray fox at Zion National Park, juniper berries and berry

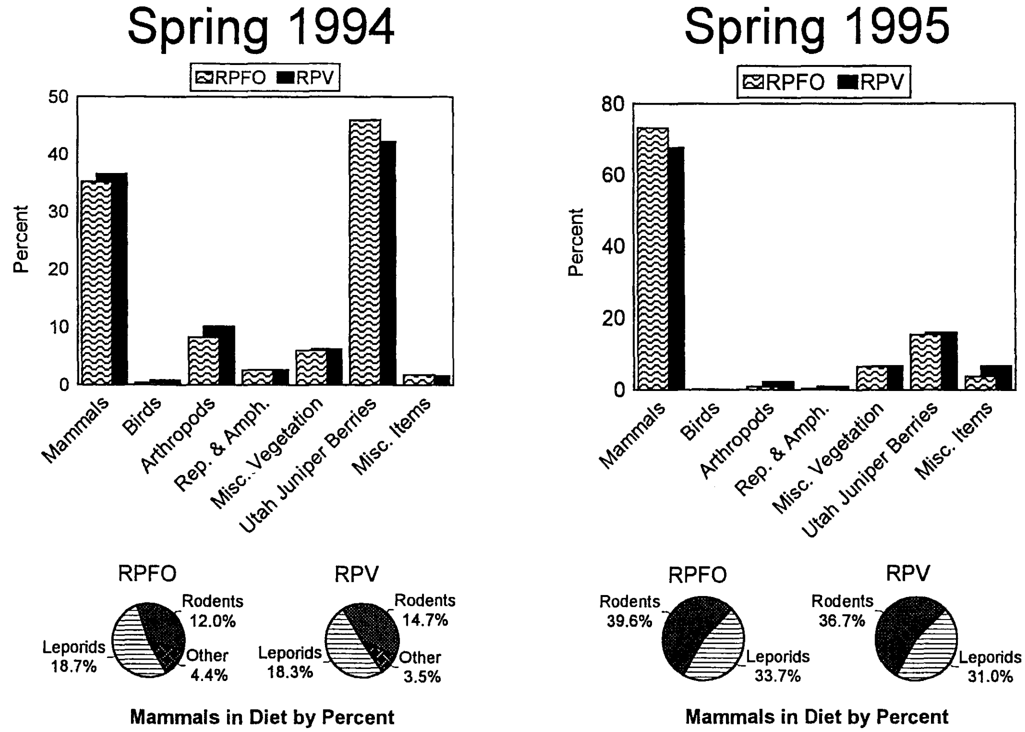

Figure 1—The 7 major diet categories of Spring (July-June) 1994 and 1995 seasons are depicted here by the RPFO and RPV values. The mammalian prey items of importance are shown beneath the major prey categories and summed to equal the percent shown in the Mammals category.

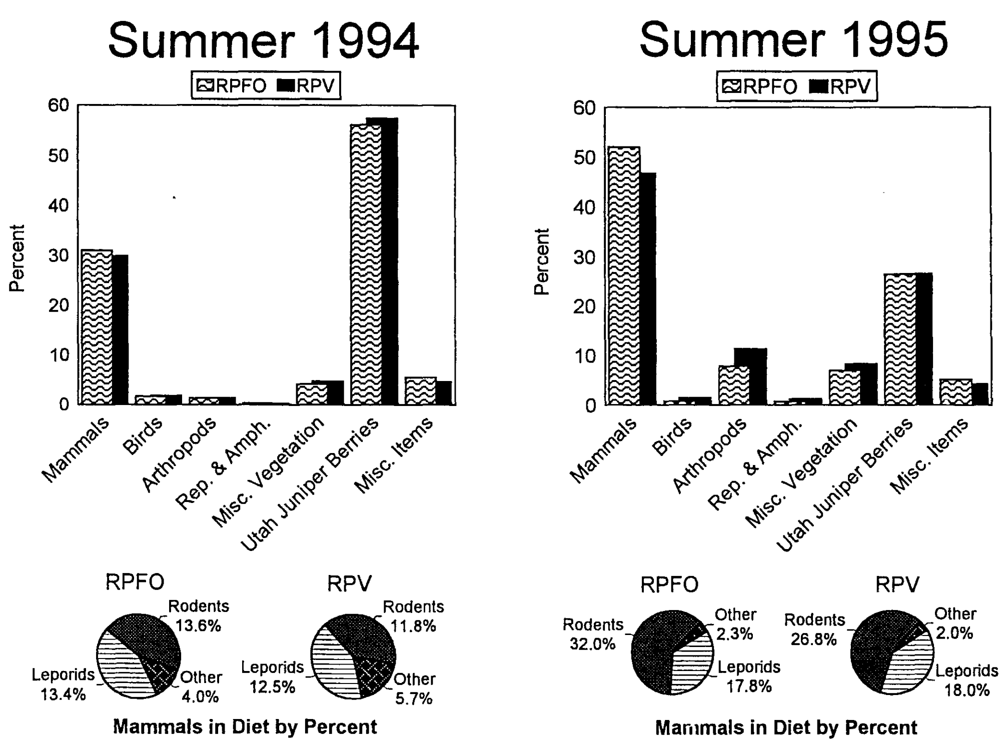

Figure 2—Shown here are the RPFO and RPV values of the 7 major diet categories for Summer (July-September) 1994 and 1995 seasons. The mammalian prey items of importance are shown beneath the major prey categories and summed to equal the percent shown in the Mammals category.

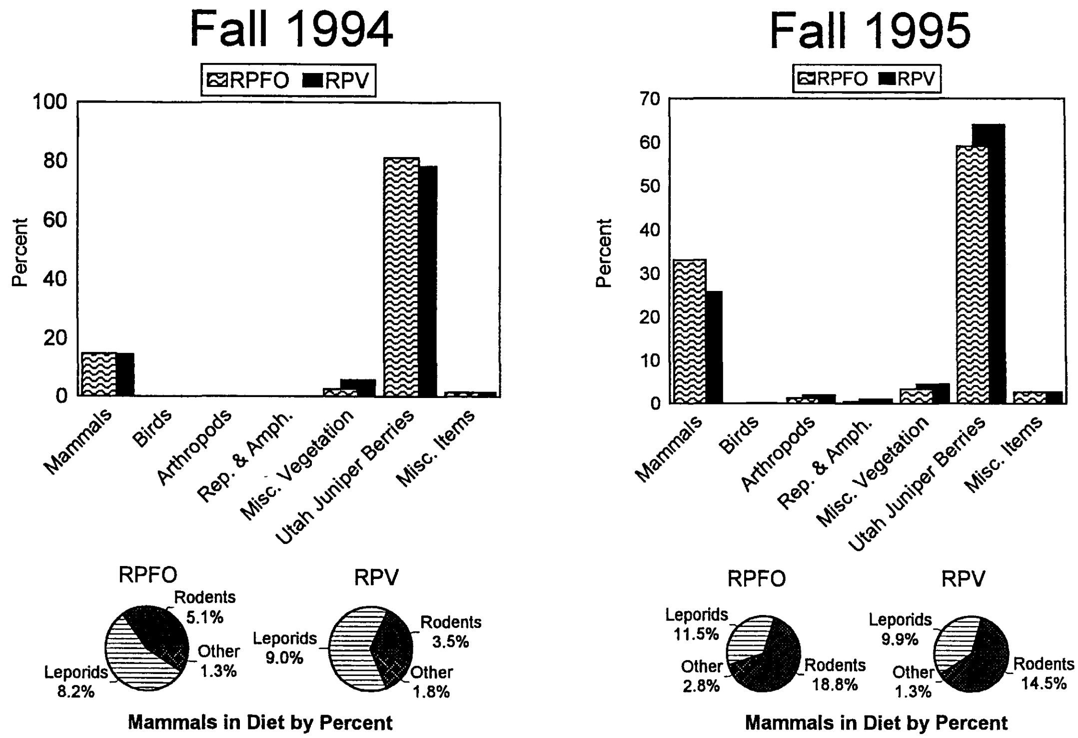

Figure 3—Depicted here are the RPFO and RPV values of the seven major diet categories for Fall (October-December) 1994 and 1995 seasons. The mammalian prey items of importance are shown beneath the major prey categories and summed to equal the percent shown in the Mammals category.

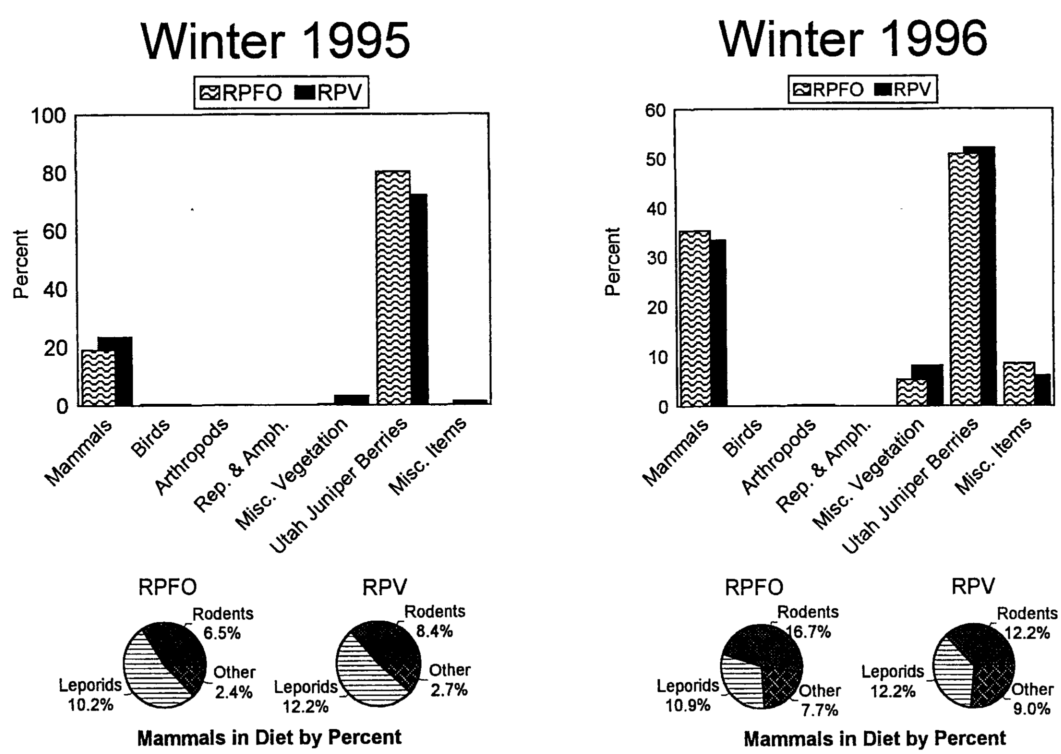

Figure 4—The 7 major diet categories of Winter (January-March) 1995 and 1996 seasons are shown here by the RPFO and RPV values. The mammalian prey items of importance are shown beneath the major prey categories and summed to equal the percent shown in the Mammals category.

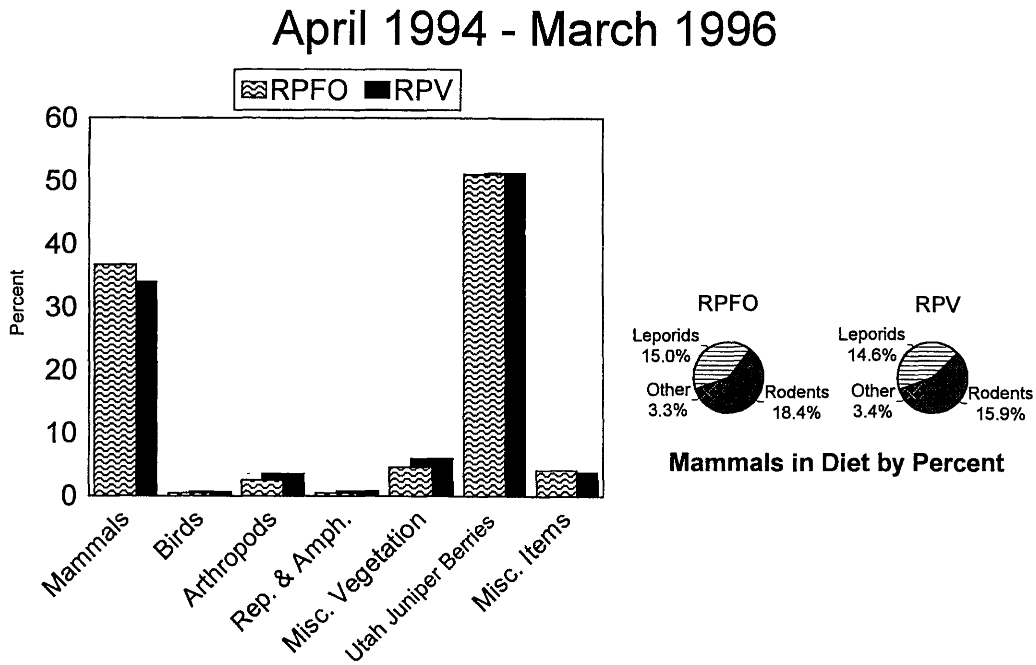

Figure 5—Shown here are the RPFO and RPV values of the seven major diet categories from April 1994 to March 1996. The mammalian prey items of importance are shown beneath the major prey categories and summed to equal the percent shown in the Mammals category.

pricklypear (*Opuntia phaeacanatha*) fruits contributed the highest frequency and the greatest volume. Mammalian prey, mainly carrion, contributed the second largest frequency value, while arthropods were the second highest group by percent volume. All three researchers noted seasonal shifts in the diet of gray fox. Seasonal periods were different in all three studies and the main prey items varied somewhat for the various seasons. Small's (1971) study in Arizona analyzed scats collected over five months (March to July) and reported juniper berries to be the most frequently observed food taken by coyote (79.7 percent) and gray fox (87.0 percent). The next most common prey item by frequency of occurrence for gray fox was invertebrates.

Our study indicated that mature Juniper berries maintained the largest RPFO and RPV values in 6 of the 8 seasons monitored. Mammals were the commonest prey item by RPFO and RPV during Spring 1995 and Summer 1996. A monthly comparison can be made for 22 of the 24 months. By RPFO, mammalian prey had the highest frequency in 7 of the 22 months. Using RPV, mammals had the highest volume in 8 of the 22 months. Utah juniper berries dominated in all other months by both methods. Leporids made up the greatest percent of the mammalian prey by RPFO and RPV during the first year, whereas Rodents contributed a greater percent to the Mammals category the second year.

A major difference between Trapp's Zion National Park study and our own was the percent frequency of arthropods (57 percent) compared to our RPFO of 2.5 percent. Trapp also reported an annual use of berry pricklypear fruit (30 percent) as well as several other types of fruits which did not occur in any of the fox scat that we examined from NWMA. This is not surprising since Welsh and others (1987) did not place berry pricklypear, and several of the plants occurring in Trapp's study area, as far north as the NWMA.

Fruits of several plant genera are known to occur in diets of black bear (*Ursus americanus*), coyote, red fox (*Vulpes vulpes*) and/or gray fox (Trapp and Hallberg 1975; Turkowski 1970; Wilson 1993). These plant genera include skunkbush or sumac (*Rhus*), elderberry (*Sambucus*), snowberry (*Symphoricarpos*), acorns (*Quercus*), serviceberry (*Amelanchier*), rose (*Rosa*) as well as several cultivated fruit trees. Surprisingly, species from several of these genera were present in NWMA but their fruits and/or seeds were not identified in the gray fox diet. The plant genera and species included skunkbush (*Rhus aromatica*), blue elderberry (*Sambucus caerulea*), snowberry (*Symphoricarpos spp.*), Gambel oak (*Quercus gambelii*), serviceberry (*Amelanchier alnifolia*), woods rose (*Rosa woodsii*), and some cultivated fruit trees. In addition, nuts of pinyon pine are seasonally quite abundant and widespread but were never observed in diets of gray fox studied. Cultivated fruit trees in the area were located at the Cunningham Ranch in the southern portion of the study area. The Ranch had a caretaker and a dog on the premises since the spring of 1994. The activity in the area possibly deterred gray fox use of these fruit trees.

Food selection by gray fox in eastern Utah did not follow the generally held belief that they are opportunistic feeders exploiting a wide range of seasonally available dietary items. Gray fox in the NWMA specialized on an interesting mix of vegetation and animal matter while avoiding some foods such as pinyon nuts, acorns, skunkbush. Sterotypic diet preference is shown by the avoidance of other available berries.

Statistical Analyses of Diet—A Spearman's Rank Correlation revealed significant correlation (p-value = 0.05) between, RPFO and RPV values, for the seven major food item categories except Rep. & Amph. (r_s = 0.63, P = 0.09). The Utah Juniper Berries category had a perfect correlation at r_s = 1.00 (P = 0.00) for the 2 indicator values. The three subcategories of Mammals (Rodents, Leporids, and Other) also showed significant correlation between RPFO and RPV. This indicates that both indicators, RPFO and RPV, predict similar use of food items by gray fox. Although it was noticeable that RPFO, which relies on a food item falling on one of the 25 randomly placed dots, did not always account for all food items found in a scat, it is not significantly different from RPV which does account for all food items found in a scat.

A statistically significant correlation was apparent across the eight seasonal periods for 4 of the 7 major food item categories by RPV and 3 of the 7 by RPFO. Gray fox, by RPFO and RPV, consumed significantly more Mammals (H = 47.61, P = 0.00 and H = 37.18, P = 0.00, respectively) in the Spring 1994 period while consuming significantly less Utah juniper berries (H = 50.70, P = 0.00 and H = 46.00, P = 0.00, respectively) during the same period. By RPV, Arthropods were consumed significantly more (H = 24.12, P = 0.001) in the Spring of 1994 and Summer of 1995. Significantly more (H = 16.08, P = 0.01) Arthropods were consumed in the Summer of 1995, by RPFO, than in other seasonal periods. Misc. Vegetation showed seasonal differences (H = 22.45, P = 0.001) by RPV, but there were no significant differences (H = 6.67, P = 0.35) between seasonal periods for RPFO. Among the subcategories of Mammals, only Rodents showed statistical significance between the eight seasonal periods by RPV (H = 21.62, P = 0.002) and RPFO (H = 27.40, P = 0.00). Although Mammals and Utah juniper berries contributed the majority of food items in the diet, it was apparent there were seasonal differences in the use of different food items.

Leporid and Rodent Availability

All three census transects were located adjacent to water and its accompanying riparian zone. Transect C had the most extensive riparian zone. Transect A and B had sections that were ≥ 500 m away from water. Transect B and C were located at higher elevations, in thicker vegetation, and had more variable topography. The lower section of Transect A was located in brush flats, while the upper section was located in habitat similar to that along Transect B.

Rodent Assessment—Scent station visitation rates by rodents varied month to month from April 1994 to March 1996 ($\bar{x}$ = 217.6, SE = 37.5). The scent stations were operated regularly for the 24 month period. A total of 170 visits by rodents were noted during 18 months of census. Rain, snow, or frost rendered the stations unreadable six months over the study period. These months were usually November, January, and February. Thus, Winter 1994 and Winter 1995 periods could not be compared with respect to Rodents in the diet and rodent activity at the scent stations. Spearman's Rank Correlation indicated no significant correlation between the amount of rodents in the diet by RPFO (R_s = –0.26, P = 0.57) and RPV, (R_s = –0.20, P = 0.65) and rodents detected at scent station censusing plates. Qualitatively, Rodents in the diet by RPFO and RPV do seem to reflect the relative abundance of rodents at scent stations from Spring 1994 to Fall 1994 and Summer 1995 to Fall 1995.

Leporid Assessment Via Spotlighting—The most observable leporids along the permanent scent station transects (via spotlight census) throughout the study were cottontail rabbits (*Sylvilagus audubonii* and *S. nuttallii*) (Durrant 1952). They were observed 13 times and black-tailed jackrabbits (*Lepus californicus*) 6 times. Leporids were most often seen on roads and assigned a perpendicular distance of "zero". Leporid density for the study area from April 1994 to March 1996 was 42.31 per km^2. Number of Leporids was also quantified by number per km (# per km) for the entire study period with the result of 0.06 leporids per km. Leporids observed by spotlighting (leporid per km) was strongly correlated with Leporids in diet by RPV (r_s = 0.78, P = 0.04) and by RPFO (r_s = 0.89, P = 0.02). The highest RPFO and RPV of leporids in the diet occurred in the Spring of 1995 and the second highest leporids per km occurred in the Spring of 1994 (fig. 1).

Leporid Assessment Via Fecal Pellet Counts—Leporid fecal counts indicated that from April 1994 to March 1996 Transect A had the highest mean number of fecal pellets with 7.5 pellets per 0.49 m^2 (SE = 2.3) and the highest leporid density at 14.9 per ha per month for all counting periods. The early summer periods showed a higher leporid pellet count per plot in August 1994 ($\bar{x}$ = 7.4, SE = 3.3) than in August 1995 ($\bar{x}$ = 2.7, SE = 1.1). Leporid availability as estimated by leporid per ha per month was not correlated with leporids in diet by RPV (r_s = 0.42, P = 0.26) or by RPFO (r_s = 0.46, P = 0.23). However, the August leporid per ha per month value was indicative of June, July, and August leporid abundance and as such, it is interesting to note that leporids in the diet also peaks in the months from April-September of both 1994 and 1995. Gray fox apparently show some response to changing leporid abundance.

Nutritional and Chemical Analyses

Of the 214 scats examined, there was not a single juniper seed that was considered to be immature. It was noted from our collection of mature and immature berries that mature seeds from Utah juniper berries have a characteristic "dark red" or dark "pigment" on the distal ⅓ to ½ of the seed. Immature seeds lack this dark coloration or have a greenish distal end. Seeds of mature Utah juniper berries generally were found with the hard seed coat intact in gray fox scat. Seeds not intact were noticeably flawed in some natural way or appeared older. Amount of scarification to the juniper seeds found in gray fox scat was not determined.

Mineral and nutritional analyses were conducted on the fleshy coats (hulls) of mature and immature Utah juniper berries. Values for 20 different minerals and nutrients were obtained from either dry or wet mature and immature hulls. Additionally, Ca:P ratio, percent moisture, and percent dry weight of berry that is hull were derived for both mature and immature berries. Caloric value was obtained

Table 1—Mature Utah juniper berries were collected between July 1995 and June 1996 at Nash Wash. Below is a listing of the means and standard deviations for the essential nutrients and minerals contained in dry hulls of the berries. Sample size of each season was 3, except for percent Moisture in the Summer 1995 (n = 2). Sample size of the 12-month average was 12, except for percent Moisture (n = 11).

Season	Crude protein[a]	TNC[b]	Crude fat[c]	ADF[d]	N	K	Mg	Ca	P	Ca:P[e]	Na	Fe	Zn	Cu	Mn	Moisture	Dry weight of berry that is hull
	- - - - - -	- - - -	- - - -	- - - -	*Percent*	- - - -	- - - -	- - - -	- - - -		- - - -	- - - -	*ppm*	- - - -	- - - -	- - - -	*Percent* - - - -
Summer 1995 July - Sept.	5.2 ± 0.4	15.9 ± 5.6	25.8 ± 3.6	28.2 ± 2.2	0.8 ± 0.1	1.9 ± 0.2	0.1 ± 0.01	0.4 ± 0.03	0.1 ± 0.03	4.1 ± 0.9	44.7 ± 25.8	34.0 ± 2.0	7.7 ± 2.1	1.7 ± 0.6	9.7 ± 3.2	3.4 ± 3.4	65.5 ± 2.7
Fall 1995 Oct. - Dec.	4.5 ± 0.2	28.3 ± 8.5	25.8 ± 3.6	27.4 ± 2.0	0.7 ± 0.03	1.9 ± 0.2	0.1 ± 0.01	0.4 ± 0.1	0.1 ± 0.03	3.2 ± 1.3	25.7 ± 15.9	46.7 ± 6.5	8.3 ± 0.6	4.3 ± 1.5	10.3 ± 0.6	4.4 ± 1.8	67.8 ± 4.1
Winter 1996 Jan. - Mar.	4.2 ± 0.7	19.9 ± 2.8	27.1 ± 0.5	32.1 ± 2.8	0.7 ± 0.1	1.8 ± 0.01	0.1 ± 0.01	0.5 ± 0.1	0.1 ± 0.02	4.4 ± 1.4	42.0 ± 14.5	38.7 ± 4.7	7.7 ± 2.1	2.0 ± 1.0	11.3 ± 1.5	7.2 ± 2.8	63.7 ± 5.3
Spring 1996 Apr. - June	3.8 ± 0.1	21.3 ± 3.0	26.8 ± 0.7	28.1 ± 0.9	0.6 ± 0.01	2.0 ± 0.2	0.1 ± 0.01	0.6 ± 0.1	0.1 ± 0.03	6.7 ± 2.7	57.0 ± 29.8	30.7 ± 5.1	8.0 ± 1.7	2.0 ± 0.0	10.3 ± 0.6	4.2 ± 0.8	64.8 ± 2.7
12-month Average	4.4 ± 0.6	21.3 ± 6.6	26.4 ± 2.3	28.9 ± 2.75	0.7 ± 0.1	1.9 ± 0.2	0.1 ± 0.01	0.5 ± 0.1	0.1 ± 0.03	4.6 ± 2.0	42.3 ± 22.4	37.5 ± 7.5	7.9 ± 1.5	2.5 ± 1.4	10.4 ± 1.7	4.9 ± 2.4	65.5 ± 3.6

[a]Crude protein is the percent of nitrogen in each sample x 6.25.
[b]Total non-structural carbohydrates (TNC) represent the percent of sugars and starch in a sample.
[c]Crude fat includes a variety of compounds such as vitamins (A, D, and E), organic acids, oils, and true fats.
[d]Acid Detergent Fiber (ADF) reflects the amount of carbohydrates, ash and other cell wall structures not solubilized by acid detergent. Cellulose, lignin, lignified nitrogen, cutin, silica, and some pectins may be represented by these non-solubilized compounds.
[e]Ca:P is the calcium-to-phosphate ratio.

Table 2—Mature Utah juniper berries were collected between October 1995 and September 1996 at Nash Wash. Here listed are the means and standard deviations for the Tannins, Phenolics, Carbohydrates (Fructose, Mannose, and Galactose), and calories obtained from the dry juniper berry hulls. Terpenes were obtained from wet mature juniper berry hulls. Sample size of each season was 3 and sample size of the 12-month average was 12.

Season	Tannins	Terpenes[a]	Phenolics[b]	Fructose	Mannose	Galactose	Calories
	mg/g			*mg/g*	*mg/g*	*mg/g*	*kcal/g*
Fall 1995 Oct. - Dec	44.3 ± 16.2	17.2 ± 16.4	154.4 ± 46.5	4.0 ± 6.9	14.2 ± 18.4	86.4 ± 92.4	4.2 ± 0.2
Winter 1996 Jan. - Mar.	42.6 ± 13.9	41.0 ± 11.4	198.8 ± 69.2	1.5 ± 1.4	7.5 ± 6.9	24.4 ± 17.2	4.2 ± 0.02
Spring 1996 Apr. - June	50.6 ± 16.7	51.6 ± 18.2	270.4 ± 25.3	0.2 ± 0.3	3.8 ± 3.4	43.1 ± 44.2	4.2 ± 0.04
Summer 1996 July - Sept.	41.9 ± 11.3	49.5 ± 9.1	158.3 ± 43.2	0.2 ± 0.3	1.2 ± 1.1	4.5 ± 3.5	4.2 ± 0.1
12-month Average	44.9 ± 13.0	39.8 ± 18.7	195.5 ± 64.0	1.5 ± 3.4	6.7 ± 9.9	39.6 ± 54.4	4.2 ± 0.1

[a]Terpenes were measured by "Total Area" per 500 mg fresh weight of tissue divided by 10,000.
[b]Phenolics were measured by "Total Area" per 200 mg dry weight of tissue divided by 10,000.

Table 3—Immature Utah juniper berries were collected between July 1995 and June 1996 at Nash Wash. Below is a listing of the means and standard deviations for the essential nutrients and minerals contained in dry hulls of the berries. Sample size of each season was 3, except for percent Moisture in the Summer 1995 (n = 2). Sample size of the 12-month average was 12, except for percent Moisture (n = 11).

Season	Crude protein[a]	TNC[b]	Crude fat[c]	ADF[d]	N	K	Mg	Ca	P	Ca:P[e]	Na	Fe	Zn	Cu	Mn	Moisture	Dry weight of berry that is hull
					Percent								*ppm*			*Percent*	
Summer 1995 July - Sept.	6.4 ± 1.1	12.1 ± 3.8	20.5 ± 1.3	33.4 ± 1.9	1.0 ± 0.2	2.0 ± 0.2	0.1 ± 0.0	0.3 ± 0.1	0.1 ± 0.1	2.8 ± 1.4	30.0 ± 9.2	46.0 ± 9.6	17.3 ± 5.0	2.7 ± 2.1	11.0 ± 1.7	47.2 ± 11.6	50.5 ± 5.7
Fall 1995 Oct. - Dec.	6.2 ± 0.5	12.2 ± 0.9	22.7 ± 1.1	25.1 ± 2.2	1.0 ± 0.1	2.1 ± 0.2	0.1 ± 0.02	0.2 ± 0.01	0.2 ± 0.02	1.3 ± 0.1	70.3 ± 63.8	44.3 ± 9.5	14.7 ± 2.9	4.3 ± 0.6	9.7 ± 1.5	25.5 ± 17.2	54.5 ± 5.8
Winter 1996 Jan. - Mar.	5.8 ± 0.1	9.1 ± 2.7	22.6 ± 4.8	33.7 ± 2.9	0.9 ± 0.02	2.3 ± 0.2	0.1 ± 0.01	0.2 ± 0.01	0.2 ± 0.04	1.5 ± 0.4	47.7 ± 7.6	68.0 ± 35.0	13.3 ± 0.6	3.3 ± 0.6	10.3 ± 1.5	35.9 ± 8.6	48.7 ± 2.9
Spring 1996 Apr. - June	7.2 ± 1.5	13.0 ± 1.9	23.0 ± 3.9	26.4 ± 1.1	1.1 ± 0.2	2.2 ± 0.5	0.1 ± 0.02	0.4 ± 0.1	0.2 ± 0.04	2.4 ± 1.0	44.7 ± 4.5	35.0 ± 8.5	12.0 ± 1.0	4.0 ± 1.0	11.0 ± 2.0	48.0 ± 1.0	47.5 ± 1.2
12-month Average	6.4 ± 1.0	11.6 ± 2.7	22.2 ± 2.9	29.6 ± 4.5	1.0 ± 0.2	2.1 ± 0.3	0.1 ± 0.01	0.3 ± 0.1	0.2 ± 0.04	2.0 ± 1.0	48.2 ± 31.6	48.3 ± 20.7	14.3 ± 3.3	3.6 ± 1.2	10.5 ± 1.6	39.1 ± 13.6	50.3 ± 4.6

[a]Crude protein is the percent of nitrogen in each sample x 6.25.
[b]Total non-structural carbohydrates (TNC) represent the percent of sugars and starch in a sample.
[c]Crude Fat includes a variety of compounds such as vitamins (A, D, and E), organic acids, oils, and true fats.
[d]Acid Detergent Fiber (ADF) reflects the amount of carbohydrates, ash and other cell wall structures not solubilized by acid detergent. Cellulose, lignin, lignified nitrogen, cutin, silica, and some pectins may be represented by these non-solubilized compounds.
[e]Ca:P is the calcium-to-phosphate ratio.

Table 4—Immature Utah juniper berries were collected between October 1995 and September 1996 at Nash Wash. Here listed are the means and standard deviations for the Tannins, Phenolics, and carbohydrates (Fructose, Mannose, and Galactose) obtained from the dry juniper berry hulls. Terpenes were obtained from wet immature juniper berry hulls. Sample size of each season was 3, except for Terpenes Fall 1995 period (n = 2). Sample size of the 12-month average was 12, except for Terpene (n = 11).

Season	Tannins	Terpenes[a]	Phenolics[b]	Fructose	Mannose	Galactose
	mg/g			*mg/g*	*mg/g*	*mg/g*
Fall 1995 Oct. - Dec.	14.9 ± 13.7	38.2 ± 13.9	153.9 ± 92.0	11.3 ± 14.8	14.5 ± 17.9	40.6 ± 37.
Winter 1996 Jan. - Mar.	0.0 ± 0.0	42.6 ± 23.3	109.0 ± 8.4	8.7 ± 9.2	4.8 ± 5.4	20.3 ± 13.7
Spring 1996 Apr. - June	0.0 ± 0.0	51.0 ± 7.1	80.1 ± 27.8	12.3 ± 12.4	13.7 ± 17.3	11.6 ± 10.6
Summer 1996 July - Sept.	0.5 ± 0.9	42.7 ± 14.9	106.2 ± 51.2	1.7 ± 2.0	3.1 ± 4.0	7.2 ± 10.3
12-month Average	3.9 ± 8.9	44.1 ± 14.3	112.3 ± 54.2	8.5 ± 10.1	9.0 ± 12.2	19.9 ± 22.7

[a]Terpenes were measured by "Total Area" per 500 mg fresh weight of tissue divided by 10,000.
[b]Phenolics were measured by "Total Area" per 200 mg dry weight of tissue divided by 10,000.

for mature berry hulls. A 12-month average was obtained for each component of the berries and data was also grouped into the same 3 month periods as those for dietary analysis (tables 1-4).

The mature and immature berries' mineral and nutrient components were compared for the 12 months they were collected. Fifteen components of juniper hulls were found to be significantly different between mature and immature juniper berries. Six of the 15 significant components were greater in mature than immature juniper hulls. Immature hulls had significantly greater contents of minerals, moisture (W = 47.0, P = 0.00), Crude Protein (W = 79.5, P = 0.00), and Fructose (W = 99.0, P = 0.00). Mature juniper berries had significantly larger values for Ca:P ratio (W = 203.0, P = 0.00), Tannin (W = 221.5, P = 0.00), and Phenolics content (W = 203.5, P = 0.00).

The greater amounts of some minerals and chemicals in mature hulls may appear to be disadvantageous to foxes. The National Research Council (NRC) (1982) recommended a Ca:P ratio for farm raised silver fox (*Vulpes fulva*) and blue fox (*Alopex lagopus*) between 1.0:1.0 – 1.7:1.0. Mature juniper hull Ca:P ratio average over 12 months was 4.6:1.0 ± 2.0:1.0 (table 4). Studies with herbivores have shown that condensed tannins bind to dietary proteins making them indigestible. The quantitative ratio of condensed tannins to dietary protein and the pH of the stomach acids likely controls the process and importance of this binding action. Logically, most research on this subject has involved herbivores. Phenolics are considered, in general, to be toxins for plant defense (Robbins 1993).

At first it may appear that the immature juniper hulls offer the gray fox significantly more minerals and nutrients. Further evaluation revealed, however, that mature juniper berries offer a significantly greater percent of total non-structural carbohydrates (TNC) (W = 212.0, P = 0.00) and a significantly greater percent of Crude Fat (W = 205.0, P = 0.00). TNC represents the percent of sugars and soluble starch in a sample and Crude Fat includes a variety of compounds including vitamins (A, D and E), organic acids, oils and true fats. Thus, a significantly greater amount of digestible energy is available in mature juniper hulls in the form of TNC and Crude Fats than in immature juniper hulls.

The supposedly undesirable aspects of higher Ca:P ratios, higher tannin contents and higher phenolic contents must be considered theoretical until further information is available on the digestion process and metabolism of the gray fox. For example, Robbins (1993) reported Ca:P ratio higher than 2:1 can be satisfactorily handled by some animals. He further stressed that excess calcium has a far lesser effect on phosphorus absorption than the reverse.

Various animals ranging from invertebrates (Martin and Martin 1984: Rhoades and Cates 1976) to vertebrates (Robbins 1993) have mechanisms that counter antidigestive action of tannins. Robbins and others (1991) has shown that some mammals including black bears are adapted for consuming tannin containing foods by secreting tannin binding salivary proteins. This enables the mammal to neutralize tannins as they are ingested. Another factor to consider when assuming the effectiveness of tannins to bind with proteins is that the optimal pH range for binding is between 5 and 6.5 (Rhoades and Cates 1976) and as pH level increases or decreases the ability to bind would decrease. Since carnivores are known to have a gastric pH of about 2.0 (Knowles, personal communication) we conclude that tannins bind dietary proteins less effectively in a carnivore stomach. It has also been shown that tannins and phenolics can reduce the infectivity of viruses or other pathogens (Keating and others 1988; Roming and others 1992).

Phenolics can also play diverse metabolic roles when ingested. When phenolic-glycosides are hydrolyzed in the lab at a pH of 2.0 sugars are cleaved off the phenolic compound. In stomachs with a low pH, phenolic-glycosides could be hydrolyzed and the resulting sugars would be an additional source of nutrition.

Analysis of juniper berries were grouped into the same 3-month seasonal periods as those for dietary analyses. This allowed us to compare possible seasonal differences in mineral and nutritional content. Since collection of berries occurred towards the end of the study (1995-1996) and the collection of fox scats only partially (Summer 1995, Fall 1995, and Winter 1996) overlapped the collection of berries, the discussion will pertain only to general trends observed between dietary contents of scats and chemistry of hulls of juniper berries.

Gray fox apparently prefer only mature Utah juniper berries, thus a Kruskal-Wallis Test for statistical differences (p-value = 0.10) was conducted on only mineral, nutritional, and chemical components of the mature juniper hulls among the seasonal periods. After determining if there were significant differences among groups of factors, individual factors were tested for significance against each other (Gibbons 1976).

Eight of the hull components showed seasonal differences at the group level, but in only 5 of the 8 seasons could seasonal differences be demonstrated within the group. Crude Protein (H = 7.23, P = 0.07) was the only non-mineral component showing seasonal differences within the group. No apparent beneficial patterns were observed for seasonal differences among the various components. However, it is possible that mature Utah juniper berries were selected in greater proportions when small increases in important nutrients and minerals were greatest. For example, the mean TNC for the entire year was 21.3 percent (SD = 6.6 percent). During the Fall season when juniper berries were taken in large amounts TNC was above the 12-month average by 7.0 percent. In addition, the percent Acid Detergent Fiber (ADF) during the fall season was lower ($\bar{x}$ = 27.4, SD = 2.0) than the 12-month average ($\bar{x}$ = 28.9, SD = 2.7). The lower percent ADF coupled with the higher percent TNC may allow the gray fox to obtain more nutritional benefit by taking this seemingly marginal food item in greater amount during the winter periods (table 1).

Ecological Conclusions

Analysis of gray fox scats for dietary content indicated that both RPFO and RPV produced similar results. Gray fox extensively used both mature Utah juniper berries and mammalian prey. Spotlight sightings of leporids (leporids per km) correlated with leporid content in the diet of gray fox. Although rodent censusing at metal scent stations did not strongly correlate with rodents in the diet, increase in rodent abundance at scent stations and rodents in the diet showed some parallels. Thus, gray fox appear to take more of both leporids and rodents during the reproductive periods of these prey mammals.

It is clear that hulls of mature Utah juniper berries comprised a large part of gray fox diets in all 8 seasons studied. The obvious question is whether or not juniper berry hulls are an adequate or inadequate major portion of gray fox diets. In the vernacular of foraging strategies, are gray fox holding the consequential error of foraging to a minimum when ingesting the quantities of juniper berry hulls found in this study? Little is known of the digestive physiology and metabolism of gray fox. Trapp (1978) claimed that berries of Utah juniper alone were sufficient to maintain gray fox in a healthy condition, however, he had little data to support his conclusion and he collected berries only in the month of December. Trapp's data is similar to that reported here with the exception that he reports a substantially lower caloric value (3.4 cal per g) than what was found in our study (4.2 kcal per g). It should be noted that Salomonson's (1978) caloric data on hulls of one-seed juniper (*Juniperus monosperma*) (4.57 kcal) were similar to our findings.

Though not well studied, the gray fox is one of a few homoiotherms and the only mammal known to forage extensively on the hulls of Utah juniper berries. Extensive seasonal use of juniper berries by avian species has been documented. Poddar and Lederer (1982) demonstrated that western juniper (*Juniperus occidentalis*) constituted the majority of the Townsend's solitaire (*Myadestes townsendi*) diet in winter. Their study indicated that mature western juniper berries had low percent moisture which concentrated more energy and nutritional content into hulls of berries. Thus mature berries offered more value per unit weight, than the immature berries with higher percent moisture. Our analyses of Utah juniper berries showed that mature berries had a significantly lower percent moisture than immature berries. Due to the lower percent moisture it can be shown that if 100 g of mature berries were consumed by a gray fox, it would obtain twice the amount of nutrients and minerals available in 100 g of immature berries. Furthermore, researcher observation indicated it took a human twice as long to collect 100 g of immature berries as it did to collect 100 g of mature berries. If this is true for a gray fox, then it would consume 200 g of mature juniper hull with twice the concentration of minerals and nutrients per 100 g, for a fourfold increase, in the same amount of time it took to consume 100 g of immature juniper hull.

It is helpful to consider other details of the nutritional value of mature Utah juniper berry hulls (tables 1 and 2). For example, 100 g of wet mature juniper berries contains an average of 4.9 percent of moisture (table 1). After the moisture is subtracted we are left with 95.1 g of dry berry. Further, we know that an average of 65.5 percent (table 1) of the remaining weight of the berry is hull, which leaves us with 62.3 g of hull. Using the 12-month averages from table 1 and 2 for selected minerals and nutrients we find that 62.3 g of hull yields 2.73 g of Crude Protein, 13.27 g of TNC, 16.45 g of Crude Fat, 18.0 g of ADF, 0.31 g of Ca, 0.06 g of P, 2.80 g of Tannins, 93.45 mg of Fructose, 417.41 mg of Mannose, 2.47 g of Galactose, and a caloric content of 261.66 kcal.

The NRC (1982) provides conflicting data regarding daily gross energy requirements for blue and silver fox. This report (NRC 1982) roughly estimates that blue and silver fox maintenance diets should contain 3,227 kcal of gross energy (which is the total combustible energy of feeds determined in a bomb calorimeter) per kilogram of dry matter. From our data Utah juniper berries offer 2,751 kcal of gross energy per kilogram of dry berry. Without the weight of the seed included, which is passed though intact, juniper hulls alone would offer 4,200 kcal of gross energy per kilogram of dry hull. Thus the juniper hull by itself would offer the minimum gross energy needed for maintenance and then some. With the seed included it reduces the amount of kcal available per kilogram of dry matter. However, an occasional addition of a rodent or leporid would likely supplement any deficiencies in the kcal level, protein or other needed minerals or nutrients. This is substantiated by Dyson (1965) who found that on a diet of rodents and fruit fed at a rate of 3.8 percent of the fox's total body weight, captive gray fox maintained excellent body condition.

Whether the gray fox can maintain itself well on the level of juniper berries shown ingested in this study is best answered by the gray fox. White and others (1997), using a body condition index designed to emphasis body weight of the individual in relation to body size, related that the majority of captured gray fox (n = 17) in the NWMA surpassed, achieved or nearly achieved predicted body weight. In addition, 6 of the 7 juveniles which were captured in months of high juniper berry consumption, were at, or nearly at (within 0.08), predicted excellent body weight. Furthermore, 3 of 4 females caught in the spring showed signs of lactation and thus were reproductive fit. The resident breeding population of gray fox in the study follow an optimum dietary strategy heavily dependent on Utah juniper berries. Rodents and leporids are nutritionally valuable augmentations to the diet as they are available.

It is also important to recognize that mature Utah juniper berries exist in large amounts in pinyon-juniper forests, thus providing a large volume of readily available minerals and nutrients. They are readily available to gray fox throughout the year since Utah juniper berries ripen on the tree and persist after ripening for up to two years (Johnsen and Alexander 1974 as cited in Young and Young 1992). Gray fox are adept at climbing trees (Trapp and Hallberg 1975) and may use a juniper tree for several purposes including resting, as a food source, and as escape cover. When the pinyon-juniper forest type occurs near a water source, it would appear to provide ideal habitat for gray fox. In White and others (1997) study, it was discovered that gray fox visit scent stations that provide dense horizontal obscuring cover, short distance (≤50 m) to escape cover, and are within 500 m of a water source. Escape Cover was often determined to be Utah juniper trees. What the Utah juniper berries may be lacking in nutrients and minerals could easily be offset by supplementing with the animal prey items as listed.

Our experimental design did not include measurements of possible zoopharmacological effects of plant secondary compounds, in ingested juniper berries, in relation to gray fox pathogens as well as internal and external parasites. We did hypothesize this could be a minor to major additive benefit derived from this behavior but unequivocal tests would require extensive laboratory and field studies. External parasite loads were assessed for livetrapped gray fox in the study area and infestations were considered minimal (White and others, unpublished data).

In summary, gray fox are likely to receive optimum benefits from riparian associated pinyon-juniper habitats in several ways. First, juniper berries are an abundant, nutritious, and reliable food. Second, juniper trees supply both secure and feeding cover. Third, pinyon-juniper communities form ecotones with riparian and other vegetative types providing habitats for rodents, leporids, and other animals found in the fox diets. Fourth, plant secondary compounds found in juniper berry hulls may have zoopharmacological, health, benefits for gray fox.

Our research of gray fox in the pinyon-juniper zone of eastern Utah revealed a uniquely strong plant-carnivore interaction. Gray fox not only derive several benefits from inhabiting this zone but also provide a valuable benefit to juniper community dynamics in the form of seed dispersal. Since scat contained a mixture of metabolic residue from several food items (that is mammal hair) and juniper seeds, gray fox provided Utah juniper berry seeds with a natural "mulch" of nitrogen and other minerals. The large seeds of Utah juniper suggests a seed dispersal strategy utilizing the larger, omnivorous, mammals in the Order carnivora such as gray fox, coyote, ringtail and black bear. These have highly acidic stomach environments that may actually contribute to the efficient digestion of berry hulls. During ingestion, gray fox do not have to break a shell or husk in order to benefit from juniper berry hulls and this may help explain why they do not actively feed on pinyon nuts or acorns. Other fleshy fruits available but not eaten contain high amounts of water in proportion to other nutrients. Gray fox occur in riparian zones and thus feed for nutrition not moisture. Our study revealed that members of the Order carnivora known to inhabit pinyon-juniper zones, and the gray fox in particular, are unusually strong contributors to the community structure, dynamics and function of the Utah juniper dominated ecosystem.

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References

Adorjan, A. S.; G. B. Kolenosky. 1969. A manual for the identification of hairs of selected Ontario mammals. Department of Lands and Forests, Ontario. Res. Rep. (Wildlife) No. 90. 64p.

Blackwell, B. H. 1991. Habitat selection, prey base, home range and reproduction of bobcats in west central Utah. M.S. Thesis, Brigham Young Univ., Provo. 100p.

Borror, D. J.; R. E. White. 1970. A field guide to the insects. Houghton Mifflin Co., Boston. 404 p.

Cochran, G. A.; H. J. Stains. 1961. Deposition and decomposition of fecal pellets by cottontails. J. Wildl. Manage. 25(4): 432-435.

Durrant, S. D. 1952. Mammals of Utah: taxonomy and distribution. Univ. of Kans. Publ. 6: 1-549.

Dyson, R. F. 1965. Experimental diet for grey foxes. International Zoo Yearbook 5: 145.

Findlay, W. R. 1992. Ecological aspects and dietary habits of river otter in northeastern Utah. M.S. Thesis, Brigham Young Univ., Provo, UT. 65 p.

Flinders, J. T.; J. A. Crawford. 1977. Composition and degradation of jackrabbit and cottontail fecal pellets, Texas high plains. J. Range Manage. 30(3): 217-220.

Fritzell, E. K. 1987. Gray fox and Island gray fox. In: Bedford, J.; G. Thompson, eds. Wild furbearer management and conservation in North America. Ontario Trappers Assoc., Ont.: 409-420.

Green, J. S.; J. T. Flinders. 1981. Diameter and pH comparisons of coyote and red fox scats. J. Wildl. Manage. 45: 765-767.

Gibbons, J. D. 1976. Nonparametric Methods for Quantitative Analysis. Holt, Rinehart and Winston, New York. 463 p.

Halfpenny, J. C.; E. A. Biesiot. 1986. A field guide to mammal tracking in North America. Johnson Publ. Co., Boulder, Colo. 163 p.

Harrison, R. L. 1997. A comparison of gray fox ecology between residential and undeveloped rural landscapes. J. Wildl. Manage. 61: 112-121.

Hayne, D. W. 1949. An examination of the strip census method for estimating animal populations. J. Wildl. Manage. 13: 145-157.

Horwitz, W., (ed). 1980. Official methods of analysis of the Association of Official Analytical Chemists. Thirteenth ed. Association of Official Analytical Chemists, Washington D.C. 1018 p.

Johnsen, T. N. Jr.; R. A. Alexander. 1974. Juniperus. In: Seeds of woody plants in the United States. Forest Service, USDA, Washington, D.C.: 460-469.

Keating, S. T.; W. G. Yendol; J. C. Schultz. 1988. Relationship between susceptibility of Gypsy moth larvae (Lepidoptera: Lymantriidae) to a baculovirus and host plant foliage constituents. Environ. Entomol. 17: 952-958.

Knowles, J. E. 1997. [Personal communication]. November. Provo, UT: D.V.M., Department of Animal Science, Brigham Young University.

Lindzey, F. G.; S. K. Thompson; J. I. Hodges. 1977. Scent station index of black bear abundance. J. Wildl. Manage. 41(1): 151-153.

Linhart, S. B.; F. F. Knowlton. 1975. Determining the relative abundance of coyotes by scent station lines. Wildl. Soc. Bull. 3(3): 199-124.

Martin, A. C.; W. D. Barkley. 1961. Seed identification manual. Univ. Calif. Press, Berkeley. 221 p.

Martin, J. S.; M. M. Martin. 1984. Surfactants: their role in preventing the precipitation of proteins by tannins in insect guts. Oecologia 61: 342-345.

Moore, T. D.; L. E. Spence; C. E. Dugnolle. 1974. Identification of the dorsal guard hairs of some mammals of Wyoming. Wyoming Game and Fish Department, Cheyenne, Wyoming. Bull. No. 14. 177 p.

National Research Council. 1982. Nutrient requirements of mink and foxes. Second ed., rev. Nat. Acad. Press, Washington D.C. 72 p.

O'Neal, G. T.; J. T. Flinders; W. D. Clary. 1987. Behavioral ecology of the Nevada kit fox (*Vulpes macrotis nevadensis*) on a managed desert rangeland. In: Genoways, H. H., ed. Current Mammalogy, Vol. 1 Plenum Pub. Co.: 443-481.

Poddar, S; R. J. Lederer. 1982. Juniper berries as an exclusive winter forage for Townsend's Solitaires. Amer. Midl. Nat. 108: 34-40.

Rhoades, D. F.; R. G. Cates. 1976. Biochemical interactions between plants and insects. In: Wallace, J.; R. Mansell, eds. Recent Advances in Phytochemistry, Vol. 10 Plenum Press, NY: 168-213.

Robbins, C. S.; B. Bruun; H. S. Zim; A. Singer. 1983. Birds of North America. Revised ed. Golden Press, New York. 360 p.

Robbins, C. T. 1993. Wildlife feeding and nutrition. Second ed. Academic Press, Inc., San Diego, Calif. 352 p.

Robbins, C. T.; A. E. Hagerman; P. J. Austin; C. McArthur; T. A. Hanley. 1991. Variation in mammalian physiological responses to a condensed tannin and its ecological implications. J. Mamm. 72: 480-486.

Roming, T. L.; N. D. Weber; B. K. Murray; J. A. North; S. G. Wood; B. G. Hughes; R. G. Cates. 1991. Antiviral activity of Panamanian plant extracts. Phytotherapy Research 6: 38-43.

Roughton, R. D.; M. W. Sweeny. 1982. Refinements in the scent-station methodology for assessing trends in carnivore populations. J. Wildl. Manage. 46: 217-229.

Salomonson, M. G. 1978. Adaptations for animal dispersal of one-seed juniper seeds. Oecologia (Berl.) 32: 333-339.

Small, R. L. 1971. Interspecific competition among three species of Carnivora on the Spider Ranch, Yavapai Co., Arizona. M.S. Thesis. University of Arizona, Tucson. 78 p.

Stebbins, R. C. 1985. A field guide to western reptiles and amphibians. Second ed. Houghton Mifflin Co., Boston. 336 p.

Trani, M. K. 1980. Gray fox feeding ecology in relation to prey distribution and abundance. M.S. Thesis. Humboldt State University Arcata, Calif. 103 p.

Trapp, G. R. 1978. Comparative behavioral ecology of the ringtail and gray fox in southwestern Utah. Carnivore 1: 3-32.

Trapp, G. R.; D. L. Hallberg. 1975. Ecology of the gray fox (*Urocyon cinereoargenteus*): a review. In: Fox, M. W., ed. The wild canids: their systematics, behavioral ecology and evolution. Van Nostrand Reinhold Co., NY: 164-178.

Turkowski, F. J. 1970. Food habits and behavior of the gray fox (*Urocyon cinereoargenteus*) in the lower and upper Sonoran life zones of southwestern United States. Ph.D. Thesis. Arizona State University, Tempe. 124 p.

U.S. Fish and Wildlife Service. 1984. Final Report: Feasibility of assessing coyote abundance on small areas. Predator Ecology and Behavior Project, Section of Predator Management Research, Denver Wildlife Research Center, CO. 14 p.

Welsh, S. L.; N. D. Atwood; S. Goodrich; L. C. Higgins. 1993. A Utah flora. Second ed., rev. Print Services, Brigham Young University, Provo, UT. 986 p.

White, C. G.; J. T. Flinders; B. H. Blackwell; R. T. Thacker; H. D. Smith. 1997. Effectiveness of census techniques as indicators of population abundance of gray fox. Final Research Report, Utah Div. Wild. Res. Salt Lake City, UT. 98 p.

White, C. G.; J. T. Flinders; B. H. Blackwell; R. T. Thacker; H. D. Smith. 1997. Utah Gray Fox Project. Unpublished data on file with: Jerran T. Flinders, Department of Botany and Range Science, Brigham Young University, Provo, UT.

Wilson, D. E.; D. M. Reeder. 1993. Mammal species of the world: taxanomic and geographic reference. Smithsonian Instituition Press, Washington D.C. 1206 p.

Wilson, M. F. 1993. Mammals as seed-dispersal mutualists in North America. OIKOS 67: 159-176.

Young, J. A.; C. C. Young. 1992. Seeds of Woody Plants in North America. Revised ed. Dioscorides Press, Portland, OR. 407 p.

Zou, J.; R. G. Cates. 1995. Foliage constituents of Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco (Pinaceae)): their seasonal variation and potential role in Douglas fir resistance and silviculture management. J. Chem. Ecol. 21: 387-402.

Habitat Relationships of Amphibians and Reptiles in the Inyo-White Mountains, California and Nevada

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Abstract—The distribution and abundance of herpetofauna was documented in the Inyo and White mountain ranges of Inyo and Mono counties, eastern California. Four species of amphibians and 26 species of reptiles were located in pinyon-juniper (*Pinus monophylla-Juniperus osteosperma*) woodland. Thirteen of the 26 reptile species recorded were snakes; the distribution of most snakes remains poorly understood. The concentration of skinks (*Eumeces* spp.) at springs identified the importance of wet areas for these species. Results indicated the generally unrecognized diversity of herpetofauna present in pinyon-juniper woodlands, and highlight specific research and management needs.

The Inyo and White mountains are the predominant ranges on the western border of the Great Basin. Because of their proximity to the Sierra Nevada, the Inyo-White mountains would be expected to harbor a larger diversity of fauna than found in more easterly, interior ranges. However, this diversity remains virtually undescribed; there have been few surveys of the fauna in the Inyo-White mountains, and research in the pinyon-juniper (*Pinus monophylla-Juniperus osteosperma*) zone is especially lacking. For example, only a few studies have documented the distribution and habitat affinities of amphibians and reptiles in these ranges (Papenfuss 1986; Macey and Papenfuss 1991a,b). Better quantification of fauna in these areas is necessary before resource professionals can develop comprehensive and inclusive management plans.

The goal of our 6 year study was to document the distribution, abundance, and habitat affinities of amphibians and reptiles (herpetofauna) in the pinyon-juniper zone of the Inyo-White mountains, eastern California and western Nevada. For this paper, we have also included results from the poorly studied, upper elevation bristlecone pine-limber pine (*Pinus longaeva-P. flexilis*) forest zone.

Study Area

The Inyo-White mountains rise from 1,515 to 4,245 m elevation and are east of, and run parallel to, the Sierra Nevada Mountains. The pinyon-juniper woodland predominates both ranges between about 1,800 and 2,900 m elevation, and is characterized by an increasing concentration of pinyon, and decreasing amount of juniper, with increased elevation. The shrub layer is sparse and composed primarily of sagebrush (*Artemesia tridentata*) and bitterbrush (*Purshia glandulosa* and *P. tridentata*), intermixed with Mormon tea (*Ephedra viridis*), rabbitbrush (*Chrysothamnus nauseosus* and *C. viscidiflorus*), cactus (*Opuntia* and *Echinocereus* spp.), and other, less common grasses and herbaceous plants.

The bristlecone pine-limber pine forest begins at the upper edge of the pinon-juniper woodland and extends up to about 3,500 m. It is composed of varying mixtures of the two pine species, with a sparse understory composed of sagebrush and mountain mahogany (*Cercocarpus ledifolius*). There are very few large meadows; the largest riparian/meadow location, Cottonwood Basin, is located in the White Mountains (at 3,300 m), and is characterized by linear stretches of aspen (*Populus tremuloides*) and willow (*Salix* spp.), but little cottonwood (*Populus* sp.). A thorough description of the environment and flora of these ranges was given by Powell and Klieforth (1991) and Spira (1991), respectively.

Methods

We determined the distribution of herpetofauna throughout the ranges by searching the literature, museum specimen records, field notes of previous workers, and by conducting our own surveys.

We examined all specimen records through 1988 in the Museum of Vertebrate Zoology (MVZ; University of California, Berkeley) and the Los Angeles County Natural History Museum (LACNHM).

We examined and summarized the field notes of expeditions conducted by teams from the Museum of Vertebrate Zoology in spring and summer 1917, 1942, and 1954. Notes from smaller and shorter-term field trips were also examined.

The only comprehensive summary of the herpetofauna of these ranges was by Papenfuss (1986) and Papenfuss and Macey (1991a,b), who visited the ranges, and also summarized literature and museum records. They conducted sampling transects across the southern Inyo Mountains, across Westgard Pass (central in the ranges), and in the northern White Mountains.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Landscape Distribution

The major east-west, paved travel route across the ranges is State Highway 168. This road crosses the central part of the ranges at Westgard Pass (2,100 m elevation). We drove this road to search for living or road-killed animals from the lower edge of the pinyon-juniper vegetation on the east and west sides of Westgard Pass, a total distance of about 15 km. At least 500 trips were made during daylight hours between May and September, 1987-1992.

The major north-south road in the ranges is the White Mountain Road, which begins at Westgard Pass and runs north to near the summit of White Mountain Peak. We drove this road from Westgard Pass up to 3,100 m in the bristlecone pine-limber pine zone, a total distance of about 20 km, on at least 200 occasions during daylight, May-September 1987-1992.

Records of all anecdotal observations of herpetofauna were also made during our studies of general vertebrate natural history in the ranges, which spanned a total of 30 months in 1987-1992, or about 75 person-months of effort.

Macrohabitat Relationships

We established both short- and long-term pitfall trapping grids. Short-term grids were placed as follows: (1) Montenegro Springs, southern White Mountains (T7S, R34E, sec. 36), opened for 1,872 trap days in June-August 1989; (2) Little Cowhorn Valley, central Inyo Mountains (T9S, R36E, sec. 15), opened for 2,337 trap days in June-August 1991; and (3) Waucoba Pass, central Inyo Mountains (T9S, R36E, sec. 28), opened for 1,189 trap days in July-August 1991.

We established three longer-term pitfall grids (T7S, R35E, sec. 30-32) to intensively sample the pinyon-juniper zone. Each grid was 4 ha in size. Thirty-six pitfalls were placed at about 25 m intervals on each grid. Pitfalls were constructed of two number 10 cans as described by Corn (1994); small holes were punched in the bottom of each can to allow water to drain. Each pitfall was covered by a raised wooden lid; no drift fences were used. Pitfalls were run as live traps and were checked at least every 2 days from late May to early September, 1989-1991, for a total of about 5,300 trap days per grid per year (48,000 total trap days for the study). Each capture was identified, the sex and age determined, and one toe was clipped to identify recaptures.

Habitat Analyses

We quantified the habitat attributes of the herpetofauna on the three long-term pitfall grids by establishing 20 m radius plots centered on each pitfall location. Within each plot we measured tree density; the cover of shrubs, grasses and herbaceous species; and cover of rocks and downed material using point-intercepts bisecting the plot.

Results

Distribution at the Landscape Scale

A total of four species of amphibians and 26 species of reptiles have been observed in the pinyon-juniper zone of the Inyo-White mountains (table 1). The western toad (scientific names in table 1), black toad, and northern leopard frog are extremely restricted in distribution and are only found in a few springs and ponds. The Inyo Mountains salamander is the only verified salamander species in these ranges; the salamander occurs in many springs and seeps in the southern Inyo Mountains. There are, however, several anecdotal records of an unknown salamander species made by reliable observers at high elevations in the northern White Mountains (table 1).

Thirteen of the 26 reptile species recorded in the pinyon-juniper zone were snakes. The speckled rattlesnake and striped whipsnake were the only snakes seen commonly throughout the zone (personal observation). We apparently made the first identification of a Nevada shovel-nosed snake, and extended the elevational range of the gopher snake (to 3,300 m) into the Cottonwood Basin, White Mountains. Additionally, we made an observation of the western rattlesnake that extended the known range of this species south in the White Mountains to near Westgard Pass (table 1).

Eight of the reptile species occurred only at the lower edges of the pinyon-juniper zone, whereas the remaining 15 species were found throughout the zone. The eight species at the lower edge of the woodland are principally associated with lower elevation (desert scrub) vegetation and apparently barely reach into the pinyon-juniper zone.

Seven species, all reptiles, extended up into the bristlecone pine-limber pine vegetation zone; no verified species was unique to the latter zone (table 1). The only exception found to date could be the possible salamander discussed above. Most species occurred only into the lower edge of the bristlecone pine-limber pine zone, with the exceptions of the sagebrush lizard, western fence lizard, and perhaps the side-blotched lizard.

Macey and Papenfuss (1991a,b) reported observations of two amphibian, three lizard, and five snake species in the pinyon-juniper zone of the Inyo and White mountains that we did not observe (table 1).

Macrohabitat Relationships

Short-term pitfall trapping did not locate any new species nor extend the range of any known species. Sagebrush lizards and western fence lizards were captured at Little Cowhorn Valley (n = 12 sagebrush and 7 fence lizards); only fence lizards (n = 8) were captured at Waucoba Pass; and both Gilbert (n = 2) and western (n = 4) skinks were captured at Montenegro Springs.

We captured a total of seven species on our three permanent trapping grids between 1989-1991 (table 2). Overall, the sagebrush lizard was the most numerous species captured, accounting for 51.3 percent of all captures. The western fence lizard (31.7 percent) was the only other species that accounted for >10 percent of total captures. The side-blotched lizard was captured regularly but accounted for only 8.9 percent of all captures. The western whiptail was captured regularly (4.2 percent) but only on one grid ("Westgard"). The western skink (2.1 percent) and Gilbert skink (1.8 percent) were captured infrequently but occurred on all three grids. The desert night lizard (0.1 percent) was captured only on one grid ("Pinyon") (table 2).

Table 1—Summary of distribution of amphibians and reptiles from the Inyo and White mountains, California and Nevada. M&P refers to Macey

Batrachoseps campi [Inyo Mountains salamander]
M&P and Marlow et al. (1979) summarized the numerous records of this relictual species in the Inyos; not recorded from the Whites. Papenfuss (1986) stated that there were reliable reports of salamanders (species unknown) from above 3,000 m in the Whites. We did not locate at new locations.

Bufo boreas [Western toad]
M&P stated has been found above 2,100 m in northern Whites. We observed what were likely toad tadpoles in a seasonal waterhole north of Montgomery Pass, northern Whites.

Bufo exsul [Black toad]
M&P noted introduced to Batchelder (Toll House) Spring but may be extinct there. We thoroughly searched this spring throughout our study and located no amphibians.

Rana pipiens [Northern leopard frog]
M&P reported from 2,300 m on east side of Whites below Boundary Peak. We did not locate at other sites.

Cnemidophorus tigris [Western whiptail]
M&P reported to 2,300 m in both ranges. We saw to 2,500 m throughout Inyos.

Xantusia vigilis [Desert night lizard]
M&P reported to at least 2,100 m in the southern Inyos north to the Mono County line. We found near Westgard Pass at 2,250 m.

Phrynosoma platyrhinos [Desert horned lizard]
M&P reported to about 2,300 m in both ranges. We had no observations.

Coleonyx variegatus [Western banded gecko]
M&P stated the northernmost locality as Westgard Pass, but we found no references for specimens or sighting above about 1,700 m.

Gerrhonotus panamintinus [Panamint alligator lizard]
M&P reported as both ranges below 2,300 m. We saw one dead on the road at 2,200 m near Westgard Pass.

Eumeces gilberti [Gilbert skink]
M&P reported as present to 2,700 m in Inyos north to Silver Creek and Wyman canyons. We captured both this species and the western skink (see below) at the same localities near Westgard Pass.

Eumeces skiltonianus [Western skink]
M&P called this a high elevation species not found below 2,300 m and may occur to 3,300 m. They had only a single record of the western skink from the ranges. We captured numerous individuals in pitfalls near Westgard Pass.

Crotaphytus insularis bicinctores [Great Basin collared lizard]
M&P reported as throughout ranges to lower extent of the pinyon-juniper woodland. However, museum specimens indicate occurrence to 2,300 m in Silver Canyon. We also found road specimens at 2,200 m near Westgard Pass, and Williamson (1954, field notes) reported from 2,200 m in Wyman Canyon.

Gambelia wislizenii [Long-nosed leopard lizard]
M&P reported as throughout the ranges below 2,300 m. We made no observations.

Sceloporus graciosus [Sagebrush lizard]
M&P reported below about 3,000 m. We captured several individuals at 3,300 m in Cottonwood Basin, White Mountains.

Sceloporus magister [Desert spiny lizard]
M&P reported below 2,300 m in both ranges. We observed at 2,300 m at Westgard Pass.

Sceloporus occidentalis [Western fence lizard]
M&P reported up to 3,000 m. We captured numerous individuals up to this elevation.

Uta stansburiana [Side-blotched lizard]
M&P reported throughout the ranges below 2,600 m. There are, however, museum specimens from 3,000 m at the Shulman Grove, White Mountains. We saw active ones near Westgard Pass as late as mid-November.

Thamnophis elegans [Western terrestrial garter snake]
M&P reported as occurring near streams on eastern slopes of Whites to at least 2,700 m. We also observed 1 in pinyon-juniper near Westgard Pass, which was at least 2 km from permanent water.

Crotalus mitchelli [Speckled rattlesnake]
M&P reported throughout ranges to 3,000 m. We observed infrequently in pinyon-juniper between 2,000-3,000 m.

Crotalus viridis [Western rattlesnake]
M&P stated range as northwestern slopes of Whites only. However, we found an adult at Montenegro Spring (2,100 m), which extends the range of this species south to near Westgard Pass.

Hypsiglena torquata [Night snake]
M&P reported as throughout the ranges below 2,300 m. We had no observations.

Lampropeltis getulus [Common kingsnake]
M&P reported as throughout the ranges below 2,300 m. We had no observations.

Masticophis flagellum [Coachwhip]
M&P reported as entire region below about 2,000 m. We had no observations.

Mastocophis taeniatus [Striped whipsnake]
M&P reported as entire region from 1,500 to 2,750 m. We observed them fairly frequently and found a road kill on 6 December at 2,300 m near Westgard Pass.

Pituophis melanoleucus [Gopher snake]
M&P reported as throughout ranges below 2,600 m. We captured several in Cottonwood Basin, White Mountains, at 3,200 m.

Rhinocheilus lecontei [Long-nosed snake]
M&P described as throughout the ranges below 2,000 m; we did not locate any individuals in the pinyon-juniper zone.

Salvadora hexalepis [Western patch-nosed snake]
M&P described as throughout the ranges below 2,100 m. We collected a road kill near Westgard Pass (2,300 m).

Sonora semiannulata [Ground snake]
M&P stated as presumed to occur throughout the White-Inyo mountains region below 2,000 m. We did not locate during any of our surveys.

Tantilla hobartsmithi [Southwestern black-headed snake]
M&P stated as occurring on western slopes of Inyos. We did not locate.

Chionactis occipitalis talpina [Nevada shovel-nosed snake]
We recovered 2 road kills near Westgard Pass during 1991: 3 June at 2,100 m and 18 June at 2,000 m; these are apparently the first records of this species for these ranges.

Table 2—Relative abundance of herpetofauna on three long-term pitfall grids, Inyo and White mountains, California, 1989-1991.

Species	Pinyon	Cedar	Westgard	Total
	---------- Number (percent) on grids ----------			
Gilbert skink	5 (1.1)	11 (3.7)	11 (2.1)	27 (2.1)
Western skink	5 (1.1)	15 (5.0)	3 (0.6)	23 (1.8)
Sagebrush lizard	195 (43.4)	169 (56.1)	284 (55.4)	648 (51.3)
Western fence lizard	196 (43.7)	93 (30.9)	111 (21.6)	400 (31.7)
Side-blotched lizard	48 (10.7)	13 (4.3)	51 (9.9)	112 (8.9)
Western whiptail	0	0	53 (10.3)	53 (4.2)
Total	449	301	513	1263

Table 3—Description of three long-term pitfall grids used in the Inyo and White mountains, California, 1989-1991. For variables with $P < 0.05$ (analysis of variance), mean values that are significantly different are denoted by different capital letters ($n = 41$ plots/grid).

Variable	Pinyon		Cedar		Westgard		P
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD	
Tree density (no./ha)							
Pinyon	40A	27.4	63B	31.7	24C	16.2	<0.01
Juniper	7A	12.2	2A	3.8	36B	16.7	<0.01
Total	47B	30.1	65A	31.9	60A	21.1	0.01
Cover (percent)							
Shrubs	4	4.7	5	5.3	3	2.7	0.24
Herbs	2	2.8	1	1.8	1	2.0	0.59
Down wood	1	1.2	1	1.6	1	1.4	0.49
Rock	14AB	4.6	16A	5.0	18B	7.2	0.05

The highest abundance of sagebrush lizards was on the Westgard grid, whereas the Pinyon grid had the highest abundance of fence lizards. Westgard and Pinyon had substantially more side-blotched lizards than did the third grid ("Cedar").

The three grids differed significantly in the density of pinyon trees, although the Westgard grid was much lower in density than the other two grids. In contrast, Westgard had a significantly higher density of juniper trees than either of the other two grids (table 3). The cover of other plants and substrates was similar among sites.

Discussion

Our landscape-level surveys of the ranges, when combined with previous field surveys, highlighted the diversity of herpetofauna in the pinyon-juniper woodland. Although the herpetofauna was predominated by sagebrush and western fence lizards, numerous other species of lizards and snakes resided in the woodland. Toads and frogs were extremely restricted in their distribution, being found primarily in wet locations in the northern White Mountains. Anecdotal sightings indicated that an unidentified species of salamander may exist at high elevations in the White Mountains. These records, in addition to the apparent affinity of skinks for wet areas, indicate that future sampling efforts should be concentrated in and around springs throughout the ranges.

We also identified the presence of many species of small snakes. However, neither our survey efforts nor those conducted previously (that is, Papenfuss 1986; Macey and Papenfuss 1991a,b; unpublished field notes) were of adequate intensity to clarify the range-wide distribution, abundance, and specific habitat affinities of these species.

Our short-term pitfall trapping did not yield any new species nor extend the previously known ranges of any species. Results from Montenegro Springs did, however, exemplify both the co-occurrence of the western skink and Gilbert skink, and an apparent affinity of these species for wet areas. Although both species of skink were found away from springs in pinyon-juniper woodland, they reached their greatest abundances near the spring. It appears that wet areas (that is, springs, seeps) may function as high-quality habitat for skinks.

Our longer-term pitfall grids identified the primary herpetofauna of the pinyon-juniper woodland as one predominated by sagebrush and western fence lizards, with a regular occurrence (but at much lower abundance) of side-blotched lizards and Gilbert and western skinks. Whiptails were added to the community only on the Westgard grid. Westgard had the lowest density of pinyon trees, but a much higher density of juniper trees compared to the other two grids. The Westgard grid had a southern aspect, whereas the other two grids were oriented primarily westward. The presence of juniper and drier conditions on Westgard probably led to the higher overall abundance of animals and presence of whiptails on the grid.

Night lizards were only captured on the Pinyon grid. Cursory surveys of the grid located additional adult night lizards under thin horizontal rock slabs. Thus, it appears that night lizards may be more abundant than indicated by the pitfall data, with their occurrence restricted to specific microsites.

In summary, we refined the distributional records for many species, including the identification of several new records for the mountains as a whole, and the pinyon-juniper zone specifically. Our results demonstrate the generally unrecognized diversity of herpetofauna present in the pinyon-juniper woodland, and highlight specific research and management needs that could lead to conservation of these species into the future.

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References

Corn, P. S. 1994. Straight-line drift fences and pitfall traps. In: Heyer, W. R. and others, eds. Measuring and monitoring biological diversity. Standard methods for amphibians. Washington, D.C.: Smithsonian Institution Press: 109-117.

Macey, J. R.; Papenfuss, T. J. 1991a. Amphibians. In: Hall, C. A. Jr., ed. Natural History of the White-Inyo range, eastern California. Berkeley, CA: California Natural History Guide 55, University of California Press: 277-290.

Macey, J. R.; Papenfuss, T. J. 1991b. Reptiles. In: Hall, C. A. Jr., ed. Natural History of the White-Inyo range, eastern California. Berkeley, CA: California Natural History Guide 55, University of California Press: 291-360

Marlow, R. W.; Brode, J. M.; Wake, D. B. 1979. A new salamander, genus *Batrachoseps*, from the Inyo Mountains of California, with a discussion of relationships in the genus. Natural History Museum, Los Angeles County Contribution to Science 308:1-17.

Papenfuss, T. J. 1986. Amphibian and reptile diversity along elevational transects in the White-Inyo range. In: Hall, C. A. Jr.; Young, D. J., eds. Natural history of the White-Inyo range, eastern California and western Nevada, and high altitude physiology. Bishop, CA: White Mountain Research Station Symposium, vol. 1: 129-136.

Powell, D. R.; Klieforth, H. E. 1991. Weather and climate. In: Hall, C. A. Jr., ed. Natural History of the White-Inyo range, eastern California. Berkeley, CA: California Natural History Guide 55, Univ. of California Press: 3-26.

Spira, T. P. 1991. Plant zones. In: Hall, C. A. Jr., ed. Natural History of the White-Inyo range, eastern California. Berkeley, CA: California Natural History Guide 55, Univ. of California Press: 77-107.

Sage Grouse Response to Pinyon-Juniper Management

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Clait E. Braun

Abstract—The response of Gunnison sage grouse (*Centrocercus minimus*) to management of pinyon-juniper (*Pinus edulis - Juniperus* spp.) was studied in southwestern Colorado during 1994 through 1997. Near Crawford, CO, numbers of male sage grouse using leks within 100 m of live pinyon-juniper were depressed because of increased raptor presence and predation associated with coniferous trees/shrubs. Removal, by cutting, of pinyon-juniper trees/shrubs in association with brush-beating to reduce height of mountain big sagebrush and deciduous brush resulted in doubling numbers of male sage grouse counted on treatment leks in years 2 and 3 posttreatment. Clearing of young age classes of pinyon-juniper that have spread into sagebrush shrub-steppe appears to have great merit for enhancing sage grouse use of treated areas through increased survival, productivity, and recruitment. This is especially significant in management of small populations of sage grouse in highly fragmented habitats which may be locally threatened with extirpation.

Sage grouse (*Centrocercus* spp.) are dependent upon sagebrush (*Artemisia* spp.) shrub- steppe throughout their distribution in western North America (Patterson 1952). While exact composition of the original sagebrush shrub-steppe is unknown, both grazing by wild ungulates and fire commonly occurred, especially in higher precipitation zones. Grazing of this habitat type increased following settlement resulting in more bare mineral soil. At the same time, fire frequency has generally decreased although intensity has increased in some areas (Bunting 1994). Primarily because of these 2 factors, seedlings of pinyon pine (*Pinus* spp.) and juniper (*Juniperus* spp.) have become established in sagebrush-dominated lands in the last 40-60 years.

Populations of sage grouse have declined in many areas of their former range (Connelly and Braun 1997). These declines are most notable where population size is constrained by habitat limitations including loss, fragmentation, and degradation of sagebrush-dominated ecosystems. Extinctions of local populations of sage grouse have occurred, especially at the periphery of the original distribution (Johnsgard 1973, Braun 1995).

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Management of sagebrush-dominated habitats is necessary if viable populations of sage grouse are to persist. Enhancement of habitats to benefit sage grouse will require management prescriptions and experiments to learn if treatments result in increased population size and/or distribution. The objective of this paper is to describe apparent sage grouse population response to pinyon-juniper treatment.

Study Area

The area studied is in northwest Montrose County, Colorado between the town of Crawford and the Black Canyon of the Gunnison National Monument. Sage grouse occur on lands administered by the Bureau of Land Management and National Park Service, with substantial areas in private ownership. Dominant vegetation types include sagebrush (*A. tridentata vaseyana*, *A. nova*), pinyon-juniper, and mountain brush (*Quercus gambelii*, *Amelanchier* spp., *Symphoricarpos* spp.) with frequent intermixing of habitats depending upon elevation, aspect, slope, and past vegetation treatments (including grazing by domestic livestock and wild ungulates) (Commons 1997).

Methods

Numbers of male sage grouse on previously (<1994) located leks were counted in 1994 (pretreatment), 1995 (1-year posttreatment) and 1996-97 (2-3 years post treatment) during April and May at 7-10 day intervals. Searches for sage grouse mortalities were made periodically throughout the display season by walking lek sites and adjacent habitats. Sage grouse were trapped at night (Giesen and others 1982) where they roosted on or near leks. Radio transmitters affixed by elastic cord or plastic collars were attached to selected sage grouse. Radio-marked birds were systematically followed to identify habitats used. Short (<1m) pinyon-juniper trees, sagebrush, and associated deciduous shrubs were brush beat with a tractor-drawn rotary mower. Taller (>1m) trees were cut using a chain saw with limbs and stems being scattered. Brush beating was initiated in August 1994 with additional sites being treated in September - October 1996. Hand cutting of trees near lek sites occurred as time permitted in fall and early winter 1994, and continued away from lek sites into 1997.

Results

Three leks were active in 1994-95 and 1996-97 (table 1). No new or unknown active lek sites were found during the

Table 1—Peak counts of male sage grouse on leks, Fruitland Mesa, Colorado, 1994-95 vs. 1996-97.

Lek	1994	1995	1996	1997
Dam	3	6	18	13
Range Cone	11	9	19	20
Section 35	8	6	9	8
Totals	22	21	46	41

study period. Total males counted increased from 21-22 (1994-95) to a 2-year average of 43 (1996-97). This doubling in number of males counted primarily occurred at 2 sites where removal of pinyon-juniper was most pronounced. Mortality searches at lek sites in 1994 located the remains of 7 male sage grouse. No mortality searches were conducted in 1995 and no mortalities were found at lek sites in 1996-97.

Twelve sage grouse were captured and fitted with radio transmitters in 1996. Habitats used by these birds indicated avoidance of pinyon-juniper except during September - November when sage grouse extensively used sagebrush-dominated areas with scattered trees ≥2 m in height (table 2). Pinyon-juniper trees were avoided from June through August when sage grouse selected disturbed areas (burned, disked, rotochopped) that had an abundance of succulent forbs.

Discussion

The apparent size of the sage grouse population on Fruitland Mesa as measured by counts of males on leks doubled between 1994-95 and 1996-97. This increase was believed to have resulted from decreased mortality of males during the breeding season and improved survival of both males and females. Prior to treatment (cutting of pinyon-juniper trees), raptors were observed perching and hunting from trees adjacent to lek sites and all documented mortalities were attributed to raptors. However, effects of cutting of pinyon-juniper trees were confounded as sagebrush at lek sites was also beat thereby increasing the ability of sage grouse to detect predators at greater distances.

Sage grouse clearly avoided pinyon-juniper trees during the breeding and summer periods. Studies elsewhere in Colorado indicate avoidance of pinyon-juniper trees throughout the year. At Fruitland Mesa, invasion of pinyon-juniper trees in the last 30-60 years has reduced the amount of area where trees do not occur. At present, there are few areas, outside of those treated in this study, where pinyon-juniper trees do not occur.

We do not know if increased survival of males at leks translates to increased survival of females as counts of females at leks are problematic because of short, irregular attendance periods. Our observations of hens and hens with broods during other field activities in this area suggest the population markedly increased between 1994-95 and 1996-97. Whether the apparent increase can be sustained or further enhanced is not known. It is also remarkable the sage grouse population apparently responded quickly to treatments designed to immediately resolve a local problem. Outside of predation, mortality of this population appears low as no hunting is allowed and primary roads do not traverse the area. This small, isolated population appears to be habitat limited. Removal of pinyon-juniper trees could increase usable habitat size by at least 100 percent.

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References

Braun, C. E. 1995. Distribution and status of sage grouse in Colorado. Prairie Nat. 27: 1-9.

Bunting, S. C. 1994. Effects of fire on juniper woodland ecosystems in the Great Basin. In: S. B. Monsen and S. G. Kitchen, comps. Proceedings—ecology and management of annual rangelands. Gen. Tech. Rep. INT-GTR 313. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 53-55.

Commons, M. L. 1997. Movement and habitat use by Gunnison sage grouse (*Centrocercus minimus*) in southwestern Colorado. M.N.R.M. Practicum, Univ. Manitoba, Winnipeg. 108 pp.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildl. Biol. 3: 229-234.

Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. Wildl. Soc. Bull. 10: 224-231.

Johnsgard, P. A. 1973. Grouse and quails of North America. Univ. Nebraska Press, Lincoln. 553 pp.

Patterson, R. L. 1952. The sage grouse in Wyoming. Sage Books, Inc., Denver, CO. 341 pp.

Table 2—Distance (m) of radio-marked sage grouse from pinyon/juniper trees ≥ 2 m tall, June- November 1996, Fruitland Mesa, Colorado.

Distance	Jun (22)	Jul (27)	Aug (16)	Jun-Aug (65)	Sep (16)	Oct (6)	Nov (7)	Sep-Nov (29)
m	*Percent of locations*							
<50	14	15	6	12	50	100	29	55
50-100	4	0	6	3	12	0	0	7
>100	82	85	88	85	38	0	71	38

( ) = number of relocations of radio-marked sage grouse.

Pinyon-Juniper Woodlands as Sources of Avian Diversity

Kathleen M. Paulin
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Abstract—Results of breeding bird point counts in mature pinyon-juniper woodlands are described and compared to data from seven other forest habitats common in northeastern Utah. Pinyon-juniper bird communities ranked second in the percentage of obligate and semi-obligate species, third in total number of individuals counted, and fourth in species richness and diversity. Bird species assemblages in pinyon-juniper were similar to those found in ponderosa pine forests but had relatively little in common with other forest habitats in the study area. The low degree of similarity to other forest habitats and high percentage of obligate and semi-obligate species suggest that pinyon-juniper habitat contributes substantially to landscape-level avian diversity. These results are consistent with those of several other studies that found mature pinyon-juniper woodlands to be an important source of nongame wildlife habitat.

Land managers often consider mature stands of pinyon-juniper to be undesirable, or at least less desirable, than earlier seral stages of this type, due to their lack of understory vegetation. Removal of trees through chaining or burning is often prescribed to produce more forage for big game and livestock, increase vegetative diversity, reduce erosion by stimulating growth of plants with high value for watershed protection, or prevent expansion of pinyon-juniper into adjacent grassland or shrub habitats.

Decisions about which stands to treat, and how much acreage to treat, have most often been made on the basis of logistical constraints such as the presence of road access or sufficiently high fuel loads to carry a fire. Habitat values of the mature woodlands themselves receive little consideration, in part because they appear so extensive that there seems to be no possibility of exhausting the supply and in part because their arid nature and lack of vegetative diversity seem inconsistent with highly productive wildlife habitat. However, a number of studies have shown that pinyon-juniper woodlands support a wide array of nongame wildlife (Finch and Ruggiero 1993), and in some cases considerably greater numbers of species and individuals than the more open habitats created through treatment (for example, Sieg 1991; Sedgwick and Ryder 1987).

The growing emphasis on ecosystem management requires that we design vegetative treatments within the context of a larger planning landscape. With this in mind, land managers must consider where to maintain mature pinyon-juniper stands for the values they provide, and where to treat to meet other objectives (Goodrich, these proceedings). This paper is intended to help managers make such decisions by describing the contribution pinyon-juniper habitats make to avian diversity in northeastern Utah landscapes.

Study Area

The study was conducted in large stands of Utah juniper (*Juniperus osteosperma*) and Colorado pinyon pine (*Pinus edulis*) located within the Flaming Gorge National Recreation Area (NRA) in northeastern Utah. Sample sites were located on dry, rocky slopes at elevations ranging from 1,890 to 1,980 m (6,200 to 6,500 ft). Trees were approximately 200 to 400 years old, and there were few understory plants of any kind. Additional information on the pinyon-juniper portion of the study area can be found in a discussion of ecological units within the Green River corridor, Daggett County, Utah (Goodrich, these proceedings).

Other forest habitats sampled were ponderosa pine (*Pinus ponderosa*), aspen (*Populus tremuloides*), Douglas fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), spruce/fir (*Picea engelmannii* / *Abies lasiocarpa*), mixed lodgepole/spruce/fir, and riparian woodlands (dominated by cottonwood trees, but often mixed with one or more of the previously listed conifers). Sample sites for these forest habitats were on the Ashley National Forest, immediately west and south of the Flaming Gorge NRA. All sample sites were occupied by mature to old stands of trees. Elevation ranged from about 1,980 m (6,500 ft; ponderosa pine sites) to nearly 3,300 m (10,800 ft; spruce/fir sites).

Methods

Data in this paper were collected as part of the Ashley National Forest's breeding bird monitoring program. Methods were based on point count protocols found in Ralph and others (1993). We established 30 sample points in each of eight forest habitats common in the study area, with points divided among three distinct sites (stands) within each habitat. All points were located at least 100 m from any edge (change in cover type), and at least 200 m apart to avoid

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double-counting birds. Each point was read twice during the 1994 breeding season (mid-May through mid-July). Counts were begun within 15 minutes of sunrise and completed by 10 a.m., to correspond with the period in which territorial males are most vocal. Bird detections (by sight, song or call) were recorded for 10 minutes at each point. All detections were recorded, regardless of distance from the observer.

Results

Total individuals counted, total species detected and diversity index values for each forest habitat are shown in table 1. Not surprisingly, the riparian woodland sites ranked first in all three categories. Many studies have shown that riparian woodlands have higher vertebrate diversity than adjacent upland sites (Finch and Ruggiero 1993). Our results simply confirm the importance of riparian areas as wildlife habitat.

Among the seven upland forest habitats, pinyon-juniper ranked second in total individuals and third in species richness and diversity. The variety and abundance of bird life in pinyon-juniper stands was comparable to that observed in Douglas fir, and considerably higher than in the lodgepole, spruce and fir stands that dominate much of the study area. In general, numbers of species and individuals tended to decrease with increasing elevation.

The diversity index values followed a similar pattern, with the exception of lodgepole pine and Douglas-fir. The Shannon-Weaver index is a function of both species richness and evenness (the distribution of individuals among the species present). A relatively species-poor habitat such as lodgepole pine can have a high diversity index if the individuals counted are evenly distributed among all species present. Conversely, Douglas-fir bird communities tend to be dominated by a few abundant species. This causes it to have a lower index value than pinyon-juniper, despite having similar numbers of species and individuals.

The total individuals counted and diversity indices in table 1 should be interpreted with caution. Bird densities in pinyon-juniper habitats are believed to be strongly influenced by juniper berry production, which can vary widely from year to year (Sieg 1991). Because we only have 1 year of bird data and did not make any estimates of berry production, we cannot say whether our results represent a peak or a low in bird numbers. We can say that pinyon-juniper is able to support a relatively high number and variety of birds, compared to other forest habitats in the study area, in at least some years.

Land managers must consider more than simply the quantity of species each habitat contributes to a management landscape. A site that supports a few rare species can be as important as one that supports many common species when trying to maintain or enhance overall diversity. We attempted to characterize each habitat we sampled in terms of the uniqueness of its contribution to the landscape-level avian diversity, compared to other habitats in the study. One measure of uniqueness is the degree to which the various bird communities overlap with one another. Table 2 shows the results of pairwise comparisons using Sorenson's quotient of similarity (as described in Morrison and others 1992). This quotient is based solely on the presence or absence of species, without consideration of abundance. The quotient varies from zero (no overlap) to one (identical species lists for each habitat). Pinyon-juniper shows relatively high overlap (0.658) with ponderosa pine, moderate

Table 1—Total species detected, total individuals counted and Shannon-Weaver diversity index by habitat.

	Ponderosa pine	Aspen	Pinyon/ juniper	Douglas fir	Lodgepole pine	Spruce/ fir	Mixed conifer	Riparian woodland
Species detected	42	38	31	29	25	22	21	49
Individuals counted	973	562	779	746	405	314	226	990
Diversity index	1.26	1.20	1.19	1.09	1.18	1.08	1.04	1.28

Table 2—Similarity of bird communities based on the proportion of species in common[a].

	Ponderosa pine	Aspen	Pinyon/ juniper	Douglas fir	Lodgepole pine	Spruce/ fir	Mixed conifer	Riparian woodland
Ponderosa pine	1	.575	.658	.676	.627	.469	.476	.462
Aspen	.575	1	.464	.627	.698	.567	.542	.598
Pinyon/juniper	.658	.464	1	.533	.429	.415	.385	.300
Douglas-fir	.676	.627	.533	1	.704	.627	.680	.385
Lodgepole pine	.627	.698	.429	.704	1	.638	.609	.405
Spruce/fir	.469	.567	.415	.627	.638	1	.791	.366
Mixed conifer	.476	.542	.385	.680	.609	.791	1	.371
Riparian canyon	.462	.598	.300	.385	.405	.366	.371	1
Number of index values greater than 0.500	4	6	2	6	5	4	4	1

[a]Calculated as Sorenson's quotient of similarity: QS = 2c/(a+b) where a = number of species in habitat a, b = number of species in habitat b and c = number of species found in both habitats

Table 3—Proportion of each forest bird community comprised of obligate or semi-obligate species.[a]

	Ponderosa pine	Aspen	Pinyon/ juniper	Douglas fir	Lodgepole pine	Spruce/ fir	Mixed conifer	Riparian woodland
Percentage of obligate species	9.5	13.2	19.4	3.4	4.0	4.5	0	36.7
Percentage of semi-obligate species	23.8	15.8	19.4	10.3	4.0	9.1	14.3	18.4
Total obligates and semi-obligates	33.3	29.0	38.8	13.7	8.0	13.6	14.3	55.1

[a]Obligate: only detected in one forest type; semi-obligate: only detected in two forest types.

overlap (0.533) with Douglas fir, and low overlap (less than 0.500) with all other forest habitats. In contrast, each of the other upland forest habitats has moderate to high overlap with at least four other habitats. The mix of bird species found in pinyon-juniper appears to be uncommon within the study area.

Another measure of uniqueness is the rarity of the species occurring within each habitat. Table 3 shows the percentage of species in each bird community that was restricted to just one habitat (obligate species), or shared between only two habitats (semi-obligate species). Of the 31 species detected in pinyon-juniper habitat, 12 (38.8 percent) fit into one of these two categories. Only the riparian woodland sites had a higher percentage of obligate and semi-obligate species. Thus, not only is the particular combination of bird species found in pinyon-juniper habitats distinctive, a relatively high percentage of those species are rare or absent from the rest of the study area.

Species we classified as pinyon-juniper obligates were ash-throated flycatcher (*Myiarchus cinerascens*), blue-gray gnatcatcher (*Polioptila caerulea*), Bullock's oriole (*Icterus bullockii*), pinyon jay (*Gymnorhinus cyanocephalus*), western scrub-jay (*Aphelocoma coerulescens*), and Virginia's warbler (*Vermivora virginiae*). Semi-obligate species that were most abundant in pinyon-juniper were juniper titmouse (*Baeolophus ridgwayi*), gray flycatcher (*Empidonax wrightii*), and black-throated gray warbler (*Dendroica nigrescens*). Semi-obligates that were less abundant in pinyon-juniper than in their second habitat were spotted towhee (*Pipilo maculatus*), violet-green swallow (*Tachycineta thalassina*), and white-breasted nuthatch (*Sitta carolinensis*). Although we did not attempt to define an ecological basis for these apparent habitat preferences, our list agrees well with obligate and semi-obligate species lists published elsewhere (Fitton 1989; Cherry 1982) and probably does reflect the importance of some specific habitat features found in pinyon-juniper sites.

Discussion

Not surprisingly, we found pinyon-juniper bird communities to be different from those of most other forest habitats we sampled. Pinyon-juniper has obvious structural and vegetative differences from the tall pine, spruce, and fir forests of northeastern Utah's mountains, or from moist, highly productive aspen and cottonwood stands. But it may have surprised some to learn that the "pygmy forest," occupying poor sites and monotonously homogenous in its composition and growth form, outranks many more stately forests in the abundance and variety of birds it supports. Designating some tracts of mature pinyon-juniper for retention is clearly a good investment for any manager interested in maintaining biodiversity on his or her management landscape.

We compared bird communities from a variety of mature forests. However, the choice facing managers is rarely which forest to manage for on a given site. Most often, it is a question of which seral stage of the existing forest is desired. We did not sample early seral pinyon-juniper habitats, but we can offer some insights from other bird studies. Sedgwick and Ryder (1987) compared bird use of chained and unchained plots and found that chaining negatively affected abundance of cavity nesters, timber gleaners, aerial foragers, and species that foraged or nested in foliage. Birds that nested or foraged on the ground were found to use both treated and untreated plots, so in effect no group was benefitted by treatment. Likewise, Sieg (1991) found significantly higher bird numbers and species richness in pinyon-juniper woodlands than in adjacent grasslands. Both studies attributed the difference in bird use to the vertical structure of the woodlands, which provided niches not found in open habitats.

This does not mean that pinyon-juniper treatments are always bad for birds. Cherry (1982) noted that slightly more bird species nested in late seral pinyon-juniper stands, but slightly more species foraged in early seral stands. This suggests that creating a mosaic of seral stages will provide the best balance of habitat features sought by birds. Sedgwick and Ryder (1987) indicated that shrub-dependent and edge-associated species can benefit from well-designed pinyon-juniper treatments. They recommended selecting sites that have good potential for shrub growth, leaving lots of woody slash, designing treatment units with a high edge-to-interior ratio, and using a varying levels of treatment so that more trees are left standing toward the edges of units. All of these measures will add structural complexity to the treated unit, thus compensating in part for the loss of the pinyon-juniper overstory. Such treatment units will be more versatile as wildlife habitat than units stripped clean of wood and seeded with grasses.

Although the discussion has so far focused on breeding season, managers may wish to consider habitat values at other times of the year. Sieg (1991) monitored bird use of pinyon-juniper throughout the year and found that it supported more birds in every season than the neighboring grasslands did. She speculated that the combination of readily available food (from cones and berries) coupled with good thermal cover made it especially attractive to birds in the winter. Cover values also make pinyon-juniper a critical element of big game winter range (Davis, these proceedings). Again, a landscape mosaic that intersperses cover patches with openings providing foraging and browsing opportunities may be the best way to meet an array of management objectives.

Conclusion

Pinyon-juniper woodlands support a rich and distinctive bird community, which makes a substantial contribution to landscape-level avian diversity. Land managers should consider the habitat values of mature woodlands when planning pinyon-juniper removals to meet watershed and forage production objectives. The best management option will likely be a landscape that is thoughtfully designed to include functional patches of all seral stages.

References

Cherry, Marion B. 1982. The effects of pinyon-juniper chaining on wildlife of the Fillmore Ranger District, Fishlake National Forest. M.S. thesis. Logan, UT: Utah State University, Department of Range Science. 114 p.

Davis, James N. These proceedings. The importance of pinyon-juniper woodland as big game critical winter range in Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Finch, Deborah M.; Ruggiero, L. F. 1993. Wildlife habitats and biological diversity in the Rocky Mountains and northern great plains. Natural Areas Journal. 13(3):191-203.

Fitton, Sam. 1989. Nongame species accounts: the Utah juniper obligates. Lander, WY: Wyoming Game and Fish Department. 48 p.

Goodrich, Sherel. These proceedings. Multiple use management based on diversity of capabilities and values within pinyon-juniper woodlands. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings:ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Morrison, Michael L.; Marcot, B. G.; Mannan, R. W. 1992. Wildlife-habitat relationships: concepts and applications. Madison, WI: University of Wisconsin Press. 343 p.

Ralph, C. J.; Geuppel, G. R.; Pyle, P.; Martin, T. E.; DeSante, D. F. 1993. Handbook of field methods for monitoring landbirds. Gen. Tech. Rep. PSW-GTR-144. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 41 p.

Sedgwick, James A.; Ryder, R. A. 1987. Effects of chaining pinyon-juniper on nongame wildlife. In: Everett, R. L., compiler. Proceedings: pinyon-juniper conference. 1986 Jan. 13-16, Reno, NV. Gen. Tech. Rep. INT-GTR-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 581 p.

Sieg, Carolyn H. 1991. Rocky Mountain juniper woodlands: year-round avian habitat. Research paper RM-296. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 7 p.

Importance of Pinyon-Juniper Habitat to Birds

Merrill Webb

Abstract—Breeding bird surveys on seven sites in pinyon-juniper communities of Utah resulted in 53 total species. Blue-gray Gnatcatcher and Black-throated Gray Warbler were the only two species occurring on all seven transects. Of total species present 77 percent are considered neotropical migrants. Understory vegetation at each location appeared to be an important factor in determining bird species composition.

The purpose of this study was to identify the species of birds using the pinyon and juniper forest habitat in Utah during the breeding season. An additional goal was to try to determine the numbers of each species. Although this effort was not funded by any government agency or private contributions this objective corresponds with the "Level 1" monitoring described by the USDA Forest Service which "will allow practitioners to estimate the overall population trends of a variety of bird species within a forest. These monitoring efforts will help the USDA Forest Service meet its legal mandate to monitor populations of "indicators" of the broader vertebrate community" (Hutto 1994).

Study Sites

Seven locations (fig. 1) were selected in the following Utah habitats and are listed by elevation, and from earliest count date to latest count date:

1. Knoll Hollow, 5,900-6,400 ft, Spanish Fork Canyon, Utah County; July 7, 1995.
2. Oquirrh Mountains, 5,400-5,600 ft, north of Cedar Fort, Utah County; May 23, 1997.
3. Beaver Dam Mountains, 4,400-4,900 ft, Washington County; May 27, 1997. The reason for selecting this site in southwestern Utah was to determine if there was a noticeable influence of Mojave Desert vegetation on the avifauna.
4. Foothills on east side of Stansbury Mountains near South Willow Canyon, 5,720-6,560 ft, Tooele County; June 19, 1997.
5. Dove Creek area, 6,000-6,100 ft, Box Elder County; June 20, 1997. Purpose in selecting this site in northwestern Utah was to determine if species composition was similar to other Great Basin habitats that had been previously sampled.
6. Long Ridge, west of Nephi, 5,900-6,200 ft, Juab County; June 27, 1997. Dog Valley to the west had suffered a serious fire the previous summer. The reason for selecting this location was to determine if bird species had been concentrated on this unburned ridge as a result of habitat lost to fire on either side.
7. Foothills at the base of the Wasatch Plateau, 6,600-7,000 ft, southeast of Spring City, Sanpete County: July 1, 1997. This was a thickly wooded area of pinyon and juniper. I felt that it was important to determine if species composition was as similar at the Colorado Plateau-Great Basin interface as it was at the other locations.

Elevations for this study ranged between 4,400 ft at the Beaver Dam Mountain site to 7,000 ft at the Wasatch Plateau site near Spring City.

Methods

Study sites in suitable habitat were randomly selected and determined by accessibility. Protocol called for each transect to be 2 miles long. Each of the 10 sampling points was positioned at 0.2 mile intervals (Hutto 1994).

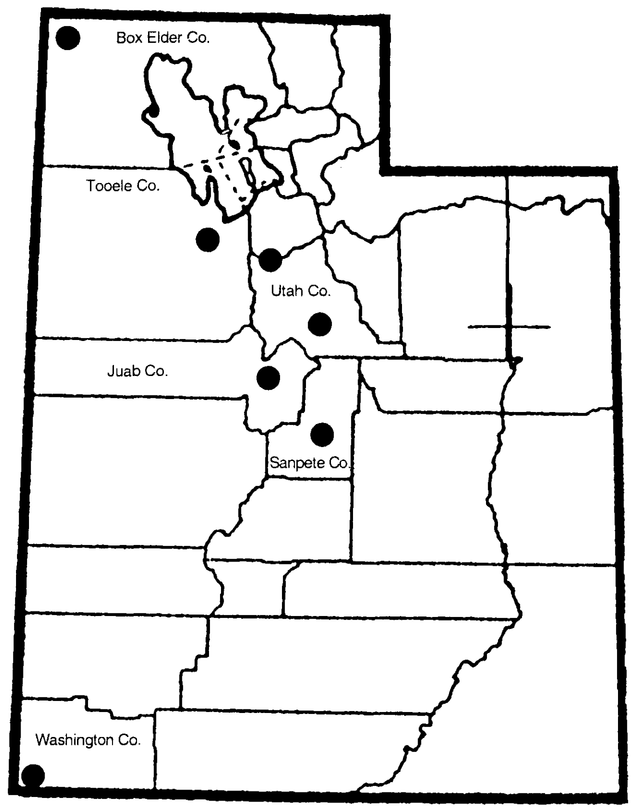

Figure 1—Location of the seven Utah study sites.

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Following the protocol (Hutto 1994), transects were established at sites with minimal disturbance. Two of the transects were conducted on tertiary roads where vehicle noise was at a minimum; five of the transects were walked using compass headings to maintain as straight a line as possible. As determined by protocol 10 minutes was the time allocated at each point during which birds were identified by sight, sound or a combination of both (National Geographical Society 1987). Binoculars (8 x 30) were used in making identification of observed birds. Birds farther than 50 yd away on either side of the transect line were not counted. Birds detected flying over the plot rather than detected from within the vegetation were recorded separately and were not listed as part of the vegetation avifauna. Counts began immediately upon arrival at the census station. No attracting devices or records of calls were used.

Counts started after the predawn chorus was over (between 6:30 and 7:00 a.m.) and concluded by 10:30 a.m. This corresponds with the period of time during which bird activity and song is more-or-less constant. It was important to not record a bird more than once at each interval point. If a bird was flushed during the move from one interval point to the next it was not included in the totals.

Results

As a result of sampling seven separate sites, a total of 53 species were identified (table 1). The Blue-gray Gnatcatcher and Black-throated Gray Warbler were the only two species that occurred on all seven transects. However, Mourning Dove, Juniper (formerly Plain) Titmouse, Spotted (formerly Rufous-sided) Towhee and Chipping Sparrow occurred on six of the seven transects (table 2).

There were 22 species that occurred only once on any of the seven transects (table 3). In terms of total numbers for all seven transects the Mourning Dove was the most abundant species (table 2). The Oquirrh mountain transect had the highest number of total bird species with 27 followed closely by Knoll Hollow in Spanish Fork Canyon with 26 (table 1).

Of the 53 total species listed on the seven transects 41 are considered neotropical migrants (table 4). By definition neotropical migrants are birds that spend their summers in Canada and the United States and their winters in Mexico, the Caribbean, Central America, and South America (the region known as the New World tropics, or neotropics). Although the name "neotropical migrant" sounds exotic, we're actually talking about common birds, and lots of them—at least 250 species, nearly one-third of the birds that breed in North America (Line 1993).

Discussion

A total of 53 bird species were identified on seven pinyon-juniper transects (table 1). In most cases the type of shrub understory appeared to influence species diversity. For example the Virginia's Warbler occurred on only three transects. The two locations with the most sightings, both n = 7, had heavy concentrations of Gambel's oak. At the other locations, there was only one sighting. The only transect where Brewer's Sparrow, a characteristic sagebrush inhabitant (Ryser 1985), occurred, was in the Dove Creek area where sagebrush was the dominant understory species. The Black-throated and Black-chinned Sparrows were found only in southwestern Utah at the Beaver Dam Mountain site in association with an understory of blackbrush, cliffrose, and yucca. Based on my observations, the Black-chinned Sparrow is more of a seasonal resident of Mojave Desert upland shrub communities whereas the Black-throated Sparrow is more of a seasonal resident of both the Mojave and Great Basin Deserts. The Beaver Dam Mountain site is, in fact, a vegetational ecotone between the Mojave and Great Basin Deserts (Holmgren 1972) so it is not surprising to find both of these sparrows in residence.

The Spanish Fork Canyon transect was completed in the summer of 1995 while I was conducting neotropical bird surveys for the USDA Forest Service on the Uinta National Forest. The site had been identified as a possible chaining area. This location harbored stands of very large pinyon pine and juniper trees, the most mature of any of the transects I studied. Sometime after the survey was conducted the decision was made to not chain the area. As it turned out this site was the second most productive of all seven transects. On this transect there were only six points on which totals were obtained instead of the usual ten because the vegetation over the brow of the hill where the additional four stops would have occurred was all Gambel's oak. Therefore, I believe, this particular example indicates the importance of obtaining bird species composition and numbers before conducting chaining operations that would seriously impact breeding birds dependant on this type of habitat.

The most productive site was the Oquirrh Mountain site. I believe that the high number of bird species there is a reflection of the layered canopy. This site had more structural diversity than any of the other sites.

The area surrounding the Long Ridge site had recently burned prompting a working hypothesis that this location might be a refugia for displaced breeding birds. The data confirm this hypothesis inasmuch as Mourning Dove (n = 16), Gray Flycatcher (n = 10), Juniper Titmouse (n = 10), Bewick's Wren (n = 12), Blue-gray Gnatcatcher (n = 7), Solitary Vireo (n = 6), Spotted Towhee (n = 12), Brown-headed Cowbird (n = 9), and House Finch (n = 13) were at their highest numbers at this site (table 1).

Of the 53 bird species documented to occur in the pinyon-juniper stands of this study, 41 of them are considered to be neotropical migrants (table 4). Data indicate that the pinyon-juniper forests provide important habitat for at least nine of these neotropical migrants (table 2). Food, cover, and nesting are three essential requirements provided by this important community type.

In summary, I discovered that the pinyon-juniper forest supported a greater variety of bird species than I had anticipated based on my limited experience in birding this type of habitat. But the total number of species depending entirely on this type of habitat for breeding purposes is low compared to other types of habitat in the state. The results verify the importance of the pinyon-juniper forest to the continued breeding success of the Blue-gray Gnatcatcher, the Black-throated Gray Warbler and the Gray Flycatcher, all of which are neotropical migrants.

Table 1— Bird species by transect (see appendix for mnemonic bird species code).

	Oquirrh	Beaver Dam Mountain	Stansbury	Dove Creek	Long Ridge	Spring City	Spanish Fork Canyon
COHA					1		
RTHA	2			1			1
GOEA	1						
AMKE			1				
MODO	9	5	10	5	16	10	
CONI			2	1			1
BLTH	2						
RSFL				1			5
GRFL	4		9	10	10	8	
COFL	2					1	
ATFL		2			2		3
SCJA	8	5			2	5	1
CLNU							1
PIJA	2						
BBMA	2						12
CORA	5					4	1
MOCH						1	5
UNCH			1	1			
RBNU							1
WBNU							4
PLTI	5	3	1	2	10	3	
ROWR					1		
BEWR	1	4			12		
HOWR	1						
BGGN	2	1	1	5	7	3	1
MOBL				3		2	3
TOSO							4
HETH							1
AMRO	7		2	9		1	2
SATH			1	5			
NOMO		1					
GRVI		11					
SOVI	1		2	2	6	5	1
WAVI	5		1				
VIWA	7					7	1
BTYW	2	4	3	1	1	5	4
WETA	4		8		1	6	2
BHGR	6		3			1	1
LAZB							3
GTTO			3	9			
RSTO	5		8	6	12	5	1
BCSP		4					
CHSP	7		15	4	8	8	9
BRES				29			
LASP	1						
BTSP		6					
WEME				2	1	1	
BRBL				3			
BHCO	2	2	1	2	9		
SCOR		1					
CAFI	1						
HOFI		8		1	13		10
PISI	4						7
Total	27	14	17	20	17	18	26

Table 2—Twelve bird species with highest total numbers on seven transects (see appendix for mnemonic bird species code).

Pneumonic	Bird species	Number	# of Locations
MODO	Mourning Dove*	55	6
CHSP	Chipping Sparrow*	51	6
GRYF	Gray Flycatcher*	41	5
RSTO	Rufous-sided Towhee*	37	6
HOFI	House Finch	32	4
BRES	Brewer's Sparrow*	29	1
PLTI	Plain Titmouse	24	6
SCJA	Scrub Jay	21	5
AMRO	American Robin*	21	5
WETA	Western Tanager*	21	5
BGGN	Blue-gray Gnatcatcher*	20	7
BTYW	Black-throated Gray Warbler*	20	7

*Neotropical Migrant

Table 3—Species occurring only once, listed by transect (see appendix for mnemonic bird species code).

Spanish Fork	Oquirrhs	Beaver Dam Mountain	Stansbury	Dove Creek	Long Ridge	Spring City
CLNU	GOEA	NOMO	AMKE	BRES	COHA	
RBNU	BLTH	GRVI		BRBL	ROWR	
WBNU	PIJA	BCSP				
TOSO	HOWR	BTSP				
HETH	LASP	SCOR				
LAZB	CAFI					

Table 4—Neotropical species occurring in the pinyon-juniper forests of Utah (see appendix for mnemonic bird species code).

1. COHA	11. ATFL	21. GRVI	31. BCSP
2. RTHA	12. ROWR	22. SOVI	32. CHSP
3. GOEA	13. HOWR	23. WAVI	33. BRES
4. AMKE	14. BGGN	24. VIWA	34. LASP
5. MODO	15. MOBL	25. BTYW	35. BTSP
6. CONI	16. TOSO	26. WETA	36. WEME
7. BLTH	17. HETH	27. BHGR	37. BRBL
8. RSFL	18. AMRO	28. LAZB	38. BHCO
9. GRYF	19. SATH	29. GTTO	39. SCOR
10. COFL	20. NOMO	30. RSTO	40. CAFI
			41. PISI

Studies should be conducted during the winter to determine the importance of pinyon-juniper habitats to the survival of wintering bird species.

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References

American Ornithologists' Union. 1995. Fortieth supplement to the American Ornithologists' Union Check-list of North American Birds. The Auk 106: 819-830.

Holmgren, N. H. 1972. Plant geography of the intermountain region. In Cronquist, A.; Holmgren, A. H.; Holmgren, N. H.; Reveal, J. L. Intermountain flora, Hafner Publishing Company, Vol. 1: 77-159.

Hutto, R. L. 1994. Field methods for landbird monitoring projects, USFS Region 1 contract #53-0343-2-00207. 9 p. + 5 appendixes. Typescript manuscript on file at the Uinta National Forest Supervisors' Office, Provo, Utah.

Line, L. 1993. Silence of the songbirds. National Geographic 183(6): 68-91.

National Geographic Society. 1987. National Geographic Society field guide to the birds of North America. 2nd ed. 464 p. Washington, D. C.: National Geographic Society.

Ryser, F. A., Jr. 1985. Birds of the Great Basin. Reno, NV: University of Nevada Press. 604 p.

Appendix—Four-letter mnemonic bird codes of all birds encountered in this study

Code	Standard bird names	Code	Standard bird names
COHA	Cooper's Hawk	HETH	Hermit Thrush
RTHA	Red-tailed Hawk	AMRO	American Robin
GOEA	Golden Eagle	SATH	Sage Thrasher
AMKE	American Kestrel	NOMO	Northern Mockingbird
MODO	Mourning Dove	GRVI	Gray Vireo
CONI	Common Nighthawk	SOVI	Solitary Vireo
BLTH	Broad-tailed Hummingbird	WAVI	Warbling Vireo
RSFL	Red-shafted Flicker	VIWA	Virginia's Warbler
GRFL	Gray Flycatcher	BTYW	Black-throated Gray Warbler
COFL	Cordilléran Flycatcher	WETA	Western Tanager
ATFL	Ash-throated Flycatcher	BHGR	Black-headed Grosbeak
SCJA	Scrub Jay	LAZB	Lazuli Bunting
CLNU	Clark's Nutcracker	GTTO	Green-tailed Towhee
PIJA	Pinyon Jay	RSTO	Rufous-sided Towhee[a]
BBMA	Black-billed Magpie	BCSP	Black-chinned Sparrow
CORA	Common Raven	CHSP	Chipping Sparrow
MOCH	Mountain Chickadee	BRES	Brewer's Sparrow
UNCH	Unknown Chickadee	LASP	Lark Sparrow
RBNU	Red-breasted Nuthatch	BTSP	Black-throated sparrow
WBNU	White-breasted Nuthatch	WEME	Western Meadowlark
PLTI	Plain Titmouse[a]	BRBL	Brewer's Blackbird
ROWR	Rock Wren	BHCO	Brown-headed Cowbird
BEWR	Bewick's Wren	SCOR	Scott's Oriole
HOWR	House Wren	CAFI	Cassin's Finch
BGGN	Blue-gray Gnatcatcher	HOFI	House Finch
MOBL	Mountain Bluebird	PISI	Pine Siskin
TOSO	Townsend's Solitaire		

[a] New name for the Plain Titmouse is Juniper Titmouse and new name for the Rufous-sided Towhee is Spotted Towhee (American Ornithologists' Union 1995.

Role of Pinyon-Juniper Woodlands in Aboriginal Societies of the Desert West

Joel C. Janetski

Abstract—Archaeological data and ethnographic accounts testify of the importance of resources available in the pinyon-juniper woodland to native peoples since the early Holocene. Food, shelter, raw material for tool construction, tinder, and preferred settlement location are a few of these. Although early evidence is sometimes inconclusive, information from more recent periods argue for increasing reliance on this vegetative community and its resources through time.

The pinyon and juniper community is widespread across the Colorado Plateau and Great Basin regions of the Desert West. This community provided aboriginal peoples with some of the most basic raw material to sustain life. The intent of this paper is to review some of the ways these resources were used in recent times as well as the evidence for use in the more distant past. I will focus on plants in the paper, and more specifically, pinyon and juniper. Clearly many other resources (animals of various kinds, grasses, sage) were present, but a discussion of all such resources and the ways in which they were used would take me far beyond the allotted time.

Aboriginal Peoples of the Desert West

The Desert West was and is home to various Shoshone (or Uto-Aztekan speaking) groups, Ute, Southern Paiute, Northern Paiute, Kawaiisu, and Washo (Hokan speaking) in the Great Basin and Colorado Plateau and the Puebloan (Hopi, Zuni, Rio Grande Pueblos) and Athabaskan (Navaho and Apache) peoples of Arizona and New Mexico. Lifeways in these diverse regions were likewise variable. Nearly all of the peoples of the Great Basin, for example, were hunters and gatherers and relied exclusively on indigenous plants and animals for their livelihood. Exception were the Southern Paiute in the St. George Basin who raised some crops: corn, squash, maybe some others. Of course, the Puebloan peoples were farmers but, nonetheless, gathered many native or wild resources both for food and for other purposes. The Navaho and Apache, recent migrants to the American Southwest, are more eclectic in their subsistence practices, with pastoralism mixed with some farming and gathering and hunting. The pinyon-juniper community provided important resources for all.

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Ethnographic Uses of Pinyon and Juniper

Food

Nuts from pinyon pine, both *Pinus edulis* (Colorado pinyon) and *P. monophylla* (singleleaf pinyon), were one of the most important foods for peoples of the Great Basin and Colorado Plateau. Wherever they were available they were gathered in large quantities. But they were particularly important to the Great Basin people. Premier Great Basin ethnographer, Julian Steward, calls pinyon "The most important single food species where it occurs..." (Steward 1938:27).

Pine nuts are high in protein and fats, although the percentages vary with the species (table 1). Singleleaf pinyon is higher in fat and protein while Colorado pinyon is higher in carbohydrates. The fat content exceeds that of chocolate and both contain all 20 amino acids required for human growth. Also, both contain tryptophan, an essential amino acid that is deficient in the diet of corn farmers (Huckell 1992:125). Singleleaf produces somewhat fewer seeds than Colorado, a tendency that is offset by the thinner hulls of singleleaf resulting in larger nutmeats. Both are ranked high on the list of available foods for people in the arid west. That is, pine nuts yield excellent returns for people who gathered wild foods for a living.

Productivity of the trees varies also. Good crops for a particular tree can occur every 4 or 5 years for *P. edulis* and every 2 or 3 for *P. monophylla*, although some nuts may be produced every year. Steward (1938:27) states: "In some years there is a good crop throughout the area, in some years virtually none." Productivity also apparently varies with the age of the stand, with old trees producing fewer filled hulls (Huckell 1992:132). An illustration of this variability is presented by Lanner (1983:170) for a stand of *monophylla* in the Raft River Mountains of northwestern Utah. A 5 year study reported per acre cone production as follows: 1975, 765 cones; 1976, 0 cones; 1977, 2,560 cones; 1978, 2,325 cones; 1979, 585 cones. In general, singleleaf is more productive and more predictable than Colorado pinyon (Sutton 1984). Sullivan (1992:200-201), on the other hand, has argued that archaeologists have tended to overplay the variable nature of pinyon nut production. Citing various sources, he maintains that pinyon production can be predicted rather accurately 2 years in advance and with considerable accuracy 1 year in advance (Sullivan 1992:200).

Gathering of Pine Nuts—Pine nuts were usually gathered in the early fall at about the time of the first frosts. Two

Table 1—Nutritional values of *P. edulis* and *P. monophylla* (kernels only—percentages by weight) (from Madsen 1986).

Species	Water	Protein	Fat	Crude fiber	Carbohydrate	Ash	Cal/100 gm
P. edulis	3.0	14.3	60.9	1.1	18.1	2.7	714
P. monophylla	10.2	9.5	23.0	1.1	53.8	2.4	488

methods were employed: green or brown cone harvesting (see Madsen 1986). The former took place before the cones opened. The green cones were either removed from branches using a hook or sometimes branches containing cones were broken off the tree. Once removed the sticky cones were placed in pits and roasted until the cones began to open. They were then pulled out of the fire with sticks, cooled, and opened, and the nuts were removed and tossed in a heap.

A graphic account of pine nut harvesting by the green cone method is suppled by Howard Egan in western Nevada in the late 1800's.

> Jack and I were taking a scouting trip high up in the Schell Creek Range of mountains, when we came across an Indian who, with his [wife] and children were busily engaged gathering pine nuts. The man had a long pole with a strong hook fastened to one end. He would reach up in the tree to the pine cones, hook the crook around the branch on which they hung and pull branch and all down, the woman and children carrying them to a place and piling them up in a heap. When they had collected as many as they wanted that day, the [man] has finished his part of the work and could pass the rest of the time sleeping or hunting squirrels just as he pleased.
>
> The women and children gathered a little dry brush which was thrown loosely over the pile of cones and set fire to. The cones are thickly covered all over with pitch, for this reason they make a hot fire, the [woman] watching and stirring it up as needed to keep the nuts from burning, as she rakes them back from the fire as a man would do when drawing charcoal.
>
> When the pitch was all burned off the burs or cones, the [woman] spreads a blanket down close to the pile, then taking up one cone at a time, would press them end ways between her hands, which opens the leaves, under which there were two nuts to every leaf, Then shaking the cones over the blanket area the nuts would all fall out as clean as you please.
>
> When the nuts had all been cleaned from the cones they were put in a large basket that would hold over two bushels and was nearly; full, the [woman] carrying that on her back to a place where they were placed all through the pine-nut grove to save carrying them too far and save time for the harvest does not last long, for a heavy frost will cause the cones to open and the nuts to fall to the ground (Egan 1917:241).

The brown cone method was practiced after the cones began to open on the tree. Large woven mats (or in recent times canvas tarps) were placed under the tree. The harvesters beat on the branches holding cones with long sticks to either knock the nuts out of the cones or the cones out of the tree. Both would then fall on to the mats. The cones and nuts were gathered and placed in large conical baskets for transport.

Of course, once nuts fell to the ground or even when cones had opened while still on the tree, they were eagerly sought by other foragers (birds, squirrels, insects).

Pine Nut Processing—Pine nut meats were eaten raw while harvesting or after toasting. But most were toasted, hulled, winnowed, and ground into a paste for making a pine nut soup or gruel. Initial roasting was done by placing a few handfuls of nuts on a winnowing tray along with hot coals. The two were mingled while moving the tray quickly to keep it and the nuts from burning. The coals were then tossed off the tray and the nuts placed on a flat rock and lightly crushed to crack the hulls. The cracked nuts were then returned to the winnowing tray and separated from the meats by tossing all into the air with the lighter hulls blown away by the wind. The meats were then toasted again in a similar fashion until the nuts were hard. After cleaning the meats with a nut paste, they were ground into flour on the grinding stones. The flour was used to make soup or gruel. The soup was sometimes mixed with meat to give it more flavor. The Navajo made a kind of pine nut-butter and spread it on corn cakes.

Pine Nut Storage—Importantly, pine nuts could be stored for future use. Pits or other storage facilities were up to 5 ft in diameter, lined with rocks, grass, or bark (probably juniper) and covered over with more bark, branches, dirt, and more rocks. Nuts were sometimes stored in cones and sometimes in hulls. Stored in this way, nuts lasted at least through the winter. Puebloan peoples would store enough pine nuts to last them 2 or 3 years. Great Basin tribes usually consumed all their stores by the late winter.

The importance of pinyon is reflected in myths and the fact that some groves were actually owned by families and defended (Steward 1933). In Owens Valley, California, for example, feuds were sometimes fought over the gathering of pine nuts in neighbors groves.

Juniper (*Juniperus* spp.) berries were occasionally used for food but had much less value as a food item than pinyon. The Apache ate them fresh and pounded them to make bread or a juniper tea (Goodwin 1935). Utes separated the berry pulp from the seed with a stone muller after which the pulp was eaten fresh or dried (Smith 1974). Harrington (1967) describes juniper berries used by Southwest people as an ingredient in bread or in stews for flavoring. Great Basin people used juniper berries sparingly, a fact suggested by the Shoshone term for Juniper, *wa'ap o pi,* which means fire material or kindling wood according to Chamberlin (1911:372), which emphasizes a nonfood role for juniper. Providing raw material for fuel and constructing shelters were the two most important uses for juniper (see below). However, juniper berries were occasionally eaten in fall and winter after boiling (Fowler 1986:73).

Shelter and Other Constructions

Pinyon and juniper were the primary materials for house construction among many peoples of the Desert West. Although Puebloan house walls were constructed of stone, the roofs of both residential and religious architecture (kivas) were constructed using pinyon and/or juniper for beams and held up with timbers of the same material. The more nomadic Navajo built hogans, sweathouses, ramadas, fences and corrals, drying racks, and storage facilities using primarily juniper and pinyon as raw material (Jett and Spencer 1981). Not only were the trunks of trees used for wall construction and roof support, but juniper bark was an integral element in roof construction.

Stansbury made numerous observations of Native American lifeways as he traversed the perimeter of the Great Salt Lake in 1852. At the north end of the lake he described a house built using juniper:

> In a nook of mountains, some Indian lodges were seen, which had apparently been finished but a short time. They were constructed in the usual form, of cedar (juniper) poles and logs of considerable size, thatched with bark and branches, and were quite warm and comfortable. The odor of the cedar was sweet and refreshing. Such houses were often floored with mats of juniper loosely woven (Stansbury 1852:111).

Medicinal and Miscellaneous Uses

Medicinal uses of pinyon were limited, although pitch or gum was sometimes put into boiling water and drunk to purge individuals infected with worms or other parasites (Chamberlin 1911:350). Juniper brewed into a tea furnished medicine for coughs and colds (Chamberlin 1911:372).

Pinyon pitch was used to line basketry water jugs and to seal and glue ceramic vessels together. Pitch also served as a mastic to hold projectile points or stone tools tightly to a shaft or handle. Juniper bark provided an important fiber for mats, diapers, menstrual pads, fire making material (hearth and tinder) as well as a cushioning and protective lining for storage pits. Open twined matting of juniper bark was a common textile manufactured by Great Basin peoples. The ubiquitous use of both woods for fuel across the Desert West seems an obvious point.

Pinyon Ecology and Shoshonean Settlement

The variability in pine nut productivity was a critical factor in Great Basin aboriginal life. As the pinyon harvest went, so went the people. As noted earlier, pine nuts are produced every year but only produce quantities adequate to supply stores for winter food demands every few years. Because of this variation in productivity and the need to spend the winter near stores or cached nuts, Julian Steward proposed a causal relationship between the unpredictability of pinyon and the high residential mobility of these peoples as they moved winter villages to be near the most recent productive areas. This fact, according to Steward, contributed to the fragmentation of aboriginal society in the Great Basin (especially the Western Shoshone in the central portion of the region).

The extreme importance placed on pinyon by Steward made life without pinyon a difficult one to understand for people in the Great Basin area. Given the nutritional value and the availability of pinyon, one would expect that pine nuts would be in the diet of native peoples as long as they were available in good numbers. In addition, the presence of pinyon in archaeological sites provided a basis for assuming a lifeway in the past similar to that documented by Steward. How long ago did pinyon appear in archaeological sites? The presence of pinyon in archaeological sites could argue that the nomadic lifeway described by Steward for the Western Shoshone was operative at the time the site was occupied. This leads to a more complex question of what kinds of archaeological evidences are there for the use of pinyon? This task proves more difficult than it might seem. A review of the evidence for the use of pinyon in the Desert West follows.

Archaeological Evidences

Archaeological excavations in Utah and elsewhere in the Desert West have demonstrated the importance of both pinyon and juniper for food, construction materials, and fibers. Demonstrating the use of either plant for medicinal use is difficult given the vagaries of archaeological data. The following is an attempt to synthesize far flung data but is not an attempt to be exhaustive.

Food

Proving that pine nuts were used for food is sometimes difficult. One must first ask what is acceptable evidence of using pine nuts for food. Certainly the most direct evidence of pinyon use would be finding pinyon remains in human feces or coprolites or in garbage dumps (middens) left by humans. Of course pinyon nut meats do not preserve, so typically the evidence consists of hull fragments. But just finding nut hulls in sites is not positive proof of dietary use since there is always some questions as to how they arrived in the site. Many critters gather, store, and eat pinyon so one has to be cautious in drawing conclusions. Charred hulls are generally accepted as good evidence for humans gathering and consuming nuts.

Indirect evidence of pinyon use would include grinding stones used for processing pine nuts. Unfortunately, nearly all hard seeds (which were an important part of the diet in the Basin) were also processed in much the same way. It is the case, however, that grinding stones show up early in the sequence at the large cave sites around the Great Salt Lake (Danger and Hogup Caves, for example).

Locations of sites in the pinyon-juniper community is also indirect evidence of pinyon use given the tendency for people to camp in such areas near caches. But, they could also simply be there for the wood, to get up and out of the colder valley bottoms, or to be close to snow fields for water. The presence of stone circles like those described for storage facilities would also argue for pine nut use and storage. These are present in the pinyon-juniper community in the Great Basin. Few have been excavated, however.

Interestingly, unequivocal use of pine nuts for food is somewhat scarce in the archaeological record, especially prior to about 1,500 or 2,000 years ago. Earliest evidence of human use of pinyon (most likely *P. edulis*) comes from heavily used dry caves in the Great Basin and the Northern Colorado Plateau. In sites such as Old Man Shelter, Atlatl Cave, and Dust Devil Cave (all in southeastern Utah), pinyon is present in the deepest deposits dated to as early as 8,000 years ago (Coulam and Sharpe 1993; Van Ness 1986). On the Colorado Plateau near the juncture of the Green and Colorado Rivers, pinyon appears in quantities in Cowboy Cave by 3,500 years ago (Hewitt 1980:135). Interestingly, the evidence at Cowboy Cave is in the form of pitch on basketry items, spindle whorls, and projectile points as well as nuts and needles. *Juniperus osteosperma* (twigs and seeds) and *Pinus edulis* (leaves and seeds) were both present in the deepest layers at Cowboy Cave, although these levels contain no clear evidence of human occupation. These botanical remains demonstrate that pinyon and juniper was present in this portion of the Colorado Plateau by 11,000 years ago (Jennings 1980:19,170).

The earliest dates for pinyon use in the Great Basin come from Danger Cave near Wendover, Utah, well to the north of the dry caves of the Northern Colorado Plateau. Madsen and Rhode (1990) have dated pine seed coats from Danger Cave to ~7,410 years ago, although this hull is apparently from limber pine (*P. flexilis*) rather than pinyon (Rhode and Madsen 1997). Pinyon pine is definitely present at Danger Cave by 6,800 years ago, however. Rhode and Madsen (1997:17) conclude that pine nuts were a part of the diet from the onset of human use of Danger Cave despite the probability that the closest groves of either limber or pinyon pine were at least 25 km to the west. These conclusions are supported in part by finds at Bonneville Estates Cave, just south of Wendover, where pine nuts (apparently pinyon) in good quantities were recovered from levels dated to 6,000 BP (Schroedl 1997). In Gatecliff Shelter in Monitor Valley, central Nevada, charred cones and twigs document the presence of pinyon in that area by 5,300 years ago and seeds and seed coat fragments are present just slightly later, about 5,200 years ago (Thomas 1983:153,174).

Madsen (1986) has argued that a strong case for an important dietary role for pinyon during these early times is lacking (Madsen 1986). The best evidence for heavy use of pinyon in the Great Basin comes from Crab Cave near the Fish Springs waterfowl refuge where thousands of hulls were found in deposits dating to sometime after 2,000 years ago (Madsen 1979). Interestingly, the closest source of pine nuts for Crab Cave inhabitants is the Deep Creek Mountains that are at least 35 km away. In Kachina Cave on the Utah-Nevada border, two caches dated to 1,350 years ago also yielded large quantities of pine nut hulls, although here pinyon groves are nearby.

In the extreme western Great Basin in Owens Valley of eastern California, archaeologists have found that evidence for intensive use of pinyon does not appear until after about AD 600 or so (Bettinger 1989). Later sites, such as Pinyon House located in the pinyon-juniper community in the White Mountains, contained all the evidences one might expect of heavy pinyon use: hulls, mullers, cache pits, roasting pits for cones, pinyon hooks, and bedrock mortars. This kind of strong evidence for pinyon exploitation is lacking at earlier sites, although there is evidence of pinyon being present in Owens Valley even earlier than that at Danger Cave. Reynolds (1997:3) reports dates of 8,790 ± 110 BP and 7,880 ± 60 PB from pack rat middens at the north and south end of the White Mountains, for example. None of these dates are from cultural contexts, however, and no evidence exists for human reliance on pinyon prior to the AD 600 date proffered above.

Explanations vary as to why pine nuts don't seem to be used abundantly until the Late Holocene in the Great Basin. Perhaps pinyon only recently migrated into areas such as Owens Valley. Or, perhaps higher ranked foods were more abundant early, making pinyon less attractive. It is also possible that our sample is simply not an accurate representation of past diet.

Also somewhat puzzling is the variability in the evidence for pinyon use at Anasazi sites often located in dense pinyon-juniper woodlands. Rohn 1971, for example, reports few evidences of pinyon use at Mug House at Mesa Verde. It is possible, however, that this scarcity is a function of not looking very closely for plant remains. More recent archaeological reports, such as those from the Grand Canyon area (Sullivan 1992), contain good evidence for pinyon use by Anasazi between AD 800 and AD 1200. In fact, Sullivan found evidence that pinyon and other wild plants (amaranth and chenopod seeds, cactus, grasses) could have been more important than corn. Likewise, Huckell (1992) reports abundant pinyon remains (seeds, seed shells, cone scales) from Anasazi sites just south of the Grand Canyon. Pinyon was also common in Antelope Cave north of the Grand Canyon on the Uinkaret Plateau in levels dated to the Anasazi occupation (AD 700-900) (Janetski and Hall 1983). Antelope Cave is currently 10 to 15 km from the nearest pinyon groves, suggesting that people were transporting pine nuts to the site. At the nearby Pine Nut Site, however, only a few charred needles were found in the float samples despite the site name. A number of possibilities come to mind to explain the site to site differences: preservation, the variation in pinyon production, and sampling bias.

Construction Material

Archaeological evidence of the importance of both pinyon and juniper for construction material is ubiquitous. Most fundamental is the use of these woods in house construction. The Fremont used both as did the Anasazi. The number of trees used for house and kiva construction in the Southwest was tremendous. Ray Matheny (1971) has suggested that the demand for pine and juniper for house construction during the maximum expansion of the Anasazi in southeastern Utah between AD 1000 and AD 1250 may have seriously depleted the pinyon-juniper community and may have contributed to the abandonment of the Four Corners region by the Anasazi in the late 13th century AD. The use of both woods for fuel is likewise evident in many archaeological contexts in the Desert West.

Juniper bark fibers are commonly recovered in archaeological contexts both in raw form and woven into textiles. Juniper bark open twined matting, for example, was in burials, perhaps as shrouds. The Mosida burial on Utah Lake, for example, was buried with juniper bark twined matting dating to 5,500 years ago (Janetski and others 1992). Examples of twined juniper bark matting found at Danger Cave date to between 3,000 and 11,000 BP. At Sand Dune Cave on the Utah-Arizona border, excavators found bundles of juniper bark dating to the early Basketmaker period (about AD 200) or earlier (Lindsay and others 1968:86). Artifacts made of juniper wood were found in the upper levels of Cowboy Cave. These include small, flat, smoothed rectangles identified as gaming pieces (Janetski 1980:81).

Conclusions

Pinyon and juniper have provided important raw material for native peoples for thousands of years in the Desert West. They depended on these familiar trees for food, fuel, shelter, and a multitude of other purposes. The ethnographic data are clear as to these uses. The archaeological data raise a number of interesting questions about pinyon use over space and time. Additional archaeological research will undoubtedly continue to yield evidences of the importance of this unique community in the Desert West.

References

Bettinger, Robert L.1989. The archaeology of Pinyon House, Two Eagles, and Crater Middens: three residential sites in Owens Valley, eastern California. Anthropological Papers No. 67. New York: American Museum of Natural History. 355 p.

Chamberlin, Ralph V. 1911. Ethnobotany of the Gosiute Indians of Utah. Lancaster, Pennsylvania: Memoirs of the American Anthropological Association. 2(5): 329-405.

Coulam, Nancy J.; Sharpe, Saxon. 1993. Paleoenvironment and ethnobotany of Old Man Cave, Utah. Ms. On file, San Juan Resource area, Bureau of Land Management, Monticello, Utah.

Egan, Howard R. 1917. Pioneering the west, 1846-1878. Richmond, Utah (privately printed).

Goodwin, Greenville. 1935. The social divisions and economic life of the Western Apache. American Anthropologist. 36: 55-64.

Harrington, H. D. 1967. Edible native plants of the Rocky Mountains. Albuquerque: University of New Mexico Press.

Hewitt, Nancy J. 1980. The occurrence of pinyon pine at Cowboy Cave. In: Jennings, Jesse D..Cowboy Cave. Anthropological Papers. 104. Salt Lake City: University of Utah Press: 135.

Huckell, Lisa W. 1992. Plant Remains. In: Whittlesey, Stephanie M., ed. Archaeological investigations at Lee Canyon: Kayenta Anasazi farmsteads in the upper basin, Coconino County, Arizona, Technical Series 38. Tucson: Statistical Research: 119-131.

Janetski, Joel C. 1980. Wood and reed artifacts. In: Jennings, Jesse D. Cowboy Cave. Anthropological Papers. 104. Salt Lake City: University of Utah Press: 75-96.

Janetski, Joel C.; Hall, Michael J. 1983. An archaeological and geological assessment of Antelope Cave (NA5507), Mohave County, northwestern Arizona. Department of Anthropology Technical Series 83-73. Provo: Brigham Young University. 77 p.

Janetski, Joel C.; Lupo, Karen D.; McCullough, John M.; Novak, Shannon A. 1992. The Mosida Site: a middle archaic burial from the eastern Great Basin. Journal of California and Great Basin Anthropology. 14: 180-200.

Jennings, Jesse D. 1980. Cowboy Cave. Anthropological Papers 104. Salt Lake City: University of Utah Press. 224 p.

Jett, Stephen C.; Spencer, Virginia E. 1981. Navajo architecture: forms, history, distributions. Tucson: University of Arizona Press. 289 p.

Lanner, Ronald M. 1981. The pinon pine: a natural and cultural history. Reno: University of Nevada Press. 208 p.

Lanner, Ronald M. 1983. The expansion of singleleaf pinyon in the Great Basin. In: Thomas, David H. The Archaeology of Monitor Valley: 2, Gatecliff Shelter. New York: American Museum of Natural History. Anthropological Papers. 59(1): 167-171.

Lindsay, Alexander J.; Ambler, J. Richard; Stein, Mary Anne; Hobler, Philip M. 1968. Survey and excavations north and east of Navajo Mountain, Utah, 1959-1962. Museum of Northern Arizona Bulletin 45—Glen Canyon Series 8. Flagstaff: The Northern Arizona Society for Science and Art, Inc. 399 p.

Madsen, David B. 1986. Great Basin nuts: a short treatise on the distribution, productivity, and prehistoric use of pinyon. In: Condie, C. J. and Fowler, D. D., ed. Anthropology of the Desert West. Salt Lake City: University of Utah Press: 21-42.

Madsen, David B. 1982. Prehistoric occupation patterns, subsistence adaptations and chronology in the Fish Springs area, Utah. In: Madsen, David B.; Fike, R. E., ed. Archaeological Investigations in Utah. Utah Cultural Resource Series 12. Salt Lake City: Bureau of Land Management: 1-59.

Madsen, David B.; Rhode, David. 1990. Early Holocene pinyon (*Pinus monophylla*) in the northeastern Great Basin. Quaternary Research. 33: 94-101.

Matheny, Ray. 1971. Possible approaches to population distribution studies in southeastern Utah. In: Gumerman, George J., ed. The distribution of prehistoric population aggregates. Anthropological Reports 1. Prescott: Prescott College: 152-164.

Reynolds, Linda A. 1997. The prehistory of a pinyon-juniper woodland. Society for California Archaeology Newsletter. 31(4): 1,3-6.

Rhode, David; Madsen, David B. 1997. Pine nut use in the early Holocene and beyond: the Danger Cave archaeobotanical record. Ms in possession by the authors. 33 p.

Rohn, Arthur H. 1971. Wetherill Mesa excavations: Mug House, Mesa Verde National Park—Colorado. Archaeological Research Series Number 7-D. Washington, DC: U. S. Department of the Interior, National Park Service. 280 p.

Schroedl, Alan R. 1997. [Personal communication].

Smith, Ann M. 1974. Ethnography of the Northern Utes. Papers in Anthropology 17. Albuquerque: Museum of New Mexico Press. 288 p.

Stansbury, Howard. 1852. An expedition to the valley of the Great Salt Lake. London: Sampson Low and Sons. (Reprint by Readex Microprint). 267 p.

Steward, Julian H. 1933. Ethnography of the Owens Valley Paiute. Publications in American Archaeology and Ethnology 33. Berkeley: University of California: 233-350.

Steward, Julian H. 1938. Basin-Plateau aboriginal sociopolitical groups. Bureau of American Ethnology 120. Washington DC: GPO. 346 p. (reprinted 1970. Salt Lake City: University of Utah Press).

Sullivan, Alan P. III. 1992. Pinyon nuts and other wild resources in western Anasazi subsistence economies. In: Isaacs, Barry, ed. Research in Economic Anthropology, Supplement 6. JAI Press Inc.: 195-239.

Sutton, Mark Q. 1984. The productivity of *Pinus monophylla* and modeling Great Basin subsistence strategies. Journal of California and Great Basin Anthropology. 6(2): 240-245.

Thomas, David H. 1983. The archaeology of Monitor Valley 2. Gatecliff Shelter. Anthropological Papers 59(1). New York: American Museum of Natural History. 552 p.

Van Ness, Margaret. 1986. Desha Complex macrobotanical fecal remains. Unpublished masters thesis, Department of Anthropology. Flagstaff: Northern Arizona University.

Van Ness, Margaret. 1987. Flotation analysis of the Pinenut site. In: Westfall, Deborah. The Pinenut Site: Virgin Anasazi archaeology on the Kanab Plateau of northwestern Arizona. Cultural Resource Series 4. Phoenix: Bureau of Land Management: 173-180.

Past, Present, and Potential Utilization of Pinyon-Juniper Species

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Abstract—Pinyon-juniper species in the Interior West are a sizeable wood fiber resource for products that can be made from smaller, irregular stems, and those that capitalize on the unique physical and chemical characteristics of the species. However, large-scale utilization of these species is largely influenced by management programs implemented to improve the range condition, hydrologic behavior, and wildlife habitat conditions of the woodlands. The past, present, and potential utilization of pinyon-juniper species is presented in this paper, specifically solid wood, chemical, and specialty pinyon products.

The pinyon-juniper woodlands, consisting of approximately 47 million acres in the Western United States (Evans 1988), and covering over a quarter of the land area of Nevada and New Mexico, are a sizeable wood fiber resource. One estimate indicates that approximately 17.6 million acres of pinyon-juniper woodlands occur in the Great Basin area, mainly Nevada and parts of Utah, California, and Idaho (Tueller and others 1979). Pinyon-juniper and juniper woodlands cover 9 million acres in Nevada and contain almost 4.4 billion ft^3 of total wood volume (Born and others 1992). Approximately 52 percent of this volume is singleleaf pinyon (*Pinus monophylla*) and 46 percent is juniper (mainly Utah juniper (*Juniperus osteosperma*). The average acre of Nevada woodland contains 6.5 cords (464 ft^3) of pinyon-juniper volume. Approximately 9 million acres of pinyon-juniper occur in Utah (Van Hooser and Green 1983). The net volume of pinyon and juniper in Utah and Nevada is estimated at over 10.3 billion ft^3 (O'Brien, This proceedings).

Pinyon-juniper species in the Interior West are primarily used for firewood, posts, and pinyon nuts. These trees, however, are potentially useful for the manufacture of wood products that can be made from smaller, irregular stems, and those that can use the unique physical and chemical characteristics of these species. Past, present, and potential uses of pinyon-juniper species are presented in this paper, specifically solid wood, chemical, and other pinyon products. Past and present utilization practices are reviewed, followed by a discussion of potential future uses of pinyon-juniper species.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Solid Wood Products

Solid wood products are those made of wood in its natural structural form. Pinyon-juniper species are used in their natural form for firewood and posts. The wood is also sawn into railroad ties and mine timbers. In addition, the wood may be reconstructed with adhesives to obtain products such as veneer, particleboard, and cement board.

Firewood

Pinyon-juniper species have been used longer and more extensively for firewood than any other product (Barger and Ffolliott 1972; Born and others 1992; Ffolliott and Clary 1986). In the Interior West, this wood remains the main fuel in some rural localities, while the popularity of wood-burning fireplaces contributes to its urban demand. In Nevada, the demand for firewood peaked in 1982 but remained fairly constant through 1989 (Born and others 1992). Harvesting is done by commercial operators for sale in population centers like Salt Lake City, Phoenix, Albuquerque, Las Vegas, and Los Angeles, and by individuals for personal use. Commercial tribal woodyards exist on several reservations (for example, Uintah and Ouray Ute Reservation in Utah) to provide employment and to generate income. Use of designated harvesting areas is an effective method to initiate sustainable management on tribal woodlands (Miller 1997). Wagstaff (1987) reported that most of the cutting permits for Federal lands were issued to private individuals. Surveys in New Mexico (McLain 1989) indicated that 41 out of 400 households harvested firewood while 25 out of 400 households in Utah conducted harvests (McLain 1997). In Albuquerque, as late as 1940, annual commercial firewood sales were estimated to exceed 6,500 tons (Space 1940). Demands remain high, almost 107,000 cords of pinyon (*P. edulis*) and assorted juniper species were harvested for firewood in New Mexico in 1986 (McLain 1989). The use of firewood appears lower in the Great Basin area. Public land records in Nevada indicate that 12,096 cords were sold in 1989. Although the harvest of forest species, such as lodgepole pine (*P. contorta*) and aspen (*Populus tremuloides*), and horticultural fruitwood, such as peach (*Prunus persica*), meets much of Utah's firewood demands, approximately 4,628 cords of juniper and pinyon were harvested for firewood in 1992 (McLain 1997).

Heat content, ignition, and burning characteristics are important firewood characteristics. Heat content, which is directly proportional to wood density, is the most important characteristic of wood used as fuel, while ignition, flaming characteristics, and fragrance are important attributes of fireplace wood (Barger and Ffolliott 1972). Based on these criteria, pinyon and juniper species make excellent firewood. There has been some interest in using pinyon and juniper chips for commercial energy production (Henderson and Baughman 1987); however, the interest in biomass fuels has fluctuated.

Firewood is commonly marketed haphazardly, with small independent operators working intermittently. Product quality and quantity sold as a cord unit are often questionable. The few commercial woodyards in the region can experience difficulty locating dependable sources and obtaining consistent quality. In the past, most firewood for the Utah Wasatch Front region came from salvaging dead material in chained and cleared areas. These sources are now depleted and cutters are cutting more live trees and travelling further to harvest them (Wagstaff 1987). Commercial firewood cutters in southern Utah dislike harvesting multi-stemmed junipers and prefer to cut other species. Harvesting juniper is labor intensive per unit of wood because of the small multiple stems, and because windblown soil lodged in the rough bark and the high wood density cause significant wear on saws. Transporting firewood to market areas is critical to the economic efficiency of marketing (LeBaron and Johnson 1965; Sowles 1966). Transportation costs are highest for small and irregular shipments. Intense competition keeps wholesale prices and profits low (Schmidt 1995), resulting in a high turnover among firewood operators.

The average wholesale price for firewood delivered to brokers within the Four Corner States, Southern California, and Nevada ranged from $50 to $100 for pinyon and $45 to $110 for juniper; the highest prices paid were in Southern California (Schmidt 1995). In Utah and Nevada, wholesale prices for pinyon firewood are $50 to $60 and for juniper are $45 to $55. Species preferences varies throughout the Interior West. Pinyon is preferred in Salt Lake City and is sold for $10 to $15 more a ton than juniper, while juniper is preferred in the Las Vegas area (Wagstaff 1987). In the Southwest, pinyon is the preferred species in New Mexico, while junipers are preferred in Arizona. Firewood generally is purchased in the spring and summer and is split and dried before selling to distributors. However, air pollution and resulting "no-burn days" in major urban centers, such as Salt Lake City and Phoenix, and recent restrictions on the construction of new wood-burning residential fireplaces, such as in the Phoenix area, may impact the regional demand for firewood.

Posts

Juniper species have been used historically for posts, because of their outstanding natural durability. Many posts were cut for personal use and for sale by commercial enterprises during the settlement period and growth of the livestock and farming industries. Posts are classified as line or corner posts depending on size; more than a third of the posts in Nevada are the larger corner posts (Born and others 1992). Juniper is used as stub posts in power and telephone line construction and for highway guardrails, although increased use of steel posts and preservative-treated pine and Douglas-fir (*Pseudotsuga menziesii*) has curtailed these uses. The annual cut of juniper posts in the late 1960s was approximately 300,000 (LeBaron 1968). Federal agencies in Nevada sold almost 38,000 posts in 1989 (Born and others 1992). Minimum specifications for juniper posts are based on a minimum serviceability of 80 percent after 40 years (Meagher 1940). Tests indicate that a juniper post could last over 50 years (Barger and Ffolliott 1972). Heartwood diameter is the limiting criterion.

Pinyon is not favored for posts because it seldom grows in a suitable form and is not a durable wood. Under normal conditions, untreated pinyon posts seldom remain in service beyond 5 years. Some pinyon is harvested for home construction, corrals, and fences. Navajos still use it for hogan poles and roof beams (Lanner 1981).

Harvesting posts in pinyon-juniper stands is a selective operation. Stems must be relatively small, slender, and straight. Young- and intermediate-aged stands are best for locating harvestable stems. Suitable posts are not found in stands that have been selectively cut or "high-graded" for posts in the past. Split posts are superior to round posts, since there is less sapwood in contact with the soil and less chance for the post to loosen as the sapwood rots. Commercial post cutting and selling is a part-time job for people involved in farming or ranching. A few larger post and pole yards in the region attempt to stock and sell juniper posts on a continuing basis. Born and others (1992) suggested that harvesting more valuable posts should be integrated with firewood harvesting in the same area to maximize returns.

Sawn Products

Pinyon-juniper species are not widely utilized for sawn products because of their small size and poor growth form. Other problems are related to high wood density and grit, which causes saw wear, and resin buildup in the equipment. Only 14,800 acres of pinyon-juniper sawtimber have been identified in Utah (Van Hooser and Green 1983). Less than 2,000 fbm of pinyon timber was harvested in Utah in 1992; this was less than 0.5 percent of the total amount harvested for sawlogs, house logs, or other products (Keegan and others 1995). However, railroad ties and mine timber have been cut from pinyon by small mills in the past, principally for use by the mining industry. Pinyon railroad ties are tougher and more resistant to breakage than ties cut from other softwood species in the region.

Juniper species have been cut into rough lumber by small mills. The lumber was usually specially ordered for use in furniture or novelty items, the latter including book ends, lamp basis, jewelry boxes, and small chests (Voorhies 1977; Swan 1995). These products capitalize on the unique fragrance, color, and grain patterns of juniper.

Veneer

Juniper species in the Interior West are physically similar to eastern redcedar (*Juniperus virginiana*) in many respects and, therefore, are considered for similar uses such as veneer and particleboard. USDA Forest Service tests indicated that Utah (*J. osteosperma*) and alligator juniper (*J. deppeana*) can be satisfactorily rotary cut or sliced into veneer sheets (Englerth and others 1953). Cutting characteristics and surface quality compared favorably with eastern redcedar. However, the veneers cut from Utah and alligator junipers are inadequate substitutes because of the deeper, more striking color, and more pronounced and lasting fragrance of eastern redcedar. Veneers from the western juniper species could be satisfactory for less demanding uses in furniture and paneling products. Questions of marketing veneers cut from junipers in the region remain.

Particleboard

The wood of almost any species can be used to manufacture particleboard, although softwoods and low-density hardwoods are favored. Pinyon could provide excellent material for particleboard, although ponderosa pine (*P. ponderosa*) is cheaper, often more abundant, and has the same characteristics. Particleboard made from singleleaf pinyon and Utah juniper logs was tested at the Forest Products Laboratory at Madison, Wisconsin (Murphy 1987). The Laboratory indicated that pinyon or juniper panels were inferior to those made from other western softwoods, but that it would be possible to make a urea-bonded panel that was satisfactory, based on strength and stability, for interior use. Additional tests at a laboratory in Germany indicated that panels made from chipped material, including bark, met the physical property levels for commercial panels.

Juniper species offer better opportunities for particleboard with distinctive qualities because of their specific gravity, texture, color, and fragrance (Ffolliott 1977). Alligator and Rocky Mountain juniper (*J. scopulorum*) bolts were converted into flakes 1 inch long, 0.015 inch thick, and random widths in a limited test (USDA Forest Service 1966). The flakes were then bonded with 8 percent urea resin into a single-layer medium-density particleboard. Strength and shrinkage characteristics of these boards were similar to those of a comparable ponderosa pine particleboard. The tests indicated that satisfactory particleboard can be manufactured from alligator and Rocky Mountain juniper. Markets for this product have not been adequately developed.

Cement Board

Tests of pinyon and juniper woods have determined their potential for use in cement board (Murphy 1987). This product is composed of cement, wood fiber, and water, and is fire resistant, relatively unaffected by water, and can be worked like particleboard. Cement board has a number of uses including exterior siding, air conditioning and utility ducts, and all-weather foundations for basements.

Chemical Products

Chemical products include those made by chemically treating or altering wood fiber and products derived from the chemical constituents or extractives of wood. Charcoal manufacture through carbonization and pulping are examples of chemical alteration of wood. Chemical constituents including turpentine, rosin, and a variety of oils can be obtained through distillation of wood and foliage and solvent extraction processes, or through processing oleoresins collected from living trees. Chemical utilization offers advantages for pinyon-juniper species, since stem size and form are not critical.

Charcoal

All of the pinyon-juniper species are suitable raw material for charcoal. All wood is about 50 percent carbon. As a consequence, the yields of charcoal from various wood species are proportional to the density of the wood. Denser species are preferred, since charcoal yield per unit of wood volume will be greater. Gambel oak (*Quercus gambelii*), a frequent associate of pinyon-juniper species in the Interior West, is well suited to the production of lump charcoal, since it is a heavy wood and will produce corresponding heavy lump charcoal (Barger and Ffolliott 1972; Voorhies 1977). Although the lighter pinyon and juniper woods produce a lighter, less desirable lump product, pinyon and juniper charcoals were used as a smelter fuel in the early mining operations throughout the region (Lanner 1981).

Well-made charcoal contains approximately one-half the volume and one-third the weight of the wood from which it is made (USDA Forest Service 1961). Using an average conversion value of 32 percent, calculated charcoal recovery per cord of wood for pinyon is 710 lb, for Utah juniper is 715 lb, and for alligator juniper is 635 lb. Actual yields of charcoal depend on the efficiency of the converting equipment and process used. Yields of 32 percent from pinyon and 36 percent from Utah juniper were obtained in a sheet metal kiln in Utah (Johnson 1965), while an average charcoal yield of 30 percent was obtained from pinyon and juniper in a block kiln in Colorado (Troxell and Johnson 1964).

The lighter lump charcoal produced from pinyon and juniper has a disadvantage in the market. A Utah study of charcoal potential for these species concluded that the best opportunities were in producing, bagging, and selling lump charcoal. This conclusion was based on a lack of competition among producers of bagged lump charcoal in the region, higher profit-to-cost ratios, and an assumption that consumers recognize the inherent advantages of lump charcoal. The same study pointed out the disadvantage of selling lump charcoal to briquetting plants, who incorporate their own charcoal production facilities into the operation and commonly buy outside charcoal at marginal prices.

Pulping

The physical and chemical properties of alligator juniper wood, its sulfate pulping characteristics, and sulfate pulp properties have been evaluated (Martin 1961). The evaluation indicated a relatively high lignin content, low pentosan content, and high extractives content, which are detrimental to the yield and quality of pulp.

The wood pulped satisfactorily but produced low yields that required nearly twice the quantity of bleach chemical than is commonly required for bleachable pulps. The strength of the pulp produced was intermediate between hardwood and softwood sulfate pulps. The pulp was too difficult to bleach for white paper stock, too weak for unbleached high-grade bag and wrapping paper, and too soft for corrugating board medium. Juniper sulfate pulp is probably best suited in blends with other softwood pulps (Martin 1961).

Pinyon has been experimentally pulped with satisfactory results (Barger and Ffolliott 1972). Brightness and bleaching characteristics are similar to those of ponderosa pine. However, because of the shorter fiber lengths, pulp strength is below the average for softwood pulps. One test found that pinyon and juniper could be used to make good quality Kraft-paper (Murphy 1987).

Information on mechanical pulp from these species is limited. However, high lignin and extractive levels could be a bonus for improving wet-strength properties and durability for packaging or paper overlays (Laufenberg, T. 1997 personal correspondence).

Pinyon-juniper stands offer some opportunity for pulpwood production since they can contain suitable material and occupy large, continuous areas. Although the growth form and debarking characteristics of pinyon are particularly adaptable to pulpwood processing, the economic feasibility of pulping pinyon-juniper species in the region is questionable. Environmental concerns related to the pulp industry must also be considered.

Extractive-Based Products

Appreciable quantities of extraneous chemical, called extractives, are found in pinyon-juniper species. These extractives occur mainly within cell cavities and intercellular structures such as resin ducts (Voorhies 1977). Some extractives are obtained from the sap or gum by tapping living trees, while others are obtained from chipped or shredded wood by solvent or steam distillation.

Pinyon wood contains large quantities of oleoresin or gum. Resin is collected by tapping the living trees in a manner similar to that used in southern pine species. Properties of the pinyon gum determine its potential use. The resin collected in an early Arizona study contained 20 percent volatile constituents or gum turpentine and 80 percent rosin (Deaver and Haskell 1955). Products obtained from laboratory analyses of pinyon resin include spirit, linseed oil, and tung oil varnishes, ester gum, and zinc resinate (Westgate 1943). Murphy (1987) reported that the branches and needles of pinyon and Utah juniper contain four times the resin of Douglas-fir. American Indians traditionally use pinyon pitch for a number of purposes. The Zunis of western New Mexico use it as an antiseptic, a pottery glaze, and burn it during religious ceremonies (Miller and Albert 1993).

Juniper woods contain large quantities of oily, fragrant extractives that are rich in cedrol and associated essential oils. Eastern and southern juniper species are exploited commercially for the production of cedarwood oil marketed for a variety of pharmaceuticals, perfumes, polishes, and insecticides (Barger and Ffolliott 1972; Voorhies 1977). However, the physical and chemical properties of the juniper species in the Interior West are largely unknown.

Foliage of juniper species contains fragrant, oily extractives potentially valuable as essential oils. Northern white-cedar (*Thuja occidentalis*) and eastern redcedar in the eastern United States have been commercially used for leaf oils (Bender 1963). While the physical and chemical properties of the leaf oils of Interior West junipers are unknown, the main components, as in most conifers, should be the terpene and sequiterpene series.

Other Pinyon Products

Pinyon has been historically a source of edible nuts and Christmas trees. Pinyon species produce nut crops at intervals of 4 to 7 years (Barger and Ffolliott 1972). Pinyon nuts are harvested commercially or by individuals for personal use. Nut crops are more frequent from trees where the species flourishes and are less frequent near the fringe of the type. Because of the staggered nature of the annual crops among sites, locally "good crops" usually occur somewhere almost every year. Nut yields from the better stands have been estimated to reach 300 lb/acre in a good crop year (Hamilton 1965). Crop variability is shown by data from woodlands administered by the USDI Bureau of Land Management in Nevada (Born and others 1992). Commercial harvesters collected about 115,000 lb of nuts in 1984, a peak year, while less than 3,000 lb were collected in 1989, a drought year. This variability is a problem for nut brokers and processors who prefer a constant supply to meet production and market demands. The price of pinyon nuts in the Southwest fluctuates between years and within a year depending on availability (Tanner and Grieser 1993). However, proper storage and handling of nuts and stable nut prices during bumper years would help sustain the nut market (Tanner and Grieser 1993).

Pinyon nuts are a popular woodland product throughout the West, which may justify increased investment in processing and shipping. Bags of unshelled Nevada pinyon nuts were sold in an Arizona supermarket chain during the winter of 1995. This was a poor nut year in much of the Southwest, and the bags of nuts sold out rapidly. Although the profitability of this effort is unknown, the suppliers and supermarket must have anticipated a profit. In November 1997, unshelled Nevada pinyon nuts were sold in bulk at one rural southern California produce stand for $5.95 a pound. Pinyon nuts have high dietary value and compare favorably with pecans and other nuts in protein, fat, and carbohydrates (Lanner 1981). Singleleaf pinyon nuts are 10 percent protein, 23 percent fat, and 54 percent carbohydrates. Commercial interests in New Mexico are attempting to increase the demand for pinyon nuts and to create additional pinyon nut products and markets.

Pinyon nuts are an important food for American Indians. The Washoe of Nevada, for example, have established pinyon collection allotments in the Pine Nut Mountains (Miller 1997).

Pinyon Christmas trees are favored by residents of the Interior West. These trees are harvested mostly from natural stands, although the species are also produced in commercial plantations (Barger and Ffolliott 1972). Recent declines in the demand for pinyon Christmas trees in some areas is partly due to a decreased supply of high-quality trees because of previous harvesting in the more accessible stands. Christmas tree cutting remains a popular recreational activity by the general public. Increasing use of artificial Christmas trees has also contributed to the decline in demand. However, the demand for pinyon Christmas trees in the Salt Lake City area has remained high with prices for pinyon being comparable to those for several species of tree-farm grown trees (Born and others 1992).

Potential Future Uses

More intensive and multiresource management of the pinyon-juniper woodlands in the Interior West depends on the development of economically and technically viable tree products. Increased demand for manufactured tree products might justify increased stumpage prices and investment in land management to improve ecosystem conditions and tree growth and yield from stands on the better sites. A main reason for low levels of management of pinyon-juniper woodlands is due to the poor economic return for all tree and non-tree products.

A group representing the forest products industry, local land owners, and government and nonprofit agencies was established to develop products and markets for western juniper (*J. occidentalis*) areas of Oregon (Swan 1995). The group has supported marketing tests of juniper for fencing, decking, and landscape timbers as well as flooring, cabinets, furniture, interior paneling, and novelty items. Swan (1997) stressed the importance of knowing the species' characteristics, potential products, manufacturing capabilities, and existing and potential market conditions. Many western juniper trees have relatively straight boles which gives them an advantage over multi-stemmed juniper species. These western junipers can be cut for logs and sawn and processed for a number of products. Different harvesting methods, including the use of mechanical delimbers, have been evaluated to determine relative production and affects on soils (Swan 1997).

However, a potential for new and expansion of existing products exists in the Interior West. The use of chips and raw fiber in particleboard, composite doors, and furniture needs further study. New technologies and compounds for binding chips and fiber should produce new product options. The decline in harvesting of forest tree species may increase the use of woodlands species, primarily pinyon, in the pulp and paper industry.

Chipping on-site, particularly of whole trees, would allow for more efficient harvesting by mechanical equipment (Henderson and Baughman 1987). The physical and economic feasibility of these methods would depend on the type of equipment used, and on site (slope, rockiness, soil conditions) and stand conditions (density, tree size, volume). Henderson and Baughman (1987) mentioned the need to develop equipment that is specifically adapted to terrain and operating conditions found in the woodlands. Economic viability also would depend on the costs of transporting the chips.

A variety of mechanical equipment, ranging from large, self-propelled machines to small, trailer mounted units, could be developed for woodland use. Mechanical methods should be used only after consideration of stand and site conditions. Woodland sites are divided into high and low categories based on their ability to grow wood products (Born and others 1992); high-site woodlands, which usually contain pinyon, occupy about 5.9 million acres in Nevada. High-quality stands on good sites should be managed under a silvicultural system that sustains the production of tree and other woodland products and maintains woodland health (Gottfried and Severson 1993). Mechanical methods allow for harvesting some smaller trees left in harvested stands and for treating marginal juniper stands. However, the use of mechanical methods must not repeat the mistakes of the pinyon-juniper control program of the late 1950's through the early 1970's, which resulted in large continuous openings that are detrimental to many wildlife species and aesthetically displeasing. Openings should be narrow enough to provide edge and encourage herbaceous use by wildlife. Trees and groups of trees should be left in treated areas to provide a savanna landscape, and adjacent untreated areas should be sufficient for wildlife. Sustainability of tree resources for the future must be considered. Some woody material, including snags, should be left for nutrient recycling, erosion control, wildlife shelter, and herbaceous plant and tree regeneration. Archeological sites would have to be identified and protected.

There is a growing demand for rustic furniture and novelty items made from native woods. The potential exists in many rural and American Indian communities to manufacture these items, provided dependable markets are developed. Observations in rural New Mexico indicate that high quality items, especially furniture, command relatively high prices. Initial start-up would require some training of wood workers and artisans, but the effort would benefit the local economies.

Management Implications

The pinyon-juniper woodlands of the Interior West represent a vast resource of wood fiber, that is potentially useful for many products. However, large-scale utilization of these species is influenced by management programs implemented to improve woodland range conditions, hydrologic behavior, and wildlife habitat conditions. Occurrence of pinyon-juniper species is generally detrimental to forage production (Clary and others 1974), but they protect natural landscapes from excessive soil loss, provide habitat for wildlife populations, and enhance aesthetic values.

Integrated resource management objectives for the pinyon-juniper woodlands must be achieved in conjunction with ecologically sound land management. Environmental concerns drive management programs for these woodlands throughout the Interior West. Enhancement of species and landscape diversity, in both spatial and temporal planes, is a major concern. Utilization of pinyon-juniper species for wood products must be carefully coordinated with the management of other resources. Future utilization of pinyon-juniper species in the Interior West depends on market availability and other economic considerations such as efficient tree harvesting and wood processing operations.

References

Barger, Roland L.; Ffolliott, Peter F. 1972. Physical characteristics and utilization potentials of major woodland tree species in Arizona. Res. Pap. RM-83. Fort Collins, CO: U.S. Department of

Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 80 p.
Bender, F. 1963. Cedar leaf oils. Pub. 1008. Ottawa, Canada. Canadian Department of Forestry: 1-16.
Born, J. David; Tymcio, Ronald P.; Casey, Osborne E. 1992. Nevada forest resources. Res. Bull. INT-76. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 64 p.
Clary, Warren P.; Baker, Malchus B., Jr.; O'Connell, Paul F.; Johnsen, Thomas N., Jr.; Campbell, Ralph E. 1974. Effects of pinyon-juniper removal on natural resources products and uses in Arizona. Res. Pap. RM-128. Fort Collins CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 28 p.
Deaver, Chester F.; Haskell, Horace S. 1955. Pinyon resources: Distribution of pinyon (*Pinus edulis*), yield and resin potentialities, Navajo-Hopi Reservations, Arizona-Utah. Tucson, AZ: University of Arizona Press: 1-37
Englerth, George H.; Lutz, John F.; Mueller, Lincoln A. 1953. Veneer cutting of western juniper. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 6 p.
Evans, Raymond A. 1988. Managing pinyon-juniper woodlands. Gen. Tech. Rep. INT-249. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 p.
Ffolliott, Peter F. 1977. Product potential of pinyon-juniper woodlands. In: Aldon, Earl F.; Loring, Thomas J., tech. coords. Ecology, uses, and management of pinyon-juniper woodlands. Gen. Tech. Rep. RM-39. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 28-31.
Ffolliott, Peter F.; Clary, Warren P. 1986. Pinyon-juniper woodlands in the Southwest. In: Ffolliott, Peter F.; Swank, Wayne T., eds. Potentials of noncommercial forest biomass for energy. Tech. Bull. 256. Tucson, AZ: Arizona Agricultural Experiment Station: 3-10.
Gottfried, Gerald J.; Severson, Kieth E. 1993. Distribution and multiresource management of piñon-juniper woodlands in the southwestern United States. In: Aldon, E. F.; Shaw, D. W., tech. coords. Managing piñon-juniper ecosystems for sustainability and social needs. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 108-116.
Hamilton, Andrew. 1965. A matter of a pinyon. American Forests. 71: 60-61, 74.
Henderson, Donald E.; Baughman, Mike L. 1987. Whole tree harvesting of the pinyon-juniper type: economic and institutional considerations. In: Everett, R.L., compiler; Proceedings—pinyon-juniper conference. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 192-195.
Johnson, Walter H. 1965. Economic analysis of charcoal production from the pinyon-juniper type. Annual Project Report and Work Plan, Project 638. Logan, UT: Utah Agricultural Experiment Station. (Unpublished).
Keegan, Charles E., III; Wichman, Daniel P.; Van Hooser, Dwane D. 1995. Utah's forest products industry: a descriptive analysis, 1992. Res. Bull. INT-RB-83. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 21 p.
Lanner, Ronald M. 1981. The piñon pine: a natural and cultural history. University of Nevada Press, Reno. 208 p.
LeBaron, Allen D. 1968. Estimating profits from sales of pinyon-juniper products. Resource Ser. 43. Logan, UT: Utah Agricultural Experiment Station. 28 p.
LeBaron, Allen D.; Johnson, Walter H. 1965. Utah wood and California fireplaces. Utah Farm and Home Science. 26: 7-11.
Martin, J. S. 1961. Sulfate pulping of alligator juniper. Rep. 2219. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 1-2.
McLain, William H. 1989. New Mexico's 1986 fuelwood harvest. Res. Bull. INT-60. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.
McLain, William H. 1997. Utah's 1992 fuelwood harvest. Res. Bull. INT-RB-89. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 p.
Meagher, George S. 1940. Service life of untreated juniper and cypress fence posts in Arizona. Res. Rep. 2: Tucson, AZ: U.S. Department of Agriculture, Forest Service, Southwestern Forest and Range Experiment Station: 1-9.
Miller, Ronald K. 1997. Cultural uses of the "forgotten forest." Journal of Forestry. 95: 24-28.
Miller, Ronald K.; Albert, Steven K. 1993. Zuni cultural relationships to piñon-juniper woodlands. In: Aldon, E. F.; Shaw, D. W., tech. coords. Managing piñon-juniper ecosystems for sustainability and social needs. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 74-78.
Murphy, Patrick M. 1987. Specialty wood products from pinyon-juniper. In: Everett, R.L., compiler; Proceedings—pinyon-juniper conference. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 166-167.
Schmidt, Lawrence A. 1995. Piñon-juniper fuelwood markets in the Southwest. In: Shaw, D.W.; Aldon, E.F.; LoSapio, C., tech. coords.; Desired future conditions for piñon-juniper ecosystems. Gen. Tech. Rep. RM-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 214-218.
Sowles, Kenneth M. 1966. Fuelwood feasibility study for the northern Rio Grande R. C. & D. project area. Santa Fe, NM: New Mexico State Forestry Department: 1-7.
Space, Jackson W. 1940. Woodland utilization study. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Region 3: 1-12.
Swan, Larry. 1995. Western juniper: an evolving case study in commercialization, ecosystem, and community development. In: Shaw, D.W.; Aldon, E.F.; LoSapio, C., tech. coords.; Desired future conditions for piñon-juniper ecosystems. Gen. Tech. Rep. RM-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 179-183.
Swan, Larry. 1997. Western juniper harvest system comparison project: final report. Klamath County Economic Development Association. 24 p. plus appendices. (Unpublished report).
Tanner, Ellis; Grieser, Don. 1993. Four generations trading piñon nuts with Native Americans: changes needed for future prosperity. In: Aldon, E. F.; Shaw, D. W., tech. coords. Managing piñon-juniper ecosystems for sustainability and social needs. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 29-33.
Troxell, H. E.; Johnson, R. J. 1964. Making charcoal from singleleaf pinyon pine and Utah juniper. Gen. Serv. Rep. 809. Fort Collins, CO: Colorado Agricultural Experiment Station. 8 p.
Tueller, Paul T.; Beeson, C. Dwight; Tausch, Robin J.; West, Neal E.; Rea, Kenneth H. 1979. Pinyon-juniper woodlands of the Great Basin: distribution, flora, vegetal cover. Res. Paper INT-229. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 22 p.
USDA Forest Service. 1961. Charcoal production, marketing, and use. Rep. 2213. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Product Laboratory. 137 p.
USDA Forest Service. 1966. Rocky Mountain Forest and Range Experiment Station 1965 annual report. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 1-46.
Van Hooser, Dwane D.; Green, Alan W. 1983. Utah's forest resources, 1978. Resource Bull. INT-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 58 p.
Voorhies, Glenn. 1977. What is known and not known about pinyon-juniper utilization. In: Aldon, Earl F.; Loring, Thomas J., tech. coords. Ecology, uses, and management of pinyon-juniper woodlands. Gen. Tech. Rep. RM-39. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 32-34.
Wagstaff, Fred J. 1987. Economics of managing pinyon-juniper lands for woodland products. In: Everett, R.L., compiler; Proceedings—pinyon-juniper conference. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 168-172.
Westgate, Mark W. 1943. Brief notes on pinyon resin and stick lac from Arizona. Circ. 665: National Paint, Varnish, and Lacquer Association: 190-198.

Endemic and Endangered Plants of Pinyon-Juniper Communities

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Abstract—Habitat relations between pinyon-juniper and narrow endemic plants of Utah and management implications of these relations are evaluated.

For this paper a narrow endemic plant is considered to be one that is restricted to one or a few counties in one or perhaps two States. Some of these are known from only a few populations while others are known from many. Nearly all plants of Utah and other Western States that have been listed as threatened or endangered by the U. S. Fish and Wildlife Service and those listed as sensitive by other agencies are narrow endemics. Ute ladies tresses (*Spiranthes diluvialus*), which is listed as threatened, is a notable exception with distribution including Colorado, Utah, Wyoming, Montana, and, at least historically, Nevada. That species is included in this paper based on its threatened status. Consideration of biological diversity, scientific interest including potential medicinal uses, and other features of these relatively rare or at least restricted plants is important to land use planning and management.

Colorado pinyon (*Pinus edulis* Engelm.), singleleaf pinyon (*Pinus monophylla* Torr. & Frem. in Frem.), and Utah juniper (*Juniperus osteosperma* [Torr.] Little) are the common trees of the pinyon/juniper thermal belt of Utah. Within their thermal belt, these generalists are found on nearly all geologic strata and soil types. Rocky Mountain juniper (*Juniperus scopulorum* Sarg.) does not seem as thermal-sensitive as the above species, and it is more common at higher elevations. It is less common on exposed geologic strata than the above species, and it is not so commonly found in closed stands. It is also more common where the soil mantle is well covered with vegetation and litter. Atwood and others (1991) listed nearly 70 taxa of narrow endemic plants for pinyon-juniper communities of Utah, and 22 species for juniper communities, and two for Rocky Mountain juniper communities. Many of these endemics have been listed as threatened, endangered, or sensitive or have been considered for listing. When plant communities are compared for presence of narrow endemic plants, it is clear that pinyon-juniper and desert shrub communities support most of these in Utah (Welsh 1979).

Because many of these plants are known within the pinyon-juniper thermal belt and sometimes coexist with these trees, the assumption might be made that some or many of these could be pinyon-juniper obligates or at least benefited by pinyon-juniper association. This paper provides an evaluation of relationships between pinyon-juniper and many of the narrow endemic plants known from the pinyon-juniper thermal belt of Utah. This evaluation is quite restricted to narrow endemic plants. There are other plants of wider distribution that might show a positive relationship with pinyon-juniper and be indicators of community type or seral status such as pinyon-juniper lousewort (*Pedicularis centranthera* Gray).

Sources of Information and Concepts

Much of the information known about narrow endemic plants is a function of botanical collections. Information taken with botanical collections often includes plant community, soil texture, geologic formation, elevation, and other habitat features. Numerous collections with this information become the foundation for written floras including *A Utah Flora* (Welsh and others 1993), which includes geologic information for many of the narrow endemic plants of Utah. It is a major source of information for this paper.

The inclusion of geologic information in that work is largely a function of observations of close relationships between plants and geology made by Dr. Stanley L. Welsh beginning with his survey of Dinosaur National Monument (Welsh 1957). From this point, Welsh continued to observe these relationships throughout Utah and sought help from geologists in recognizing geologic strata (Welsh 1978; 1984). His interest and knowledge became infectious, and his students caught the fascination of the strong relationships between narrow endemic plants and geologic substrate. Use of geological maps and observations for exposed geologic strata became standard tools in surveys for endemic plants as well as more common plants (Goodrich 1981; Goodrich 1984; Goodrich and Neese 1986; Huber 1995). Looking for these unusual habitats yields new species and range extensions of other species, and contributes greatly to the knowledge of the flora of Utah.

Surveys conducted specifically for plants listed or considered for threatened and endangered status such as those of Neese and Smith (1982), Petersen and Baker 1982, Shultz

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(1982), Shultz and Mutz (1979), Fertig (1995), and Heil and Melton (1995) are greatly facilitated by recognizing and searching on appropriate exposed geologic strata. The above and several other publications and surveys are major sources of information for this paper, including Franklin (1989, 1992, 1993). In addition, numerous collections of these species have been made by the authors of this paper, and field experience while making those collections are part of the information provided here.

Edaphic control by geological formations is greatest in areas where the strata are exposed (Welsh 1979). For geologic substrates to be controlling, in Utah at least, the area must be xeric. Desiccation is apparently a necessity for ultimate expression of edaphic control of vegetation (Welsh 1984). On geologic badlands or semibarrens, the interaction of various substrates with low annual precipitation through long periods has led to the demonstration of edaphic differences on a grand scale. Soil formation is minimal. The substrate surface is often merely residual parent material only slightly modified from that of a few inches below the surface where conditions for plant growth are often rigorous at best.

Geologic or edaphic control of plants is not as common in areas of high precipitation. Where precipitation is abundant, the influence of water has a strong tendency to override the influence of geology. However, xeric conditions are not only associated with low precipitation. They are also associated with steep slopes and cliff faces, and with wind swept slopes and ridges, especially where geologic substrates with features that shed water quickly are exposed. Thus, some higher elevations in Utah with relatively high precipitation provide xeric or at least desiccating habitats where plant specialists are protected from competition of generalists. Plants capable of establishment and reproduction in these harsh conditions are few in number. Competition is therefore limited (Welsh 1978). Thus Utah, with much exposed geology under xeric conditions, supports numerous relatively narrow endemic plants.

The concept that narrow endemic plants are favored by exposed geology under xeric conditions is well supported by the large number of such taxa found in such habitats, and relatively few that have been found where the geology is well mantled by vegetation. Viewing the photographs of habitats of the threatened, endangered, and sensitive species provided in Atwood and others (1991) provides an excellent array of semibarrens or badlands of Utah. There are a few plants listed in that work for which the habitat is shown to be well mantled by vegetation. With few exceptions, these plants are broadly distributed and are included in that work based on a narrow range known in Utah. Examples are *Potentilla palustris* (L.) Scop., which has circumboreal distribution, and *Carex leptalea* Wahl., which is known from Alaska to Labrador and south to California and Florida.

Also, viewing the photographs of rare plants of Wyoming as provided in Fertig (1994) and endangered and sensitive plants of Idaho and Wyoming as provided by U.S. Department of Agriculture, Forest Service (without date of publication) shows a similar theme. However, the works from these States seem to show more species in areas of dense vegetation. Once again, however, several of these taxa from well-vegetated habitats are not narrow endemics but are listed in these works based on narrow distribution within the state only. Examples are *Carex bauxbaumii* Wahl. with circumboreal distribution and *Salix candida* Fluegge ex Willd., which is known from Alaska to Labrador and south to British Columbia and Indiana.

The photographs of habitat for sensitive plants of the Humboldt National Forest, NV, which are mostly narrow endemics (U.S. Department of Agriculture, Forest Service 1991), show a propensity of these plants for open, sunny sites free of trees. Where pinyon-juniper are present, the endemic plants often grow in rock outcrops or talus within pinyon-juniper communities.

Plants that occupy well-developed soils tend not to be specialists, and they are broadly distributed (Welsh 1984). The Duchesne River Formation of the Uinta Basin, Utah, provides an example. At lower elevations this formation weathers to badlands or semibarrens as seen along U.S. Highway 40 between Roosevelt and Vernal and along Utah Highway 121 between Lapoint and Vernal. At higher elevations (around Strawberry Reservoir) under higher precipitation much of this formation is comparatively well mantled by vegetation. At the lower elevations where the formation has weathered to semibarrens, at least 17 taxa of narrow endemic plants have been found. None are known from the upper elevations of the formation where it is well mantled by vegetation.

The propensity of narrow endemic specialists for open sites of badlands or semibarrens with little competition from generalists is critical to understanding their relationships with pinyon and juniper.

Relation Between Narrow Endemic Plants to Pinyon and Juniper

The list of plants treated below was derived mostly from Atwood and others (1991). However, other narrow endemics listed by Welsh and others (1993) for pinyon or juniper communities of Utah are included. Page limitations for this paper prevent a discussion of each of the numerous narrow endemic plants of Utah found within the pinyon-juniper belt. The representative taxa discussed below are arranged in three categories of apparent relationship to pinyon-juniper. These categories are obligatory, apparent associate, and incidental. An expanded list of taxa for each of these categories without discussion is also provided below.

Obligatory or Semiobligatory

Arabis vivariensis Welsh Park rockcress—**Geology/soils**: sandstone and limestone outcrops and sandy soil. **Plant Communities**: Mixed desert shrub, pinyon-juniper. **Notes**: Presence on sandstone and limestone outcrops, and in mixed desert shrub communities indicates no obligatory relationship with pinyon or juniper. However, this plant does grow under the canopy of and in the duff of these trees on sandy soil, and apparently it is more abundant and vigorous in shade including that provided by pinyon or juniper. A positive relationship is strongly indicated between this plant and pinyon-juniper.

Camissonia exilis (Raven) Raven Meager camissonia—**Geology/soils**: Gypsiferous **Plant communities**: sagebrush, galleta, pinyon-juniper. **Notes**: This species seems to have a true affinity for growth under the canopy of other vegetation. Most often the other vegetation is either pinyon or juniper. However, on some occasions it grows under the canopy of bitterbrush and rarely in the open. The presence of duff is not a deterrent to its growth. It is unknown if there is dependence on canopy cover or duff or both, but a strong relationship to pinyon-juniper is evident.

Echinocereus triglochidiatus var. *inermis* (K. Schum) Rowley Spineless hedgehog cactus—**Geology/soils**: Brushy Basin and Saltwash Formations, and sandstone members of the Morrison Formation, shallow, rocky soils. **Plant communities**: Pinyon-juniper/galleta grass, pinyon-juniper/yucca/black sagebrush. **Notes**: This plant shows affinity for shade of pinyon-juniper trees and tall mountain brush.

Penstemon pinorum L. Shultz & J. Shultz Pinyon penstemon—**Geology/soils**: Often on Claron Limestone or its gravels. **Plant communities**: Pinyon-juniper, mountain mahogany, ephedra, oak, sagebrush, and less commonly greasewood. **Notes**: The specific epithet for this species is definitely descriptive of its habitat. Although it has been found in shrubby communities, it is most often found in duff directly under pinyon-juniper canopy and becomes increasingly less common into open interspaces. When found in association with shrubs, it is often not far from thick pinyon-juniper cover. In such instances, it is again found in the litter underneath woody species, becoming uncommon in the open. It is unclear whether the association is a function of the duff or the protection of the canopy cover or both, but a dependency is indicated. Removal of pinyon-juniper canopy has been associated with reduction of the species.

Apparent Associates

Allium geyeri var. *chatterlyi* Welsh Chatterley's onion—**Geology/soils**: Soils are mostly fine textured sandy loams, found in small pockets, protected depressions, and cracks in open slick rock of the Navajo Sandstone Formation. **Plant communities**: Ponderosa pine/Manzanita/Western wheatgrass, Ponderosa pine/Oak brush/Ross sedge. **Notes**: Although this plant is found in association with ponderosa pine and pinyon, it prefers the more unshaded sites.

Astragalus desereticus Barneby Desert milkvetch—**Geology/soils**: Sandy to clay soils of the Moroni Formation (ash flow tuff) and occasionally on a sandy member of the North Horn Formation located just above the Moroni Formation. **Plant communities**: Pinyon-juniper (mostly Utah juniper) with an understory including bitterbrush and Indian ricegrass. Some plants have been found in a basin big sagebrush community adjacent to the pinyon-juniper type. **Notes**: This plant has a strong affinity for the Moroni formation and pinyon/juniper/bitterbrush communities.

Draba pectiniphila Rollins Woods draba—**Geology/soils**: Sandy and other soils underlain by Weber Sandstone, Park City, and other formations. **Plant communities**: Big sagebrush, black sagebrush, mountain brush, ponderosa pine, Douglas-fir, pinyon-juniper. **Notes**: This plant grows in shade of pinyon and juniper and some tolerance of pinyon-juniper cover is evident. However, it is found in vigorous form outside duff and shade associated with these trees. Its abundance in black sagebrush and mountain brush communities indicates no obligatory relationship with pinyon or juniper.

Lepidium barnebyanum Reveal Barneby peppergrass—**Geology/soils**: White shale outcrops of the Uinta Formation where most common on ridge crests. **Plant communities**: Pinyon-juniper and mound plant communities. **Notes**: Although known from within the pinyon-juniper belt, the plant is most common on ridge crests where semibarrens or mound plant communities have developed in sparse or open pinyon-juniper communities. Presence of this plant in open pinyon-juniper but not closed pinyon-juniper communities indicates tolerance of pinyon-juniper presence but intolerance of crown closure of these trees.

Lesquerella tumulosa (Barneby) Reveal Kodachrome bladderpod—**Geology/soils**: White, bare shale knolls of Winsor Member of the Carmel Formation. **Plant Communities**: Among scattered juniper in a gramma grassland. **Notes**: While this species seems to be correlated with geologic strata, it is only found amongst scattered juniper. Typical habitat is bare shale knolls where any other vegetation is quite uncommon. While most often found in the bare inner spaces between juniper, plants are also be found directly in duff under the canopy of individual trees. Growth of individual plants does not seem to be influenced by presence or absence of duff and/or canopy.

Pediocactus despainii Welsh Despain footcactus—**Geology/soils**: Limestone gravels. **Plant communities**: Open pinyon-juniper. **Notes**: The distribution of this species being largely limited to within the pinyon-juniper belt might indicate a positive relationship to these trees. This species is found scattered within pinyon-juniper communities. However, it does not seem to be dependent on either of these tree species. It is often found in open, unvegetated spaces, on gravelly substrate. It is not found in thick canopy cover, nor directly under canopy of woody species. A negative relationship is indicated for pinyon-juniper canopy closure.

Pediomelum epipsilum (Barneby) Welsh Kane breadroot—**Geology/soils**: Chinle and Moenkopi Formations. **Plant communities**: Sparse sagebrush and pinyon-juniper **Notes**: This species occurs with sparse sagebrush and pinyon-juniper. It often found growing in desert pavement within the open spaces of pinyon-juniper. This hardy species has also been observed growing through eroding highway gravels. Decline in numbers of this species has been concurrent with loss of pinyon-juniper. While no definite relationship is known to exist, there is an indication that this species survives best in pinyon-juniper openings.

Penstemon atwoodii Welsh Atwood penstemon—**Geology/soils**: Kaiparowits, Wahweap, and Straight Cliffs Formations on grayish sand and clay loam soils. **Plant communities**: Ponderosa pine and pinyon-juniper. **Notes**: Presence of this species in both ponderosa pine and pinyon-juniper indicates no obligatory relationship to either one. However, with its range essentially limited to pinyon-juniper and ponderosa pine communities a positive relationship to these trees is indicated.

Penstemon bracteatus Keck. Red Canyon beardtongue or platy penstemon—**Geology/soils**: Pink and white limestone members of the Wasatch Formation. **Plant communities**: Ponderosa pine, pinyon-juniper, limber pine, and bristlecone pine-manzanita. **Notes**: This species is found within exposed strata of the Wasatch Formation. It commonly occurs in sparsely vegetated areas within many different woody communities. It does not seem to demonstrate an obligatory relationship with any one of these tree covered communities, but it is geologically selective. However, a secondary relationship to trees is indicated by the distribution being essentially limited to tree covered communities.

Penstemon concinnus Keck. Elegant penstemon or Tunnel Springs beardtongue—**Geology/soils**: Calcareous or igneous gravels usually of pale limestone parent materials. **Plant communities**: Pinyon-juniper and sagebrush. **Notes**: This species commonly occurs within a moderate canopy cover of pinyon-juniper and does not seem deterred by the presence of duff or litter. It is most often not found directly under canopy of pinyon-juniper, but within the small inner spaces between trees. However, canopy cover is not a deterrent to its occurrence. In rare circumstances it can be found in sagebrush communities at the edge of pinyon-juniper communities.

Townsendia aprica Welsh & Reveal Last chance townsendia—**Geology/soils**: Clay or clay silt soils of Arapien and Mancos Shale Formations. **Plant communities**: Salt desert shrub and pinyon-juniper. **Notes**: This species is most commonly found within the pinyon-juniper belt where it occurs in open to moderately dense cover. Although it does grow directly under pinyon-juniper, it is just as easily found in vast open areas within the pinyon-juniper belt. A positive relationship between tree cover, duff, or other habitat feature that is a function of pinyon-juniper is not apparent.

Incidental

Aquilegia barnebyi Munz Shale columbine—**Geology/soils**: Semibarren slopes, ridges, cliffs, ledges, and talus of Douglas creek and Parachute members of the Green River Formation and Uinta Formation. **Plant communities**: Mixed desert shrub, Salina wildrye, pinyon-juniper, Douglas-fir. **Notes**: This is a plant of open sites. It is not favored by shade nor duff or any other microsite feature that is a function of pinyon or juniper. It's association with these trees is incidental to its affinity for the Green River and Uinta Formations. It's independence from habitat features that are a function of pinyon or juniper is verified by its abundance in mixed desert shrub and Salina wildrye communities and by populations of high numbers on high elevation, wind swept ridges beyond the influence of pinyon and juniper.

Astragalus chloodes Barneby Grass milkvetch—**Geology/soils**: Outcrops of Entrada, Navajo, Frontier, Dakota, and other sandstone hogbacks and cuestas. **Plant Communities**: Mixed desert shrub, mountain brush, and pinyon-juniper. **Notes**: A strong propensity for sandstone barrens in full sun without litter or shade indicates the association of this species with juniper is incidental. The association is a function of the ability of pinyon-juniper to tolerate sandstone barrens and the propensity of this species for these barrens.

Astragalus hamiltonii C. L. Porter Hamilton milkvetch—**Geology/soils**: Heavy clay soils and road cuts in the Duchesne River and perhaps Wasatch Formations. **Plant communities**: Road cut, sparsely vegetated desert shrub and juniper. **Notes**: This uncommon plant is often favored by road cuts where robust specimens produce abundant flowers and fruit. It is found on badlands of inherently high erosion rates in full sun. Associated vegetation is sparse. There is no indication this species is favored by shade or duff or any other habitat feature that could be a function of pinyon or juniper. Indeed the distribution of this species indicates it would be adversely effected by increasing density of these trees. The association of this plant with juniper and perhaps rarely with pinyon is a function of the ability of these trees to occupy the badlands of the Duchesne River Formation to which this plant has a strong affinity. The inference by Davidson and others (1996) that this plant would be favored by wilderness status (designated wilderness as an act of congress) demonstrates a misconception of many narrow endemic plants which are well adapted to disturbance. The propensity of *A. hamiltonii, A. saurinus, Eriogonum viridulum,* and many other endemic species for road cuts, roadsides, and other disturbance does not support the concept that wilderness status is necessary or even helpful for the perpetuity of many of these plants.

Astragalus iselyi Welsh Isely milkvetch **Geology/soils**: Heavy clay derived from shale members of the Morrison and Paradox Formations. **Plant communities**: Salt desert shrub/blackbrush/greasewood and Utah juniper/galleta grass communities. **Notes**: This plant is widely scattered around the LaSal Mountains where it seems to be more restricted by the geological strata on which it grows than by plant type association.

Astragalus lutosus Jones Dragon milkvetch—**Geology/soils**: Green River Shale barrens. **Plant communities**: Desert shrub, mountain brush, limber pine, Douglas-fir, pinyon-juniper. **Notes**: Although reported for the above communities, this plant is one of barrens where pinyon, juniper, and other trees occur as scattered individuals. The affinity of this species for the Green River Shale is evident across a wide elevational range from 1,570 to 2,870 m (5,150 to 9,400 ft). That the range of the species includes elevations both below and above the pinyon-juniper belt demonstrates no obligatory relationship with these trees. The strong affinity for geologic substrate indicates little or no response of this species to habitat conditions that could be a function of pinyon or juniper. Association of pinyon and juniper with this plant is a function of the common ability of these plants to occupy this harsh substrate. In the case of *Astragalus lutosus*, the geology is obligatory. In the case of pinyon and juniper, this substrate is just one of many that these species tolerate.

Perhaps as well as any Utah endemic specialist, the Dragon milkvetch demonstrates an affinity for specific geologic strata. This plant is known from Rio Blanco County, Colorado to Utah County, Utah on the Tavaputs Plateau where it is most common in the White River drainage including the Pieance Basin and Two Waters drainage. The total range of the species is over 200 km long. Toward the west, known populations are isolated and separated by as many as 50 km. These isolated population are found on barrens or semi barrens of exposed Green River Shale. No population of this plant is known from this or any other substrate where the geologic strata is well mantled by vegetation.

Astragalus pattersonii Gray ex Brand. Patterson milkvetch—**Geology/soils**: Seleniferous soils of Blue Gate member of the Mancos Shale Formation and other formations that tend to weather to badlands. **Plant**

communities: Mixed desert shrub, pinyon-juniper/black sagebrush/galleta grass. **Notes**: This plant is sometimes found under shade of juniper and other overstory plants. Its presence in mixed desert shrub communities does not indicate an obligatory relationship with pinyon or juniper. However, its presence in shade of overstory indicates tolerance or perhaps a beneficial relationship.

Cryptantha brevifolia (Osterh.) Payson Short-flower cryptanth—**Geology/soils**: Mostly heavy clay soils of the Morrison and Duchesne River Formations. **Plant communities**: road-cut, salt desert shrub, sagebrush, rabbitbrush, pinyon-juniper, mountain brush **Notes**: The presence of this species in desert shrub and road-cut communities where it is found in full sun indicates no obligatory relationship with pinyon-juniper. Where it is found with pinyon-juniper, the trees are mostly scattered and of little influence on habitat conditions.

Cryptantha creutzfeldtii Welsh Creutzfeldt-flower—**Geology/soils**: Seleniferous soils of Mancos Shale. **Plant communities**: Mat saltbush and scattered Utah juniper/salina wildrye. **Notes**: This plant is restricted by geologic substrate. Its presence in mat saltbush communities indicates shade, duff, or other habitat feature that is a function of Utah juniper is not critical to the species.

Erigeron maguirei Cronq. Maguire daisy—**Geology/soils**: Rocky canyon bottoms of Wingate and Navajo sandstone, rim rock and other slick rock of Navajo sandstone **Plant communities**: Mountain brush, pinyon-juniper, ponderosa pine, and Douglas-fir. **Notes**: No specific associations occurs with any plant community. Plants occur on open windswept outcrops and under shaded canopy within deep canyon bottoms. Although associated with pinyon-juniper, this plant is quite limited to cracks and crevices in rock outcrops. The association with pinyon-juniper is indicated to be incidental.

Gilia caespitosa Gray Rabbit Valley gilia—**Geology/soils**: Carmel and Navajo Formations. **Plant communities**: Pinyon-juniper. **Notes**: This species occurs in crevices, sand, and open rocky outcrops associated with Navajo Sandstone. Other vegetation is sparse and includes ponderosa pine. Known populations are from semibarrens where there is no indication of obligatory relationship with pinyon-juniper.

Lomatium latilobum (Rydb.) Mathias Canyonlands lomatium or broad-leafed biscuitroot—**Geology/soils**: Mainly on Entrada Sandstone and Navajo Sandstone on fine textured loose sand. **Plant communities**: Pinyon-juniper/Blackbrush/Indian ricegrass, Pinyon-juniper/Mixed mountain brush/Needlegrass and desert shrub. **Notes**: Plants are mostly found in crevices of rock and on sandy deposits. Although found within pinyon-juniper woodlands, they are more common on open exposed, sunny (hot) sites where there is no indication that they are dependent on pinyon-juniper.

Penstemon grahamii Keck in Graham Graham penstemon—**Geology/soils**: White to tan semi-barren, shaley slopes, ridges and knolls of the Parachute member of the Green River Formation. **Plant communities**: Shadscale, greesebush, Salina wildrye, and pinyon-juniper. **Notes**: Habitat affinity for this species is exposed geologic strata with comparatively little soil development. Presence in shrub and grass communities indicates no dependency on shade or duff or other habitat feature that is a function of pinyon-juniper. Where associated with pinyon-juniper, the trees are scattered. It is not found in stands of trees with moderate or high crown closure indicating tolerance of limited presence of these trees but intolerance of crown closure or intolerance for soil conditions that allow for closure of pinyon-juniper canopy.

Penstemon idahoensis Atwood & Welsh Idaho penstemon—**Geology/soils**: Barrens, semi-barrens, and road cuts in white tuffaceous outcrops. **Plant Communities**: Sagebrush and scattered juniper. **Notes**: Habitat propensity of this species is for exposed tuffaceous materials. Association with juniper is incidental and a function of juniper to tolerate this material as well as nearly every exposed geologic strata within the pinyon-juniper belt of Utah.

Phacelia argillacea Atwood Clay phacelia—**Geology/soils**: Semi-barrens of the Green River Formation. **Plant communities**: Rocky mountain juniper/Gambel oak sites **Notes**: Although within the range of the pinyon-juniper belt, this plant is not dependent on or obligate to pinyon-juniper. It is in no way associated with the trees. It is found on open, actively eroding Green River Shale slopes with only limited vegetation. This species does not do well in competition with any other vegetation.

Spiranthes diluvialis Shev. Ute lady's tresses—**Geology/soils**: Moist to wet soils of wetlands and riparian areas. **Plant communities**: Riparian, meadow, wetland areas within cottonwood, tamarix, willow, and pinyon-juniper communities. **Notes**: This species is obligate to moist soils of riparian or wetland communities. The association with pinyon-juniper is accidental, and the listing of this species for pinyon-juniper communities is mostly based on riparian inclusions within the pinyon-juniper belt. However, the ecological amplitude of pinyon-juniper includes riparian settings. Ute lady's tresses is more common in open grass and forb dominated communities than where shrub and tree density or canopy closure is high. A negative relationship is indicated for this species with pinyon-juniper crown closure.

Talinum thompsonii Atwood & Welsh Thompson talinum—**Geology/soils**: Silicious conglomeratic gravels of the North Horn Formation. **Plant communities**: Pinyon-juniper/cliffrose/needlegrass, pinyon-juniper/alder-leaf mountain-mahogany/Salina wildrye. **Notes**: The most vigorous populations of this plant occur in the cracks and crevices of the conglomerate rock outcrops without pinyon-juniper cover which is primary habitat for the species. A small population occurs in a dense stand of mature pinyon-juniper trees with an understory of crytograms which is marginal habitat.

Summary List of Taxa

A list of taxa for each of these categories without discussion is provided below. For brevity neither authors nor common names are given in these lists. For the most part, nomenclature follows that of Welsh and others (1993) and Atwood and others (1991) where authors and common names are provided.

Obligatory or Semiobligatory

These plants are found in shade and/or duff of pinyon-juniper more commonly than not, and they appear to be either dependent upon or at least greatly favored by habitat features that are a function of pinyon and/or juniper.

Arabis vivariensis
Camissonia exilis
Echinocereus triglochidiatus var. *inermis*
Penstemon pinorum

Apparent Associates

These plants are known only, or mostly, from within pinyon and/or juniper communities but are mostly found in inner spaces of the trees and often on exposed geologic substrate where substrate more than trees could be the habitat feature these plants respond to most.

Allium geyeri var. *chatterlyi*
Astragalus desereticus
Cryptantha jonesiana
Draba pectiniphila[2]
Lepidium barnebyanum
Lesquerella tumulosa
Pediocactus despainii
Pediomelum epipsilum
Penstemon atwoodii[1]
Penstemon bracteatus[1]
Penstemon concinnus
Townsendia aprica
Trifolium friscanum

[1]Although known from other tree dominated communities, this is mostly known where trees are present, and it could be positively related to pinyon-juniper as well as other trees.
[2]Although known from habitats without pinyon-juniper, this plant appears to do well under pinyon-juniper. Although not necessary for the plant, habitat created by pinyon-juniper is favorable to the plant.

Incidental

These are species known from within the pinyon-juniper belt, but which also extend below the belt into salt desert shrub communities or above the belt and often to open wind swept slopes and ridges of exposed geology where geology is clearly the feature to which these species respond. Their association with pinyon and/or juniper is incidental and often a function of the ability of pinyon and juniper to inhabit a broad range of exposed geological strata without substantially modifying the environment of the exposed strata.

Aquilegia barnebyi
Artemisia nova var. *duchesnicola*
Asclepias cutleri
Asclepias welshii
Aster kingii var. *barnebyana*
Astragalus ampullarius
Astragalus anserinus
Astragalus barnebyi
Astragalus chloodes
Astragalus coltonii var. *moabensis*
Astragalus consobrinus
Astragalus duchesnensis
Astragalus eastwoodii
Astragalus equisolensis
Astragalus hamiltonii
Astragalus henrimontanensis
Astragalus iselyi
Astragalus lutosus
Astragalus monumentalis
Astragalus musiniensis
Astragalus oophorus var. *lonchocalyx*
Astragalus pattersonii
Astragalus saurinus
Astragalus serpens
Astragalus subcinereus var. *basalticus*
Cirsium ownbeyi
Chrysothamnus nauseosus var. *uintahensis*
Cryptantha brevifolia
Cryptantha cinerea var. *arenicola*
Cryptantha creutzfeldii
Cryptantha johnstonii
Cryptantha ochroleuca
Cryptantha paradoxa
Cryptantha witherillii
Cycladenia humilis var. *jonesii*
Cymopterus beckii
Cymopterus coulteri
Cymopterus duchesnensis
Draba kassii
Epilobium nevadense
Erigeron maguirei
Erigeron untermanii
Eriogonum aretioides
Eriogonum batemanii var. *eremicum*
Eriogonim batemanii var. *ostlundii*
Eriogonum brevicaule var. *ephedroides*
Eriogonum brevicaule var. *viridulum*
Eriogonum corymbosum var. *cronquistii*
Eriogonum soredium
Festuca dasyclada
Gilia caespitosa
Gilia stenothyrsa
Gilia tenuis
Gutierrezia pomariensis
Hedysarium occidentale var. *canone*
Hymenoxys acaluis var. *nana*
Hymenoxys lapidicola
Lepidium montanum var. *stellae*
Lepidium ostleri
Lomatium latilobium
Lygodesmia grandiflora var. *entrada*
Mentzelia argillosa
Mentzelia goodrichii
Mentzelia multicaulis var. *librina*
Mentzelia multicaluis var. *multicaluis*
Oreoxis trotteri
Pediocactus winkleri
Pediomelum pariense
Penstemon acaulis var. *acaulis*
Penstemon ammophilus
Penstemon angustifolius var. *dulcis*
Penstemon duchesnensis
Penstemon fremontii
Penstemon goodrichii
Penstemon grahamii
Penstemon idahoensis
Penstemon nanus
Penstemon pachyphyllus

Penstemon parvus
Penstemon scariosus var. *albifluvis*
Penstemon tidestromii
Penstemon wardii
Phacelia argillacea
Selaginella utahensis
Schoencranbe suffrutescens
Sclerocactus pubispinus var. *pubispinus*
Sclerocactus wrightiae
Silene petersonii
Sphaeralcea caespitosa
Spiranthes diluvialis
Talinum thompsonii
Thelesperma subnudum var. *alpinum*
Thelesperma subnudum var. *caespitosum*
Townsendia jonesii
Townsendia mensana
Xylorhiza cronquistii

Discussion

Many of the narrow endemic plants of Utah including those of the pinyon-juniper belt are found on semibarrens or badlands where geologic strata are exposed or on wind deposited sands. These relationships are repeated in so many taxa that it is apparent that these plants have evolved where geology and erosion are primary drivers of plant community composition and dynamics. Chemical and water relations are closely allied to geological formations. Ecology of most endemic plants of Utah indicate an inability of these plants to occupy well-developed soils, inability to compete for resources with the generalists that are commonly found there, or they are suppressed by shading of shrubs and trees (comparatively few endemic plants of Utah are shrubs and none are trees). The implication is strong that the open sites of harsh substrates and special conditions provide opportunities for development for specialists that have not developed the ability to compete with aggressive generalists. Aggressiveness of generalists such as pinyon and juniper is evident in the wide range of these species and the super dominance (West and Van Pelt 1987) they are capable of expressing. Even on sites where endemics are the most common plants, plant density often remains low. Here survival appears more a function of adaptation to harsh substrates and dry conditions than an ability to compete with other plants.

Colorado pinyon, singleleaf pinyon, and Utah juniper each have a broad ecological amplitude, and they are capable of colonizing on all, or nearly all, exposed geologic strata within their thermal belt. However, their presence on many of these substrates is often limited to depauperate, scattered individuals that are obviously stressed by the harsh conditions where they do little to modify the environment. Such harsh environments are open to colonization by narrow endemic specialists. In contrast to the depauperate and stressed nature of generalists that do exist on these harsh sites, many of the specialists flower and fruit in profusion with appropriate timing and amounts of precipitation, and they have developed mechanisms which enable them to survive through times without favorable moisture.

Layers of alluvium, which represent mixtures of materials from different sources tend to insulate vegetation from peculiar chemical and water relations of exposed geologic strata (Welsh 1979). With increasing depth of alluvium and increasing soil profile development, conditions become increasingly favorable for plant growth and greater productivity. Generalists such as big sagebrush, Colorado pinyon, Utah juniper, and common widespread grasses occupy such sites. Here competition among different species and among individual plants drives plant community dynamics where the most aggressive species express high percent crown cover in the absence of disturbance. In such highly competitive environments, most narrow endemic specialists are excluded.

A concept of dependency on pinyon or juniper for narrow endemic specialists is contrary to the concept of specialization. The propensity of narrow endemic specialists for open sites in contrast to the paucity of occurrences within pinyon-juniper communities with high crown closure supports the concept of specialization on open habitats and not dependency on pinyon or juniper. The occurrence in desert shrub communities of many of the narrow endemics that are reported for pinyon-juniper communities is additional, and quite conclusive, evidence that many of these taxa are not dependent on shade, duff, or any other habitat feature that is a function of pinyon or juniper.

The coexistence of Colorado pinyon and Utah juniper with narrow endemic specialists throughout Utah is evidence of the potential of pinyon and juniper to occupy or at least exist on nearly all (if not all) exposed geologic strata within their thermal belt. Their general occurrence on alluvial surfaces within their thermal belt is additional evidence of their broad ecological amplitude. These highly competitive species, which are capable of near complete dominance on many sites and which can effectively eliminate such highly competitive species as sagebrush and perennial grasses, can hardly be expected to be nurse plants for many narrow endemic specialists.

This concept is supported by the few species listed by Atwood and others (1991) for aspen communities of Utah. Of the seven species listed for aspen, five are indicated to be specific for rocky open places. Botanical collections from sagebrush communities are mostly not specific to the dominant sagebrush taxon at a site. Thus, it is not possible to compare endemic plants with habitat as indicated by different sagebrush taxa. However, it is the experience of the authors that relatively few endemic species are found in mountain big sagebrush communities, which tend to be on Mollisols. Relatively few are found in Wyoming big sagebrush communities with high crown closure. A greater number seem to be associated with black sagebrush, which indicates less favorable conditions for plant growth.

In general, endemic plants are few on soils of the Mollisol, Alfisol, or other orders indicating high degree of soil profile development. Many endemic species are found on cliff faces, talus slopes, and semibarrens of exposed geologic strata where soils of the Inceptisol and Entisol Orders are indicated.

The harsh exposed unfavorable habitats presented by exposed geologic strata under xeric conditions provide a refuge for narrow endemic specialists against the competitive and often dominating influence of pinyon and juniper. With the exceptions of four species listed above as obligatory or semiobligatory and the possible exceptions of

14 species listed above as apparent associates, a neutral or negative relationship with pinyon-juniper crown closure is suggested for most narrow endemic species of the pinyon-juniper thermal belt of Utah. Of the 14 apparent associates, woods draba and a few other species show considerable tolerance to pinyon-juniper cover without being dependent on pinyon-juniper cover. For these species a negative or positive relationship is not clear.

Management Implications

The nature of narrow endemic specialists to occupy semibarren habitats indicates low potential for vegetation manipulation projects on these sites. Indeed, the presence of many of these species could be used as an indicator of low potential. However, the more obvious barren nature of many of their habitats should be indicator enough that these are not appropriate sites for forage improvement projects. There are a few exceptions, and generalized conclusions are not an appropriate substitute for specific surveys and specific data bases for local areas. However, from data available in 1979, Welsh (1979) concluded it was possible to prepare a model with predictive capability that could aid in the search for these plants. Information gained since 1979 supports this concept. Sites with alluvial soils or where soil profiles are well developed, or where dense stands of pinyon-juniper with high percent canopy closure are present are indicated to be better sites for projects for high production of shrubs and herbaceous species. These habitats provide sites for such projects with low potential for narrow endemic plants.

Distribution of rare species is not equal. Certain areas appear to lack them while other areas support concentrations of several species. Unless a specific mineral to be exploited is located within an outcrop that supports one or more narrow endemic species, or unless the area to be occupied by a particular development is large, there seems little reason why activities should impress known endangered or threatened plant species. Even in these two exceptional instances there should be opportunity for mitigation. The best site for industrial development is not always the only good alternative (Welsh 1979). In some cases, narrow endemic plants of threatened or endangered status do come into conflict with development. An example is the low bearclaw-poppy (*Arctomecon humilis* Cov.) and urban development in and around the city of St. George, UT, where economic values for semibarrens or badlands are high. Such economic values are driven by urban development. No such value is indicated for cultural practices such as burning or chaining for forage or watershed improvement projects. The nature of the habitat should serve to protect many of these plants from these kinds of projects. The remainder can be addressed and protected by referring to well-documented inventories. Where such inventories are lacking, management should place high priority for achieving such inventories.

The habitat for many narrow endemic specialists might be considered at less than desired condition because of low production or high rates of erosion and delivery of salts to rivers. This might be suspected to be a function of use of the land by non-Native Americans and their livestock. However, the strong relationship between highly erosive, exposed geologic strata and narrow endemic specialists indicates an evolutionary ecology dependent on harsh conditions and high rates of erosion that predates the advent of European settlers and their livestock by thousands of years.

The comparatively rare nature of these plants indicates their high value for biodiversity and for the study of speciation, evolutionary biology, reproductive ecology, biogeography, taxonomy, species interactions and species rarity (Heil and Melton 1995). Additionally some of these plants, such as the several penstemons, contribute to aesthetics of semibarren landscapes. Some have potential for flower gardens. Also some, such as the Duchesne buckwheat (*Eriogonum brevicaule* var. *viridulum* [Reveal] Welsh), offer some potential to greatly soften the visual aspects of road cuts.

Maintenance of these plants is dependent on semibarrens or badlands with high rates of erosion and sometimes high delivery of salts. Attempts to alter these habitats by structures or establishing highly competitive plants that are capable of slowing erosion can be expected to have a high rate of failure. Any such project that might be successful would likely be highly detrimental to narrow endemic plants present in the project area.

As dense pinyon-juniper stands develop on sites, ground cover is often reduced as a function of bearing of interspaces where rill and sheet erosion increase with increasing pinyon-juniper cover. This relationship might be suspected of creating habitat for narrow endemic specialists that are often favored by erosion and bare surfaces. However, this is not indicated to be a major source of habitat for narrow endemics. Sites favorable enough for pinyon and juniper to achieve high cover are not indicated to be sites of evolutionary development of many rare species. Dense cover of these species is indicative of plant competition far beyond the tolerance of many narrow endemic specialists.

A concept labeled "properly functioning condition" is currently of high profile in some Federal agencies. Under this concept, narrow endemic plants and the badlands on which they have evolved present some different values to consider compared to those of landscapes that have the potential to be well mantled by vegetation. One of the functions of badlands in Utah is production of narrow endemic plant specialists including most of those listed as threatened and endangered. The evolutionary ecology of these plants indicate these badlands have been so for thousands of years. They have been highly erosive. They have contributed salts to drainage. These are inherent functions of these lands. Difficulty in applying the term "proper function" to this scenario demonstrates values of questionable application to badlands or semibarrens where geologic strata are exposed or where they are near the surface or where xeric conditions prevent development of dense vegetative cover.

Inherently highly erosive geologic substrates are well accepted as national treasures inside National Parks. There are reasons to accept these conditions as inherent on lands administered by other agencies. Narrow endemic plants are one of those reasons. Indeed production of these plants should be a measure of proper function.

There seems to be a tendency for those opposed to hands-on management of pinyon-juniper ecosystems to look at threatened and endangered species as a reason to stop projects designed to manage vegetation. Also, it seems those who support practices used to manage vegetation sometimes demonstrate an attitude of resentment toward threatened and endangered plant species. Neither of these attitudes seem appropriate for narrow endemic plants of Utah. Holmgren (1979) advised against taking a strong stand pro or con without sufficient knowledge. He also warned against advocacy for preservation by those who might view these plants mainly as instruments for political strategy. In view of the value of these rare or restricted plants and in view of the laws and regulations dealing with some of them, continued botanical surveys that lead to well-documented inventories are appropriate. Planning and management based on such inventories also seem appropriate. In the case of pinyon-juniper, it seems highly likely that most potential conflicts between vegetation management and narrow endemic plants can be rather easily resolved with well-documented inventories and an understanding of the habitat and biology of these species.

Using geologic maps, recognizing geologic strata, recognizing soils that tend to repel water and are inherently sparsely vegetated can facilitate inventory for many of these plants.

References

Atwood, N. D. 1979. Management programs for plants on Federal lands. Great Basin Nat. Memoirs. 3: 81-85.

Atwood, N. D.; Holland, J.; Bolander, R. and others. 1991. Utah threatened, endangered, and sensitive plant field guide. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 1 vol.

Davidson, D. W.; Newmark, W. D.; Sites, J. W. Jr.; and others. 1996. Selecting wilderness areas to conserve Utah's biological diversity. Great Basin Nat. 56: 95-118.

Fertig, W. 1995. Status report on *Thelespema cespitosum* in southwestern Wyoming. Cooperative Agreement # K910-4A-0011. Laramie, WY: Wyoming Natural Diversity Data Base. 45 p.

Fertig, W.; Refsdal, C.; Whipple, J. 1994. Wyoming rare plant field guide. [Place of publication not given]. The Wyoming Rare Plant Technical Committee. [Pages not numbered].

Franklin, M. A. 1989. Target species: *Erigeron untermannii* Welsh & Goodrich (Untermann daisy). Report for 1990 Challenge Cost-share Project, Ashley National Forest. Salt Lake City, UT: Utah Natural Heritage Program. 9 p. with appendices.

Franklin, M. A. 1992. Target species: *Penstemon acaulis*. Report of 1992 Cost-share Project Ashley National Forest. Salt Lake City, UT: Utah Natural Heritage Program. 11 p. with appendices 1-5.

Franklin, M. A. 1993. Report for 1992 joint challenge cost share project Ashley National Forest and Section Six Agreement, U.S. Fish and Wildlife Service, target species: Ute ladies'-tresses (*Spiranthes diluvialis*) Sheviak. Salt Lake City, UT: Utah Department of Natural Resources, Utah Natural Heritage Program. 22 p. with appendices.

Goodrich, S. 1981. A floristic study on central Nevada. Provo, UT: Brigham Young University. 400 p. Thesis.

Goodrich, S. 1984. Checklist of vascular plants of the Canyon and Church Mountains. Great Basin Nat. 44: 277-295.

Goodrich, S. 1986. Vascular plants of the desert experimental range, Millard County, Utah. Gen. Tech. Rep. INT-209. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 72 p.

Goodrich, S.; Neese, E. 1986. Uinta Basin Flora. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 320 p.

Harper, K. T. 1979. Some reproductive and life history characteristics of rare plants and implications of management. Great Basin Nat. Memoirs. 3.

Heil, K. D.; Melton, B. 1995. Status reports for *Astragalus hamiltonii* C. L. Porter, *Penstemon flowersii* Neese and Welsh, and *Penstemon goodrichii* N. Holmgren. Farmington, NM: Kenneth D. Heil. 3 reports.

Holmgren, A. H. 1979. Strategies for preservation of rare plants. Great Basin Nat. Memoirs. 3: 95-99.

Neese, E.; Smith, F. 1982. Threatened and endangered plant inventory for the oil shale RMP, Bookcliffs Resource Area, Bureau of Land Management, Vernal District. Unpublished report on file at: Vernal District Office, Bureau of Land Management, Vernal, UT. 5 Vol. [Prepared by Bio/West Inc., Logan, UT].

Peterson, J. S.; Baker, W. L. 1982. Inventory of the Piceance Basin, Colorado; threatened and plants, plant associations, and the general flora. Unpublished report on file at: Craig District Office, Bureau of Land Management, Craig, CO. 5 vol. [Prepared by Colorado Natural Heritage Inventory, Denver, Co.].

Shultz, J. S. 1982. Report on the search for rare and endangered plant species in the Uinta Basin of Utah on Quintana Minerals Corporation Land Holdings. Unpublished report on file at: Vernal District Office, Bureau of Land Management, Vernal UT. 54 p. [Prepared by Western Wildland Resources, Logan, UT].

Shultz, L. M.; Mutz, K. M. 1979. Threatened and endangered plants of the Willow Creek drainage. Unpublished report on file at: Vernal District Office, Bureau of Land Management, Vernal, UT. 2 vol. [Prepared by Meiiji Resource Consultants, Bountiful, UT.]

U.S. Department of Agriculture Forest Service. [n.d.]. Idaho and Wyoming endangered and sensitive plant field guide. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 192 p.

U.S. Department of Agriculture Forest Service. 1991. Humbolt National Forest sensitive plant field guide. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. [Pages not numbered]

Welsh, S. L. 1957. An ecological survey of the vegetation of the Dinosaur National Monument, Utah. Provo, UT: Brigham Young University. 65 p. Thesis.

Welsh, S. L. 1978. Problems in plant endemism on the Colorado Plateau. Great Basin Nat. Memoirs. 2:191-195.

Welsh, S. L. 1979. Endangered and threatened plants of Utah: A case study. Great Basin Nat. Memoirs 3: 69-80.

Welsh, S. L.; Atwood, N. D.; Goodrich, S.; Higgins, L. C. 1991. A Utah Flora. Provo, UT: Brigham Young University Print Services. 986 p.

West, N. E; Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. In: Everett, R. L. compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

Ecological Restoration

Ecology and Management of Pinyon-Juniper Communities Within the Interior West: Overview of the "Ecological Restoration" Session of the Symposium

Robert B. Campbell, Jr.

Abstract—Restoration of pinyon and juniper landscapes is a complex subject. Notable strides made during the past decade provide information to restore many sites. An array of treatments and plant materials are available for restoration of a variety of sites and plant associations. Restoration will not be successful without commitment and proactive treatments on a broad scale. This session included oral papers, poster presentations, and portions of an informative field trip.

I summarize the 29 presentations from the "Ecological Restoration" session of the conference. This summary highlights significant concepts and weaves together themes frequently shared in many of the presentations. With two exceptions, the references cited are found in this proceedings or were presented at the conference. This synthesis also includes information presented on the field tour and a few poster presentations not printed in the proceedings.

In the context of this session, ecological restoration means restoring the community balance of native species that existed prior to European settlement and reinstituting succession complete with historical functions and processes (Monsen). Emphasis should be to favor, if still present, or reintroduce the species that were historically present. In contrast, McArthur and Young explained that rehabilitation implies a renewal of land productivity but with an associated change in the composition and structure of the ecosystem.

I synthesized the themes and concepts from this session's papers in the following general areas:

1. Site selection (historical cover types and objectives and guidelines)
2. Treatments (chaining, fire use, chemical control, roller-chopping, and harvests)
3. Species composition and selection (native and introduced species, seed mixes and stockpiling, weed control, and seed certification).

I offer a reaction to the chaining demonstration, followed by a discussion of new information, management implications, prioritizing potential treatment areas, and the "land ethic and ecological conscience."

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Site Selection

Historical Cover Types

Ecological restoration of pinyon-juniper landscapes requires a basic understanding of plant associations, distributions, and areas of occupation. It is important to recognize cover types that existed throughout the landscape prior to European settlement. It is also essential to know if landscapes currently supporting pinyon or juniper or both previously sustained mature and old pinyon or juniper, or if areas were dominated by grasses, forbs, and shrubs.

Two steps are basic to all considerations for ecological restoration including site selection, potential treatments, and species composition. First, recognize what the historical cover type for the area was 200 to 400 years ago. This historical cover type generally is assumed to be the plant association that is ecologically adapted for the area. Second, land managers, with information from stakeholders, should decide what cover type is desired for the area in the future.

Mature and Old Pinyon and Juniper—Many closed stands of pinyon and juniper were open or savanna-like communities with grasses and forbs flourishing in the interspaces. With altered ecosystem processes (such as heavy grazing and altered fire return intervals), Jacobs and Gatewood note that these areas have degraded as young trees filled the interspaces and displaced understory species. These authors explained that degraded "communities appear to have little capacity to recover.... Exclusion of grazing alone is insufficient to promote recovery of these systems." In many cases lack of ground cover results in erosion, soil loss, and removal of seed banks for the native understory species.

Young Pinyon and Juniper—Many of these areas were also historically grass/forb cover types with scattered shrubs (Goodloe). Periodic fires precluded the survival of few, if any, pinyon or juniper trees, and seed sources for these trees were less abundant.

Objectives and Guidelines

Past rehabilitation efforts in pinyon and juniper types often have been conducted to improve livestock and big game forage and to provide cover and soil stability (McArthur and Young).

Soil and Watershed Protection—Planted species respond differently depending on growing conditions including soil, climate, and topographic features; thus, soil standards should reflect the capabilities to support different plant associations (Goodrich and Huber). Davis, Farmer, and Vernon concluded that chaining methods and the presence of litter left in place to protect soils also benefit establishment of seeded species. Goodrich and Reid compared the ground cover on burned and seeded and unburned pinyon-juniper sites in northeastern Utah. After 7 years, treated sites had 15 percent less bare soil and rock pavement and 24 percent greater cover from litter and vegetation.

Ground cover is a major factor preventing soil loss and sustaining good water quality. Farmer, Harper, and Davis found protective ground cover significantly reduced runoff and soil erosion from treated pinyon-juniper sites. They reported that "untreated control plots produced an average of nearly six times more runoff and nine times more sediment than chained plots." Considerable diversity in pinyon-juniper landscapes exist, and different responses to similar treatments are common. Lopes, Ffolliot, and Baker reported that "suspended sediment concentrations, above a threshold discharge, increased as a result of the cabling treatment, while no change in sediment concentrations was observed as a result of the herbicide treatment." Monsen and Pellant reported that "chaining did not reduce the percent of sites with hydrophobic conditions on or near the soil surface, but did reduce the number of sites having hydrophobic zones or layers at depths below 2.5 cm." Although infiltration conditions were not improved by tillage of the soil surface from chaining, the practice did significantly improve seedling establishment and plant cover. A more diverse assembly of species established as a result of creating better seedbed conditions. Presence of annual weeds was reduced by chaining and seeding over sites that were seeded but not chained. Chaining obviously improved seedbed conditions, resulting in improved ground cover during the first 2 years after treatment.

Improve Wildlife Habitat—Fairchild explained that forage production for livestock was emphasized in some chaining projects on public lands during the 1950's and 1960's. However, by the 1970's most project objectives included wildlife habitat restoration with a focus on improved big game winter range. He shared the basic premise that increased availability of foraging areas within larger pinyon-juniper woodlands, which provide thermal cover that is critical to animal survival, would reduce the home range of elk and deer on key winter ranges. Studies indicated that no more than 40 percent of home range for mule deer winter range (for areas of 125+ acres) should be chained at one time. Also, leave areas of 40+ acres should be distributed on a variety of slopes and aspects.

Restore Native Species and Ecosystem Processes—McArthur and Young explained that, in the past, site adaptability and resource values were the most important criteria used to determine the particular species planted. Currently many other factors are considered. Stevens stated, "Converting juniper-pinyon communities to only an assembly of foreign species is not advisable." Desired objectives of the project will determine what species are planted (Britton, Anderson, Horrocks, and Horton).

Bates, Miller, and Svejcar explained that in eastern Oregon, understory diversity and productivity were restored when competing western juniper were cut. They stated "that, prior to juniper cutting, a qualitative prediction of early succession species assemblages and dominance patterns can be made based on a site's initial floristics."

Walker discussed the competitive and aggressive nature of many exotics, which "are often detrimental and have an adverse impact on natural functioning plant communities and ecosystems." During the conference, Monsen implored the participants to place less emphasis on watershed restoration, wildlife habitats, or cattle forage. Rather, he suggested focus on restoring functional plant communities, and re-establishment of diverse plant associations.

Rodent Control—Monsen indicated that rodent control measures are critical, maybe as important as any factor for the protection of treated areas and the establishment of new seedlings.

Treatments

Chaining

Stevens described the types of anchor chains commonly used for chaining treatments: (1) smooth chains with the links unmodified, (2) Ely chain with lengths of steel bar or railroad rail welded crossways, and (3) Dixie sager with a rail welded horizontal to each link. He explained chains may be from 90 to 350 feet long and individual links may weigh 40 to 160 pounds. Two crawler tractors are required to pull a chain, complete with swivels on the ends and often in the middle. Depending on the position of and distance between tractors, chaining patterns may be J-shaped, U-shaped or half-circle patterns. Different chains and treatment patterns result in varying degrees of percent kill to trees and shrubs as well as differential soil scarification and seedbed preparation. Stevens listed many advantages for leaving downed trees in place.

Stevens expanded on the desirable characteristics of chaining, describing it as a successful way to restore areas with pinyon and juniper. Studies show chaining to be less destructive to vegetation and soil than plowing, disking, fire use, or herbicides. Appropriate chaining releases, rather than destroys, understory species and does not harm native seed banks. Studies by Monsen and Pellant confirmed that chaining did not disrupt or reduce recovery of native grasses and broadleaf herbs. Stevens stressed that chaining treatments, including time of use, offers more flexibility than any other treatment with minimum impact to resource values. Seeding, often done aerially with fixed-wing aircraft or helicopters, may occur before or during treatments such that the final pass of the chain covers the seed with soil. At the conference Monsen emphasized, "creating suitable seedbeds for all species planted is an important aspect of restoration, yet, of all of the things we fail to do, this is key."

Davis, Vernon, and Farmer reported the use of a lightweight chain in treating a mature stand of pinyon-juniper with cliffrose interspersed in the understory. The treatment resulted in a dramatic recovery of cliffrose as plants were released from tree competition. The treatment minimized the impact to mature cliffrose plants, but still provided a

92 percent elimination of the pinyon and juniper trees. Monsen and Pellant evaluated chainings in eight paired watersheds following the Boise Foothills fire of 1992. The treatment did not hamper recovery of perennial forbs or grasses. The treatment significantly increased establishment of all seeded species including those with both small and large seeds. Beck, Stevens, and Walker reported the dynamics of herbaceous understory species over 31 years following anchor chaining of five pinyon-juniper woodlands sites in south-central Utah. The areas included no use and use by mule deer, lagomorphs, and livestock. During the first 5 years following treatment, annual plants increased in numbers and density. However, perennial species increased while annuals decreased after the initial 5 years.

Beyond the specifics of various types of chaining treatments, many feel that these treatments hold promise for the restoration of native communities. Chaining may be the treatment of choice for landscapes with mature or old pinyon and juniper (Monsen). Stevens recognized that native communities can be restored by chaining as endemic species are allowed to recover after tree competition is reduced. In addition, planting select native species may be required to supplement reestablishment of species that have been eliminated.

Fire Use

Prescribed fire is usually more economical and ecologically compatible for areas with younger pinyon and juniper and for treatment of mature and older trees located on steep slopes and less accessible sites. Erskine and Goodrich indicate that, following prescribed burning, areas of younger pinyon and juniper respond well with respect to improvement of ground cover, minimal soil erosion, and recovery of native species that dominate post-treatment seral communities. Costs for prescribed fire (more than 1,000 acres), seed, and aerial seed application were about $20 per acre (1989 dollars). Costs go down as treated areas enlarge. Favorable conditions for prescribed fire include high temperatures, low humidity, and clear skies. Where prescribed fire is used to treat steeper slopes, drainage bottoms are excellent ignition sources to create desired crown fires. Helitorches were the ignition source for all of the fires discussed in their paper.

Fire is an economically feasible tool to enhance or change plant succession to grass-forb dominated communities created by initial chaining projects (Fairchild). However, chained areas that are 20 to 30 years old often provide excellent big game habitat, and burning these areas can significantly reduce fire-intolerant shrubs. Habitat could be impaired by burning at this time, so delaying burning for two to three decades may be advisable.

Chemical Control

Cheatgrass, an annual, often thrives on pinyon-juniper rangelands following burning or mechanical treatments, and thus competes vigorously with native perennials. Pellant, Kaltenecker, and Jirik reported the use of OUST® herbicide to control cheatgrass on rangelands in southwestern Idaho and northern Nevada. OUST® is water-dispersable and functions as a pre- and post-emergent herbicide. OUST® may be applied either from the ground or aerially for $25 to $28 per acre. Both methods have provided control of cheatgrass for up to 2 years. Data indicate this means of control was more effective than disking or burning. The authors found remnant perennial grasses regained dominance and were more vigorous in the areas treated with the herbicide than nontreated sites.

Other chemicals, such as Spike, have been used with mixed results to control or directly kill pinyon and juniper. None of the papers in this session dealt with any of these chemicals.

Rollerchopping

Large expanses of pinyon-juniper woodlands treated in past decades, often with a combination of chaining and seeding, are prime for a maintenance treatment. However, fire may not always be appropriate. Rollerchopping is relatively inexpensive and effectively restores site productivity (Sorensen). The treatment can be done any time or season the area is accessible and the soil is not sufficiently wet to be damaged by mechanical action.

Sorensen explained that rollerchopping can be used to control sagebrush, juniper, and pinyon. During the treatment, brittle, woody plants are crushed and chopped in place. The treatment does not concentrate piles of slash that may need to be dispersed later. The action removes woody competition of nonsprouting species allowing remaining vegetation to increase. Some areas need not be rested prior to treatment. Other design advantages include the ability to leave groups, strips, or individual trees and also to provide irregular patterns that are visually pleasing and may improve wildlife habitat. Treatment costs usually vary from $25 to $30 per acre.

Harvests

Fuelwood Cutting—Loftin described a simulated fuelwood cut in a pinyon-juniper woodland on the Santa Fe National Forest. All pinyon less than 8 inches diameter and all junipers were removed during the treatment. The purpose of the treatment was to increase the number of herbaceous plants, stabilize soils, and increase water availability. Trees were hand-cut, limbed, and lopped. Within 2 years, herbaceous plant cover increased to nearly 2.5 times more than the control. This method may not be as efficient as treating with heavy equipment; however, the treatment is less destructive and is well suited for sensitive areas. This treatment reduced both soil erosion and establishment of invasive weeds. Fire will be re-introduced to the treated area to control stump sprouts and abundant new pinyon and juniper seedlings and return the functional processes of this productive grassland ecosystem. This treatment was for both thinning and providing fuelwood.

Thinning and Slashing—Jacobs and Gatewood reported the results of a slash mulching and overstory reduction project in north-central New Mexico that yielded two- to seven-fold increases in total herbaceous cover. However, additional soil surface preparation and seeding treatments did not improve the benefits over the initial treatment.

The character of the pinyon-juniper savanna was restored when mature trees were spaced about 15 to 20 meters apart. They "suggest that tree overstory removal reduces competition for limited water and nutrient resources while the scattered slash provides benefits to exposed soils: reducing runoff and sediment transport, increasing infiltration and soil moisture, moderating soil temperature, freeze-thaw and evaporation, redistributing nutrients, and mitigating grazing impacts."

Thinning and slashing can also be used to treat historic grasslands where tree encroachment may occur. Managers can determine the shape and size of the treated areas, and selectively decide which trees to cut and which to leave (Barber and Chapman). These authors indicated that a more natural appearance occurs with better big game movement when groups of trees are left standing. Selective cutting can be effective but expensive (Davis). In another study, costs per acre for thinning were much higher than for chaining (Chadwick, Nelson, Nunn, and Tatman), and the authors concluded that "thinning did not create an effective seed bed or provide for adequate seed burial. Mechanical means should be employed to create a seed bed and cover the seed, introducing additional costs to the treatment."

Species Composition and Selection

Most of the information in this section applies to plant species. However, an underlying assumption is implied: diverse communities of native flora provide habitat for diverse communities of native fauna.

Young stated, "Decisions as to what plant materials to use in a given revegetation project are made on many levels, with economic considerations often competing with those of ecology. The decision nearly always boils down to what is the revegetation objective for this site." The Bridger Plant Materials Center, affiliated with USDA-NRCS, focused projects on the selection and establishment of native species to revegetate a wide array of difficult restoration situations (Majerus, Winslow, and Scianna).

When harsh environmental conditions complicate reclamation of arid and semi-arid rangelands, efforts often fail to meet the objectives (Britton, Anderson, Horrocks, and Horton). These authors evaluated the performance of a large group of species at two sites, sagebrush/grass and greasewood, and suggested further studies to determine which mix of species grow best together.

Native and Introduced Species

Stevens discussed how to create stable communities. Restoration efforts should include seeding with native species if the site does not have sufficient understory to exclude exotic weeds that would dominate the area otherwise. Walker indicated that competition from seeded introduced species affected differences in species composition for up to four decades (the length of the studies). This significantly reduced the frequency and cover of the desired native species. He shared four case studies from various cover types: gambel oak, aspen-mountain brush, juniper-pinyon woodlands, and Great Plains grassland ecosystems. Smooth brome, intermediate wheatgrass, and crested wheatgrasses were some of the exotic species in the examples. In all cases, a shift in species composition occurred where exotic species were favored at the expense of native communities. Walker underscored that resource values declined with this loss of species diversity.

McArthur and Young reported on seed sales and marketing information from two surveys. The first survey presented detailed data on seed production and sales of 47 species from the Intermountain and Pacific Northwest regions. The potential to use these species greatly exceeds current use and the volume of seed that is or can be harvested from wildland stands. To meet the demand for many species, field-grown seed will be needed. The second survey contained information provided by five seed companies in Utah that sold seed of native species in 1996. These companies reported marketing significant amounts of native seed of 29 grasses, 39 forbs, and 42 shrubs.

McArthur and Young indicated that recently increased enthusiasm to reconstruct natural plant communities by using regionally adapted native plants has resulted in more native plant materials becoming available from private suppliers. However, seeds of wheatgrasses (and their relatives) and legumes (rangeland alfalfas and clovers) continue to be the most available and are the plants of choice for most rehabilitation projects in pinyon-juniper areas (McArthur and Young). Jensen and Asay reported that "breeding programs are progressing to develop improved grasses and legumes for resource conservation as well as for grazing and habitat for livestock and wildlife.... Improved forage yield, forage quality, and resistance to insects and diseases are receiving major attention. Added emphasis is being placed on persistence of perennial ryegrass and development of endophyte-free cultivars of tall fescue."

Seed Mixes and Stockpiling

McArthur and Young recognized that stockpiling seed of native species by principal users will assure that seed will be available when needed. Consistent production from private industry should result from the orderly stockpiling of native seed in public sector (such as Forest Service) warehouses. The authors described two successful stockpiling programs by public agencies: the Utah Division of Wildlife Resources Seed Warehouse in Ephraim, Utah, and the Bureau of Land Management Seed Warehouse in Boise, Idaho.

Weed Control

Goodrich and Huber stated, "features of pinyon-juniper communities strongly point to the need to develop a wide array of plant materials with the potential to compete with cheatgrass on a variety of exposures and many geological substrates and soil types." Monsen explained that weeds are a major concern to most wildland communities, and pinyon-juniper woodlands are prone to invasion of annuals. Cheatgrass and other annuals have been a problem for decades, but squarrose knapweed, skeletonweed, and other perennials are rapidly expanding, and a new generation of perennial weeds appears adapted to extensive rangeland communities (Monsen).

Seed Certification

If requirements and standards of the Association of Official Seed Certifying Agencies are followed, seed quality (purity, germination, and presence of foreign material) as well as genetic identity and purity can be assured (McArthur and Young). "The certification system is applicable to seed and other propagating materials both wild collected and grown in production fields, whether natural or genetically manipulated populations" (Young). The seed industry and government agencies are expending efforts to improve seed testing, selecting native species, training collectors and growers, and providing standards for seed cleaning and storage.

Field Tour and Chaining Demonstration

A weed may be defined as a plant out of place. During the pinyon-juniper chaining demonstration of the field tour for this conference, that definition flashed through my mind. Indeed, grasses and forbs along with some scattered brush species dominated much of this area that is seral to pinyon or juniper during at least the past five centuries. Historically, fire occurred in the areas we visited with sufficient frequency to preclude survival of pinyon and juniper seedlings and, thus, perpetuated grass and forb cover types. In these areas, pinyon and juniper on the landscape are similar to pigweed in a garden plot. Chaining overgrown stands of pinyon and juniper is similar to a gardener pulling or hoeing out abundant "pigweed" on a vast landscape. The result is the removal of competition and recovery of desired communities of native and/or introduced species.

Discussion

New Information

Notable strides made during the past decade demonstrate that restoration is possible for many landscapes. More information, seed sources, and native plant materials are available for restoration of pinyon-juniper areas than for any other vegetative type (Monsen). As the demand and supply increase, the cost of using native material in restoration projects should continue to decrease.

There is a need to increase the amount of field-grown seed of native plant species (McArthur and Young). Walker showed that well-meaning introductions of exotic species adversely impacted the natural functioning of plant communities and ecosystems. His caution underscores the need for studies about the compatibility of exotics in natural systems.

Management Implications

Potential Conflicts—The potential for conflicting objectives exists with management of pinyon-juniper communities. Efforts to restore closed stands of pinyon-juniper by prescribed burning or chaining large areas (Monsen) and at the same time maintain sufficient "leave areas" are key to improvement and management of big game winter range (Fairchild). Collaborative stewardship and accurate identification of key big game winter ranges are needed to reduce potential conflicts.

The advent of OUST® as an herbicidal control of cheatgrass shows considerable promise. However, public perceptions about herbicides in general and effects on wildlife can limit herbicide use on public lands (Pellant, Kaltenecker, and Jirik). If OUST® is deemed suitable for large-scale application, an opportunity exists to treat areas with mixed stands of native species and selectively remove undesirable species. There will be a need to share information with the public about the benefits and relative risks of this herbicide before widespread acceptance will be found.

Partnerships—Joint ventures among State and Federal agencies and private landowners will be important for future management of pinyon-juniper woodlands (Fairchild). For example, he suggested that range managers could redesign old chainings by thinning or clear-cutting to increase the area of usable mule deer habitat. Davis underscored the critical importance of the age structure of the stand to be treated.

Prioritize Potential Treatment Areas

Land managers with the responsibility to discern areas to be treated should recognize at least four landscape situations (Monsen):

1. Restoration may be accomplished relatively quickly with some changes in management practices (such as altering grazing systems, burning, chaining, etc.).
2. Restoration is feasible but will require supplemental seeding with native species.
3. Restoration may be possible for some areas, but substantial alteration of the site and existing weed communities before restoration begins.
4. Restoration is not possible but areas may still be rehabilitated.

Monsen concluded that when designing restoration projects, diverse areas should be identified. These include areas separated by soil type, terrain, slope, aspect, and presence of herbs, shrubs, and trees. Land managers and researchers should work closely to develop a systematic way to delineate these site conditions. Managers could then categorize the pinyon-juniper areas into one of the four landscape situations. Only after sites have been properly classified, can managers determine which actions are required to restore an ecological balance. Care should be given not to prioritize all restoration effort on the basis of total acres restored for the dollars spent. Such priorities could in effect preclude treatments in critical pinyon-juniper sites where watershed and ecological stability are necessary.

Where restoration is possible, but some rehabilitation is needed initially, it is important to ensure that the first treatments (such as seeding with certain exotics) do not compromise or preclude later restoration measures. However, in some situations where restoration is not currently possible, the goal should be to promote ecologically sensitive rehabilitation using species that will not dominate the area but rather occupy a niche in the newly derived community. Sadly, some areas may be too expensive to rehabilitate.

The "Land Ethic and an Ecological Conscience"

The title of this session is "Ecological Restoration." Thus, I interject some considerations from the ecological perspective with themes taken from the writings of Aldo Leopold.

While visiting Germany in 1935, Leopold penned part of an essay on the back of hotel stationary. He wrote: "One of the anomalies of modern ecology is that it is the creation of two groups, each of which seems barely aware of the existence of the other. The one studies the human community, almost as if it were a separate entity, and calls its findings sociology, economics, and history. The other studies the plant and animal community, and comfortably relegates the hodge-podge of politics to the liberal arts. The inevitable fusion of these two lines of thought will, perhaps, constitute the outstanding advance of the present century" (Bradley 1997). The close parallel of the papers presented in the "Ecological Restoration" session and in the "Management Implications" session of this conference demonstrate that this "fusion of two lines of thought" is occuring in the management of pinyon-juniper landscapes. It will be the challenge and the hope of this generation of researchers and managers to cement this fusion on behalf of sustaining productive historical pinyon-juniper woodlands and recovering and restoring landscapes that were previously healthy grass/forb/shrub communities but invaded by pinyon or juniper in the past several decades.

In "Oregon and Utah—Cheat Takes Over" Leopold (1949) wrote: "I listened carefully for clues whether the West has accepted cheat as a necessary evil, to be lived with until kingdom come, or whether it regards cheat as a challenge to rectify its past errors in land-use. I found the hopeless attitude almost universal. There is, as yet, no sense of pride in the husbandry of wild plants and animals, no sense of shame in the proprietorship of a sick landscape. We tilt windmills in behalf of conservation in convention halls and editorial offices but on the back forty we disclaim even owning a lance."

Leopold's (1949) concept of the land ethic enlarged the community boundaries to consider soils, waters, plants, and animals collectively as the land. "A land ethic, then, reflects the existence of an ecological conscience, and this in turn reflects a conviction of individual responsibility for the health of the land. Health is the capacity of the land for self-renewal. Conservation is our effort to understand and preserve this capacity." An A-B cleavage exists in many disciplines or specialized fields. "In each field one group (A) regards the land as soil, and its function as commodity-production; another group (B) regards the land as a biota, and its function as something broader.... Group B feels the stirrings of an ecological conscience."

For ecological restoration to occur, factors other than big budgets and strong financial backing are critical. Leopold's philosophy and concluding challenge at the end of his "Land Ethic" has direct application to the situations that occur today on pinyon-juniper dominated landscapes in the West. He wrote:

> "The 'key-log' which must be moved to release the evolutionary process for an ethic is simply this: quit thinking about decent land-use as solely an economic problem. Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.
>
> It of course goes without saying that economic feasibility limits the tether of what can or cannot be done for land. It always has and it always will. The fallacy the economic determinists have tied around our collective neck, and which we now need to cast off, is the belief that economics determines *all* land-use. This simply is not true. An innumerable host of actions and attitudes, comprising perhaps the bulk of all land relations, is determined by the land-users' tastes and predilections, rather than by his purse. The bulk of all land relations hinges on investments of time, forethought, skill, and faith rather than on investments of cash. As a land-user thinketh, so is he.
>
> ...By and large, our present problem is one of attitudes and implements." *(Leopold 1949)*

At the close of the "Ecological Restoration" session of the conference, Richard Stevens gave a stirring challenge to the group. "The biggest problem is attitude!" Many native species can recover. However, native species may need to be rested more than 2 years, and a project cannot be judged a failure in the first 3 years. If the objective is to promote natives, plan for it. "If you build it, they will come! Have this kind of an attitude with native species," Stevens said.

These are challenging and demanding times with complex issues for those who manage landscapes of expansive pinyon and juniper. Leopold's guiding keywords to make investments of "time, forethought, skill, and faith" must be applied if we hope to improve existing situations in pinyon-juniper ecosystems. We must be proactive, albeit at times on a shoestring. We cannot and must not be complacent with our ecological conscience and model a "hopeless attitude." We must challenge the status quo in our larger circles of influence and convey to politicians and the public that, although the "landscape is sick," without thoughtful and skilled attention, conditions can and will become much worse.

Should we burn? chain? harvest? or do nothing? If treatments are made, then the questions become: how big? what shape? seed with natives? seed with exotic species? rely only on the seedbank? Such questions land managers will ask. Answers should depend on the desired conditions for the landscapes as determined by managers after weighing input from informed stakeholders in a forum of collaborative stewardship. The full range of alternatives (including doing nothing) should be applied to the full range of sites and situations on these landscapes. Also, monitoring of conditions, treatments, and responses is essential to understand the effects of treatments and then to adapt future actions. Refer to the four compelling case studies in Walker to appreciate the value of long-term monitoring.

Land managers must judiciously weigh the prudent use of chaining and where feasible restore the ecosystem process of fire to its historical function. These are challenging times with the hope of an improved future. Steps must be taken to value native species in sustainable communities. Unless we use landscape-scale measures to control undesirable exotic species, the legacy of this generation to coming generations will be populations of even less desirable exotic species on these landscapes.

The challenge for researchers and land managers is to be proactive in restoring the ecological integrity of pinyon-juniper ecosystems. These landscapes have the potential to sustain healthy and diverse biological communities. Let this be our legacy to future generations.

References

Bradley, Nina Leopold. 1997. Of the Land. American Forests. 103(2)25-29.

Leopold, Aldo. 1949. A Sand County Almanac and Sketches Here and There. New York, NY: Oxford University Press. 226 p.

All other citations are to presentations at the symposium, most of which are included in these proceedings. All are in abstract form in "Brigham Young University, 1997. Ecology and mangement of pinyon-juniper communities within the Interior West." Brigham Young University, Provo, UT. Non-paginated.

Pinyon-Juniper Chaining Design Guidelines For Big Game Winter Range Enhancement Projects

John A. Fairchild

Abstract—There are numerous examples of pinyon-juniper chaining projects in the Intermountain Region. The design of each reflects the objectives of the project and the "state-of-the-art" at the time of the chaining. Projects carried out on public lands in the 1950's and 1960's emphasized forage production for livestock. The early pinyon-juniper chainings were characterized by large treatments with borders closely tied to property boundaries. In the 1970's, the list of project objectives expanded to include wildlife habitat restoration, with an emphasis on enhancement of big game winter range. These projects were designed with irregular boundaries, "leave areas" and travel corridors to capitalize on the "edge effect" described by Aldo Leopold back in the 1930's . Consideration of mule deer habitat requirements and behavioral adaptations for winter survival is critical for planning projects on winter ranges. Guidelines are presented for treatment designs to protect and enhance wildlife habitat on these ranges.

The Utah Division of Wildlife Resources has been involved in chaining projects on mule deer winter ranges for more than 40 years. The practice has been used to improve winter range habitat on numerous wildlife management areas throughout the state. Projects have been carried out on public land in cooperation with the U.S. Forest Service and the Bureau of Land Management. In addition, the Division has contributed browse and forb seed to landowners that have selected chaining as a method for increasing forage production on their private rangeland. In most cases, the landowners have developed a conservation plan for their property with the assistance of the Natural Resource Conservation Service.

The basic premise has been that if we increase the availability of foraging areas within the larger woodland, then we should be able to reduce the home range of elk and mule deer on their winter range. If successful, animals should be able to conserve energy, and be better equipped to survive harsh winters. Treatment design, seeding success and long-term management will determine the ultimate value of these projects for wildlife. The following is a summary of the key habitat requirements and behaviors that must be considered when developing guidelines for a chaining design.

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Effect of Home Range

To understand the constraints that need to be imposed on chaining to achieve benefits for mule deer, it is important to keep in mind that the project will affect a species whose home range during the winter may be as small as 125 acres. Estimates vary depending on the area, but to conserve energy, it is not uncommon for deer to limit their activity to a ¼-mile activity radius. A treatment can be expected to have a positive effect on a local mule deer population if the project scale (chained vs. unchained area) is set based on this critical acreage. For example, a 200-acre chaining, without leave areas, could totally displace the animals that traditionally use a particular area and force them to move into an area occupied by another group. Long-term carrying capacity for the area could be reduced.

Thermal Cover

For mule deer, energy conservation during the winter is the key to survival. Deer carry a portion of their winter range on their back in the form of fat. Regardless of range conditions, deer continue to lose weight during the winter. The rate of loss, which is affected by habitat conditions and the severity of the winter, determines survival. The thermal cover provided by pinyon-juniper woodlands provides a buffer against exposure to severe weather conditions. The trees serve as a windbreak which reduces the wind-chill factor. Deer move to the interior of dense stands to avoid the strong winds associated with winter storms. To conserve energy at night, deer select areas beneath the tree canopy to bed down. The tree canopy absorbs heat during the day and reradiates the heat back to the ground at night, thereby increasing the air temperature beneath the canopy.

Interspersion of Vegetative Cover Types

Deer are attracted to areas where thermal cover and feeding areas are in close proximity. Again, energy conservation probably drives this behavior, but predator avoidance is also involved. Recognition of this "edge effect" has influenced the design of chaining projects over the last 20 years. First introduced as a concept by Aldo Leopold in the 1930's, it took a while to get incorporated into land management practices. Since treatment designs are often driven by watershed and forage production objectives, wildlife habitat remains an issue that must be negotiated for most projects.

Mule Deer Distribution on Winter Ranges

It is important to keep in mind that mule deer are not evenly distributed on their winter range. When planning a chaining project, we need to distinguish between normal and critical use areas. The nutritional status of mule deer changes as they are forced by severe weather to occupy lower elevation pinyon-juniper stands. If there is insufficient thermal cover available on these critical winter ranges, then the herd will be subjected to additional stress.

Deer tend to concentrate in what are called "key areas." Due to a combination of elevation, slope, aspect, topography, thermal cover and the presence of sites that support preferred browse species, deer are not distributed uniformly throughout their range. Chaining design is especially critical in these key areas, if they are to be chained at all.

Chaining Design Guidelines

Thermal Cover

The chaining design should reflect the importance of thermal cover over the need for foraging areas. Studies have suggested that no more than 40 percent of a pinyon-juniper stand should be chained within the expected home range of wintering mule deer (Thomas and others 1979). If the conservative estimate of a ¼ mile radius is used as an estimate for home range during the winter, then no more than 50 acres should be chained in a 125 acre area. An upper limit of about 260 acres per section would be possible, depending on terrain.

Interspersion

To maximize interspersion of cover types, and increase utilization by deer, the distance from any chained location to the edge of an untreated stand (leave area) should be no greater than ⅛ mile (660 feet). Terrel (1973) found that deer use in a chained area was greatest near the edge and dropped off significantly 400 feet in either direction. Consequently, chaining widths should be no greater than ¼ mile. Leave areas should be at least 40 acres in size and be distributed on a variety of sites (different slopes and aspects).

Leave Areas

The oldest stands should be incorporated into the leave areas. These stands provide considerable amount of concealment and thermal cover for mule deer. They generally occupy the shallowest soils, with less potential for forage production.

Scattered Trees

Clumps of trees should be left scattered throughout the chaining. These clumps are not considered leave areas, but provide hiding cover and habitat diversity within the chaining. These sites provide perching areas for raptors, and facilitate movement through the area by other bird species. The spacing for the clumps should be at least every 300 feet.

Travel Corridors

Travel corridors (ridges and drainage bottoms) should be excluded from treatment. The corridors should be at least 300 feet wide. Leave areas should be arranged so that they are connected by travel corridors.

Site Selection

Chainings should be located on soil types that have the potential to produce a diverse stand of vegetation. The best sites for browse production should be included in the chaining (Plummer and others, 1968).

Vegetation Management

The reestablishment of Utah Juniper and Pinyon Pine on previously chained areas has been well documented (Van Pelt and others 1990, Stevens 1987). Most of the trees, in these treated areas, were young plants at the time of the chaining and were not affected by the treatment. Shrubs, including highly nutritious browse species, can become the predominant species in the understory. Gradually, as tree and shrub densities increase, herbaceous production decreases. When one of the management objectives is to provide livestock forage, as is the case on most Western rangelands, pinyon-juniper maintenance treatments are often considered to restore maximum productivity.

Fire can be an effective, low-cost tool to arrest plant succession and reestablish a grass-forb dominated community in the openings created by the initial project. Although a prescribed burn may have a positive effect on forage production for livestock, the loss of browse production on a critical big game winter range could have serious consequences for the local deer herd. Key browse species are often just beginning to contribute significantly to the diet of the wintering deer herd when a maintenance treatment is carried out. After 20-30 years, these chained areas often have higher habitat value for big game, based on cover and forage characteristics, than during the early post-chaining period. Consideration should be given to the importance of an area for wintering big game when evaluating the need for maintenance.

Conclusions

Pinyon-juniper woodlands provide key winter use areas for mule deer and elk throughout Utah. The thermal cover provided by this ecosystem has an important function in energy conservation by big game. Consequently, the habitat value of a chaining is more closely tied to the proportion of the woodland that is left untreated, and its interspersion with treated areas, than to the amount of acreage that is converted to herbaceous cover.

Range managers have an opportunity to redesign old chainings to increase the acreage of usable habitat by mule deer. Many of these early projects failed to take into consideration the thermal cover requirements of big game. If prescribed burning is selected as the tool to retreat key use areas, careful consideration will have to be given to the post-burn design to maintain wildlife benefits. Another option that is available to land managers in Utah is to contract with the Utah State Division of Forestry, Fire and State Lands, Lone Peak Conservation Center, to clearcut or thin previously chained areas. The Lone Peak Conservation Center, in cooperation with the Utah State Department of Corrections, employs a prison work force to carry out a variety of conservation practices.

Joint ventures involving federal land management agencies, private landowners, state agencies, and Soil Conservation Districts, will play a bigger role in the management of pinyon-juniper woodlands in the future. The high cost of rangeland conversion projects dictates the need for partnerships. It is very important that wildlife habitat protection and enhancement be among the objectives identified for these projects.

References

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. 1968. Restoring big game range in Utah. Utah Div. Fish and Game, Publ. 68-3, 183 p. Publishers Press, Salt Lake City.

Stevens, R. 1987. Thirty years of pinyon-juniper big game habitat improvement projects: what have we learned. In: Everett, R. L., comp. Proceedings: pinyon-juniper conference; 1986 Jan. 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 558-571.

Terrel, T. L. 1973. Mule deer use patterns as related to pinyon-juniper conversion in Utah. Ph.D. thesis. Utah State Univ., Logan. 174 p.

Thomas, J. W.; Black, H. Jr; Scherzinger, R. J.; Pedersen, R. J. 1979. Deer and Elk. In: Thomas, J. W., Tech. Ed. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agric. Handb. No. 553: U.S. Department of Agriculture, Forest Service. 104-127.

VanPelt, N. S.; Stevens, R.; West, N. E. 1990. Survival and growth of immature *Juniperus osteosperma* and *Pinus edulis* following woodland chaining in central Utah. The Southwestern Naturalist 35(3): 322-328.

Mechanical Chaining and Seeding

Richard Stevens

Abstract—Density of pinyon and juniper trees and shrubs can be effectively reduced, large shrubs can be pruned, seedbeds can be created, and seed covered with an anchor chain pulled between two crawler tractors. Positioning of the tractor, chain size, and modification to the chain can produce a multitude of results. Seeding is most often done aerially using fixed-wing and helicopter aircraft.

Chaining

Anchor chains are primarily used to uproot trees and shrubs, to create seedbeds, to top or prune large shrubs, and to cover seed. Anchor chains from large destroyer or cruiser ships, 40- to 160-lb per link and 90 to 350 ft long are employed. To be effective, swivels are required at both ends and are recommended additionally, at least in the middle of the chain.

Anchor chains are pulled behind two crawler tractors traveling parallel to each other. To be effective, chains should not be stretched taut, but must be dragged in a loose, J-shaped, U-shaped, or half circle pattern. The half-circle configuration provides the greatest swath width, lowest percentage kill, and should only be used in mature, even-age tree stands. Kill and disturbance increases as the width of the J- or U-shaped pattern decreases. As the proportion of trees and shrubs change, chaining width should decrease or increase in order to achieve the desired amount of kill. The heavier the link, the better the chain stays on the ground, and the higher the percentage kill (Stevens and Monsen, In press).

Chaining commonly occurs on slopes of up to 50 percent slope but has been successfully accomplished on 65 percent slope (Vallentine 1989; Stevens and Monsen, In press). Chaining can occur up and down or across the slope without adversely affecting watershed values.

Success in removing trees and shrubs varies with species composition, age structure, density, and rooting habit. Trees in mature, even-age stands can be killed more effectively and efficiently than in uneven-age stands. Young trees less than 48 inches tall may not be killed with single or double chaining because the chain may ride over them. Small junipers can be uprooted and killed more effectively than small pinyons that tend to be more flexible than junipers.

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Three basic types of chains are used in pinyon-juniper projects:

1. Smooth Chain—Unmodified smooth links of various lengths and weights. Swivels are required on both ends.
2. Ely Chain—Anchor chains with steel bars, hard surfaced railroad rail, are I-beam welded crossways to every link, every other link, or every third link. Bar length will vary with link size but should extend 4 to 6 inches beyond both sides of the link. The 10 to 15 lead links at either end of the chain are left smooth. Swivels are required at both ends and in the middle of the chain.
3. Dixie Sager—An anchor chain with railroad rail welded to each side of each link, horizontal to the link. Length of rail depends on link length. The rail should be approximately one-half the total length of the link. Rails are welded with the crown of the rail next to the link, and base of rail out. Lead chains on each end consist of 10 to 15 smooth links. Swivels are required at both ends and in the middle of the chain.

With all three chain types, percent kill and amount of soil disturbance increases with link size. Compared to a smooth chain, Ely chains do a better job of scarifying soil and preparing a desirable seedbed. Tree and shrub kill is improved with an Ely chain over a smooth chain. The Ely chain does, however, have a tendency to hook and roll downed trees and shrubs to the center of the chain. The Dixie sager was designed to uproot big sagebrush. It does an excellent job of uprooting sagebrush and scattered pinyon and juniper. The Dixie chain will do a better job than a smooth chain of soil scarification, and of sagebrush, small juniper, and pinyon kill. The Dixie sager does not work well in pinyon-juniper stands since the railroad rails tend to hook trees and carry them along; this lifts the chain off the ground and reduces soil scarification and the number of trees and shrubs killed. Smooth chains are preferred when the objective is to release and open up tree and shrub communities such as pinyon-juniper, big sagebrush, aspen, mahogany, serviceberry, Gambel oak, chokecherry, bitterbrush, cliffrose, winterfat, and shrubby eriogonum. When removing trees and most shrubs, twice-over chaining is necessary. The first chaining completely uproots some trees; however, many trees are not completely uprooted and are laid down in the direction of chaining with some roots still in the ground. The second chaining should occur in the opposite direction, this generally uproots and tips the downed trees over. Many shrubs that come in contact with the chain can be uprooted or broken off. Twice-over chaining increases percent kill and topping of shrubs. Seeding should occur between chainings, as the second chaining covers the seed. If single chaining occurs, seeding should take place prior to chaining. Once-over chaining may be adequate when sufficient understory remains, trees are mature, an objective is to only reduce tree density, and seeding is not planned.

It is generally advantageous to leave downed trees in place and not pile or burn them. Some advantages to leaving trees in place include: (1) increased amount of infiltration by increased retention and detention of surface water; (2) increased ground cover; (3) decreased erosion; (4) cover maintained for wildlife; (5) big game and livestock movement onto and throughout the treated area is encouraged, resulting in more even distribution and use; (6) provide shade for livestock and big game; (7) decreased livestock trailing; (8) provides safe sites for seedlings to establish, seedling survival is improved, especially shrubs, and (9) cost of piling and burning is eliminated. Some advantages to removing trees are: (1) improved vehicular access; (2) enhanced access to all forage by grazing animals; (3) fewer rodents; (4) reduction in fire potential, and (5) esthetics (Stevens and Monsen In press).

Desirable characteristics of chaining include:

1. **Chaining is an effective method for restoring juniper-pinyon communities**. Chaining can be effectively used to regulate or manipulate a community without destruction of understory species. Chain link size, modifications to links, and placement of crawler tractor will determine disturbance severity to understory species. Types and size of chain and chaining practices can be regulated to retain most all existing understory species including threatened and endangered species, yet sufficiently reduce tree competition to facilitate seeding or promote natural recovery of understory species. Native seedbanks are not harmed by appropriate chaining.

Through extensive testing and development of alternate equipment, chaining has proven to be the least destructive technique to existing vegetation and soil. Compared with other methods of mechanical treatment (plowing, disking), or use of herbicides or fire, this practice can be selectively used to reduce tree density in desired locations without disruption of understory plants and non target areas.

Soil conditions, including watershed stability, can be improved with chaining (Farmer and others, this Proceedings). Many treatment practices, including burning, leaves bare soil and sites subjected to extensive erosion for considerable periods. Chaining can leave considerable litter on the surface, which improves watershed protection by retaining and detaining surface moisture and increasing the amount of infiltration (Roundy and Vernon, this Proceedings; Wood 1988; Wood and Javed 1994; Wilcox 1994). Debris is also deposited in gullies, draws, and waterways, thereby improving retention and detention of surface moisture and decreasing amounts and duration of runoff and sedimentation.

A primary advantage of chaining, to watershed and vegetative conditions, is the practice can be used at most any season of the year. Plowing, spraying, and burning must be conducted at very specific times, depending on soil moisture, stage of plant growth, and site access. Treatment by these methods is often completed at a time when sites are subjected to erosion or seedbed conditions are not the most desirable. In many situations, burning, cutting, hula dozing, or other methods of plant control require follow up seeding treatments to reduce soil erosion or limit weed invasion. Chaining allows treatment to be conducted at the most appropriate season to benefit soil stability, create a desirable seedbed, cover seed, and reduce the invasion of weeds. Currently, no other treatment provides the flexibility afforded by chaining.

Chaining and seeding can also be effectively used to help control understory weeds that normally exist within depleted juniper-pinyon status. Since chaining does not generally disrupt the existing perennial understory species, desirable perennials can recover quickly (Jacobs and Gatewood, this Proceedings) and provide immediate competition to potential weeds. Adding species by seeding can also increases competition with weedy plants. Soil nutrients and site productivity can be maintained by chaining. Surface litter and plant debris are maintained on site, whereas burning removes nutrients, litter and debris. Soil profiles are not disrupted with chaining as they would be with plowing or disking.

2. **Chaining can be an effective method for selectively removing a desired density and age class of trees**. Chaining is a technique that can be used to maintain selected trees, if desired. The amount or number of trees removed can easily be regulated by widening or narrowing the operating distance between the crawler tractors, or changing speed or direction of operation. The weight or size of the chain used and the number and position of swivels located in the chain can also be used to regulate the extent of tree removal. Different types of equipment are not required to effectively treat highly variable site conditions. Prior to chaining, the area can be inventoried and a chain of appropriate size and length can be selected to treat most all circumstances. Once a chain size is selected, operational procedures can be developed to assure proper treatment is attained on all sites. Hula dozing or cutting of individual trees also provides considerable flexibility, but costs and treatment time are normally prohibitive and number of acres treated per day is low and most treated areas still have to be properly seeded.

Chaining can be very site specific, and can easily be regulated to specific community types, aspects, or acreage. Compared with burning, this practice can be specifically targeted to desired sites including small, irregular tracts. The degree of tree removal using chemical sprays or burning is difficult to control. Areas treated with either of these practices normally result in complete removal of all vegetation, although stands or patches may be left that are untreated. However, it is much more difficult to remove only a certain fraction of the trees without also affecting the understory by burning or chemical spraying.

Since chaining can be conducted during almost any season, the extent of trees or understory removed can somewhat be regulated by treatment dates and condition of the soil and vegetation. Chaining, during early winter, when plants are brittle and snow covers the understory, generally results in removal of trees and some shrubs, including big sagebrush, without damage to understory herbs. Chaining, during the growing season when woody species are more flexible, normally leaves more shrubs undamaged. Chaining late in the growing season, when soil moisture has been depleted, results in more complete uprooting of trees, than if sites are chained in early spring.

Chains with attached swivels and couplings are available to most public agencies and private users. Transportation and set up costs can be quite variable. Individual chains require little maintenance and repairs are very infrequent.

Compared with other machinery, repair costs are minimal and little investment is needed for tools or items to support chaining.

3. **Chaining can provide adequate seedbeds for many species and is a technique that can be used to cover seed on diverse sites**. Various practices used to control trees—spraying, burning, hula dozing, and hand cutting do not prepare a seedbed nor aid in actual seeding. Chaining can, however, prepare satisfactory seedbeds on steep, irregular, even and uneven terrain, and on critical watershed sites. Under normal chaining conditions, suitable seedbeds are created to plant seeds of a number of species, having different seedbed requirements. The chain creates numerous micro sites and allows for shallow or deep planting depths. In addition, seeds can be broadcast before or after chaining, to achieve the desired planting depth, surface compaction, and stand establishment. Planting before or after chaining will have an influence on which species may initially establish, and ultimately become prominent in the plant community.

Natural seeding of a selected native species can be promoted when chaining is conducted following seed production. Chaining also promotes sprouting of some species, and if done at the correct season favors their recovery and spread. Chaining can also be scheduled to diminish or control the spread of weeds. If understory herbaceous weeds occur, chaining can be completed in the early summer prior to weed seed maturation. At this date, good control of the trees can be achieved without planting weed seeds.

Chaining and seeding can be conducted at the most appropriate season favoring establishment of the planted species. Fall seedings over the majority of the Intermountain west has proven to be the most ideal time to seed. Where spring seedings are employed, they need to occur prior to mid-March. In southern Utah, southern Nevada, and northern Arizona, seeding just prior to the mid-July summer storms has resulted in good success.

A uniform seedbed can be prepared with chaining even on rough, steep, and irregular sites. Few sites are left untreated with chaining where weeds may gain control. Attaining uniform and competitive stands on irregular terrain and variable soil conditions is extremely difficult with most conventional seeding practices. Chaining produces the most uniform stands on poorly accessible sites of any technique now available.

Although burning or spraying can be used to control tree competition, an additional technique is needed to prepare a seedbed and to plant desirable seeds. Seeds may be broadcast on fresh burns or sprayed sites, however most all species require some degree of seed coverage. Seeds of many desirable species must be incorporated into the soil, others do best surface seeded on disturbed soil. Chaining provides all degrees of coverage, resulting in the establishment of a diversity of species. Chaining will favor soil moisture accumulation. The practice can be accomplished without seriously disturbing the soil and causing the surface to dry rapidly. Litter is retained on site to protect and enhance the seedbed. Chaining and seeding can be accomplished when sites are bare or covered with snow, without accelerating runoff and loss of moisture. Although some land managers fail to recognize the importance of having seed in the ground at specified periods when soil moisture is most favorable, this is one of the most critical issues determining planting success. Chaining offers a seeding option to quickly and effectively treat small and large divers sites.

Removing trees from steep mountain slopes with fire and spraying can create excessive runoff and soil erosion unless additional practices are used to stabilize the soil. In contrast, chaining will improve ground cover, retains and detains surface moisture, increases amount of infiltration, reducing runoff and providing a stable seedbed and watershed. With chaining, no additional treatments are required to assure site stability.

4. **Chaining can have minimum impact on resource values**. Any plant conversion or regulation practice can impact a number of wildland resources. Most revegetation or restoration measures should be designed to remove existing weedy species and reestablish natural plant succession. Removal of existing weedy trees creates an abrupt and often dramatic change in plant density, structure, and age class. Recovery of the native species can frequently take many years to provide a visible mature assembly of plants. During the recovery period the impacts can be quite apparent. When properly done, chaining will not degrade or destroy soil or watershed resources. It is a practice designed and modified to stabilize erosion and provide a desirable seedbed. The selection of an appropriate treatment practice should be based on the desirable impacts imposed on all resource values. Because of depleted understory and erosion, potential seeding of desirable adapted compatible species is most often required.

Seeding

The majority of juniper-pinyon chaining and fires in the Intermountain west have been aerially seeded. If double chaining is employed, seeding should occur before the final treatment. The final chaining normally provides good seed coverage. Seeding should occur prior to the chaining when one-way chaining is employed. Aerial broadcasting using a fixed-wing aircraft and helicopters is used to distribute seed on areas that have been chained. Planting success is usually dependent upon time of seeding, seedbed conditions and thoroughness of seed coverage.

Aerial seeding can seed large acreages in an extremely short period. Large revegetation projects can often be more successfully seeded using aerial techniques and chaining than drill seedings, as planting can be completed during short planting periods or windows when seedbed and weather conditions are most favorable. Aerial seeding can be conducted when wet soil conditions hamper drilling. Drill seeding occurs at a much slower rate than does aerial seeding. Many times it is impossible to physically get over large acreages during various seeding periods with drills. This can result in considerable acreages being seeded out of season or totally omitted. With aerial broadcasting, seeding can be delayed until late fall or early winter, and then seeded in a relatively few days and covered with chains, rails, or cable scarifiers.

Aerial seeding is also an effective method of seeding different seed mixtures on specific sites. Areas that support distinct and different plant communities like riparian areas can be easily defined and planted separately from adjacent sites.

Helicopter seeding is usually selected over fixed-wind aircraft if highly irregular shaped sites and variable terrains are seeded and when air strips are unavailable. Effective seeding of right-of-way, fence lines, steep slopes, small areas, rough rocky terrains, riparian drainage, and specific species placement can be accomplished with helicopters.

Down draft and wind can cause seeds of different species to dissipate and fall separately, sometimes creating differences in stand composition and density. Variation in seeding and establishment is often advisable allowing for natural succession and spread of desirable species.

Where downed trees and debris does not interfere, seed can also be covered successfully using drags or a pipe harrow. Single disk harrows, or similar light machinery, can also be used to cover seed in open debris, free areas. Care must be taken to ensure that seeds are not covered too deep and seedbeds are not too loose.

Rangeland, or similar type drills can be used to seed many species on open areas. Again, care should be taken to ensure that seeds are properly covered. As a general rule, most seed should not be covered more than three times their own thickness, or to a depth of $\frac{1}{4}$ to $\frac{3}{8}$ inch. Some species do, however, require seeding on a disturbed soil surface.

Seeds that are in short supply or those that should be seeded in a firm seedbed can be seeded with a Hansen seed dribbler or thimble seeder mounted on the deck of a crawler tractor. These two seeders allow seed to be metered out onto the crawler track, then embedded in the soil by the tractor's weight.

Late fall until midwinter (October through January) is the preferred planting period. Seeding should not be attempted in frozen ground. Seedings should only occur when seed can be properly covered. Delaying seeding until late fall or midwinter can reduce seed depredation by rodents and birds. Fall and winter plantings provides adequate time for stratification of planted seeds, and ensures that seed is in the ground when temperature and soil moisture conditions are most favorable (early spring) for germination and seedling establishment.

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References

Farmer, M. E.; Harper, K. T.; Davis, J. N. 1998. These Proceedings. The influences of anchor- chaining on watershed health in a juniper-pinyon woodland in central Utah.

Roundy, B. A.; Vernon, J. L. 1998. These Proceedings. Watershed values and conditions associated with pinyon-juniper communities.

Stevens, R. 1998. These Proceedings. Restoration of native communities by chaining and seeding.

Stevens, R.; Monsen, S. B. In Press. Pinyonjuniper. In: Monsen, S. B.; Stevens, R., eds. Restoration and revegetation of western ranges and wildlands. U.S. Department of Agriculture, Forest Service, Gen. Tech. Rep.

Vallentine, J. F. 1989. Range development and improvement, 3rd ed. San Diego, CA: Academic Press Inc. 524 p.

Wilcox, B. P. 1994. Runoff and erosion in intercanopy zones of pinyon-juniper woodlands. Journal of Range Management 47:285-295

Wood, M. K. 1988. Rangeland vegetation-hydrologic interactions. In: Tueller, P.T., ed. Vegetation science applications to rangeland analysis and management. Boston, MA: Kluwer Academic Publishers. 469-491 p.

Wood, M. K.; Javed, N. 1994. Hydrologic responses to fuelwood harvest and slash disposal in a pinyon pine and juniper dominated grassland. Trends in Hydrology 1:179-190.

Restoration of Native Communities by Chaining and Seeding

Richard Stevens

Abstract—With the use of proper equipment, techniques, seeding, and management, native communities can be restored. Reduction in competitive weedy tree density is essential in community restoration. Where sufficient understory exists, seeding may not be necessary. In most areas some degree of seeding is required. Species should be seeded that are adapted to site conditions, are ecologically adapted and are compatible with on site endemic and seeded species. Consideration has to be given to seedbed and seeding requirements of each seeded species. Native communities can be restored when endemic species are given every opportunity to express them self and when native seeded species are provided maximum opportunity to germinate, establish, and become an active component of the community.

Juniper-Pinyon communities have been in a consistent state of flux for the past 100 years. From the late 1800's to the present, distribution and density of pinyon and juniper and accompanying native understory has been significantly altered. A majority of the juniper-pinyon stands in the Great Basin prior to settlement were confined to selected areas, and supported a diverse understory of perennial grasses, forbs, and shrubs. Fire, combined with perennial understory competition, controlled the spread and thickening of existing juniper-pinyon stands. The understory vegetation controlled or regulated the incidence and spread of fires, which, in turn, regulated the presence and distribution of juniper and pinyon (Tausch, this Proceedings; West, this Proceedings; Gruell, this Proceedings; Gottfried and others 1995). Heavy grazing by livestock over many years has resulted in community changes and the eventual loss of the native perennial understory and, in some locations, establishment of exotic annuals that now dominate some understories. These changes have resulted in lost or damaged archaeological sites (Chong 1993), reduction in deer and elk numbers (Short and McCullock 1977; Suminski 1993) and degredated watersheds (Roundy and Vernon, this Proceedings).

Adjoining semiarid grass and shrublands underwent similar changes as desirable perennial species were eliminated or reduced in density and vigor by grazing. The loss of dominant perennial grasses and other understory species, and resulting absence or reduction in fire incident allowed for an increase in juniper and pinyon trees, and substantial tree invasion into many adjoining grass and shrublands (Aro 1975; Tausch, this Proceedings; West, this Proceedings; O'Brien and Woudenberg, this Proceedings).

Removal or controlled use of livestock from depleted juniper-pinyon dominated areas will not facilitate the recovery of native vegetation, stabilize the soil, or return these areas to their pre-settlement conditions (Goodloe 1993; Stevens and Monsen, In press). Principle reasons are the absence of an adequate seed source and the competitive attributes of the pinyon-juniper trees. In order to return many juniper-pinyon areas to a more natural state, tree competition has to be reduced, a suitable seedbed has to be created, and sites will need to be properly seeded to adapted compatible species.

Chaining

Native communities can only be reestablished if the density of pinyon and juniper is reduced and desired native species have an adequate seed bank or are seeded. Changes in tree density can range from near complete stand removal to limited thinning. Chaining and other mechanical treatments used to reduce tree density are substitute methods of natural tree control most frequently attained by wildfires. The objective of most improvement projects should not be to remove all trees, but to remove sufficient numbers to allow recovery of the understory species and to facilitate artificial seeding (Stevens and Monsen, In press). Tree removal, by whatever means is simply a technique used to change the seral status of many sites.

Removal of undesirable, competing weedy trees can be accomplished in a number of ways. Twice-over anchor chaining, with 90 lb links, in opposite directions has been used extensively. Use of cable or a chain of lighter links is satisfactory where it is desired to leave more trees and most shrubs. Once-over chaining may be adequate when sufficient understory remains, and trees are sparse and mature, and seeding is not required. Cabling is less effective than chaining in removing trees, but it disturbs less understory. There are three basic types of chain; smooth, Ely, and Dixie sager (Stevens, this Proceedings).

Anchor chains are pulled behind two crawler tractors traveling parallel to each other. For maximum tree removal, chains cannot be dragged while stretched taught, but must be dragged in a loose, J-shaped, U-shaped, or half-circle pattern. The half-circle configuration provides the greatest swath width and lowest percentage tree kill. It is primarily used in mature, even-aged stands and when a low percent tree kill is desired. Tree kill increases as the width of the J or U-shaped pattern decreases. As the proportion of young trees change in a stand, chaining width should increase or decrease in order to achieve the desired amount of tree kill.

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Chaining can be effectively used to regulate or manipulate a community without destruction of understory species. Chain link size, modifications to links, and placement of crawler tractor will determine disturbance severity to understory species. Types and size of chain and chaining practices can be regulated to retain most all existing species including threatened and endangered species, yet sufficiently reduce tree competition to facilitate seeding or promote natural recovery of understory species. Native seedbanks are not harmed by appropriate chaining.

Not all juniper-pinyon sites support similar composition of understory species. A variety of herbaceous and woody plants exists in different amounts depending on degree of depletion, community site, and climatic conditions. Species composition of juniper-pinyon communities may be altered to a different seral status with and without the introduction of species attained by seeding. In some situations, juniper-pinyon woodlands can be converted by only burning or chaining to reduce tree density. This is possible if sufficient native understory composition and density exists, and is capable of recovery following treatment (Jacobs and Gatewood, this Proceedings).

Seeding

Juniper-pinyon sites that have been void of understory species for many years will most likely lack a sufficient seedbank and natural recovery will not occur even if trees are removed (Poulsen and others, this Proceedings). Understory shrub and herbaceous species that have been weakened by heavy grazing and competition from tree encroachment normally bears very little seed, and may persist for years before eventually succumbing. Under these conditions, undisturbed stands of juniper-pinyon may exist for many years with little understory seed being added to the natural seedbank. Removal of competitive trees on many sites will result in a slow, erratic recovery of associated native species. Unless sites are artificially seeded, natural recovery is often ineffective. Without sufficient understory, exotic weeds can become established and dominate the area.

Juniper-pinyon restoration programs should be designed to allow for restoring native vegetation, and create stable communities. Converting juniper-pinyon communities to only an assembly of foreign species is not advisable.

Under normal chaining conditions, suitable seedbeds are created to plant seeds of a number of species, having different seedbed requirements. The chain will create numerous micro sites and allow for shallow or deep planting depth requirements. In addition, seeds can be broadcast before or after chaining, to achieve the desired planting depth, surface compaction, and stand establishment (Stevens and Monsen, In press).

Natural seeding of targeted native species can be promoted when chaining is conducted following seed production. Chaining also promotes sprouting of some species, and, if done at the correct season, favors their recovery and spread. Chaining and seeding can be conducted at the most appropriate season favoring establishment of the planted species. Fall seeding, over the majority of the Intermountain West, has proven to be the most ideal time to seed. Where spring seedings are employed, they need to occur prior to mid-March. In southern Utah, southern Nevada, and northern Arizona, seeding just prior to the mid-July summer storms has resulted in good success (Stevens, this Proceedings).

A majority of juniper-pinyon chainings and fires in the Intermountain West have been successfully aerially seeded. Most grasses and forbs and small seeded shrubs such as sagebrush, and rabbitbrush can be seeded successfully with both fixed-wing aircraft and helicopter. Helicopters generally do a better job of distributing seed over small or irregular areas. Downdraft from helicopters can somewhat separate seed in a mix by size and weight. There is a tendency for lighter seed to drift to the outer edge. When downed trees do not interfere, seed can also be covered successfully using drags or a pipe harrow. Single disk harrows, or similar light machinery, can also be used to cover the seed in open debris-free areas. Care must be taken to ensure that seeds are not covered too deep and seedbeds are not too loose. Chaining, or equivalent treatments, are required to cover seed when burned sites are broadcast seeded. When this does not occur, seeding is best done on top of the first snow over disturbed soil, results may, however, be erratic.

Rangeland type drills, especially those with multiple seed boxes and planting depth capabilities can be used to seed many species on clear large open areas. Seeds that are in short supply or those that require a firm seedbed can be seeded with a Hansen seed dribbler or thimble seeder mounted on the deck of a crawler tractor. Seed is metered out onto the crawler tracks, the seeds are embedded in the soil by the tracks. When seeding species with very different seeding requirements, more than one seeding procedure may be required. Many species can be aerially seeded and then planted by chaining. Following chaining, the surface seeded species can then be aerially broadcast seeded.

Chaining can be the first essential action in reestablishing native communities. The second essential action is properly seeding adapted, compatible species that will lead to community restoration. Some native species have been seeded for years, however, the number of native species seeded and pounds of seed seeded has generally been less in comparison to the seeding of exotic species.

Following are a number of reasons or excuses given for not seeding natives more extensively:

1. Little or no desire to seed natives. This is very common with individuals that are single resource oriented and those that are comfortable with doing business as they always have.

2. Seed of few native species are available. People have perceived this and used it as a problem for years, however, seed of more and more native species are becoming available. Utah Division of Wildlife and U.S. Forest Service have put considerable effort into selecting native species and into promoting and developing native seed sources for restoration seedings (McArthur and Young, this Proceedings). Species being selected and promoted today include:

Bluebunch wheatgrass
Sheep fescue
Prairie junegrass
Mutton bluegrass
Sandberg bluegrass
Mountain bluegrass
Needle-and-thread
Thurber needlegrass
Bottlebrush squirreltail
Showy goldeneye

Table 1—Number of native species seeded by Utah Division of Wildlife Resources, 1959 through 1996.

	Year					
Species	1959	1966	1979	1989	1995	1996
Grasses	0	4	6	9	11	16
Forbs	0	6	8	9	11	17
Shrubs	8	16	22	20	18	18
Total	8	26	36	38	40	51

In 1959, Utah Wildlife Resources seeded only eight different native species (table 1). In 1996 they seeded 51 native species.

Seed of a large number of native species is becoming available each year. A 1996 survey of all Utah seed companies with only five responses shows that seed of 113 native species were available and sold in 1996 (table 2). Species are being added yearly. Demand will determine the availability of native seed.

3. Native seed is unavailable in sufficient volume. With some planning, this should not be an excuse or problem. Natives are becoming more available every year. Table 2 shows that 530,816 lb of native seed was sold by only five of Utah's 13 seed companies in 1996. Seed is available or will be available if there is a consistent demand. Amount of native seed seeded has increased significantly through the years. Utah Division of Wildlife Resources has moved from where native seed only accounted for less than 5 percent of the seed seeded in 1959 to over 47 percent in 1995 (table 3). In order for an agency to do this, they need to; a) develop a native attitude, b) plan ahead at least one season in advance so that basic seed needs are known, c) order seed ahead so that seed companies have sufficient time to acquire the seed, d) have a seed warehouse program and adequate seed inventory, e) manage lands for seed production, and f) develop and implement seed collection permits and regulations that will allow for obtaining sufficient seed at a desirable price.

4. Native species do not produce sufficient quantity of forage. If a manager's objectives are truly multiple resources and community and ecological restoration, then volume of livestock forage production will not be a major governing factor. It is not uncommon for the total production of a complete community to be equal to or exceed that of a few species seeding. Communities will have longer succulent periods, and respond more positively to fire and variations in precipitation, insects, and diseases than will few species seedings.

5. Natives are difficult to establish. Natives may be somewhat harder to establish if they are not properly seeded. Most exotic grasses and forbs were agronomically selected. As such, they respond well to agronomic seeding requirement. Many managers try to employ exotic species seeding requirements on native and fail. Native species have evolved with differing seeding requirements, some have evolved with the seed being buried deep and others do best when seed is surface seeded on disturbed bare ground. Some species do best seeded in litter, where others establish best in bare ground. Seeding techniques have to match seeding requirements.

Table 2—Pounds of native seed sold in 1996 by five Utah seed companies.

Grasses	Pounds of seed sold
Bluegrass, Sandberg	1,144
Bluegrass, Sherman big	2,500
Brome, mountain	19,202
Dropseed, sand	950
Fescue, Idaho	123
Fescue, sheep	9,950
Foxtail, meadow	1,202
Galleta	1,150
Grama, blue	300
Grama, sideoats	2,000
Hair-grass, tufted	110
Junegrass, prairie	105
Needle-and-thread	620
Needlegrass, green	2,865
Needlegrass, Letterman	210
Redtop	10
Ricegrass, Indian	11,555
Sacaton, alkali	2,000
Squirreltail, bottlebrush	7,685
Three-awn, purple	100
Timothy, alpine	200
Wheatgrass, bluebunch	9,552
Wheatgrass, slender	14,400
Wheatgrass, Snake River	15,000
Wheatgrass, streambank	11,850
Wheatgrass, thickspike	27,305
Wheatgrass, western	23,616
Wildrye, beardless	100
Wildrye, Great Basin	22,522
Total	188,326
Forbs	
Aster, blueleaf	356
Aster, Engelmann	20
Aster, Pacific	410
Balsamroot, arrowleaf	625
Balsamroot, cutleaf	140
Beeplant-spiderflower	3,200
Columbine	50
Cowparsnip	70
Eriogerons	300
Eriogonums	100
Fairwell to spring	100
Flax, Lewis	3,965
Gallardia	80
Geranium, sticky	10
Gilia	2
Globemallow, desert	900
Globemallow, gooseberryleaf	360
Globemallow, munro	500
Globemallow, scarlet	60
Goldeneye, showy	530
Helianthella, oneflower	60
Ligusticum, Porter	20
Louisiana sage	115
Lupine, desert	58
Lupine, mountain, silky, silver	2,681
Marigold, desert	100
Mulesear	140
Paintbrush, Indian	10

(con.)

Table 2 (Con.)

Grasses	Pounds of seed sold
Forbs	
Penstemon, Eaton-firecracker	40
Penstemon, Palmer	2,010
Penstemon, Rocky Mountain	500
Penstemon, Rydberg	140
Penstemon, thickleaf	20
Penstemon, Wasatch	220
Poppy, California	2,000
Poppy, Iceland	100
Sunflower, common	5,900
Sweetanise	490
Sweetvetch, Utah-northern	597
Yarrow, western	8,443
Total	35,422
Shrubs	
Bitterbrush, antelope	6,047
Bitterbrush, desert	900
Buffaloberry, roundleaf	45
Buffaloberry, silver	10
Chokecherry	785
Cliffrose	802
Currant, golden	80
Currant, wax	120
Dogwood, redosier	50
Elderberry, blue	400
Elderberry, red	150
Ephedra, green	1,605
Ephedra, Nevada	1,255
Eriogonum, Wyeth	10
Greasewood	955
Hopsage, spiny	180
Mahogany, curlleaf mountain	605
Mahogany, true mountain	830
Rabbitbrush, Douglas	2,200
Rabbitbrush, low	1,600
Rabbitbrush, mountain rubber	5,350
Rabbitbrush, white rubber	11,765
Rose, Woods	2,200
Sagebrush, black	405
Sagebrush, silver	150
Sagebrush, basin big	20,230
Sagebrush, fringed	560
Sagebrush, mountain big	22,522
Sagebrush, sand	200
Sagebrush, silver	400
Sagebrush, Wyoming big	120,000
Saltbush, Quail	100
Saltbush, fourwing	76,350
Saltbush, Gardner	4,200
Saltbush, mat	310
Saltbush, shadscale	14,250
Serviceberry, Saskatoon	347
Serviceberry, Utah	675
Snowberry, mountain	810
Sumac, Rocky Mountain	350
Sumac, skunk bush	1,820
Winterfat	5,445
Total	307,068
Grand Total	530,816

Table 3—Percentage of Total Pounds Seeded of Native and Introduced Species by Utah Division of Wildlife Resources; 1953-1996.

Species	Year					
	1959	1966	1979	1989	1995	1996
Natives	5	24	38	46	47	40
Introduced	95	76	62	54	53	60

There are native species whose seed viability lasts only a few days and others that retain good viability for 30 plus years. Seed dormancy, afterripening and need for scarification varies between species. These all need to be considered when seeding natives.

Poor establishment is generally a result of poor action and management rather than species and seed characteristics. There is a great need for managers to not do things as they have always done them, but rather to gain new knowledge and experience and move forward into community restoration and sound ecological management. Good establishment occurs where seed is given every opportunity to germinate and establish.

Successful native seedings occur:

1. On sites where competition has been reduced sufficiently to allow for successful establishment of seeded species and recovery of on site endemic species.
2. When species are seeded that are adapted to the site conditions.
3. When species that are compatible with each other and with endemic on site species are seeded.
4. When species are seeded into the ecological nitch they are most adapted. One cannot expect a late seral species to do well on a disturbed site. Pioneer species will establish and perform better on disturbed sites than will late seral species.
5. When seed is planted in the proper season. Late fall and early winter are the most preferred time to seed. One needs to ask the question; when and how does each native species naturally seed and establish the most successfully?
6. When seed is properly placed in the soil. Species seeding requirements vary between species. The most ideal seeding location and depth can range from surface to 3 to 4 inches deep, in a firm to loose seedbed and in or under litter or on exposed soil.
7. When the right equipment and techniques are used to prepare the seedbed and to plant the seed.
8. When on site endemic species are given every opportunity to express them self. Site preparation and seeding equipment and techniques need to favor the desirable endemic species rather than eliminate or harm them.

Native communities can be restored through a combination of proper community management practices and proper seeding of compatible species ecologically adapted to the site and endemic communities.

Acknowledgments

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References

Aro, R. S. 1975. Pinyon-juniper woodland manipulation. In: Gifford, G. H.; Busby, F. E. eds. The pinyon-juniper ecosystem: A symposium. 1975 May; Logan, UT. Utah State University: 67-75.

Chong, Geneva. 1993. Revegetation of pinyon-juniper woodlands with native grasses. In: Aldon, Earl F.; Shaw, Douglas W., technical coordinators. Managing pinyon-juniper ecosystems for sustainability and social needs; proceedings of the symposium. 1993 April 26-30; Sante Fe, New Mexico, Gen. Tech. Rep. RM-236. Fort Collins, Co: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 34-41.

Goodloe, Sid. 1993. The pinyon-juniper invasion: an inevitable disaster. In: Aldon, Earl F.; Shaw, Douglas W., technical coordinators. Managing pinyon-juniper ecosystems for sustainability and social needs; proceedings of the symposium. 1993 April 26-30; Sante Fe, New Mexico, Gen. Tech. Rep. RM-236. Fort Collins, Co: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 153-154.

Gottfried, G. J.; Swetnam, T. J.; Allen, C. D.; Betancourt, J. L.; Chung-MacCoubrey, A.L. 1995. Pinyon-juniper woodlands, Chapter 6. In: Finch, D. M.; Tainter, J. A., eds. Ecology, diversity and sustainability of the middle Rio Grande basin. Gen. Tech. Rep. RM-268. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station .

Gruell, G. E. 1998. These Proceedings. Historical and modern roles of fire in pinyon-juniper.

Jacobs, B. F.; Gatewood, R. G. 1998. These Proceedings. Restoration studies in degredated pinyon-juniper woodlands of north-central New Mexico.

McArthur, E. D.; Young, S. A. 1998. These Proceedings. Development of native seed supplies to support restoration of pinyon-juniper sites.

O'Brien, R. A.; Woudenberg, S. W. 1998. These Proceedings. Distribution of pinyon-juniper woodlands in Utah and Nevada from an inventory perspective.

Poulsen, C. L.; Walker, S. C.; Stevens, R. 1998. These Proceedings. Soil seed banking in pinyon-juniper with differing levels of tree cover, and understory density, and composition.

Roundy, B. A.; Vernon, J. L. 1998. These Proceedings. Watershed values and conditions associated with pinyon-juniper communities.

Short, H. L.; McCulloch, C. Y. 1977. Managing pinyon-juniper ranges for wildlife. Gen. Tech. Rep. RM-47. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 10 p.

Stevens, R. 1998. These Proceedings. Mechanical chaining and seeding.

Stevens, R.; Monsen, S. B. In Press. Pinyon juniper. In: Monsen, S. B.; Stevens, R., eds. Restoration and revegetation of western ranges and wildlands. U.S. Department of Agriculture, Forest Service, Gen. Tech. Rep.

Suminski, Rita R. 1993. Management implications for mule deer winter range in northern pinyon-juniper. In: Aldon, Earl F.; Shaw, Douglas W., technical coordinators. Managing pinyon-juniper ecosystems for sustainability and social needs; proceedings of the symposium. 1993 April 26-30; Sante Fe, New Mexico, Gen. Tech. Rep. RM-236. Fort Collins, Co: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 133-139.

Tausch, R. J. 1998. These Proceedings. Transition and thresholds: influences and implications for management in pinyon and juniper woodlands.

West, N. E. 1998. These Proceedings. Distribution, composition, and classification of current juniper-pinyon woodlands and savannas across western North America.

Thinning Versus Chaining: Which Costs More?

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Abstract—In 1990, 320 acres of pinyon-juniper were chained as part of a big game winter range improvement project in Spanish Fork Canyon. Areas were double-chained: units were chained in one direction, seed was broadcast aerially, and the units chained in the opposite direction. In conjunction with the chaining, 40 acres were thinned and seeded with the same mix in order to compare implementation costs and results between the two treatments. Trees were dragged and hand-piled in drainage ways and seed was raked into the soil so as to better simulate the effects of chaining. Per-acre cost for thinning was considerably greater than for chaining.

During the mid to late 1980's local wildlife biologists became concerned by the rate at which critical winter range for mule deer and elk was being lost to the recent growth of communities along the Wasatch Front. As development encroached onto these areas, big game began to overuse the range still available to them. Wildlife biologists looked to nearby Spanish Fork Canyon for opportunities to improve early spring/late fall transitional range, as well as critical winter range in order to relieve pressure along the Front. It was decided that creation of small openings in dense pinyon-juniper stands would produce a mosaic-like effect, increasing forage and browse while maintaining adequate cover. Partners in the project believed that chaining was the most economical way to accomplish this. A thinning was performed as a comparison to chaining in order to determine which treatment was the most cost effective. Costs are evaluated and results compared between the two treatments.

Methods

Chaining

In the fall of 1990, 320 acres of pinyon-juniper woodland scattered over five square miles were doubled chained and reseeded. The 11 units range in size from 20 to 60 acres. Each unit was chained once, after which seed (a mixture of grasses, forbs and shrubs) was applied aerially, then chained again in the opposite direction. Browse species, having a relatively large seed, were applied with dribblers mounted on the dozers. All forb and grass species as well as small-seeded shrub species, were applied aerially. A 290-foot smooth anchor chain was pulled with two D-9 dozers. Great care was taken to assure a varied and natural looking edge effect as well as to minimize the amount of open space away from the edge. Many islands, drainage bottoms and ridgetops were left unchained for use as cover and travel routes. Large and mature pinyon pine and mountain mahogany were also left unchained in order for natural reseeding to occur.

Thinning

During the spring of 1991, 40 acres of the same pinyon-juniper woodland was seeded and thinned as one unit. Grass and forb seeds were broadcast by hand prior to the treatment. It was believed that the seed would be buried during the thinning through the activities of workcrews. The Flame In Goes firecrew (Utah Department of Corrections) utilized chainsaws to thin the area, removing 25-40 percent of the stems per acre. The downed trees were then "lopped and scattered" with some trees being thrown into gullies to slow runoff and soil erosion. Once the thinning was complete, bitterbrush seeds were planted by hand. The unit was laid out so that the edge was varied and adequate travel routes were protected. The treatment protected healthy pinyon pine as well as valuable browse species like mahogany, oak, bitterbrush and sagebrush.

Seed Mix

Both treatment areas were seeded with the same mix in order to compare results between the two treatments. The seed mix was chosen for its ability to provide the quantity and quality of forage required to support big game during critical time periods, as well as provide food for a variety of small game and non-game species. Included in the mix were species known to establish quickly, in order to rapidly provide ground cover and readily bind soils to reduce erosion. The seed mix contained a variety of grasses, forbs and shrubs to mimic plant communities currently present on the site without using more than 50 percent non-native species.

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The seed mixes used were:

Broadcast Mix
- Intermediate wheatgrass
- Hard sheep fescue
- Tall fescue
- Western wheatgrass
- Big bluegrass
- Basin wildrye
- "Regar" brome
- Crested wheatgrass
- Orchardgrass
- Blue lewis flax
- Palmer penstemon
- Small burnett
- Ladak alfalfa
- Yellow sweetclover
- Low elevation mountain big sagebrush
- White stemmed rubber rabbitbrush

Dribbler Mix
- Antelope bitterbrush
- True mountain mahogany
- Curlleaf mountain mahogany
- Fourwing saltbush
- Cicer milkvetch

In the thinned unit, only bitterbrush was planted. Seed was hand planted after thinning activities were completed.

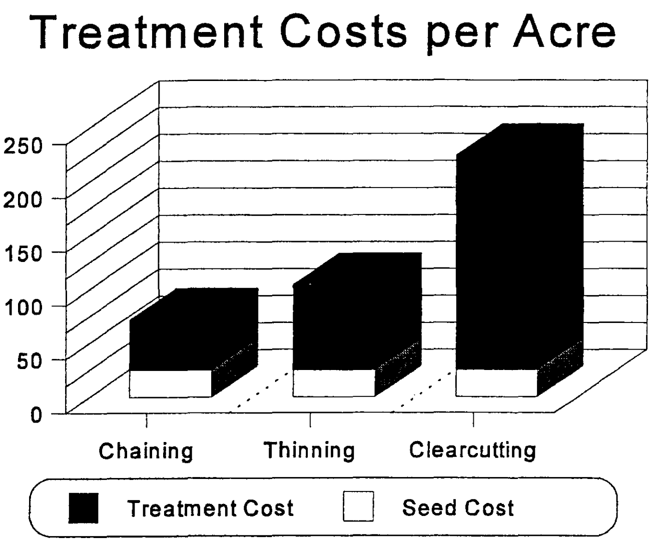

Figure 1—Comparison of costs of three techniques (chaining, thinning and clearcutting) to create small openings in pinyon-juniper woodland. Values shown include only direct implementation costs (materials, labor, contracts and supervision) and represent actual costs in 1990-1991. Costs for clearcutting were extrapolated from thinning costs.

Results

Costs

The economics associated with each treatment were evaluated on a per acre basis, taking into consideration costs of the actual treatment, application of seed, and on-site supervision. The cost for thinning was found to be 44 percent greater than for chaining (fig. 1). It is important to note that figures represent only direct treatment costs. Costs for planning and layout and general administration (for example, resource identification and classification, interagency cooperation, environmental analysis, and monitoring) are not included. These costs represent a real and often large expense, but would be similar for each so are not presented here. Figures presented represent costs in 1990 and have not been adjusted to reflect inflation.

Chainings

Prior to treatment, units were dominated by pinyon-juniper and bare soil. Seven years after treatment total ground cover on the site had increased from 47 percent (prior to treatment) to 80 percent. Forage production within the chained unit increased from <20 lbs per acre in 1990 to approximately 1000 lbs per acre in 1997 (USDA Forest Service 1997).

Thinning

Thinning did not create an effective seed bed or provide for adequate seed burial. Mechanical means should be employed to create a seed bed and cover the seed, introducing additional costs to the treatment.

The effects of thinning seem to be dependent upon opening size. Increases in vegetative cover were only observed where larger openings were created. Opening size must be controlled by close supervision of thinning crews or extensive marking of the treatment areas, which increases the cost of the treatment.

The opening size also effects the overall amount of acres treated and the lifespan of the treatment. Retreatment of the area would need to be completed sooner, at yet another cost to the overall project.

Clearcutting

Although a clearcut was not completed, figure 1 shows the cost estimate for this treatment. In order to evaluate clearcutting, costs were extrapolated from the cost of the thinning. The thinning in Spanish Fork Canyon removed, on average, 33 percent of the stems per acre. Assuming that a clearcut (removal of 100 percent of the stems) would require three times more work than the thinning, the cost of this treatment is estimated to be 3-times the cost of thinning, or nearly 4 times the cost of chaining.

Conclusion

The intent of the Spanish Fork Canyon big game winter range enhancement project was to increase the quantity and quality of the forage available to big game animals during transition periods and critical winter months. The creation of openings in pinyon-juniper stands was needed to increase forage and browse production while maintaining cover. Two treatments were applied to the degraded habitat in order to compare the cost efficiency and benefit of each. Chaining seemed to provide an adequate seed bed and sufficient seed burial, which resulted in increased forage production. Thinning did not prepare an adequate seed bed or provide sufficient seed burial, and results were unsatisfactory. It is important to note that the costs and benefits can vary with soil type, tree density, and topography and many other local factors. However, chaining was more effective than thinning in meeting the goals for the Spanish Fork Canyon winter range enhancement project and at a much lower cost.

Acknowledgments

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Reference

USDA Forest Service. 1997. Unpublished data. Uinta National Forest, Provo, UT.

Advantages and Effectiveness of Rollerchopping

Douglas Sorensen

Abstract—Rollerchopping is a mechanical method, using a 12-foot wide drum encased with large blades, that can be used to remove trees for improvement of site productivity. Advantages of rollerchopping over other land-clearance methods include treating slash, creating aesthetic sites, leaving soil undamaged, and leaving selected strips, groups, or individual trees.

Thousands of acres of pinyon-juniper woodland have been treated by removing trees in order to increase the watershed qualities, produce livestock forage, and improve wildlife habitat. Typically, these areas were anchor chained and then seeded. Overtime, pinyon, juniper and sagebrush have again increased site dominance. For many of these sites, the ability to use fire as a treatment method is not feasible. Rollerchopping is an effective, relatively inexpensive mechanical method that can be used to again improve site productivity.

Rollerchopping can be done anytime the treatment site is accessible and the soil will not be damaged by mechanical action. Even light snows should not stop the treatment. As with any mechanical treatment the site should not be worked if excessive soil moisture is present that would adversely impact the soil structure or cause rutting. Unlike prescribed fire, treatment can be done during or immediately following grazing. There is no need to rest the area before treatment. Rollerchopping provides excellent control of pinyon, juniper and sagebrush in the treated area.

The treatment layout can be designed to leave strips, groups or individual trees. The roller is maneuvered easily between groups of trees or even leave selected individual trees. The only limitation is the working width of the roller. In areas where hiding cover, archeological sites or special habitats must be preserved, rollerchopping has big advantages over other mechanical methods.

In high visibility areas rollerchopping can provide irregular boundaries that are visually pleasing and enhance wildlife habitats and cover. Pinyon and juniper are able to out-compete the herbaceous vegetation for the limited water and nutrients on the site. The effect of rollerchopping on the vegetation is to crush and chop the brittle woody vegetation in order to allow the existing residual vegetation to increase its production. Because of the excellent seedbed preparation and water availability the site may be seeded to augment the existing plant composition and improve the site characteristics.

The rollerchopping treatment is very effective in treating slash. The treatment does not leave piles or concentrations of slash requiring later treatment. Crushing the woody material greatly improves the water retention and availability on the treated area. The litter cover will reduce or prevent overland flow and soil erosion. The water previously taken up by the trees is readily available for the grasses and forbs.

Desirable browse, such as bitterbrush, sagebrush or fourwing saltbrush can be avoided. Root sprouting species are rejuvenated by the roller. On some sites, it may be desirable to treat root-sprouting species.

The roller drum is 12 feet wide and 5 feet in diameter with steel blades 1 inch thick by 10 inches high and 12 feet long. The overall width is 14 feet. The roller weighs 16,000 pounds empty and can be filled with over 800 gallons of water. The replaceable blades will wear with use and must be replaced. These blades are typically the cutting blade used on some earth moving equipment.

The rollerchopping limitations are the standard working limitations of the tractor. As a rule, steep slopes should be avoided. Tree size is generally not a problem. The dozer will push over larger trees for the roller to crush and chop. Obviously, if a site has many large trees, anchor chaining would be the preferred treatment.

The working speed of the roller varies with site conditions such as slope, surface rock, and tractor horsepower. The roller should be able to travel at 2 to 3 miles per hour on most sites. At 3 miles per hour working speed, the roller can treat about 4.5 acres per hour. The cost of treatment varies from $25 to $30 per acre.

The grazing activity immediately before and following the rollerchopping treatment will greatly influence the response and long term productivity of the site. For maximum production and site improvement, rest the site from grazing at least 2 years following the treatment.

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Restoration Studies in Degraded Pinyon-Juniper Woodlands of North-Central New Mexico

Brian F. Jacobs
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Abstract—Small scale experiments were initiated in 1994, at two degraded pinyon-juniper (*Pinus edulis* Engelm. and *Juniperus monosperma* [Engelm.] Sarg.) woodland sites in north-central New Mexico, to evaluate the efficacy of restoration methodologies for reestablishment of native herbaceous cover. Results after three years post-treatment were highly significant: a primary, overstory reduction and slash mulching treatment produced two to sevenfold increases in total herbaceous cover relative to both controls and pre-treatment condition. Secondary, soil surface preparation and seeding treatments appeared to confer no significant benefits over the primary treatment herbaceous response.

Degraded pinyon-juniper (*Pinus edulis* Engelm. and *Juniperus monosperma* [Engelm.] Sarg.) communities occupy thousands of hectares within Bandelier National Monument and the adjacent Santa Fe National Forest in north-central New Mexico. These woodland areas were inhabited during prehistoric times by Puebloan Indians who left behind an abundance of cultural remains. Overgrazing, loss of a fire regime and drought during the last 120 years are thought to be causative factors of the overstocked and degraded nature of many woodlands in this area. As increasing tree cover supplanted herbaceous cover, savanna like communities were gradually transformed into closed woodlands. Older growth trees are common in many of these woodland areas, but tree reproduction less than 120 years old accounts for much of the observed density. Interspaces between trees are characterized by scant herbaceous cover and exposed, rapidly eroding soils. Rapid soil loss in these degraded pinyon-juniper communities is unsustainable and ultimately threatens the integrity of thousands of prehistoric archeological sites embedded in the cultural landscape of north-central New Mexico.

The current study was initiated in 1994 to evaluate the efficacy of potential methodologies for the restoration of degraded pinyon-juniper (*Pinus edulis* Engelm. and *Juniperus monosperma* [Engelm.] Sarg.) woodlands at Bandelier National Monument and on the adjacent Santa Fe National Forest. Specifically, we wanted to determine if a primary, overstory reduction and slash mulching treatment would yield a suitable herbaceous response and whether secondary, soil surface preparation and seeding treatments would enhance reestablishment of an effective ground cover.

Previous work by Chong (1994) at Bandelier National Monument and by land managers on the Santa Fe National Forest (Elson, pers. comm.) set the stage for the current study. Chong (1994) demonstrated the importance of favorable microsites in the establishment of herbaceous plants from seed on degraded pinyon-juniper sites. She also noted that without the addition of seed material, no new grass plant establishment was observed (Chong, 1994) suggesting a depleted soil seed bank. Santa Fe National Forest land managers have repeatedly observed robust herbaceous responses following fuelwood harvests in pinyon-juniper woodlands, particularly when follow-up efforts were made to thin out smaller diameter trees and scatter the resulting slash (Elson, pers. comm.; Loftin, 1998). While numerous studies have documented an herbaceous response to overstory thinning in pinyon-juniper systems (Arnold and Schroeder, 1955; Bledsoe and Fowler, 1992), it is important to assess the efficacy of restoration methodologies relative to specific site conditions and management objectives.

Intensive grazing pressures, beginning around 1880, are thought to have reduced continuity of fine grass fuels, effectively preventing fire from propagating in pinyon-juniper woodlands (Gottfried and others, 1995) as well as in adjacent plant communities (Allen, 1989). Although pinyon-juniper communities are generally poor recorders of fire occurrence, evidence of periodic fire in these systems is provided by charcoal deposits in the soil and fire scars on woody remains and living trees (Gottfried and others, 1995). In addition, excellent fire history data documenting recurrent fire events are available from Ponderosa Pine communities immediately adjacent (Gottfried and others, 1995; Touchan and others, 1994). We suggest fire was an important process in maintaining the former savanna like structure of pinyon-juniper communities in our area. The thinning effects of periodic fire prior to 1880 and the subsequent loss of a fire regime would account for the pattern of widely spaced, older growth trees within a now dense woodland matrix of a much younger age.

The loss of fire disturbance, initially as a result of overgrazing, and subsequently through active suppression (Gottfried and others, 1995), has had a profound influence on the dynamics of pinyon-juniper systems. Age class information from pinyon-juniper study sites in our area suggest an exponential increase in pinyon-juniper stem densities in former savanna areas beginning around 1880 (Allen, pers. comm.; Davenport and others, 1996; Gottfried and others, 1995;). Pinyon and juniper also expanded their ranges, with

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both species invading upslope into Ponderosa Pine dominated forests and juniper invading downslope into former shrub and grassland communities (Gottfried and others, 1995).

Active soil erosion on degraded pinyon-juniper sites during the last fifty years is clearly evidenced by exposed soils and bedrock, soil pedestals, lobes of active sediment and sediment accumulation behind fallen logs (Davenport, 1997). While previous episodes of erosion are documented in soil profiles from local pinyon-juniper sites (Davenport, 1997; Reneau, pers. comm.), the timing of the current erosional episode appears linked to historic landuse practices. In addition, an extended drought during the mid-1950's is thought to have intensified competition for water in overstocked woodlands, perhaps reducing herbaceous cover below thresholds necessary to contain erosional processes (Wilcox and Breshears, 1995; Wilcox and others, 1996a,b). Occasional trunk remnants of Ponderosa Pine from individuals killed during the 1950's drought can be found on both sites, but no live Ponderosa Pine is currently present within study site boundaries.

Intensive characterization of erosional processes in a one hectare portion of a degraded pinyon-juniper woodland at Bandelier (Wilcox and others, 1996a,b) suggest average annual soil losses of 10,000 to 20,000 kg/ha, most of it occurring during intense thunderstorm events typical of the summer monsoons. On the basis of both soil erosion bridge and sediment catchment data, soil loss within degraded pinyon-juniper communities at Bandelier can be conservatively estimated at 2.5 cm per decade; an unsustainable rate given shallow soils with average depths of 1.0 to 12.0 dm (Davenport, 1997; Davenport and others, 1996; Wilcox and Breshears, 1995).

Rapid soil loss in degraded pinyon-juniper communities threatens the integrity of the thousands of prehistoric cultural sites located within Bandelier National Monument. Well over three-quarters of the prehistoric sites at Bandelier National Monument occur within pinyon-juniper communities; of these cultural sites, nearly 99 percent have sustained erosional impacts (Mozzillo, in preparation).

Despite the cessation of intensive livestock grazing pressure around 1940, in Bandelier National Monument and on portions of the Santa Fe National Forest, degraded pinyon-juniper communities appear to have little capacity to recover. Repeated measures of herbaceous cover in ungulate exclosures established in 1975 on degraded pinyon-juniper sites at Bandelier, suggest exclusion of grazing alone is insufficient to promote recovery of these systems. (Chong, 1992).

Overstocked with young trees and lacking an effective ground cover, degraded pinyon-juniper systems are poorly equipped to manage limited soil and water resources. These degraded communities can yield significant amounts of runoff and sediment, at various scales, particularly from bare ground interspaces during high intensity summer thunderstorms (Wilcox and others, 1996a,b). Freeze-thaw action on exposed soils is thought to facilitate erosional processes, both by inhibiting new plant establishment through root shear effects and by creating light textured crusts vulnerable to the forces of wind and rain. Harsh physical site conditions, characterized by exposed, nutrient poor soils, impose severe restrictions on the successful establishment of new herbaceous plants. Soil seed banks appear to be depleted of perennial grass propagules and the depauperate grass individuals are incapable of producing viable seed in many years. With generally low herbaceous productivity, seed predation by birds, rodents, and harvester ants can be very efficient. High levels of mortality are common, in both germinating seed and young herbaceous seedlings. Herbivory of cool season grasses by native ungulates may limit abundance and productivity of these species relative to warm season grasses.

At Bandelier, the selection of restoration methodologies is constrained by self-imposed restrictions designed to protect cultural, natural, and wilderness resource values (Sydoriak, 1995). Overstory reduction must be accomplished using minimum tools and techniques that are sensitive to multiple park resources. Rough terrain, high cultural site density, and the presence of designated wilderness essentially preclude mechanized ground disturbing activities (such as chaining, drilling and other agronomic techniques utilizing heavy equipment) typically associated with large scale restoration efforts. Planting methodologies for seed material are generally limited to hand methods. All plant materials must be locally native, requiring custom production at considerable expense.

Methodology

Two degraded pinyon-juniper sites were included in the current study; one located on Frijoles Mesa within Bandelier National Monument and a second on Garcia Mesa in the adjacent Santa Fe National Forest. Study sites are located at the upper end of the pinyon-juniper zone on gently sloped mesas between 1980 m (6600 ft) at Frijoles Mesa and 2160 m (7200 ft) at Garcia Mesa. Canopy closure ranged from 23.0 to 60.0 percent, with herbaceous cover ranging from 5.0 to 15.0 percent, litter ranging from 38.0 to 84.0 percent and bare soil ranging from 7.0 to 56.0 percent. Soils are derived from volcanic ash deposits and are generally shallow and poorly developed (Davenport, 1997; Davenport and others, 1996; Wilcox and Breshears, 1995). Precipitation increases with elevation and ranges from around 40.0 cm. (16 in.) at the Frijoles Mesa site to nearly 50.0 cm. (20 in.) at the Garcia Mesa site (Wilcox and Breshears, 1995). Summer thunderstorms account for nearly half of the annual rainfall; winter snows are variable in depth and persistence (Wilcox and Breshears, 1995).

Experimental Design

The experiment consisted of 18, 15m^2 plots at each of two sites. Because of constraints in implementing this study, the primary, overstory reduction and slash mulching treatment was assigned to 15 contiguous plots, in a non-random fashion, with the remaining three plots serving as controls. Evaluation of the primary treatment relative to controls, is considered separately from the secondary treatment.

For the purposes of evaluating secondary treatments, the 15 plots within the bounds of the primary, overstory reduction and slash mulching treatment, were divided into three blocks of five plots each. Within each block, plots were randomly assigned one of five secondary treatment combinations: slash mulch only; slash mulch + imprinting; slash mulch + seeding; slash mulch + imprinting + seeding; or slash mulch + raking + seeding.

Data Collection Protocols

Herbaceous cover was measured as an indicator of system response to treatment, since these data can be reliably collected by a seasonal workforce and are indicators of available soil moisture and rates of soil erosion. Changes in soil surface cover (that is vegetation, litter, bare soil) were measured using a modified University of New Mexico, Long Term Ecological Research program design; vegetation data was collected by species and growth form and included basal intercept and canopy cover components. Two 21.21 meter vegetation transects were permanently established in each plot for a total of 42.42 m sampled per plot. Pre-treatment data was collected from both study sites during the fall of 1994. Year 2 and 3 post-treatment data was subsequently collected at each study site during the fall of 1996 and 1997. These data were compiled and summarized using the Statistical Package for Social Sciences. Large and small scale repeat photos were taken along the vegetation transects to provide additional visual documentation of treatment response.

Restoration Treatments

The primary, overstory reduction and slash mulching treatment was applied to both sites in the spring of 1995. Overstory reduction treatment was applied using chainsaws. Bledsoe and Fowler (1992) suggested overstory reduction of pinyon-juniper woodlands through selective thinning, as compared with agronomic techniques such as chaining, can meet multiple management objectives. Main limbs were lopped off and the trunk was flush cut at the base. The resulting slash, lopped branches and trunk sections, were then scattered preferentially into the bare interspaces to serve as a rough mulch. On the basis of land manager recommendations (Elson, pers. comm.), previous experimental restoration work (Bledsoe and Fowler, 1992), spatial patterns of older growth trees, and water relation studies in pinyon-juniper systems (Breshears and others, 1997), a spacing between mature tree individuals of from 15 to 20 m was considered optimal for restoration of former pinyon-juniper savanna types in the study area. Following these recommendations, we elected to remove all of the tree canopy within and immediately adjacent to individual plots for the purposes of this small scale experiment.

Secondary soil surface preparation and seeding treatments were applied to bare soil areas of both sites during the summer of 1995. Soil surface preparation techniques applied prior to seeding included: no soil surface preparation, light raking, and imprinting. Raking was accomplished using a council fire rake to cut shallow (1-2 cm deep) furrows perpendicular to the slope. Imprinting was accomplished using custom made, hand implements to create a pattern of sloped depressions (5 cm deep) on moist soil surfaces. Imprints provide temporary catchments for seed, litter, soil and water and thus may serve as favorable microsites for germinating plant materials. Seed material was applied at a rate of 1291 seeds/m^2 and consisted of a mix of blue gramma (50 percent), little bluestem (30 percent), and sand dropseed (20 percent). The relatively high seeding rate was used in an attempt to compensate for anticipated losses due to seed predation, seed mortality and marginal seedbed preparation. Seeding was accomplished by broadcasting the seed mix onto designated treatment plots subsequent to soil surface preparation. Loose dirt was lightly brushed back into the furrows cut on raked plots.

Results

Primary Treatment

A comparison of the primary, overstory reduction and slash mulching treatment to controls suggests that exposed soil coverage decreased by a mean of 222.0 percent at the Frijoles Mesa site and 200.0 percent at the Garcia Mesa site (fig. 1a,b). Total herbaceous cover had a mean increase of 773.0 percent at Frijoles Mesa and 241.0 percent at Garcia Mesa, by the third year post-treatment (fig. 1a,b). Grass cover increased 446.0 percent at Frijoles Mesa and 179.0 percent at Garcia Mesa (fig. 1c,d), while forbs increased 1267.0 percent at Frijoles Mesa and 705.0 percent at Garcia Mesa (fig. 1c,d). The difference in relative contributions of forbs and grasses at the two sites may be due to the initially high grass cover at Garcia Mesa (25.0 percent) as compared with Frijoles Mesa (6.0 percent). The low initial grass cover at the Frijoles Mesa site may have provided more opportunities for annual and biennial forbs to establish.

Secondary Treatment

Analysis of the secondary, soil surface preparation and seeding treatments suggest that there was no significant increase in total grass cover over the primary treatment response (fig. 2). While Blue Grama (*Bouteloua gracilis* [H.B.K.] Lag.) showed a mean increase of 252.0 percent cover on seeded versus 119.0 percent cover on unseeded plots, this increase was apparently offset by contributions to total grass cover on unseeded plots by other non-seeded species (fig. 2). The other two seeded species, Little Blue Stem (*Schizachyrium scoparium* [Michx] Nash) and Sand Dropseed (*Sporobolus cryptandrus* [Torr.] Gray), had mean increases of less than 1.0 percent across both sites.

Discussion

Additional work is clearly needed to more completely understand the mechanisms responsible for the observed herbaceous response. Breshears and others (1997) provide evidence to support shallow water harvest by one-seed juniper from intercanopy spaces. Bledsoe and Fowler (1992) document an increasing herbaceous response to decreasing densities of overstory trees and report no significant increases in grass production without a minimum two-thirds overstory thinning. Preliminary greenhouse studies conducted at Bandelier support the benefits of litter and slash as moderators of soil moisture and temperature; growth performance of blue gramma seedlings was significantly

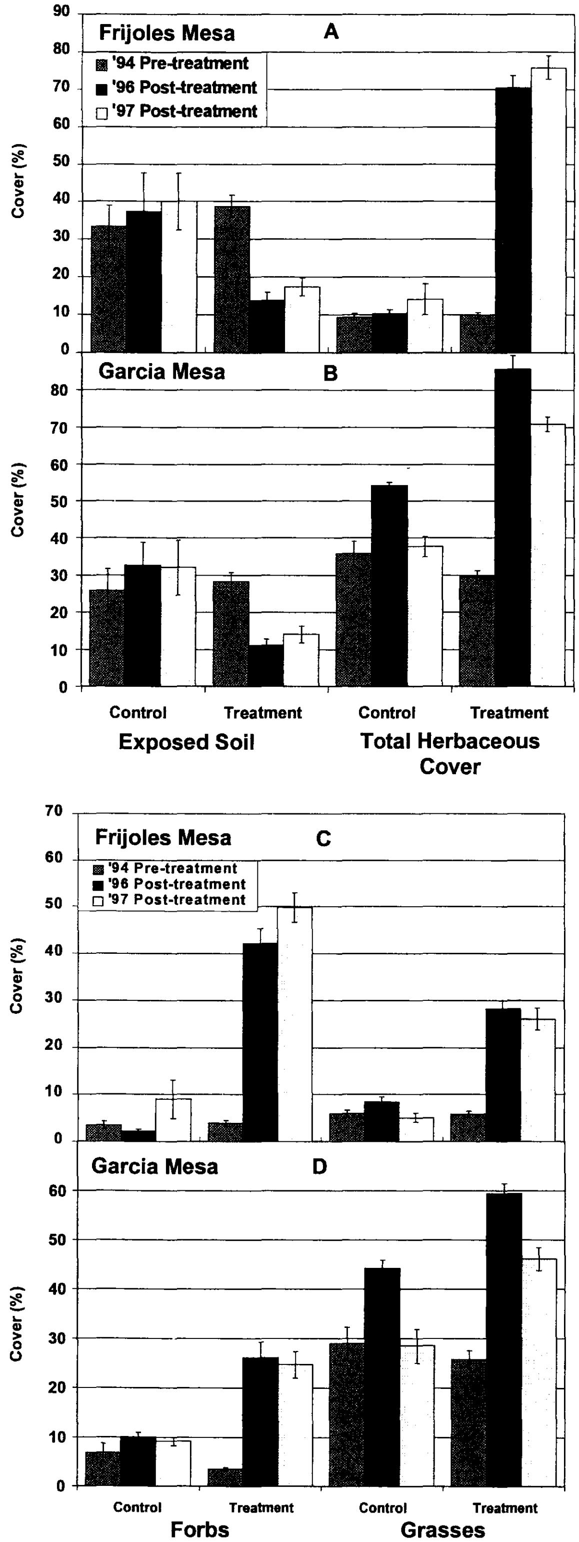

Figure 1—Comparisons of the primary, overstory reduction and slash mulching treatment (n = 15) to control (n = 3) using four cover components measured at Frijoles Mesa (Graphs A and C) and Garcia Mesa (Graphs B and D). The clustered bars represent three years of measurements: 1994 (pre-treatment), 1996 (two years post-treatment), and 1997 (three years post-treatment). Graphs A and B compare treatment effects on exposed soil and total herbaceous cover across both sites. Graphs C and D compare the forb and grass response between control and primary treatment plots for each site. The standard error bars are times one standard error.

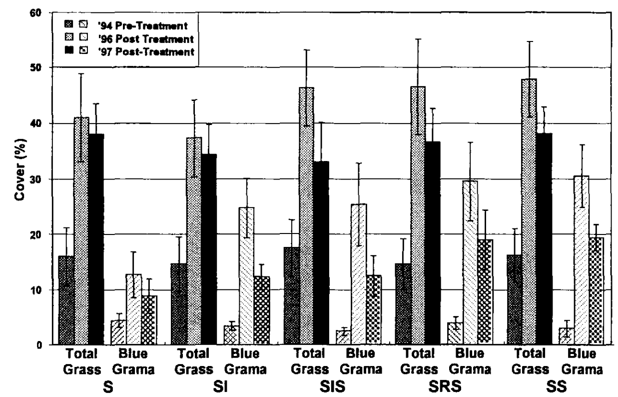

Figure 2—Comparisons of total grass cover among secondary, soil surface preparation and seeding treatment combinations, for each year of measurement, and relative to one of the seeded species, blue grama (Bogr). Treatment codes: S = Slash only; SI = Slash Mulch + Imprinting; SIS = Slash Mulch + Imprinting + Seeding; SRS = Slash Mulch + Raking + Seeding. Standard error bars are times one standard error.

enhanced by litter and/ or slash mulching treatments (Snyderman and Jacobs, 1995). Watershed level restoration studies underway at Bandelier National Monument are attempting to correlate the herbaceous response to overstory reduction and slash mulching treatment with soil moisture and soil erosion.

We suggest that tree overstory removal reduces competition for limited water and nutrient resources while the scattered slash provides benefits to exposed soils: reducing runoff and sediment transport, increasing infiltration and soil moisture, moderating soil temperature, freeze-thaw and evaporation, redistributing nutrients, and mitigating grazing impacts. Combined, these effects create favorable microsites for increased productivity of remnant herbaceous plants as well as for germination, establishment and growth of new individuals from seed.

High seed loss in secondary treatments, from some combination of predation and mortality, was evident at both sites based on seedbank analysis at one, three, and twelve weeks post-seeding (Jacobs and Snyderman, 1995). Marginal planting techniques, which did not effectively provide seed with good soil contact, combined with uneven precipitation patterns may have been responsible. Slash mulch was observed to be effective in keeping wind and rain from transporting broadcast seed off of individual plots. Intense seed predation by harvester ants was observed at the Frijoles Mesa site, beginning soon after application and continuing until effective rain either concealed seeds or stimulated germination several weeks later. Surprisingly, loss of seed was also high at the Garcia Mesa site, despite the apparent absence of harvester ants and occurrence of effective precipitation within several days of planting.

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References

Allen, C. D. 1989. Changes in the landscapes of the Jemez Mountains. Ph.D. dissertation, Univ. of Calif, Berkeley, CA.

Arnold, J. F. and Schroeder, W. L. 1955. Juniper control increases forage production on the Fort Apache Indian Reservation. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station Paper No. 18, Fort Collins, CO.

Bledsoe, F. N. and Fowler, J. M. 1992. Economic evaluation of the forage-fiber response to pinyon-juniper thinning. New Mexico State University Agricultural Experiment Station Bulletin 753, Las Cruces, NM.

Breshears, D. D., Myers, O. B., Johnson, S. R., Meyer, C. W. and Martens, S. N. 1997. Differential use of spatially heterogeneous soil moisture by two semiarid woody species: *Pinus edulis* and *Juniperus monosperma*. J. Ecology. 85:289-299.

Chong, G. W. 1994. Recommendations to improve revegetation success in a pinyon-juniper woodland in New Mexico: a hierarchial approach. M.S. thesis, Univ. of New Mexico, Albuquerque, NM.

Chong, G. W. 1992. Seventeen years of grazer exclusion on three sites in pinyon-juniper woodland at Bandelier National Monument, New Mexico. Unpublished report, Bandelier National Monument, Los Alamos, NM.

Davenport, D. W. 1997. Soil survey of three watersheds on South Mesa. Unpublished report, Bandelier National Monument, Los Alamos, NM.

Davenport, D. W., Wilcox, B. P. and Breshears, D. D. 1996. Soil morphology of canopy and intercanopy sites in a pinon-juniper woodland. Soil Sci. Soc. J. 60:1881-187.

Gottfried, G. J., Swetnam, T. J., Allen, C. D., Betancourt, J. L. and Chung-MacCoubrey, A. L. 1995, Pinyon-juniper woodlands, Chapter 6, in: Ecology, diversity and sustainability of the middle Rio Grande basin, Finch, D. M. and Tainter, J. A., eds., USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, RM-268.

Jacobs, B. F. and Snyderman, D. 1995. Restoration Studies. Unpublished report, Bandelier National Monument, Los Alamos, NM.

Loftin, S. R. 1998. Initial response of soil and understory vegetation to a simulated fuelwood cut of a pinyon-juniper woodland in the Santa Fe National Forest. In: Monsen, S. B., Stevens, R., Tausch, R. J., Miller, R. and Goodrich, S., eds. Proceedings: ecology and management of pinyon-juniper communities within the interior west. 1997 Sept. 15-18, Provo, UT. USDA, Forest Service, Intermountain Research Station, General Technical Report INT-000. Ogden, UT.

Mozzillo, E. O., in preparation, Management summary of the Bandelier archeological survey. Unpublished report, Bandelier National Monument, Los Alamos, NM.

Sydoriak, C., ed. 1995. Resources management plan. Unpublished report, Bandelier National Monument, Los Alamos, NM.

Touchan, R., Allen, C. D. and Swetnam, T. W. 1994. Fire history and climatic patterns in Ponderosa pine and mixed-conifer forests of the Jemez Mountains, northern New Mexico. In: Fire effects in southwestern forests, Proceedings of the second La Mesa Fire symposium. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, RM-286.

Wilcox, B. P., and Breshears, D. D. 1995. Hydrology and ecology of pinyon-juniper woodlands: conceptual framework and field studies. In: Desired future conditions for pinon-juniper ecosystems, 1994 August 8-12, Flagstaff, AZ: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, RM-258.

Wilcox, B. P., Newman, B. D., Allen, C. D., Reid, K. D., Brandes, D., Pitlick, J. and Davenport, D. W. 1996a. Runoff and erosion on the Pajarito Plateau: Observations from the field. New Mexico Geological Society Guidebook, 47th Field Conference, Jemez Mountain Region, Los Alamos, NM.

Wilcox, B. P., Pitlick, J., Allen, C. D., and Davenport, D. W. 1996b. Runoff and erosion from a rapidly eroding pinyon-juniper hillslope. In: Advances in Hillslope Processes. Vol. 1. eds: M.G. Anderson and S.M. Brooks. John Wiley and Sons LTD.

The Influence of Anchor-Chaining on Watershed Health in a Juniper-Pinyon Woodland in Central Utah

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Abstract—In 1990 the U.S. Forest Service anchor chained and seeded 121 ha of juniper-pinyon woodland in Spanish Fork Canyon. Twenty, 10 m^2 runoff-plots were established in 1991, to quantify anchor chaining's effect on runoff and soil erosion. Plots were paired, one in the chained area and one on comparable terrain and soil type in the untreated juniper-pinyon woodland. Each enclosed runoff-plot channels runoff water and suspended sediments into collection containers. During five years of data collection, unchained plots produced 5.8 times more runoff and 9.2 times more sediment than chained plots. Ground cover values for runoff plots show that vegetation increased from 27.1 percent in 1991 to 41.3 percent in 1995 on chained plots, while litter increased from 22.6 percent to 51.5 percent during the same time period. Vegetation cover on untreated plots varied from 7.5 percent in 1991 to 3.4 percent in 1995. Litter cover averaged 18 percent. Results indicate that anchor chaining significantly reduced runoff and soil erosion by providing more protective ground cover.

Juniper-pinyon woodlands are an important rangeland type in the western United States where it currently covers about 24.3 million hectares. In Utah, Juniper-pinyon woodlands cover approximately 6 million hectares. These woodlands have greatly expanded their distribution in the past 150 years because of effective fire control and heavy grazing by domestic livestock (West 1984). Without competition from a vigorous understory of grasses, forbs and shrubs and occasional wild fires, pinyon-juniper woodlands have become more dense and claimed much of the available nutrient and water resource previously used by a heavier cover of understory plants (Doughty 1986). Areas dominated by pinyon-juniper produce little useable forage for wildlife or domestic grazers, and the bare interspaces are prone to erode during high intensity summer storms. Juniper and pinyon trees can often survive for 600 to 1000 years. Without some sort of mechanical removal, they may dominate a site for years and put at risk soils that support the ecosystem (West 1984).

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Anchor chaining is a tree removal technique that has been used for the past 50 years. It is an economic method of converting juniper-pinyon woodland to vegetation rich in herbaceous perennial plants similar to that existing at the time of settlement of the region by European peoples. Many land managers have long assumed that reducing tree cover and encouraging grass, forb and shrub cover had a positive effect on infiltration, runoff and soil erosion on watersheds heavily dominated by juniper and pinyon, but quantitative data to support that assumption are uncommon. The purpose of this study is to quantitatively document the influence of anchor chaining on watershed health in juniper-pinyon woodland.

Methods

To determine the effects of chaining on runoff and soil erosion, 10 paired, 10 m^2 runoff-plots were placed, one in the chaining and one in a comparable unchained area. The enclosed plots channel runoff water and suspended sediments down slope into a pipe connecting a series of covered containers. A storage rain gauge was also placed near each plot to estimate precipitation on the plot. Runoff water was collected periodically and its volume recorded. Sediments were collected, weighed, oven dried and re-weighed. Water content in sediment samples was added to the runoff total. Ground cover values were estimated using a modified Daubenmire (1959) cover estimation procedure. Percent cover of vascular plants, bare ground, rock, litter and cryptogamic plants was estimated annually at each runoff-plot.

Results

All runoff plots were placed during the summer of 1991. Data were collected from August through October of that year. During that period, untreated control plots produced an average of nearly 6 times more runoff and 9 times more sediment than chained plots. In 1992 data were recorded from May through October. Control plots, during that six month period, generated an average of 5½ times more runoff and over 6 times more sediment than the chained plots (fig. 1 and 2). During the summer (May-October) of 1993, control plots produced 3 times more runoff and over 6 times more sediment.

In the first summer after chaining, chained plots averaged 27.1 percent vegetative cover, compared to 6.2 percent on untreated plots (table 1). Protective ground cover consisting of vegetation and litter, averaged 49.7 percent on chained

Table 1—Relative percent ground cover of control and chained runoff plots. Each year's total is an average of 10 measurements.

Unchained plots	1991	1992	1993	1994	1995	Average
Bare ground	46.6	31.6	39.3	50.6	43.8	42.4
Rock	31.1	40.1	33.5	25.1	33.5	32.7
Litter	14.7	21.0	19.6	19.4	14.8	17.9
Vegetation	7.5	7.3	7.6	4.8	3.4	6.1
Chained plots						
Bare ground	43.1	25.1	19.5	27.1	15.4	26.0
Rock	7.2	4.7	6.9	3.8	13.7	7.3
Litter	22.6	26.9	37.9	38.1	51.5	35.4
Vegetation	27.1	43.3	35.6	31.0	41.3	35.7

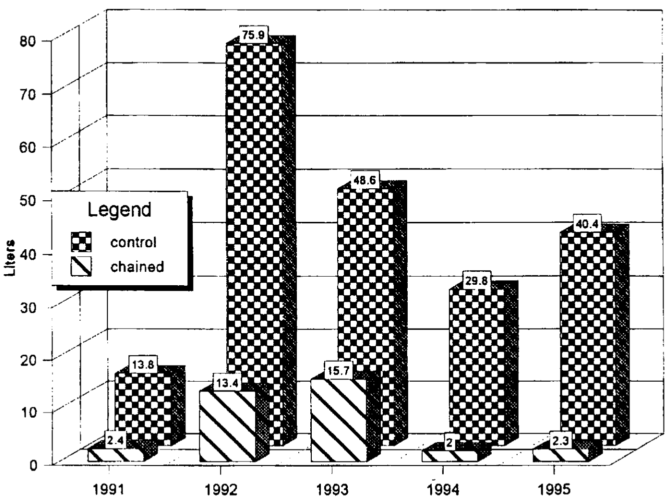

Figure 1—Average liters of summer runoff from 1991 to 1995. Each year's total is an average of 10 measurements.

plots and 20.9 percent on control plots. In 1992, vegetative cover averaged 43.3 percent on chained plots and 7.3 on control plots. Protective ground cover averaged 70.2 percent on chained plots while control plots averaged 28.3 percent. By 1995 vegetative cover on chained plots averaged 41.3 percent and protective cover (vegetation and litter) averaged 92.8 percent. Untreated control plots averaged only 3.4 percent vegetation cover and 18.2 percent protective cover.

Discussions

The primary forces which are related to water erosion are, raindrop energy and surface runoff, which remove and transport soil particles (Blackburn and others 1986). Vegetation is important in impeding overland flow and reducing raindrop energy. Blackburn and others (1986) state that the amount of vegetative cover is the primary erosion controlling factor. Control areas on the Spanish Fork Site during the study period, contained an average of 6.1 percent vegetation cover, 60 percent of which was tree canopy cover. Simanton and others (1991) discovered that the significance of canopy cover was small compared to ground cover in soil erosion prediction models. Khan and others (1988) found that as canopy height increases the soil erosion rate also increases. Ground cover of understory vegetation is most effective at reducing soil erosion. Anchor chained sites in the Spanish Fork study provided more uniform protective vegetation cover closer to the ground surface than untreated juniper-pinyon sites.

Conclusions

Over the five year period of study, Anchor Chaining allowed vegetative cover to increase 6 times on the average plot and litter cover to increase an average of 2 times. Runoff, on the chained plots, was reduced an average of 6 fold and erosion reduced an average of 9 fold. Results show that anchor chaining significantly reduced runoff and erosion by providing more protective ground cover.

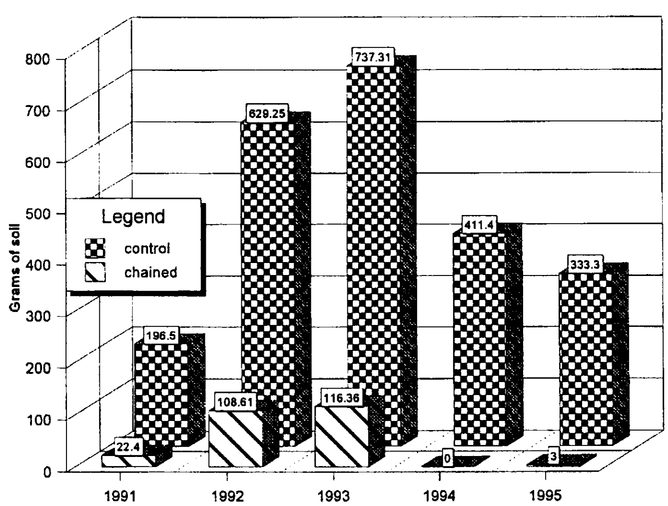

Figure 2—Average grams of sediment yield from 10 plots during the summers of 1991-1995.

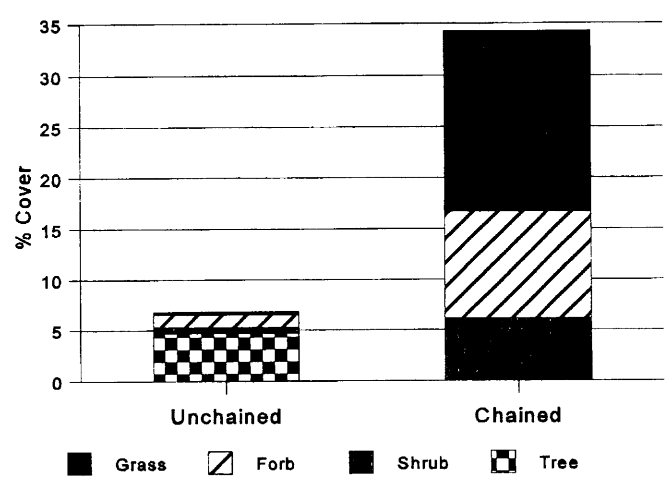

Figure 3—Average relative percent vegetation cover by class of unchained and chained runoff plots from 1991-94.

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References

Blackburn, W. H., T. L. Thurow and C. A. Taylor, Jr. 1986. Soil erosion on rangelands. In: Proceedings, Range Monitoring Symposium, Society of Range Manage. Denver, CO: 31-39.

Daubenmire, R. 1959. A canopy coverage method of vegetational analysis. Northwest Sci. 33: 43-66.

Doughty, J. W. 1987. The problems with custodial management of pinyon juniper woodlands. In: Proceedings, Pinyon-juniper Conference, USFS Gen. Tech. Report INT-215: 29-33.

Khan, M. J., E. J. Monke, and G. R. Foster. 1988. Mulch cover and canopy effect on soil loss. Trans. of the Amer. Soc. Agr. Engr. 31: 706-711.

Simanton, J. R., M. A. Weltz, and H. D. Larsen. 1991. Rangeland experiments to parameterize the water erosion prediction project model: vegetation canopy cover effects. J. Range Manage. 44(3): 276-282.

West, N. E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. In: Developing Strategies for Rangeland Management. Westview Press, Boulder: 1301-1332.

Impacts of Vegetative Manipulations on Sediment Concentrations from Pinyon-Juniper Woodlands

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Malchus B. Baker, Jr.

Abstract—This paper reports on relationships between suspended sediment concentrations and streamflow discharges from pinyon-juniper watersheds subjected to cabling treatments and applications of herbicides. These relationships are compared to relationships from a control watershed that represents untreated conditions to provide a basis for describing the effects of pinyon-juniper conversions on sedimentation processes. The effects are further analyzed by separating the data sets on the basis of streamflow generation mechanisms, that is, snowmelt-runoff events and high-intensity, short-duration convectional rainfall events. Findings from the study indicate that suspended sediment concentrations, above a threshold discharge, increased as a result of the cabling treatment, while no change in sediment concentrations was observed as a result of the herbicide treatment. These results improved on earlier evaluations of the impacts of conversion treatments in the pinyon-juniper woodlands on suspended sediment discharges.

Pinyon-juniper woodlands occupy large areas in the Interior West of the United States. Management of these ecosystems has been controversial, however, because their hydrology has been a concern. Rates of erosion have accelerated in recent years and, as a consequence, extensive areas have unsatisfactory soil and water conditions (Gottfried and others 1995). This assessment has been largely based on evidence of surface and gully erosion, soil compaction, and vegetative indices.

The decline in watershed condition has been attributed to increases in overstory tree densities, and corresponding decreases in understory grasses, forbs, and half-shrubs, which provide a protective cover on soil surfaces (Gottfried and others 1995). Overstory trees have been removed from many sites in the hope of remedying this situation by encouraging the production of understory plants. Another possibility is that the observed erosion is a residual of past land-use practices, and causes of erosion are more complex.

The controversy over the hydrology and erosional dynamics in pinyon-juniper ecosystems has generated a number of research studies (Gifford 1975, Wright and others 1976, Baker 1982, Wilcox 1994, Lopes and others 1996). As part of a general research effort to study the hydrologic and sediment-transport regimes of watersheds, the relative magnitudes of sediment exports are being analyzed in relation to watershed condition, streamflow-generation mechanisms, and land management activities. Sediment rating curves, developed to describe relationships between the amount of sediment in suspension and streamflow discharge, can be used to estimate the effects of management activities on suspended sediment (Brooks and others 1997, Lopes and Ffolliott 1993)

This paper reports upon the development of sediment rating curves for watersheds in pinyon-juniper woodlands of the Interior West. It presents an analysis of suspended sediment concentration-streamflow discharge relationships for two pinyon-juniper watersheds subjected to vegetative conversion treatments, and a control watershed that represents untreated conditions. These comparisons provide a basis for determining the effects of the conversion treatments on sedimentation processes. Differences between snowmelt-runoff and convectional rainfall streamflow-generation events were also considered.

Study Area

The watersheds studied are located about 80 km south of Flagstaff, Arizona, a tributary of the Verde River, in the Colorado Plateau physiographic province. These watersheds, established by the USDA Forest Service to evaluate the effects of vegetative conversion treatments on multiple use values, supported stands of Utah juniper (*Juniperus osteosperma*) and pinyon (*Pinus edulis* var. *fallax*). Descriptions of overstory tree species compositions and density conditions have been presented by Clary and others (1974), Ffolliott and Thorud (1974), and Baker (1982) and, therefore, will not be presented here.

The watersheds average 1,600 m in elevation. Springerville very stony clay soils derived from basalt and cinder parent materials predominate (Williams and Anderson 1967). The clays are primarily montmorillonite which swell and shrink during each wet and dry cycle (Baker 1984). Infiltration rates for this soil series range between 2.0 and 6.4 cm/hr (Baker 1982). Stream channels on the watersheds have a southwesterly orientation. Annual precipitation average 450 mm, occurring largely in two seasons. The most important precipitation from a streamflow-generating standpoint is that originating from the frontal storms of October

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through April, when about 60 percent of the annual precipitation (both rain and snow) falls. A second precipitation season is July through early September, when high-intensity, short-duration, localized convectional storms are common. Average winter water yields (22.9 mm) account for 85 percent of the total annual water yield (Baker 1982). Suspended sediment accounts for 75 to 80 percent of the total annual sediment discharge from the watersheds studied.

Vegetative Conversion Treatments

A cabling treatment was applied to a 131-ha watershed (WS 1) in 1963. Larger trees were uprooted by a heavy cable pulled between two bulldozers. Smaller trees missed by cabling were hand-chopped, slash was burned, and the watershed seeded with a mixture of forage species. The treatment did not result in significant increases in annual water yields. In a second conversion treatment, a mixture of picloram (2.8 kg/ha) and 2,4-D (5.6 kg/ha) was applied by helicopter to 114 ha of a 147-ha watershed (WS 3) in 1968. The remaining 35 ha were either not treated or the trees were sprayed with a backpack mist-blower. The intent of this treatment was to reduce transpiration losses by killing trees, reduce evaporation losses from the soil by leaving the dead trees standing, and reduce the amount of overland water flow trapped in the pits created when trees were uprooted by cabling (Baker 1984). The herbicide treatment resulted in an increase in annual water yields of about 15.5 mm. The third watershed was a 51-ha control (WS 2) against which the cabling and herbicide treatments were evaluated. Conditions on this control watershed represented those obtained through custodial management, that is, through the use of minimal managerial inputs.

Procedures

A total of 191 paired suspended sediment concentration-streamflow discharge measurements (in excess of 0.05 m/s) obtained from 1975 through 1982 (12 years after the cabling treatment in one watershed and 7 years following the herbicide treatment in the other) were used in deriving sediment rating curves. Either grab samples or integrated samples obtained with a DH-48 were analyzed by filtration to determine suspended sediment concentrations. Streamflow was measured in concrete trapezoidal flumes (Baker 1986). When a sample of suspended sediment was collected, the time was indicated on a digital tape on continuous water-level recorders at the gauging stations. The sediment data used in this analysis were collected at time intervals greater than 1 hr to avoid the possibility of correlation among the paired data sets.

Two types of events served as the basis for studying the effects of streamflow-generation mechanisms on suspended sediment concentrations:

- Type 1. Snowmelt-runoff events not proceeded by precipitation; relatively slow response time to peak streamflow discharge; streamflow duration of several days or weeks; occurs in late winter-early spring.
- Type 2. High-intensity, short-duration, mostly convectional rainfall events; rapid response time to peak streamflow discharge; streamflow duration of hours or a few days; occurs in late summer-early fall.

Rain-on-snow events, which represented less than 10 percent of the streamflow-generation mechanisms on the watersheds studied, were excluded from the analysis.

Sediment rating curves most frequently take a power function form, such as:

$$C = aQ^b \qquad (1)$$

where C = suspended sediment concentration (mg/L), Q = streamflow discharge (m^3/s), and a, b = constants for a particular stream. Sediment rating curves to be derived as a power function are commonly approximated by least-square linear regressions of logarithmic-transformed data (Walling 1977). Therefore, this transformation was used to develop the sediment rating curves in this study. The coefficient of determination, R^2, was used to compare the goodness-of-fit of the sediment rating curves. To correct for the dependence of goodness-of-fit on degrees of freedom, an adjusted coefficient of determination, Ra^2, was used:

$$Ra^2 = R^2 - [P(1 - R^2)/(N - P - 1)] \qquad (2)$$

where N = number of observations, and P = number of independent variables = 1.

Results and Discussion

A summary of statistics for suspended sediment concentration and streamflow discharge for the three watersheds are shown in table 1. Analysis of suspended sediment concentrations began with the complete data sets from each of the watersheds studied. These data sets were subsequently partitioned into the type of streamflow-generation mechanisms (snowmelt-runoff or convectional rainfall). The "Chow test," details of which are presented by Kmenta (1986), was performed in this second step to test the null hypothesis that the parameters of the curves (a and b) had not changed significantly at the 95 percent level of significance.

Measurements made during periods of high-streamflow discharges (Type 2 events) were assigned the same weight as measurements made during low-streamflow discharges (Type 1 events) in deriving sediment rating curves for each watershed. The parameters "a" and "b" of the relationships are presented in table 2 with the 95 percent confidence limits, fitted standard errors, coefficients of determination, and F statistic.

There was a difference in the "a" and "b" values between the sediment rating curve for the cabled watershed (WS 1) and that for the untreated control watershed (WS 2) at streamflow discharges greater than 0.15 m^3/s. This difference indicates that there are higher suspended sediment concentrations from the cabled watershed than from the control for streamflow discharges greater than 0.15 m^3/s. These higher concentrations are likely a reflection of the soil disturbances caused by uprooting trees in the cabling treatment (Clary and others 1974). However, there was not a statistical difference for sediment rating curves derived for the watershed treated with herbicides (WS 3), which

Table 1—Summary of statistics for suspended sediment concentration and streamflow discharge.

WS[1]	Event type[2]	n[4]	Sediment Concentration (mg/L) Mean	StDv	Min	Max	Streamflow (m^3/s) Mean	StDv	Min	Max
1	ALL	117	8.88	13.33	0.39	73.37	0.102	0.056	0.058	0.261
1	1	104	8.97	13.64	0.38	73.07	0.101	0.056	0.058	0.261
1	2	12	5.50	5.38	1.17	15.99	0.104	0.030	0.058	0.127
2	ALL	32	7.87	6.94	2.10	40.17	0.093	0.035	0.058	0.216
2	1	21	7.74	8.21	2.10	40.17	0.096	0.030	0.060	0.216
2	2	10	7.25	2.59	4.29	12.01	0.073	0.011	0.058	0.084
3	ALL[3]	42	10.55	13.69	0.74	80.17	0.088	0.028	0.059	0.151
3	1	41	10.18	13.64	0.74	80.17	0.087	0.027	0.058	0.151

[1]WS 1 = cabled watershed, WS 2 = control watershed, and WS 3 = herbicide watershed.
[2]ALL = complete data set for each watershed; 1 = snowmelt-runoff events, 2 = convenctional rainfall events.
[3]Event type 2 is not represented in the data set for WS 3.
[4]Sample (n) for the streamflow-generation mechanisms do not add up to the n for the complete data set for each watershed studied because of the inclusion of 1 frontal rainfall event occurring in late-fall in the complete data sets.

Table 2—Sediment rating curve parameters with the 95 percent confidence limits, standard errors, coefficients of determination, and F statistics.

WS[1]	Event type[2]	n[4]	a	95 Percent Confidence limits[5]	b	95 Percent Confidence limits[5]	Fitted Error	R^2	F
1	ALL	117	639.04	421.70 - 968.28	2.10	1.77 - 2.44	0.23	0.58	158.32
1	1	104	697.71	448.95 - 1084.17	2.13	1.77 - 2.48	0.23	0.57	140.17
1	2	12	356.71	55.41 - 2296.24	1.98	0.54 - 3.43	0.29	0.43	9.42
2	ALL	32	107.26	53.63 - 214.53	1.17	0.58 - 1.76	0.18	0.33	16.36
2	1	21	196.01	69.34 - 554.09	1.48	0.63 - 2.34	0.22	0.38	13.15
2	2	10	616.84	220.64 - 1724.20	1.71	0.63 - 2.79	0.05	0.58	13.41
3	ALL[3]	42	435.75	135.94 - 1397.76	1.74	0.70 - 2.27	0.38	0.21	11.58
3	1	41	344.52	103.53 - 1146.69	1.65	0.57 - 2.72	0.39	0.18	9.59

[1]WS 1 = cabled watershed, WS 2 = control watershed, and WS 3 = herbicide watershed.
[2]ALL = complete data set for each watershed; 1 = snowmelt-runoff events, 2 = convenctional rainfall events.
[3]Event type 2 is not represented in the data set for WS 3.
[4]Sample (n) for the streamflow-generation mechanisms do not add up to the n for the complete data set for each watershed studied because of the inclusion of 1 frontal rainfall event occurring in late-fall in the complete data sets.
[5]Confidence limits have been retransformed to original units for interpretation.

experienced little soil disturbances as a result of treatment, and the untreated watersheds.

Sediment rating curves were developed to represent suspended sediment responses to the type of streamflow-generation mechanisms. There were no consistent differences in sediment rating curves when the data sets used to derived the equations were partitioned according to streamflow-generation mechanisms. This finding differs from that reported for a higher-elevation ponderosa pine (*Pinus ponderosa*) watershed on Beaver Creek, where a significant increase in suspended sediment concentration occurred due to streamflow-generation mechanisms (Lopes and Ffolliott 1993, Dong 1996).

Management Implications

There was a significant difference in the suspended sediment concentrations when the cabled and control watersheds are compared. Soil disturbance caused by the uprooting of trees on WS 1 is the likely reason for this change. Earlier studies on Beaver Creek had indicated that uprooting of trees by cabling can increase the potential for soil loss by overland water flow (Skau 1960, 1961). Sedimentation parameters can also change, in general, because of increased streamflows, although this did not occur after this cabling treatment (Clary and others 1974). The difference in results can be attributed to the fact that finer sediments (silt and clay) require less energy to remain in suspension and, as a consequence, can be transported by smaller water flows than would be needed to more larger particles.

This result, and those of Clary and others (1974) and Baker (1982), are different than might be expected from the hypothesis that removal of overstory trees to increase production of the herbaceous plants forming a protective cover will cause less soil erosion. No changes in suspended sediment concentration occurred on WS 3 when herbicides were applied in a conversion treatment. The soil surface on this watershed was not disturbed by the treatment, since most of the herbicide was applied by helicopter.

Large-scale vegetative conversions of pinyon-juniper woodlands have been less frequent in the Interior West than in recent years, due largely to the increased environmental concerns and the increasing emphasis being placed on more holistic management of the pinyon-juniper ecosystems (Shaw and others 1995). Little changes in suspended sediment concentration because of conversion treatments, therefore, are likely to occur in the near future.

Conclusions

Sediment rating curves have been developed for three pinyon-juniper watersheds in northern Arizona that had been subjected to treatments ranging from custodial management to vegetative conversions by cabling and application of herbicides. The cabling treatment resulted in increased suspended sediments at specified streamflow discharges because of the soil disturbances caused by the uprooting of trees, while the herbicide treatment did not result in a change. This finding differs from previous studies (Clary and others 1974, Baker 1982), and could be helpful to managers in responding to questions about the impacts of vegetative manipulation on sediment concentrations from pinyon-juniper woodlands with similar soils and precipitation regimes throughout the Interior West.

References

Baker, M. B., Jr. 1982. Hydrologic regimes of forested areas in the Beaver Creek watershed. Gen. Tech. Rep. RM-90. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Baker, M. B., Jr. 1984. Changes in streamflow in a herbicide-treated pinyon-juniper watershed in Arizona. Water Resources Research. 20:1639-1642.

Baker, M. B., Jr. 1986. A supercritical flume for measuring sediment-laden streamflow. Water Resources Bulletin. 20:847-851.

Brooks, K. N.; Ffolliott, P. F.; Gregersen, H. M.; DeBano, L. F. 1997. Hydrology and the management of watersheds. Ames, IA: Iowa State University Press.

Clary, W. P.; Baker, M. B., Jr.; O'Connell, P. F.; Johnsen, T. N., Jr.; Campbell, R. F. 1974. Effects of pinyon-juniper removal on natural resource products and uses. Res. Pap. RM-128. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Dong, C. 1996. Effects of vegetative manipulations on sediment concentrations in north-central Arizona. MS Thesis. Tucson, AZ: University of Arizona.

Ffolliott, P. F.; Thorud, D. B. 1977. Water yield improvement by vegetation management. Water Resources Bulletin. 13:563-571.

Gifford, G. F. 1975. Approximate annual water budgets of two chained pinyon-juniper sites. Journal of Range Management. 28:73-74.

Gottfried, G. J.; Swetnam, T. W.; Allen, C. D.; Betancourt, J. L.; Chung-MacCoubrey, A. L. 1995. Pinyon-juniper woodlands. In: Finch, D. M.; Trainer, J. A., tech. coords. Ecology, diversity, and sustainability of the middle Rio Grande Basin. Gen. Tech. Rep. RM-268. Fort Collins, AZ: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 95-132.

Kmenta, J. 1986. Elements of econometrics. New York, NY: Macmillian Publishing Company.

Lopes, V.L.; Ffolliott, P. F. 1993. Sediment rating curves for a clearcut ponderosa pine watershed in northern Arizona. Water Resources Bulletin. 29:369-382.

Lopes, V. L.; Ffolliott, P. F.; Gottfried, G. J.; Baker, M. B., Jr. 1996. Sediment rating curves for pinyon juniper watersheds in northern Arizona. Hydrology and Water Resources in Arizona and the Southwest. 26:29-33.

Shaw, D. W.; Aldon, E. F.; LoSapio, C., tech. coords. 1995. Desired future conditions for pinon-juniper ecosystems: Proceedings of the symposium. Gen. Tech. Rep. RM-258. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Skau, C. M. 1960. Some hydrologic characteristics in the Utah juniper type of northern Arizona. PhD Dissertation. East Lansing, MI: Michigan State University.

Skau, C. M. 1961. Some hydrologic influences of cabling juniper. Res. Note 62. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station.

Walling, D. E. 1977. Assessing the accuracy of suspended sediment rating curves for a small basin. Water Resources Research. 13:531-538.

Wilcox, B. P. 1994. Runoff and erosion in intercanopy zones of pinyon-juniper woodlands. Journal of Range Management. 47: 285-295.

Williams, J. A.; Anderson, T. C. 1967. Soil survey on Beaver Creek area, Arizona. Washington, DC: U.S. Department of Agriculture, Forest Service and Soil Conservation Service, in cooperation with the Arizona Agricultural Experiment Station.

Wright, H. A.; Churchill, F. M.; Stevens, W. C. 1976. Effects of prescribed burning on sediment, water yield, and water quality from dozed juniper lands in Texas. Journal of Range Management. 29:294-298.

The Panguitch Wildlife Habitat Improvement Project

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Abstract—The purpose of this project was to remove a significant amount of pinyon-juniper trees and establish an understory more conducive to big game. Tree removal was accomplished using prison crews and hand tools. Crews removed trees in a mosaic pattern leaving groups of trees standing together to allow for better movement of big game and a more natural appearance. Fire and chaining were not options during the period of time the trees were removed. By use of the prison crews the Bureau of Land Management was able to open up an encroaching stand of trees allowing native grasses and shrubs to flourish.

The pinyon-juniper vegetation type is found in the Intermountain Region mostly at intermediate elevations in areas that receive less than twenty inches of precipitation annually (Vallentine 1980).

In the Kanab Resource Area (KRA) there are a number of areas that appear to be filling in with both pinyon and juniper trees. It is evident that as the trees encroach into shrub or grass/forb sites production is reduced in these areas. As these areas fill in with pinyon-juniper trees they become less productive and decrease available forage to big game species.

In 1997 the Bureau of Land Management, Kanab Resource Area (KRA) and the Division of Wildlife Resources, Southern Region (DWR) formed a cooperative agreement. In the agreement it was determined that prison crews would be hired to hand-cut encroaching trees in the more desired sagebrush parks adjacent to dense stands of mostly pinyon-juniper trees. The project was carried out near Panguitch, UT. on public lands administered by the KRA. It was the opinion of those involved that the more dense stands of trees located along the rocky ridges probably represented a more climax situation and should not be disturbed. Burkhardt and others (1969), determined in their work that juniper was climax only on rocky ridges and rimrock where soil development was limited.

Prison crews worked on the project for several weeks using chain saws to cut the trees down. Some parameters were provided the crews in terms of what trees should be cut and what trees should remain standing. Under no circumstances were the crews to cut ponderosa pine (*Pinus ponderosa*).

Crews were instructed to cut the younger pinyon and juniper trees. The younger trees (<10 ft) appeared to be most responsible for the encroachment into the more open areas. Crews were also instructed to leave patches of trees standing at random locations within the areas they were cutting in. It was determined that these patches would allow animals greater protection as they moved through the area. Peek (1986), demonstrated that where large clearcuts may be beneficial to livestock, smaller cuts are more important to big game species. Tree removal in some KRA projects was carried out on a larger scale than was done by the prison crews. When large areas were cleared of trees the areas usually had to be seeded. Success of these seedings was highly dependent on time of year, moisture. Seeding costs for native seed are fairly high. By cutting the younger, smaller trees that were encroaching into preferred big game sites no seeding was necessary. Native grasses and shrubs were present in numbers sufficient to provide seed in areas where trees were removed. Indian Ricegrass (*Stipa hymenoides*) and needle-and-thread grass (*Stipa comata*) were the two dominant grasses in the area where trees were removed.

Since this work was accomplished in the Fall of 1997 no conclusions as to the success of the project can be made at this time. Vegetative and wildlife transects are being placed in the areas where trees were removed to determine if work of this kind should be carried out in the future. Several photo plots have also been established. It is expected that native grasses and shrubs will better maintain themselves without the competition of encroaching pinyon and juniper trees. It is likely that the BLM and DWR will do more work of this nature with prison crews in 1998.

It is important to note that managers were able to be highly selective in determining what trees should be cut and how the shape of the cuts should be made by using prison crews. It was learned that if the crews are experienced and have some knowledge of big game foraging habits with little instruction the crews could create openings in the trees in a mosaic pattern.

References

Burkhardt, J. Wayne; Tisdale, E. W. 1969. Nature and successional status of western juniper vegetation in Idaho. J. Range Mgt. 22(4):264-270.

Peek, James M. 1986. A review of wildlife management. Englewood Cliffs, NJ: Prentice-Hall Publishing. 486 p.

Vallentine, John F. 1980. Range developments and improvements, second ed. Provo, UT: Brigham Young University Press. 545 p.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Watershed Restoration Through Integrated Resource Management on Public and Private Rangelands

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Abstract—Until recently much of the rangeland in the Western United States was in a serious downward trend. Water quality and quantity was declining as the result of the continuous livestock grazing practices employed at the turn of the century followed by 80 years of fire suppression. Thirty-five years of integrated/holistic resource management at the Carrizo Valley Ranch has reversed this trend. In addition to restoration of rangeland productivity, the riparian area on the ranch has been restored, wildlife populations enhanced, and perennial streamflow restored. The practical experience gained at the ranch should be useful to private landowners, public land managers, and water quality agencies throughout the brittle ecosystems of the Southwestern United States. Some of the techniques perfected at Carrizo Valley Ranch are being demonstrated on an adjacent watershed in the Smokey Bear Ranger District of the Lincoln National Forest.

The shortgrass rangelands found in the Western United States are generally harsh ecosystems. Careful management of these areas is essential if they are to maintain sustained production or recover from past land management mistakes (Stoddart and others 1975). Many watersheds in the West contribute massive loads of sediment washed from the land surface or scoured from eroding gullies and streambanks to the streams and rivers that drain them. The New Mexico Environment Department reports that 95 percent of the State's surface water is impacted by nonpoint source pollution (NMED 1990) and that turbidity is one of the major causes of use impairment in these waters (NMED 1988). Reports by early surveyors, naturalists, and trappers detail the abundance of grass and clear clean water found on these same watersheds (Leopold 1933/1991), a sharp contrast to the conditions seen today.

Many factors have contributed to the drastic changes that can be seen in the rangeland watersheds of the Western United States, but most range management professionals agree that the heavy stocking rates and the continuous grazing practiced by stockmen at the end of the 1800's followed by increasingly efficient fire suppression are the leading causes of these changes. H. L. Bently and E. O. Wooten, early agricultural agents in Texas and New Mexico, described the situation: "In a short time every acre of grass was stocked beyond its fullest capacity.... The grasses were entirely consumed; their very roots were trampled into the dust and destroyed" (Bently 1898). "The stockman could not protect the range from himself, because any improvement of his range was only an inducement for someone else to bring stock in upon it; so he put the extra stock on himself" (Wooten 1908). As a result, native grasses were replaced by sagebrush, mesquite, juniper, and other invading brush species that were less suited for holding soil in place (Chaney and others 1990) and that were more efficient at water extraction (Stoddart and others 1975). Topsoil, which requires thousands of years to develop in harsh ecosystems (Brady 1974), washed away; gullies formed from unchecked, concentrated runoff; streambanks eroded and downcut; water tables lowered; and perennial streams became intermittent or dry (Chaney and others 1990; Platts 1990).

The ability of the land to recover from these effects has been greatly reduced because the entire ecosystem had been so radically altered. The harshness of the environment contributes to the difficulty in reestablishing the climax or the highest ecological condition of the range. As a result, simple manipulation of a single range management factor, such as reducing livestock numbers, is not sufficient to result in significant environmental improvement (DeBano and Schmidt 1989). These systems will take many years to recover by themselves. Direct actions aimed at total watershed rehabilitation and applied in a holistic and integrated system are necessary to ensure the restoration of Western watersheds and associated natural resources of water, timber, grass, wildlife, and fisheries (Platts 1990). This type of integrated or holistic resource management has been successfully demonstrated on the Carrizo Valley Ranch.

Integrated Resource Management on Private Lands

There are many definitions of Integrated/Holistic Resource Management (IRM), but I like to define it as the integration of all components, economic, human and environmental into a synergistic, comprehensive plan that allows management for long-term sustainability rather than short-term production. This type of management is essential for protecting valuable natural resources found in our Western watersheds and is also an essential management tool for protecting the entire planet. Considering the unlimited supply of examples of bad natural resource management in every U.S. State and in every country in the world, it is clear that we are now charged with the responsibility of not only managing the resources under our jurisdiction in

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an integrated manner, but we must also inform politicians and populations everywhere that we are no longer in the pioneering/unplanned development mode. We have reached the point that resource interrelationships must be recognized and development planned accordingly. Pressing needs of growing populations must be met but not at the expense of the ecosystems' sustainability.

Initial Actions

My ranch is in the South Central Mountains of New Mexico at about 7,000 ft elevation. Average annual precipitation is about 46 cm (18 inches), half of which falls as snow. The soils range from gravelly hillsides to clay and clay loam bottoms. Watercourses on the ranch were actively eroded and brush infestation flourishing when I purchased the property. My most demanding problem was the homogeneous vegetative composition and low herbage production. The major grass found was an almost pure, tightly packed turf of blue grama that grew very little because of its sod-bound condition. A major portion of the ranch had scattered to thick stands of pinyon-juniper that were even-aged populations. Areas between the trees as well as directly under the canopy were bare and subject to erosion.

I began to study the origination of this eroded, brush-infested condition. I realized that year-long grazing and brush infestation were severely limiting herbage production. My initial strategies were (1) to divide the ranch into summer and winter pastures so I could at least reserve some winter grazing and (2) to begin a systematic brush control program. Although these changes were beneficial, it was not until I spent time in Rhodesia (Zimbabwe) in 1964 that I experienced firsthand and began to understand the principles of Short Duration Grazing in action, and the dynamics of an open savanna ecosystem. I recorded my findings in a paper published in the November 1969 issue of the *Journal of Range Management*, returned to my ranch, and after some very low budget fencing, put these principles into practice.

Rotational Grazing System

I divided large paddocks into much smaller ones using posts cut on the ranch to support a three-wire suspension fence. Paddock division was planned according to topography, existing fences, and available water, not in the wagon wheel or grazing cell pattern often advocated. Once the rotation had become established, the cattle practically moved themselves, anticipating paddock changes. I found that graze and rest periods could be adjusted to fit the current precipitation and season of use. I also found that as the vegetative growth rate increases, so should the frequency of rotation and that rotation during the dormant season was not necessary. My initial goal now became "to produce the maximum pounds of marketable beef per hectare while improving range condition." This naive but commendable goal was economically impractical in a period of low beef prices, so I needed to find other profitable uses of available resources.

Additional Income Source

Fee hunting of deer and turkey became a significant income producer immediately after I built a cabin to facilitate game harvest. As a result, improved wildlife habitat and overall aesthetic quality became my secondary goal.

Return to Climax Condition as the Primary Goal

The pieces of the puzzle then began to fall into place. I realized that if fish and beaver appeared on the 600 year old Indian Petroglyphs on my place, there certainly must have been running streams where I now found only arroyos with steep banks and dry rocky bottoms. I researched 100 year old surveyors notes that described the terrain as an open savanna rather than an almost solid canopy of invading brush species. I realized that the invading brush, made possible by year-long grazing and 80 years of total fire suppression, was not only removing most of the moisture from the soil, but was also shutting down herbage growth, thereby causing sheet and gully erosion. I recognized that although I had previously discounted a return to climax or near climax condition, I might be able to make economic sense out of that approach if it became my primary goal. I visualized the open savanna as it was over 100 years ago, with mixed conifers on the north slopes and the highly productive riparian areas that made up the mosaic of the Carrizo Valley.

Brush Management and Watershed Stabilization

I then began to implement a cautious return to climax in a manner that was economically justifiable in my situation. Mechanical removal of invading pinyon-juniper in an area that requires 10 to 15 ha per animal unit could not be justified because costs were higher than land values. However, some mechanical brush control in the better soil types was required as was erosion control (that is, reseeding, pushing invading brush into active gullies, and building water retention dams). It was necessary to finance this using other available resources.

Selective thinning of young invaders, followed by prescribed burning and reseeding with native grass species, became the major thrust of the plan to return to a climax ecosystem. The by-products: fence posts, fuel wood, vigas, trees for landscaping, and Christmas trees financed the plan. Another beneficial by-product was the increase in mule deer population, not only because of habitat improvement, but because ponderosa pine vigas must be cut and peeled during the winter months. This provided an adequate supply of green browse (tree tops) throughout the winter, resulting in a significant (30 to 50 percent) increase in the fawn crop. The open savanna created contained 500 to 800 year old juniper trees, scattered ponderosa pines, and is carpeted with a mix of warm and cool season grasses and forbs. I have found that because deer and turkey evolved under this type of ecosystem, they seem to prefer it to the contiguous brush-infested public land. This is what I call an "eco-recreation benefit." These factors sharply increased income from hunting and paid for more of the necessary mechanical rehabilitation work.

Role of Fire

The long sought-after open savanna is now well established in the Carrizo Valley, but it must be maintained with periodic fire as it was in the climax. Tree ring research in New Mexico indicates that most forest areas burned, on the average, at 7 to 10 year intervals (Stoddart and others 1975) before fire suppression began. The key to the successful maintenance burn is the fuel load (as well as the climatic conditions of course). There must be enough herbaceous material to carry a fire that is hot enough to kill brush but cool enough not to damage the beneficial species. The damaging fires in Yellowstone a few years ago demonstrated that the no-burn policy, which originated in the ecologically different European forests, was an incorrect choice for Western watersheds. Now after many years of fire suppression, similar fuel loading is evident throughout the Western United States and has made the initial prescribed burn risky.

Livestock Suited to Their Environment

The pivotal economic component of my operation is the production of weaner calves, both for breeding and beef. Low-input, sustained production is my goal and is achieved by using an animal that is fine-tuned to the environment and produces a desirable, marketable product. The hostile factors in our environment are snow, cold, wind, and dry weather. A cow that can produce under these conditions must be, first of all, fertile in that environment. She should be black so that wind and snow will not cause or aggravate pink eye and cancer eye. Black, of course, absorbs as much sparse winter sunlight as is possible and black udders do not blister in spring snowstorms. The animal that fulfills all these requirements is a composite breed that I have developed through 20 years of selective breeding, called the Alpine Black—three-quarters Angus and one-quarter beef-type Brown Swiss. Just as the Zebu composites fit the Gulf Coast and southern deserts, the Alpine Black fits the western mountains of Northern America.

Tangible Benefits

The road back to climax has revealed many changes in 30 years. Water sources that were dry now have permanent running water and lush riparian areas. Grass production has increased dramatically and provided more carrying capacity. Alpine Black cattle are in sync with their environment and their habitat has improved as well. Recreation potential is greatly enhanced due to a more pleasing aesthetic atmosphere and larger wildlife population.

Applicability of Study Results to Western Watersheds

The pinyon-juniper complex comprises more than 63 million acres of the rangeland in the Southwest. This ecotype is a critical component of the arid region. Pinyon and juniper generally form the intermediary boundary between the flatter grassland type climax community found on the lower slopes and the conifer forest climax community of the mountain tops. Considerable debate regarding the density of the pinyon-juniper canopy in climax conditions has hindered some watershed restoration efforts. Most range conservationists agree, however, that much of the pinyon-juniper found on the lower slopes has escaped its original range and modified some of the original savanna type ecosystem to a more woodland type. Originally the pinyon-juniper occupied a discrete ecotone in many watersheds, but lack of fire and overuse by livestock have left these once stable areas in poor condition. Many, however, have a high potential for range improvement and revegetation. In areas where the pinyon-juniper complex is in especially poor condition, range improvement can substantially reduce the erosion and sedimentation originating from these degraded areas (Stoddart and others 1975). Some of the most informed members of the environmental community support restoration of Western watersheds but question the removal of pinyon and juniper vegetation from those areas where the species are in the climax community. As opposed to brush removal and range reseeding on areas historically known or reasoned to be grassland, brush removal on certain areas can have the potential to increase sedimentation and erosion rather than decrease it. Information gained from the Carrizo Valley Ranch can be useful to managers needing to determine if brush management efforts can be reasonably and safely completed and a sustainable system established.

Riparian areas and the water they surround are of special consequence in arid ecosystems. These areas constitute only about 2 percent of the total Western acreage, yet they are among the most productive and valuable lands. DeBano and Schmidt (1989) have described the relationship of upland watershed condition to riparian condition and found, not surprisingly, a direct correlation between degraded upland watershed condition and degraded riparian area condition. They concluded that adequate treatment of all critical areas in the upper watershed is necessary to provide a stable and sustainable riparian area and is critical when attempting any riparian restoration project. On Carrizo Valley Ranch, we completed most of the upper watershed work (stabilizing gullies, removing invading brush, and revegetating bare ground) before being able to maintain a stable riparian area. Chaney and his coworkers (1990) and Platts (1990) found that maintenance of riparian areas, once restored, requires a different grazing strategy than upland sites. Although I have done some riparian corridor fencing, which works to protect the riparian area from livestock access, I have demonstrated that as long as the principle—limited and managed access—is applied, fencing is not always a required component. The key to the effective riparian protection demonstrated at Carrizo Valley Ranch is protection during the growing season if possible and rapid rotation when not.

Carrizo Demonstration Area

The watershed above the Carrizo Valley Ranch is part of the Smokey Bear Ranger District of the Lincoln National Forest. In 1989 the USDA Forest Service began a watershed restoration and demonstration project on 55,000 acres of National Forest of the pinyon-juniper ecosystem. The project area contains large expanses of continuous canopy pinyon-juniper that, prior to the introduction of livestock in the 1800's and subsequent fire suppression, supported a wide variety of native grass plants. As the range degraded, trees out-competed grass for available moisture, and soon much of the productive soil beneath these dense woodland stands eroded away leaving behind an extensive and active gully system that continues to transport silt-laden water into streams and rivers (Edwards 1991). With the urging of private land owners that for years had to contend with the deposition of millions of tons of sediment that originated on National Forest land, and who had demonstrated that watershed rehabilitation was not possible on their private landholdings, a unique, cooperative watershed-based project was begun. The project focuses on soil stabilization practices, vegetation management, water resource development, vehicular travel management, and sound grazing management practices. The project's goals include control of soil erosion, stabilization of steep gully slopes, restoration of permanent riparian vegetation, and the rehabilitation of native rangelands to support a sustainable mix of native grass and woody plants.

As the result of treatments, begun in 1989, cool season native species of grass and forbs long absent from the National Forest have returned; in several drainages springs have begun to flow again, and a wide variety of upland and riparian wildlife species have returned to the area making use of the increased edge areas, water supplies, and additional food sources. On private lands adjacent to the Forest, benefits have also been reported. In one area, 4,800 cubic yards of sediment from gully and sheet erosion originating on National Forest land was cleaned out of a pond. The following spring, after implementation of watershed restoration treatments on the Forest, a spring that had not run for 50 years began to flow and continued to flow throughout the summer, filling the pond with clear water. The pond has now been stocked with trout and catfish.

Summary

Integrated resource management is the professional vernacular describing what managers do who are in tune with efficient, sustained use of the resources that are their responsibility. If the use of one resource affects the health or production of another adversely, than the whole is diminished and economic and environmental costs are guaranteed to surface somewhere sometime. Common sense and vision provide the foundation for bringing all parts of the whole together into a comprehensive management plan. Interestingly enough, as are many things in life, it is elusive because it is so simple. And yet, if we intend long-term survival we must implement this approach in every phase of natural resource management.

As watershed restoration and rehabilitation work continues, it is important to understand that there will never be sufficient government resources to treat every problem in every area. Thus, success lies in demonstrating techniques such as those developed on Carrizo Valley Ranch, which proved internal and self-sustaining motivation for adoption on both private and public lands.

References

Bently, H. L. 1898. Grasses and forage plants of Central Texas. Bulletin No. 10. USDA Special Agent in Charge of Grass Experiments, Abilene, TX.

Chaney, E.; Elmore, W.; Platts, W. S. 1990. Livestock grazing on Western riparian areas. U.S. Environmental Protection Agency, Denver, CO.

DeBano, L. D.; Schmidt, L. J. 1989. Improving Southwestern riparian areas through watershed management. USDA Forest Service General Technical Report RM-182, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Edwards, R. 1991. Carrizo Demonstration Area. United States Department of Agriculture, Forest Service. Lincoln National Forest, Smokey Bear Ranger District.

Goodloe, Sid. 1990. Twenty years of integrated/holistic resource management, from integrated resource management symposium, Morelia, Mexico, March 27, 1990.

Leopold, Aldo. 1933/1991. The virgin Southwest, reprinted in The River of the Mother of God and other essays by aldo Leopold. Flander, S.; Barid, J., eds. University of Wisconsin Press. 1991.

New Mexico Environment Department. 1990. Biennial Water Quality Report. NMED, Santa Fe, NM.

Platts, W. S. 1990. Managing fisheries and wildlife on rangelands grazed by livestock. Nevada Department of Wildlife.

Stoddart, L. A.; Smith, A. D.; Box, T. W. 1975. Range management, third edition. McGraw Hill Book Co., St. Louis, MO.

Wooten, E. O. 1908. The range problem in New Mexico. Bulletin 10. Agri. Expt. Station, New Mexico College of Ag. and Mech. Arts.

Initial Response of Soil and Understory Vegetation to a Simulated Fuelwood Cut of a Pinyon-Juniper Woodland in the Santa Fe National Forest

Samuel R. Loftin

Abstract—The Santa Fe National Forest, Espanola Ranger District, the Bandelier National Monument, and the Rocky Mountain Research Station are evaluating a treatment designed to stabilize the soils and increase the abundance of herbaceous plants in degraded pinyon-juniper ecosystems. The treatment removed all pinyon less than 8 inches in diameter and all juniper. The trees were felled, lopped, and the wood and limbs (slash) were scattered across the site. Cover of herbaceous vegetation nearly doubled on the treated site after one growing season and more than doubled after two growing seasons. Significantly higher plant species richness was recorded on the treated site. The preliminary results indicate that this could be an effective pretreatment to the reintroduction of fire.

Many grasslands in the western United States are dependent upon periodic fire to maintain their productivity and stability (Clements 1936). The absence of fire could lead to the succession of grasslands to woodlands or desertscrub (Dick-Peddie 1993). Throughout the western United States, a combination of widespread livestock grazing and periodic drought has promoted woody plant expansion and dominance in areas believed to have been predominantly grassland (Burkhardt and Tisdale 1976; Buckman and Wolters 1986; Grover and Musick 1990; Miller and others 1994). Livestock can reduce fine fuel loads and alter fire frequencies or eliminate fire completely. Periodic drought can select for deep-rooted woody species over shallow-rooted grasses and forbs (Schlesinger and others 1990).

Regardless of the extent of grasslands that have been replaced by pinyon-juniper or juniper woodlands, the type conversion of grassland to woodlands is not necessarily considered to be a problem. The expansion and contraction of woodland and grassland boundaries is a natural process that has been occurring across this landscape for thousands of years (Betancourt 1986; Jameson 1986; Miller and Wigand 1994; Van Devender and others 1984). The problem, as commonly perceived, is the increase in surface runoff and soil erosion that often accompanies a loss of herbaceous plant cover. Surface runoff and soil erosion remove the two resources necessary for maintaining the stability and productivity of these ecosystems, water and soil. Once the soil is gone, the system cannot support a grassland and the question of whether grasslands or woodlands belong on the site becomes academic.

Objectives

The objectives of this research are to evaluate methods for restoring properly functioning edaphic and hydrologic processes, which preserve our options for future land management. More specifically, we hope to stabilize the soil, increase water availability, and increase herbaceous plant abundance, which should further stabilize the soil. This should initiate a positive-feedback cycle of increasing stability and productivity and disrupt the present cycle of increasing degradation. We plan to re-introduce fire back into this system, initially as a restoration treatment to control tree seedlings. Ultimately, fire must be used as a management tool to maintain the structure and function of the grassland component of this ecosystem.

Approach

The thinning treatment should affect several processes that could lead to increased soil stability, plant water availability, and herbaceous plant abundance. Removing trees will result in a reduction in competition for water between trees and herbaceous plants. The slash mulch should increase soil surface roughness and reduce runoff, thereby increasing infiltration and water availability. The mulch will shade the soil and reduce air flow, thereby reducing evaporative loss. The mulch will reduce raindrop impact on bare soils which will reduce the potential for erosion. The mulch will insulate bare soils in the winter, thereby inhibiting frost heave which loosens the soil and also damages seedling plants. Finally, the slash mulch will inhibit grazing by large ungulates that prefer not to nose around in the piles of sticks and twigs.

The trees were cut with chain saws, rather than chaining, cabling, or pushing which requires the use of heavy equipment. This method reduces the disturbance associated with the treatment and reduces the potential for soil erosion and establishment of invasive weeds. This treatment can be implemented as a fuelwood sale which would reduce labor costs for the management agency and provide a resource for the public. This type of fine-scale management also allows managers to tailor the treatment to the desired future condition for the site.

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Methods

Site Description

The study site is located in northcentral New Mexico, on the Santa Fe National Forest, Espanola Ranger District. The site is approximately 25 ha on a south-facing slope which, previous to treatment, supported a dense stand of pinyon (*Pinus edulis*) and juniper (*Juniperus monosperma*) trees. Dominant herbaceous plant species include blue grama (*Bouteloua gracilis*), mountain muhly (*Muhlenbergia montana*), muttongrass (*Poa fendleriana*), tarragon (*Artemisia dracunculus*), and pinque (*Hymenoxys richardsonii*). Soils on the site are classified as fine-loamy to loamy-skeletal, mixed mesic Typic Haplustalf (USDA 1993).

Treatment

The treatment used in this study was removal of all pinyon less than 8" diameter at breast height, and all juniper. Trees were cut at ground level, limbed and lopped. The slash was distributed evenly across the surface of the site. The treatment was conducted in April, 1995 by personnel from the Espanola Ranger District.

Experimental Design

There was no replication of treatments in this experimental design. Each treatment (thinned and control) was approximately 10-15 ha. The treatments were positioned end to end along a south-facing slope. Each treatment was divided into five blocks. Within each block there are three, 100 m transects, one for vegetation sampling, one for soil sampling, and one for soil erosion estimates. Only the vegetation analysis will be discussed in this paper.

The vegetation was sampled using the Community Structure Analysis (CSA) technique of Pase (1981). This sampling technique generates estimates of cover, frequency, and density for sampled plant species. Only cover estimates will be presented in this paper. Estimates of species richness (number of species) can be extracted from the CSA data. Vegetation was sampled in Fall 1994 (pretreatment), Fall 1995 (one growing season post-treatment) and Fall 1996 (two growing seasons post-treatment).

Statistical Analysis

Due to the lack of treatment replication, this study must be considered a case study, the results of which are not to be extrapolated beyond the spatial and temporal limits of the data collected. The effect of thinning was tested by comparing post-treatment conditions on the treated plots to any change on the control plots for comparable time periods. A repeated measures analysis was utilized with thinned vs. control included as a treatment factor, post-treatment years as repeated measures, and the pre-treatment year (1994) as a covariate. In some instances, the effect of thinning was not the same for both post-treatment years (that is, significant interaction between treatment and time). In these instances, significance of thinning for individual years was assessed by applying a t-test to the change from pre-treatment conditions for each treatment for a particular year. Similarly, significance of potential time trends was assessed by applying a t-test to the change from pre-treatment conditions for each post-treatment year within a particular treatment category. Type I error for these sets of t-tests was maintained by applying a Bonferroni adjustment to significance levels of individual tests (Miller 1981). All statistical analyses were conducted using the Statistical Software for the Social Sciences (SPSS Inc. 1990).

Results

Analysis of cover shows significant treatment effects on all cover types (table 1). Tree cover and bare soil both decreased as a direct result of the thinning treatment and there was no significant ($P \leq 0.05$) difference between post-treatment years. Total herbaceous cover was significantly greater on the thinned area and increased significantly from Fall 1995 to Fall 1996. Forb cover and grass cover

Table 1—Cover (%) means (N = 5) and standard errors for various cover types on control and thinned areas for Fall 1994[a] (pretreatment), Fall 1995, and Fall 1996.

		Sampling Period					
		94		95		96	
Cover Type	Treatment	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Tree	Control	36.4	3.9	39.9ax	5.2	39.2ax	5.7
	Thinned	25.5	2.6	7.9bx	3.0	9.2bx	3.1
Total	Control	7.1	1.1	6.9ax	1.1	9.2ax	2.2
Herbaceous	Thinned	6.8	0.5	12.2bx	0.8	22.6by	2.1
Forb	Control	1.4	0.3	1.5ax	0.5	1.5ax	0.5
	Thinned	1.8	0.3	4.9bx	0.5	8.6bx	1.2
Grass	Control	5.7	1.1	5.4ax	0.8	7.7ay	2.2
	Thinned	5.0	0.3	7.3bx	0.5	14.0by	1.0
Bare Soil	Control	36.0	3.6	35.6ax	2.0	35.7ax	2.7
	Thinned	42.9	2.7	27.4bx	0.7	21.7bx	1.3

[a]Pretreatment means are presented for the reader's information; however, they were used as covariates in the repeated measures analysis and are not included in the multiple t-test evaluation of means. Means followed by the same letter (a,b,c), within a cover type and year, are not significantly different ($P \geq 0.05$). Means followed by the same letter (x,y,z), within a cover type and treatment, are not significantly different.

Table 2—Species richness means (N = 5) and standard errors for various vegetation categories on control and thinned areas for Fall 1994[a] (pretreatment), Fall 1995, and Fall 1996.

		Sampling Period					
		94		95		96	
Category	Treatment	x̄	SE	x̄	SE	x̄	SE
All	Control	19.6	1.8	17.2ax	1.3	23.0ay	1.7
Species	Thinned	19.4	0.9	22.0bx	1.3	29.0by	1.09
Forb	Control	9.4	1.2	8.8ax	0.9	13.8ay	1.4
Species	Thinned	10.0	0.6	13.0bx	0.7	16.8by	1.2
Grass	Control	6.0	0.8	4.6ax	0.7	5.6ay	0.4
Species	Thinned	5.0	0.5	5.4bx	0.2	7.4by	0.6

[a]Pretreatment means are presented for the reader's information; however, they were used as covariates in the repeated measures analysis and are not included in the multiple t-test evaluation of means. Means followed by the same letter (a,b,c), within a cover type and year, are not significantly different ($P \geq 0.05$). Means followed by the same letter (x,y,z), within a cover type and treatment, are not significantly different.

(components of total herbaceous cover) both increased significantly following the thinning treatment but only grass cover had a significant time effect.

Significant thinning and time effects were recorded for species richness for all vegetation categories (table 2).

Discussion

The treatment achieved the immediate goals of reducing tree cover and bare soil cover. Total herbaceous plant cover on the treated area was twice that on the control area after one growing season and almost 2.5 x greater than controls after two growing seasons. Both forb and grass cover (the two components of total herbaceous cover) increased as a result of the treatment. Clearly, the objective of increasing herbaceous plant abundance was realized after only two growing seasons.

The concept of biodiversity is important with respect to species preservation and ecosystem stability (Tilman 1996; Tilman and others 1996). Although species richness is not the best estimator of biodiversity response to disturbance (Barbour and others 1987), it is the only index that can be generated from the CSA data. The response observed in this study was probably due to a combination of climatic effects (increased rainfall may have resulted in more recorded species on both sites), and possibly to an improvement of our taxonomic skills. Most of the response in species richness is due to an increase in forb species. The number of grass species has remained relatively constant throughout the study.

The next phase of the project is to re-introduce fire back into the treated area. The objective of the initial (restoration) fire will be to control the resprouting stumps and abundant seedling trees that were released from competition with the mature trees. There are often 15 to 20 seedlings existing under the canopy of a mature tree. If this cohort is not controlled the future density of trees on this site could be many times greater than the pretreatment density. The timing of the first burn is somewhat critical. If we burn too soon, the fuel loads from the slash and herbaceous plants could be high enough to scorch and sterilize soils. However, if we wait too long to burn, the seedling trees and resprouting stumps could get too big to be effectively controlled by the fire. Prescribed fire is most effective 3 to 5 years following mechanical treatments to control redberry or blueberry juniper resprouts in Texas (Erramouspe 1994). We anticipate conducting the initial prescribed fire sometime between 3 to 5 years post-treatment.

Conclusions

The treatment method of hand-thinning trees in a degraded pinyon-juniper woodland significantly increased herbaceous plant abundance (without seeding) within 2 years at this site. Additionally, the treatment has significantly increased species richness. Although this method may not be as efficient at removing trees as techniques involving heavy equipment, it is much less destructive, and much more appropriate for sensitive areas. The treatment has initiated the process of ecosystem restoration. We plan to re-introduce fire as a means to complete the restoration of the site and maintain the functional processes of a stable and productive grassland ecosystem.

References

Barbour, M. G.; Burk, J. H.; Pitts, W. D. 1987. Terrestrial plant ecology. Menlo Park, CA: The Benjamin/Cummings Publishing Company, Inc. 634 p.

Betancourt, J. L. 1986. Paleoecology of pinyon-juniper woodlands: summary. In: Everett, R. L., comp. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV: Intermountain Research Station General Technical Report INT-215: 129-139.

Buckman, R. E.; Wolters, G. L. 1986. Multi-resource management of pinyon-juniper woodlands. In: Everett, R. L., comp. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV: Intermountain Research Station General Technical Report INT-215: 2-4.

Burkhardt, J. W.; Tisdale, E. W. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 57: 472-484.

Clements, F. E. 1936. Nature and structure of the climax. Journal of Ecology 24: 252-284.

Dick-Peddie, W.A. 1993. Ecology and diversity of piñon-juniper woodland in New Mexico. In: Aldon, E. F.; Shaw, D. W., tech. coords. Managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30; Santa Fe, NM: Rocky Mountain Forest and Range Experiment Station General Technical Report RM-236: 72-73.

Erramouspe, R. 1994. Juniper control begins with good grazing management. The Cattleman 91(6): 18-32.
Grover, H. D.; Musick, H. B. 1990. Shrubland encroachment in southern New Mexico, U.S.A.: An analysis of desertification processes in the American Southwest. Climatic Change 17: 305-330.
Jameson, D. A. 1986. Climax or alternative steady states in woodland ecology. In: Everett, R. L., comp. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV: Intermountain Research Station General Technical Report INT-215: 9-13.
Miller, R. F.; Wigand, P. E. 1994. Holocene changes in semiarid pinyon-juniper woodlands. Bioscience 44(7): 465-474.
Miller, R. G., Jr. 1981. Simultaneous statistical inference, 2nd edition. New York: Springer-Verlag. 299 p.
Miller, R.; Rose, J.; Svejcar, T.; Bates, J.; Painter, K. 1994. Western juniper woodlands: 100 years of plant succession. In: Shaw, D. W.; Aldon, E. F.; LoSapio, C., tech. coords. Desired future conditions for piñon-juniper ecosystems; 1994 August 8-12; Flagstaff, AZ: Rocky Mountain Forest and Range Experiment Station General Technical Report RM-258. Fort Collins, CO: 5-8.
Pase, C. P. 1981. Community structure analysis—a rapid, effective range condition estimator for semi-arid ranges. In: Lund, H. G.; XXX tech. coords. Arid land resource inventories: developing cost-efficient methods; 1980 Nov. 30-Dec. 6; La Paz, Mexico: U.S. Department of Agriculture, Forest Service General Technical Report WO-28, Washington, D.C: 425-430.
Schlesinger, W. H.; Reynolds, J. F.; Cunningham, G. L.; Huenneke, L. F.; Jarrell, W. M.; Virginia, R. A.; Whitford, W. G. 1990. Biological feedbacks in global desertification. Science 247: 1043-1048.
SPSS Inc. 1990. SPSS Statistical Data Analysis, SPSS/PC + 4.0. Chicago, IL.
Tilman, D. 1996. Biodiversity: population versus ecosystem stability. Ecology 77(2): 350-363.
Tilman, D.; Wedin, D.; Knops, J. 1996. Productivity and sustainability influenced by biodiversity in grassland ecosystems. Nature 379:718-720.
USDA Forest Service. 1993. Terrestrial ecosystem survey of the Santa Fe National Forest. Southwestern Region, Albuquerque, NM. 563 p.
Van Devender, T. R.; Betancourt, J. L.; Wimberly, M. 1984. Biogeographic implications of a packrat midden sequence from the Sacramento Mountains, south-central New Mexico. Quaternary Research 22: 344-360.

Applying Fire to Pinyon-Juniper Communities of the Green River Corridor, Daggett County, Utah

Ivan Erskine
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Abstract—Between 1984 and 1993, prescribed fire was applied to about 3,900 acres of pinyon-juniper woodland on the Ashley National Forest in the Green River corridor of Daggett County, UT. Prior to burning, much of the area was covered by mature and old stands of pinyon and juniper with little understory. Most of the burning required creating crown fires. Methods, results, and management implications of burning are discussed.

Prior to a burning program that began in the 1980's, the pinyon-juniper belt on the Ashley National Forest in the Green River corridor of Daggett County, UT, was dominated by about 20,000 acres of nearly continuous stands of mature and old pinyon-juniper. Young stands of pinyon-juniper were advancing across the few areas where sagebrush-grass and mountain brush-grass communities were present. Objectives of burning included reducing pinyon-juniper in parts of the corridor with the intent of creating greater diversity of plant communities and more favorable habitat for wild sheep, elk, deer, and other wildlife.

Methods and Results

Prior to some of the burns, automated weather stations with voice recorders were placed in the vicinity of the proposed burns. Readings from these weather stations were accessed frequently by radio prior to and during burning. Readings from these weather stations were supported by measurements with portable field weather instruments. Burning experience under various weather conditions was used to develop prescriptions for prescribed burning. Weather conditions under which seven burns were conducted are listed in table 1.

Some attempts at burning failed when conditions were not favorable. Under favorable conditions, as much as 1,100 acres were burned in 1 day. The Goslin A burn indicates weather conditions not favorable for burning. Although windspeeds of 18 to 20 miles per hour, with gusts of up to 34 miles per hour, were comparatively high for this burn, the low temperature (62 °F), higher relative humidity (26 percent), and cloud cover (10 to 30 percent) were not favorable. An afternoon of ignition attempts yielded 191 acres of burning for the Goslin A burn.

With an afternoon of ignition, 970 acres (Goslin II) and 141 acres (Rifle Canyon A) were burned. Weather conditions associated with this burning included temperatures of 75 to 79 °F, relative humidity of 15 to 18 percent, cloud cover of 0 percent, and winds of 10 to 25 miles per hour. With about 3 hours of ignition, 980 acres were burned at the Hideout East A burn, with temperatures of about 76 °F, relative humidity of 18 percent, cloud cover of 0 to 10 percent, and winds of 5 to 15 miles per hour.

Experience at these and other burns listed in table 1 shows the importance of low-percent cloud cover as well as high temperatures and low humidity. This seems to be expected because these features are often related. Lower temperatures and higher humidity are generally associated with cloud cover. Even on a relatively clear day when burning was favorable, ignition and fire spread were greatly hampered when a passing cloud shaded the burn site from the sun.

All of the burns listed in table 1 were ignited by helitorch. Other burns were ignited with drip torches by ground crews. Use of drainage bottoms as ignition sources was found to be highly useful. By using drainage bottoms as ignition sources, crown fires necessary for fire spread were started with comparatively little ignition time.

Costs of treatment varied with successful attempts at burning. Cost of burning at one project included a failed attempt related to a training session when the schedule training session did not fall on days that were favorable for burning. Including this failed attempt in the cost, $9.54 per acre were spent in burning. Excluding the failed attempt, cost per acre was $4.54. Cost of the seed was $10.83 per acre, and cost of aerial application of seed was $4.17 per acre. Considering ideal conditions and the failed attempt, a range between $19.54 and $24.54 per acre (1989 dollars) is indicated for most projects.

Watershed recovery and plant response were monitored on at least 12 study sites within these burned areas. Ground cover was reduced to near 0 by burning, and it remained low for one to two growing seasons after burning. High intensity storms washed considerable ash and some soil from some of the burned surfaces into drainage bottoms. However, within 5 years, high percent ground cover was achieved (Goodrich and Huber, these proceedings; Goodrich and Reid, these proceedings), and little sediment movement was apparent after that time.

Recovery of ground cover was more rapid in areas where vigorous understory communities were associated with young stands of pinyon-juniper than where understory

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Table 1—Seven burns and weather conditions under which they were burned.

Burn		Gradient	Temperature	Relative humidity	Cloud cover	Wind[a]
	Acres	*Percent*	*°F*	---- *Percent*	----	*Miles per hour*
Hideout East A	980	15-60(85)	76	18	0-10	5-10 (15)
Jarvies Canyon A	301	(10)20-50	71	25	0-10	10-15(25)
Jarvies Canyon B	223	20-60	71	25	0-10	10-15(25)
Rifle Canyon A	141	5-30(60)	79	18	0	20-25
Rifle Canyon B	160	5-60(80)	78	17	0	5-10(20)
Goslin A	191	15-35	62	26	10-30	18-20(34)
Goslin II	970	5-15	75	15	0	10-15

[a]For each burn, winds were from the southwest. Numbers in parentheses show the speed of gusts.

communities had been depleted under closed stands of mature and old pinyon-juniper. Recovery of native understory plant communities was much more rapid where associated with young stands than where associated with mature and old stands. Seeded species and introduced annuals dominated the early seral communities where stands of mature and old pinyon-juniper were burned. Native species dominated early seral communities where young stands of pinyon-juniper were burned. Much greater diversity in early seral plant communities was found where young stands burned compared to mature and old stands (Huber and others, these proceedings).

Forage benefits for elk and deer were readily apparent with large numbers of elk concentrating in these burns for parts of the year. Benefits to wild sheep are indicated to be slow in developing. Smith (1992) found that wild sheep used older burns where skeletons of mature pinyon-juniper had mostly fallen, but he found wild sheep avoided the recent burns where these skeletons were rather dense and where there was a flush of tall forage. Few to several decades are indicated for these burns to develop into high-value habitat for wild sheep. However, wild sheep showed high preference for areas where open stands of pinyon-juniper had recently been burned.

Management Implications

Experience of burning pinyon-juniper in the Green River corridor indicates that temperatures of above 70 °F, relative humidity of less than about 25 percent, and winds of 10 to 30 miles per hour provide the most favorable conditions for burning. A Haines index (Haines 1988) of 5 or 6 was helpful for large fire growth and successful burning. A Haines index of 5 or 6 indicates the lower atmosphere is dry and unstable. Cloud-free days are necessary for sustained fire spread.

Crown fires are necessary to burn mature and old stands of pinyon-juniper with little understory. Ignition in drainage bottoms can help achieve crown fires.

Longevity of burning as a habitat treatment in the pinyon-juniper belt of the Green River corridor is indicated to be 100 to 150 years or more (Goodrich and Barber, these proceedings). Comparatively low initial cost and longevity of treatment indicate comparatively high economic returns compared to chaining. However, burning leaves watersheds highly vulnerable to erosion for a few seasons after fire compared to chaining where debris is left in place.

Fire is more easily applied to steep slopes, especially those likely to be selected by wild sheep, than chaining. Fire is more easily applied where slopes contribute to flame spread than on low gradients. However, in the Goslin II burn, over 900 acres were burned with one afternoon of ignition where gradients were commonly 5 to 15 percent.

Fire perimeters are much less certain than with chaining or other mechanical treatments. Use of fire is indicated for areas where other methods are difficult to apply and where precise confinement of treatment is not critical. However, climatic features, fuel loading, and abundance of fire-tolerant species in early and mid-seral communities of this pinyon-juniper belt indicate an ecological history in which fire was a strong player. Escape of fire beyond prescribed boundaries has importance for manmade structures and other economic values, but the ecological history indicates this to be of little ecological relevance.

Comparatively low cost and longevity are additional benefits for this treatment where it is appropriate in terms of habitat objectives and confinement constraints.

Fire applied to open stands of relatively young pinyon-juniper has the following features: rapid recovery of indigenous understory plant communities, rapid recovery of ground cover sufficient for watershed and soil protection, and rapid improvement of favorable habitat for wild sheep.

Fire applied to close stands of mature and old pinyon-juniper has the following features: slow recovery of indigenous understory plant communities with development of communities dominated by introduced annuals or seeded species, recovery of ground cover highly dependent on introduced annuals or seeded species, and slow improvement of favorable habitat for wild sheep.

References

Haines, D. A. 1988. A lower atmospheric severity index for wildfires. National Weather Digest. 13: 23-27.

Smith, T. S. 1992. The bighorn sheep of Bear Mountain: ecological investigations and management recommendations. Provo, UT: Brigham Young University. 425 p. Dissertation.

Soil and Watershed Implications of Ground Cover at Burned and Unburned Pinyon-Juniper Sites at Rifle Canyon and Jarvies Canyon

Sherel Goodrich
Chad Reid

Abstract — Quantity, dispersion, and quality of ground cover is compared for adjacent burned and seeded and unburned pinyon-juniper sites. Comparison of these features indicates greater soil protection for the burned and seeded site with 15 percent less bare soil and pavement and 24 percent greater vascular plant and litter cover 7 years post treatment. Ground cover is also compared between 5 and 10 years post burning and seeding at one site. This comparison indicates ground cover continued to increase for up to 10 years post treatment.

Total ground cover, dispersion of ground cover, and quality of ground cover appear to be highly important for soil and watershed protection (Blackburn and others 1986; Khan and others 1988; Osborn 1955; Payne 1980; Simanton and others 1991; Watters and others 1996). Over 4 years, Farmer (1995) found an average of five times more runoff and eight times more sediment associated with a mature stand of pinyon-juniper than in an adjacent area that had been chained and seeded with litter left in place. The sites in the Ashley National Forest at Rifle Canyon and Jarvies Canyon were burned, which greatly reduced ground cover for 1 or 2 years. However, within 7 years, plant and litter cover exceeded that found in a mature stand of pinyon-juniper, and ground cover continued to increase for up to 10 years.

Study Sites

The study sites are located within the Green River corridor in Daggett County, Utah, where there are about 8,100 ha (20,000 acres) within a belt of Colorado pinyon (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) on the Ashley National Forest. The belt extends well beyond the National Forest boundary down river toward the Colorado and Utah line. Prior to the 1980's when a burning program was started within this area, pinyon-juniper formed nearly continuous stands and was advancing into the few remaining sagebrush/grass and mountain brush communities. Much of the belt on National Forest lands was closed to permitted livestock grazing in the 1960's as mitigation for recreation and other values associated with Flaming Gorge Reservoir.

Low forage values for wild ungulates were recognized in this area with extensive stands of mature pinyon and juniper covering much of the corridor and with young stands expanding into sagebrush/grass and mountain brush/grass communities. Bighorn sheep were of special concern as they were known to use the Green River corridor. Bighorn sheep avoided mature and old stands of pinyon and juniper (Smith 1992). Burning and seeding of some sites were proposed and accomplished by the Ashley National Forest and Utah Division of Wildlife Resources. The Bureau of Land Management also burned some sites lower in the corridor.

Prescribed fire was applied to pinyon-juniper woodlands at Jarvies Canyon in the fall of 1985 and in Rifle Canyon in September 1989. Study sites within these burns are about 4.8 km (3 miles) west and about 2.4 km (1.5 miles) northwest of Dutch John, UT. Mean annual precipitation at the Flaming Gorge Climate Station near Dutch John is 31.75 cm (12.50 in) (Ashcroft and others 1992). The study sites are within the Uinta Mountain Section as defined by McNab and Avers (1994). They are within a landtype composed of ridge and ravine topography underlain by Precambrian quartzitic materials and shales of the Uinta Mountain Group.

Within the landtype there are two general phases. One phase is on dip slopes of northerly exposures where alderleaf mountain-mahogany/bluebunch wheatgrass (*Cercocarpus montanus* Raf./*Elymus spicatus* [Pursh] Gould) communities with high plant diversity are seral to pinyon-juniper. The other phase is on scarp slopes of southerly exposures where plant communities of big sagebrush (*Artemisia tridentata* Nutt.), rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Birtt.), and grasses are seral to pinyon-juniper. On southerly exposures cheatgrass has proven to be highly competitive. It is generally of lower frequency on the northerly exposures. Both study sites reported here are on the phase with southerly exposures at about 2,042 m (6,700 ft) elevation on gradients of about 20 to 40 percent.

Both burns were aerial seeded in November or December of the same year in which they were burned. Seed for both sites was provided by Utah Division of Wildlife Resources. By weight, the seed mix at Jarvies Canyon included smooth brome (*Bromus inermis* Leysser) (20 percent), Piute orchardgrass (*Dactylis glomerata* L.), hard fescue (*Festuca ovina* var. *duriuscula* [L.] Koch.), Ladak alfalfa (*Medicago sativa* L.), and small burnet (*Sanguisorba minor* Scop.) (13 to 14 percent each), and Fairway crested wheatgrass (*Agropyron cristatum* [L.] Gaertner), intermediate wheatgrass (*Elymus hispidus* [Opiz] Meld.), yellow sweetclover (*Melilotus*

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Table 1—Comparison of ground cover at the Rifle Canyon burn site five growing seasons after treatment

Treatment	Veg.	Litter	Moss	Rock	Pave.	Soil	Total
Burn and seeded (points)	31[a]	202[a]	6	68[a]	23[a]	70[a]	400
Unburned, not seeded (points)	18	134[a]	0	110[a]	54[a]	101[a]	400
Burn and seeded (percent)	8	50	1	17	6	18	100
Unburned, not seeded (percent)	0	34	0	28	14	25	101

[a]The spread in scores for these parameters between the two areas is indicated to be significant at 80 percent probability (Chi Square = 1.642 with one degree of freedom).

officinalis [L.] Pallas), and mountain big sagebrush (*Artemisia tridentata* var. *pauciflora* Winward & Goodrich) (6 percent each). By weight, the seed mix at Rifle Canyon included: crested wheatgrass, orchardgrass, and ladak alfalfa (20 percent each), and intermediate wheatgrass, smooth brome, hard fescue, and yellow sweetclover (10 percent each). The study site at Rifle Canyon provided a sharp contrast between burned and unburned areas.

Methods and Results

At the Rifle Canyon site, quantity of ground cover was compared in 1996 (7 years post treatment) by recording ground cover at 400 points along five belt lines 30.5 m (100 ft) long in each of the burned and seeded and unburned sites. Results are shown in table 1. Frequency of plant species were recorded in 100 quadrats of 50 by 50 cm placed along the belt lines. Nested frequency was also determined in four plot sizes of 5 by 5 cm, 25 by 25 cm, 25 by 50 cm, within the 50 by 50 cm quadrat which made up the fourth nested plot size (U.S. Department of Agriculture, Forest Service 1993).

At the Jarvies Canyon site, which is less than 3 miles away from the Rifle Canyon site, the same study methods described above were applied at five and 10 growing seasons postfire. Results are shown in table 2.

At the Rifle Canyon Site, dispersion of ground cover was compared by line intercept measurements along the five belts for a total intercept of 152 m (500 ft) in each of the treated and untreated sites. Distance of intercept without live plant or litter cover was recorded. Range of variability for distance without live plant or litter cover was 0.3 to 2.7 m (1 to 9 ft) for the burned and seeded area and 0.9 to 21 m (3 to 69 ft) for the mature pinyon-juniper stand. Mean distance of intercept without live plant or litter cover was 0.82 m (2.7 ft) for the treated area and 5.4 m (17.6 ft) for the untreated area.

Quadrat frequency also indicates dispersion of plant cover. Seven years after treatment at Rifle Canyon, 86 of the 100 quadrats (50 by 50 cm) contained perennial plants in the treated area compared to 37 of 100 in the mature pinyon-juniper stand. At the Jarvies Canyon site, perennial plants were found in 90 and 99 of the 100 quadrats 5 and 10 years post treatment, respectively. Comparison of perennial plants in nested plots of 25 by 25 cm also indicated dispersion of cover. In the mature pinyon-juniper stand at Rifle Canyon only 15 of 100 plots had at least one perennial plant in them. In the burned and seeded area 59 of 100 plots had at least one perennial plant in them. At Jarvies Canyon, 67 and 92 of the 100 nested plots of 25 by 25 cm had at least one perennial plant in them at 5 and 10 years post treatment, respectively.

At the Rifle Canyon site, crown cover of pinyon and juniper was also determined by line intercept along the five belts. On the untreated site, crown cover of pinyon was 20 percent, and for juniper it was 19 percent for a combined value of 39 percent. On the treated area, crown cover was estimated by measuring the intercept of dead crowns. This indicated crown cover of 17 and 18 percent for pinyon and juniper, respectively, for a combined value of 35 percent. Similar crown cover for the two sites prior to the burn is indicated. Crown cover of trees was not determined at the Jarvies Canyon site. However, density of skeletons indicated similar or greater cover of pinyon-juniper prior to burning.

Essentially all the ground cover provided by live vegetation and litter in the untreated area was composed of basal area of trees and needles of these trees that were confined beneath the crowns of trees. Combined crown cover of pinyon and juniper on the untreated site was 39 percent. Combined ground cover of vegetation and litter was 34 percent. The litter of pinyon and juniper was composed of needlelike or scalelike leaves, cones, and broken twigs. The needlelike leaves of Colorado pinyon are 1.5 to 5 cm long, and the pistillate cones are ovoid and 2 to 5 cm long. The scalelike mature leaves of Utah juniper are 1 to 3 mm long with juvenile ones 2 to 8 mm long. The pistillate cones are subglobose and 6 to 12 mm thick (Welsh and others 1993).

Ground cover in the burned and seeded area was composed of numerous fine stems comparatively closely spaced, which served to anchor litter. Stem length of grasses and forbs on the site varied from a few cm to over 1 m in length. Herbaceous litter consisted of comparatively fine, long, stems with branches or leaves that provided for a higher

Table 2—Comparison of ground cover at 5 and 10 years following burning and seeding at the Jarvies Canyon site.

Year	Veg.	Litter	Moss	Rock	Pave.	Soil	Total
1991 (points)	24[a]	117[a]	0	93[a]	47	119*	400
1996 (points)	96[a]	184[a]	1	35[a]	39	45[a]	400
1991 (percent)	6	29	0	23	12	30	100
1996 (percent)	24	46	0	9	10	11	100

[a]The spread in scores for these parameters between the 2 years is indicated to be significant at 80 percent probability (Chi Square = 1.642 with one degree of freedom). The lower value for rock in 1996 is considered a function of plant and litter cover spreading across exposed rock and not from rock being removed from the site.

interlocking and lodging of litter than on the untreated site. This herbaceous litter was associated with course woody debris of pinyon and juniper trees that had fallen since the fire in addition to the basal area of the trees that remained standing. As expected cheatgrass increased rapidly in the burned area, and higher ground cover here was a function of this species as well as the seeded species.

Discussion

Exposed soil and small gravel fragments are easily displaced by the forces of water especially as gradients increase. Live and dead plant material and rock provide cover that can protect soils from the forces of water. Ground cover is the principle protection against both raindrop splash and sheet erosion (Farmer 1995; Osborn 1955; Blackburn and others 1986). Plant cover at or near the ground surface is more effective than canopy cover for preventing erosion (Simanton and others 1991; Khan and others 1988). Watters and others (1996) found basal cover, average distance to nearest perennial plant, and frequency of quadrats with no rooted perennial plant showed strong relationships to a subjective site stability rating for determining the point at which accelerated erosion occurs.

Quality of ground cover is indicated by how well it is anchored or how well it is able to stay in place under rain drop splash and surface flow of water. Rooted vegetation has greater ability to stay in place than detached litter. Dispersion of ground cover is important to quality of cover. Vegetation with many fine stems well dispersed provides the best protection (Osborn 1955). This well dispersed, rooted vegetation also helps keep detached litter in place. Length and roughness of litter also contribute to stability of litter cover. Long pieces of flexible litter become interlocked more than do short, ridged pieces. Litter of stems with branches or leaves is more likely to interlock and lodge against live vegetation or larger woody debris than is litter composed of short, unbranched pieces.

The shape of the pistillate cones of pinyon and juniper (ovate to subglobose) greatly facilitate their movement down slope by water and gravity. The staminate cones disintegrate in to small fragments that are easily moved by water or wind. The pistillate cones were found in great numbers in the drainage bottom below the Rifle Canyon study site. The short needles of pinyon and juniper form a comparatively incohesive duff beneath the trees that is held in place by the base of the tree and where it is somewhat protected by the crowns of the trees. Where this litter is exposed to raindrop slash, it seems unstable compared to the litter of the burned site.

Comparisons of runoff and movement of sediment were not made in this study. However, the conditions described above are similar to those described by Farmer (1995) where he found an average of five times more runoff and eight times more sediment produced in a mature or old pinyon-juniper stand than on a treated area. However, the treated area in his study had been chained and seeded with debris left in place. Much higher levels of woody debris can be expected in that treatment than with burning. Less watershed protection can be expected following burning. Davis and Harper (1990) found bare soil decreased from 47 percent before treatment to 11 percent 3 years postchaining with debris left in place. Slower increase for soil cover is indicated for burning at Rifle Canyon where bare soil and pavement totaled 39 percent in the untreated area and 24 percent 7 years post treatment in the burned and seeded area.

However, the increase in quantity, quality, and dispersion of ground cover with burning and seeding at the Rifle Canyon site indicates a strong trend toward soil stability. Monitoring at the Jarvies Canyon site indicates recovery will continue for up to 10 years, after which high values for soil and watershed protection have been achieved.

At the Rifle Canyon site, ground cover provided by vegetation and litter was 34 percent in the untreated area. In the treated area this cover was 58 percent 7 years post treatment. At the Jarvies Canyon site no comparison was made with comparable treated and untreated sites. However, between the fifth and 10th years postfire and seeding, ground cover increased from 35 to 79 percent. This increase of 44 percentage points is indicated by point data to be significant (see table 2). The higher quadrat frequency and nested frequency of perennial plants in the treated area also indicates higher dispersion of cover of many fine stems that are more closely spaced than found in the untreated area.

In the untreated site at Rifle Canyon, a relationship of litter cover to crown cover of trees is indicated by the similar values of 34 percent litter cover and 39 percent for crown cover of pinyon and juniper. This relationship is visibly conspicuous at this site. In the mature pinyon-juniper stand, little litter is deposited in the interspaces between trees where it is poorly anchored and of low structural quality. Comparatively rapid removal of what little litter is deposited in the interspaces is indicated by the barren nature of the interspaces. Thus, the interspaces which make up over 60 percent of the surface are essentially devoid of plant and litter cover. A mantle of exposed gravel-sized rock fragments (28 percent of cover) did provide a well dispersed cover in these interspaces, which is indicated to be quite effective in slowing erosion. However, this exposed rock cover is indicated to be a function of past erosion. In the high precipitation summer of 1997, rills were greatly expanded in spite of the pavement and gravel cover on the untreated area. In the treated area, rock as well as bare soil are being covered by vegetation and litter where rills were not greatly expanded in 1997.

Management Implications

Pinyon and juniper appear to have the capacity to dominate nearly all ecological sites within the thermal belt to which they are confined. With long-term absence of disturbance, crown closure of these trees increases with a decrease in understory plants. On some sites this is associated with lower total ground cover, spotty dispersion of ground cover, and lower quality of ground cover. On some sites these conditions are conducive to greater erosion and sediment delivery to drainages.

However, pinyon and juniper communities appear to be self-sustaining in this condition. Strongly implied is a long history of erosion and sediment delivery as a function of pinyon-juniper dominance of some sites. In view of this history, Gifford (1987) made a point that the pinyon-juniper type has sustained itself on many diverse landscapes over the past 5,000 years or more and where it has obviously been designed to withstand at least 5,000 years of extreme hydrologic events. The concept of pinyon and juniper being self-sustaining on eroding surfaces is supported by their presence on many of the exposed, eroding geologic strata of Utah that weather to badlands. This contributes to the concept of a broad ecological amplitude for these species including strata that are low in nutrients, repel water, and contain gypsum and other chemicals that might inhibit growth. Pinyon and juniper are also capable of dominating more productive alluvial soils.

That pinyon and juniper are self-sustaining on nearly all soils and geologic strata within their thermal belt including eroding surfaces is a point of this paper. However, conditions conducive to erosion and sediment yield are associated with mature and old stands of pinyon and juniper on some areas. These areas present an opportunity to reduce erosion by reducing the presence of pinyon and juniper and increasing the presence of plants with numerous fine stems that are closely spaced that serves to increase the dispersion and quality of litter.

The barren interspaces of the mature pinyon-juniper stand at the Rifle Canyon site collaborate the views of West and Van Pelt (1987), Everett (1987), and Bunting (1987) that these trees contribute to the death of herbs and shrubs that grow on these sites at earlier stages of succession, which creates barren interspaces that are then exposed to the forces of erosion as a function of pinyon-juniper dominance. The general lack of understory species on the untreated site is consistent with the view of Hironaka (1987) that the simple mix of overstory and lack of understory in mature stands makes classification based on climax unsatisfactory.

Langbein and Schumm (1958) reported maximum sediment yields occur on areas where annual precipitation is between 25.4 cm (10 inches) and 35.5 cm (14 inches). Payne (1980) considered the pinyon-juniper belt of the Intermountain Region to generally fall within this range. Ronco (1987) noted precipitation in pinyon-juniper woodlands of the Great Basin does not appear sufficient to adequately support both trees and herbaceous vegetation. This is consistent with the view of Arnold (1959) that pinyon-juniper woodlands produce more sediment than other woodlands. Low percent ground cover and high rates of erosion might be expected to be inherent in some mature and old pinyon-juniper stands. This concept is strongly supported by the work of Farmer (1995) where over 4 years he found an average of five times more runoff and eight times more sediment associated with a mature stand of pinyon-juniper than in an adjacent area that had been chained and seeded with litter left in place.

Data from the Rifle Canyon and Jarvies Canyon sites indicate development of potential ground cover will take up to 10 years or longer following fire. For 1 or 2 years, burning can be expected to greatly expose the soil surface to the forces of erosion compared to chaining where debris is left in place. However, pinyon-juniper communities are indicated to be self-sustaining under high rates of erosion. Thus short-term exposure to erosion is indicated to be well within the range of natural variability for these sites.

The ability of pinyon and juniper to occupy, dominate, and to be self-sustaining on eroding surfaces indicates the preservation of many mature and old stands of these trees will be associated with low watershed values. Perhaps the super dominance of plants with broad ecological amplitudes are not always appropriate indicators of a broad range of values that might be achieved from a landscape. Pinyon and juniper are capable of sustaining themselves on an eroding soil regime to which they are apparent contributors. Treatments like those at Rifle Canyon and Jarvies Canyon offer an opportunity for communities that indicate a soil building regime.

Visual and structural values for mature and old pinyon-juniper stands for some wildlife species are important considerations. The point of this paper is not to justify wholesale elimination of pinyon-juniper from large areas. It is to recognize a range of values and opportunities within the pinyon-juniper thermal belt. The challenge is to obtain site specific data that will facilitate choosing appropriate sites to manage for a diversity of values (Goodrich, these proceedings).

Where watershed protection and long-term soil productivity are values to be emphasized, early seral communities are indicated to be of higher value than are mature or old stands where canopy cover of these trees has reached 40 percent. Observations in other stands of the Dutch John area indicate high watershed values can be maintained with crown cover of pinyon and juniper of up to 10 to 15 percent (Huber and others, these proceedings).

These features strongly indicate that choice of sites to be managed for mature and old stands should include areas of more gentle gradient and areas of high percent large rock where erosion hazards are comparatively low. Depth and duration of snow cover are comparatively low on the steep gradients of southerly exposure at the Rifle Canyon and Jarvies Canyon sites. This indicates high value of these sites for wintering wild ungulates for which early and mid seral communities are of higher forage value than late seral or old stands. This concept is supported by a study in central Utah where Davis and Harper (1990) found lower mortality of deer where their habitat included early seral communities compared to that of large stands of mature juniper-pinyon without openings of early seral communities.

In the case of this study, in an area where nearly 8,100 ha (20,000 acres) within the pinyon-juniper thermal belt was at or trending toward mature and old pinyon-juniper stands, the treatment seems appropriate for diversity of habitats. Reduced rates of erosion could be an additional benefit where the slopes at Rifle Canyon and Jarvies Canyon are only about 3.2 km (2 miles) above Flaming Gorge Reservoir.

References

Arnold, J. F. 1959. Effects of juniper invasion on forage production and erosion. Your Range-Its Management. Tempe, AZ: Arizona Agricultural Extension Service Report 2 : 17-18.

Ashcroft, G. L.; Jensen, D. T.; Brown, J. L. 1992. Utah climate. Logan, UT: Utah State University, Utah Climate Center. 125 p.

Blackburn, W. H.; Thurow, T. L.; Taylor, C. A. Jr. 1986. Soil erosion on rangelands. In: Proceedings, Range Monitoring Symposium, Society of Range Manage. Denver, CO. 31-39.

Bunting, S. C. 1987. Use of prescribed burning in juniper and pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 141-144.

Davis, J. N.; Harper, K. T. 1990. Weedy annuals and establishment of seeded species on a chained juniper-pinyon woodland in central Utah. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tuller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 72-79.

Everett, R. L. 1987. Plant response to fire in the pinyon-juniper zone In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 152-157.

Farmer, M. 1995. The influence of anchor chaining on the watershed values of a pinyon juniper woodland in central Utah. Provo, UT: Brigham Young University. 46 p. Thesis.

Gifford, G. F. 1987. Myths and fables and the pinyon-juniper type. In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 34-37.

Goodrich, S. These proceedings. Multiple use management based on diversity of capabilities and values within pinyon-juniper woodlands. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Hironaka, M. 1987. Classification of the pinyon-juniper vegetation type. In: Everett, R. L., compiler. Proceedings—Pinyon-juniper conference; 1986 January 13-16; Reno, NV. Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 199-201.Khan, M. J.; Monke, E. J.; Foster, G. R. 1988. Mulch cover and canopy effects on soil loss. Trans. of the Amer. Soc. Agr. Engr. 31: 706-711.

Langbein, W. B.; Schumm, S. A. 1958. Yield of sediment in relation to mean annual precipitation. America Geophysical Union, Trans. 39: 1076-1084.

McNab, W. H.; Avers, P. E. 1994. Ecological subregions of the United States: Section descriptions. Administrative Publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

Osborn, B. 1955. How rainfall and runoff erode soil. In: Stefferud, A. editor. Water the yearbook of Agriculture 1955. Washington DC: U.S. Department of Agriculture. 126-135.

Payne, J. F. 1980. A multi-site evaluation of pinyon-juniper chaining in Utah. Logan, UT: Utah State University. 77 p. Thesis.

Ronco, F. Jr. 1987. Stand structure and function of pinyon-juniper woodlands. In Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 14-22.

Simanton, J. R.; Weltz, M. A.; Larsen. H. D. 1991. Rangeland experiments to parameterize the water erosion effects. J. Range Manage. 30: 44-49.

Smith, T. S. 1992. The bighorn sheep of Bear Mountain: ecological investigations and management recommendations. Provo, UT: Brigham Young University. 425 p.

U. S. Department of Agriculture, Forest Service. 1993. Rangeland ecosystem analysis and management handbook. FSH 2209-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 4 ch.

Watters, S.E.; Weltz, M. A.; Smith, E. L. 1996. Evaluation of a site conservation rating system in southeastern Arizona. J. Range Manage. 49: 277-284.

Welsh, S. L.; Atwood, N. D.; Goodrich, S.; Higgins, L. C. 1993. A Utah flora. Provo, UT: Brigham Young University Print Services. 986 p.

West, N. E; Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

Use of OUST® Herbicide to Control Cheatgrass in the Northern Great Basin

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Abstract—The herbicide OUST® (sulfometuron methyl) is being used on rangelands in the northern Great Basin to control cheatgrass (*Bromus tectorum*) for 1 to 2 years, thereby improving the success of rehabilitation projects. Experimental data indicate that OUST® provides more effective cheatgrass control than either burning or disking. OUST® was applied to a 100-acre cheatgrass-infested seeding near Mountain Home, Idaho, where it reduced cheatgrass density by 91 percent compared to an adjacent untreated control. Remnant perennial grasses were more vigorous in the OUST® treatment. OUST® can be used to effectively control cheatgrass for up to 2 years at a cost of $25-$28 per acre (herbicide and application costs), using either ground or aerial application.

The Problem: Exotic Annual Grass Invasion on Western Rangelands

The introduction of two exotic annual grasses, cheatgrass (*Bromus tectorum*) and medusahead wildrye (*Taeniatherum caput-medusae* ssp. *asperum*), onto rangelands of the western United States was undoubtedly one of the most significant ecological events in North American history (Peters and Bunting 1994). Anthropogenic disturbances associated with settlement and growth of the human population, expansion of transportation systems and agriculture created openings in native plant communities for invasion and eventual dominance of exotic species (Mack 1981). Exotic annual grass accumulation in the understories of native shrub communities creates a continuum of fine, combustible fuels (Billings 1994), resulting in dramatic increases in wildfire frequency and size (Pellant 1990; Whisenant 1990). These exotic species have adapted to a broader range of habitats, including salt-desert shrub and pinyon-juniper (*Pinus-Juniperus*) communities, resulting in the conversion of diverse natural landscapes to fire-maintained annual grass rangelands (Billings 1994; Monsen 1994; Sparks and others 1990).

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The establishment and spread of cheatgrass and the subsequent wildfires have had serious impacts on wildlife habitat and populations. Habitat loss has resulted in population declines for shrubland-obligate wildlife, ranging from breeding birds and rodents to wintering ungulates (Knick and Rotenberry 1995; McAdoo and Klebenow 1978). Food web dynamics are modified by loss of forage for herbivorous species and breeding habitat for both prey and predators. Herbivores exert additional pressure on the remaining native plant community resulting in depletion of forage and browse (McAdoo and Klebenow 1978). Livestock can be similarly affected by loss of forage following wildfire.

The costs associated with wildfire suppression and rehabilitation are also growing as wildfires increase due to the pervasiveness of flammable annual grasses in the Great Basin (Pellant 1990). Additional concerns arise as more people move to urban-wildland interfaces and wildfire threats to private property increase. The issues surrounding the impacts of cheatgrass and associated wildfires will continue to grow unless effective and economical control treatments are applied on selected cheatgrass rangelands.

Traditional Cheatgrass Control Methods

Traditional methods to control cheatgrass—livestock grazing, burning, mechanical (disking or plowing), or broad-spectrum herbicides—have all been used with varying degrees of success. Results are highly dependent on timing of treatment application with regards to cheatgrass phenology, soil moisture, and pre- and post-treatment climatic conditions (Hull and Holmgren 1964). Livestock grazing prior to seedripe can reduce biomass and seed production, however heavy use will only partially suppress cheatgrass while resulting in negative impacts to perennial grasses (Young and Tipton 1990) and biological soil crusts (Beymer and Klopatek 1992; Brotherson and others 1983). Burning prior to seed maturity can significantly reduce cheatgrass density (Pechanec and Hull 1945; Stark and others 1946; Stewart and Hull 1949), although results are variable due to the failure of fire to deplete the soil seed reserve and the enhanced seed production of post-fire cheatgrass plants. Plowing or disking can be effective if done before seedripe, and if the existing seed bank is buried at least 2.5 inches (Hulbert 1955), however treatment of steep or rocky areas may be impractical.

Herbicide use on public lands was limited until 1991 when the Final Environmental Impact Statement for Vegetation Treatment on BLM Lands in Thirteen Western States

Table 1—Seedbed preparation treatments applied to degraded rangeland in the 1992 Elko Cheatgrass Suppression Study.

Treatment type	Description	Acres treated
Mechanical	Disk plow with double offset disk after germination with at least 1 inch of growth but prior to dough stage.	3.9
Burn	Controlled burn prior to cheatgrass seedripe.	4.5
OUST® herbicide	Spring application at 1.0 oz/acre prior to seedripe.	2.5
Control	No treatment.	2.0

(USDI 1991) was approved, allowing the use of 21 herbicides to control cheatgrass and other weeds. Factors limiting the use of herbicides include chemical and application costs, selectivity, interception and inactivation of the chemical by surface litter, and weed seed longevity (Ogg 1994). Perceptions of the public about herbicides and their impacts on wildlife can also negatively influence the application of herbicides on public lands.

OUST® (Sulfometuron Methyl)

OUST® is a water-dispersible herbicide approved for use on rangelands in the 1991 Record of Decision for the Vegetation Treatment EIS (USDI 1991). OUST® functions as both a pre- and post-emergent herbicide through inhibition of the enzyme acetolactate synthase (ALS), which catalyzes the production of three amino acids: leucine, isoleucine, and valine (Keeler and others 1993; Boutsalis and Powles 1995). The ultimate result of ALS inhibition is death of meristematic tissue and eventual plant mortality (Keeler and others 1993; Höfgen and others 1995). OUST® has low toxicity and does not accumulate in animal tissue, nor does it persist in the environment for extended periods (DuPont 1996). The half-life ranges from 20 to 100 days, depending on soil chemistry, temperature and moisture. If applied in the fall, OUST® requires rainfall to move into the soil where it kills germinating annual grasses. Spring-applied OUST® is absorbed by the roots and foliage of growing plants causing target plant mortality within 4 to 6 weeks. OUST® should be applied prior to flowering to prevent viable seed production. OUST® affects actively growing tissue, thus it is effective in controlling rapidly growing annual plants. New spring growth of perennial plants may be stunted by OUST® but are generally not killed since they have established roots that penetrate below the level of the herbicide movement.

Project Summaries

1992 Cheatgrass Suppression Study, Elko, NV

An experimental project was initiated in May 1992 near Elko, Nevada to compare cheatgrass control techniques on degraded rangeland prior to drilling with a perennial plant seed mixture. Strips within a 13 acre study area were treated with one of four seedbed treatments: burning, mechanical, herbicide, and control (table 1). The entire area was drilled with a perennial plant seed mixture using a no-till Amazon drill in October 1992. Frequency data were collected in July 1993 and June 1994 using 10 nested plot frequency frames on five 50-ft transects in each treatment.

OUST® proved to be the most effective treatment for reducing cheatgrass, followed closely by burning (fig. 1). Both the OUST® and burning treatments maintained cheatgrass at lower frequencies than in the control in 1994 (the second growing season). The disking treatment provided moderate cheatgrass control in 1993, however cheatgrass frequencies in the disked treatment exceeded even the control in 1994. Disking with an off-set plow rarely buries all cheatgrass seed and creates a disturbed seedbed that is ideal for post-treatment establishment of cheatgrass from the seedbank.

No data on seeding success are presented here because the seed mixture was mistakenly applied at roughly one-half of the planned application rate. Seeded plant establishment was very spotty. The only species in the seed mixture that is present in more than a trace quantity today is 'Immigrant' forage kochia (*Kochia prostrata*), a perennial half-shrub imported from the steppes of Eurasia.

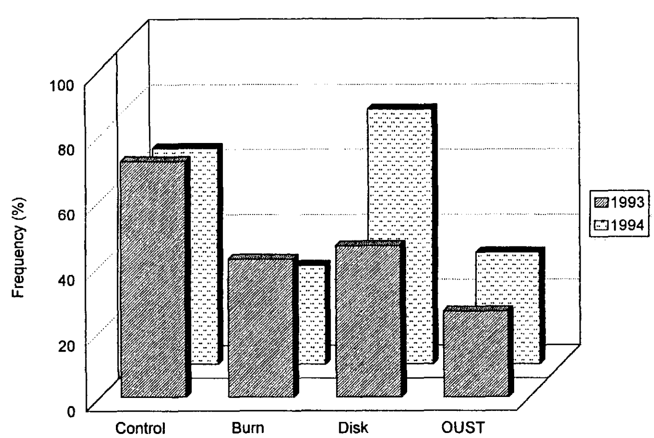

Figure 1—1992 Cheatgrass Suppression Study, Elko, NV. Frequency of cheatgrass recorded in 0.0625 m² frames.

1994 OUST® Pilot Project, Mountain Home, ID

In April 1994, OUST® was applied to a portion of a marginally established vegetative fuelbreak ("greenstrip") (Pellant 1990) near Mountain Home, Idaho. The site was originally plowed and seeded with a disk chain (Pellant 1988) to a perennial grass and forb mixture in fall 1987. In 1989, the original seeding was determined to be a failure due to an extended drought. To remedy this condition, a burn treatment was applied in September 1989, followed by drill-seeding with crested wheatgrass at 8 lb/acre in November 1989. This seeding was not successful due to cheatgrass competition and unfavorable climatic conditions after the seed application. Part of the site reburned in July 1993, providing an opportunity to test the use of OUST® on 100 acres. OUST® was applied at 1 oz/acre in April 1994 when cheatgrass was actively growing and prior to the boot stage. In September 1994, a multi-species seed mix comprised of approximately 50 percent crested wheatgrass was applied to the OUST®-treated area with a rangeland drill at 10.5 lb/acre. An unburned, untreated portion of the greenstrip was monitored as a control.

Density of cheatgrass and crested wheatgrass plants in each area was determined along five 50-ft transects with 10 plots per transect. Plot size was 0.0625 m^2 for cheatgrass and 0.25 m^2 for crested wheatgrass. Densities were converted to number of plants/m^2 for comparison of treatments.

Cheatgrass density was dramatically reduced by the OUST® treatment compared to the control in 1995, 1996, and 1997 (figs. 2 and 3). Although cheatgrass increased in 1996, densities remained below 100 plants/m^2. Density of an exotic annual forb, bur buttercup (*Ranunculus testiculatus*), increased considerably from 1995 to 1996. This was probably due to a large, residual seedbank in the soil combined with decreased competition from cheatgrass. In 1997, bur buttercup density was substantially lower in the OUST®-treated area compared to the control. The mechanism for this decline could be competition from the seeded crested wheatgrass combined with climatic influences.

The effects of reduced cheatgrass competition on seeded species is demonstrated by the success of the crested wheatgrass. Treatment with OUST® released existing crested wheatgrass plants from cheatgrass competition, resulting in improved plant vigor of the remnant perennial grasses in the treated area compared to the control in 1995. The perennial plants in the treatment area had greater biomass and number of seedstalks compared to similar plants in the control. They were also a darker green, possibly indicating more efficient use of available nitrogen where cheatgrass competition was reduced.

Treatment with OUST® also promoted the establishment of crested wheatgrass in the first growing season. An average of 17 crested wheatgrass seedlings/m^2 established in the seeded treatment during the 1996 growing season (fig. 4). Crested wheatgrass densities were considerably lower in 1997 due to seedling mortality, but were still twice as great in the treatment area compared to the control.

Figure 3—1994 OUST® Pilot Project, Mountain Home, ID. Control of cheatgrass (left side of photograph) by OUST® application in April 1994. The photograph was taken in June 1995.

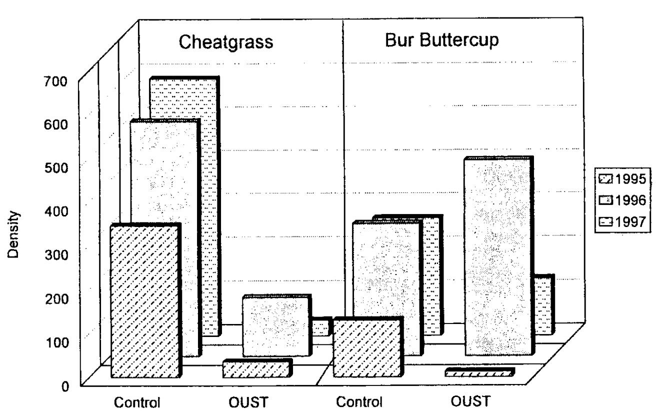

Figure 2—1994 OUST® Pilot Project, Mountain Home, ID. Density (plants/m^2) of cheatgrass and bur buttercup in control and OUST®-treated areas, 1995-1997.

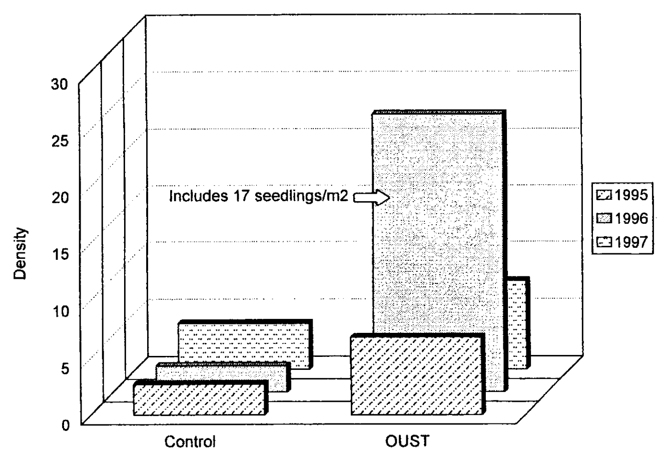

Figure 4—1994 OUST® Pilot Project, Mountain Home, ID. Density (plants/m^2) of crested wheatgrass in control and OUST®-treated areas, 1995-1997. The OUST® treatment was seeded in September 1994; the control was not seeded in 1994.

Table 2—Comparison of cost and efficiency of ground and aerial application of OUST® herbicide.

	Ground	Aerial
Herbicide cost ($)	10.50/oz	10.50/oz
Application cost ($)	11.00-15.00/acre	8.00-18.00/acre
Average acres treated/day	50-100 (60 ft boom)	1500-2000 (45 ft boom)

Operational Use of OUST®

In 1996, the Bruneau Resource Area in the BLM's Lower Snake River District began using OUST® to control cheatgrass in large post-wildfire rehabilitation projects in the Snake River Birds of Prey National Conservation Area. Cheatgrass and wildfires are two of the greatest management concerns in this area which supports North America's largest concentration of nesting raptors (Kochert and Pellant 1986). Once cheatgrass density is reduced by OUST®, rehabilitation with perennial vegetation, especially shrubs, is conducted to reestablish habitat for raptor prey species and ground-nesting birds, and provide livestock forage.

Ground and aerial application methods are being evaluated to determine the most practical and cost-effective OUST® application procedures. While herbicide and application costs are similar for ground and aerial application (table 2), trade-offs exist with regards to the amount of rangeland that can be treated per day and the impacts of label restrictions for each application method (DuPont 1996, 1997). Aerial application is recommended for large tracts of land and treatment of rocky sites that might cause application equipment damage. However, small tracts with adjacent cropland or dwellings are better treated with ground application, where no buffer is required as opposed to the 200 ft "no treatment" buffer required for all aerial applications.

There are a number of label restrictions associated with the use of OUST® on non-crop lands. Application of OUST® requires equipment dedicated for non-crop use. Application equipment cannot be used on cropland once it is used to apply OUST®. Livestock use of treated rangeland cannot occur within 1 year of application. Because of the potential persistence of the herbicide in soil, seeding into the treatment area should be delayed for one growing season. Both aerial and ground application require wind speeds between 3 and 10 mph. OUST® cannot be applied on frozen ground.

OUST® can be applied in late fall or early spring to control cheatgrass. Initial observations indicate that fall application of OUST® provides better cheatgrass control than spring application since both fall- and spring-germinated cheatgrass plants are killed. However, viability tests on cheatgrass seeds and results from previous projects (for example, the 1994 OUST® Pilot Project) indicate that spring treatments may be effective if application is done in advance of seed ripening.

Most native perennial plants are not adversely impacted by an OUST® application of 1.0 oz/acre, however a temporary chlorosis and stunted growth is often observed on treated areas. Sandberg bluegrass (*Poa secunda*) has been observed to suffer some mortality following spring OUST® application at 1 oz/acre. Viability of seed produced by native plants may be reduced in treated areas, affecting potential recruitment during the first growing season following OUST® application. Monitoring studies established on treated areas will provide more quantitative information on the effects of OUST® on native vegetation.

Ongoing Studies

Initial results indicate that OUST® is an effective tool for cheatgrass control over a 1 to 2 year period, allowing release of native and seeded perennial species from cheatgrass competition. Studies are currently being conducted by the USDA Forest Service, Rocky Mountain Research Station, Boise State University, and the USDI Bureau of Land Management to determine: 1) minimum application rate that provides effective cheatgrass control; 2) effectiveness of fall versus spring application; 3) effects of OUST® on survival and reproduction of native plants and microbiotic crusts; 4) effects of OUST® on germinating (seeded) perennial plants; and 5) effectiveness of OUST® in controlling medusahead wildrye. Results from these studies will provide managers with better guidelines on the use of OUST® in the management and rehabilitation of cheatgrass-infested rangelands.

References

Beymer, Renee J.; Klopatek, Jeffrey M. 1992. Effects of grazing on cryptogamic crusts in pinyon-juniper woodlands in Grand Canyon National Park. American Midland Naturalist. 127: 139-148.

Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. 1994. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 22-30.

Boutsalis, P.; Powles, S. B. 1995. Resistance of dicot weeds to acetolactate synthase (ALS)-inhibiting herbicides in Australia. Weed Research. 35: 149-155.

Brotherson, Jack D.; Rushforth, Samuel R.; Johansen, Jeffrey R. 1983. Effects of long-term grazing on cryptogam crust cover in Navajo National Monument, Ariz. Journal of Range Management. 36(5): 579-581.

DuPont Agricultural Products. 1996. OUST® herbicide product label. Wilmington, DE: E. I. du Pont de Nemours and Company, DuPont Agricultural Products. 9 p.

DuPont Agricultural Products. 1997. Special local need 24© labeling:OUST® herbicide for noncropland weed control, State of Idaho. Wilmington, DE: E. I. du Pont de Nemours and Company, DuPont Agricultural Products. 1 p.

Höfgen, R.; Laber, B.; Schüttke, I.; Klonus, A.; Streber, W.; Pohlenz, H. 1995. Repression of acetolactate synthase activity through antisense inhibition. Plant Physiology. 107: 469-477.

Hulbert, L. C. 1955. Ecological studies of *Bromus tectorum* and other annual bromegrasses. Ecological Monographs. 25: 181-213.

Hull, A. C., Jr., Holmgren, R. C. 1964. Seeding southern Idaho rangelands. Res. Pap. INT-10. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 31 p.

Keeler, S. J.; Sanders, P.; Smith, J. K.; Mazur, B. J. 1993. Regulation of tobacco acetolactate synthase gene expression. Plant Physiology. 102: 1009-1018.

Knick, Steven T.; Rotenberry, John T. 1995. Landscape characteristics of fragmented shrubsteppe habitats and breeding passerine birds. Conservation Biology. 1059-1071.

Kochert, M. N.; Pellant, M. 1986. Multiple use in the Snake River Birds of Prey Area. Rangelands. 8: 217-220.

Mack, R. N. 1981. Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. Agro-Ecosystems. 7: 145-165.

McAdoo, J. Kent; Klebenow, Donald A. 1978. Native faunal relationships in sagebrush ecosystems. In: The sagebrush ecosystem: a symposium; 1978 April; Logan, UT. Logan, UT: Utah State University: 50-61.

Monsen, Stephen B. 1994. The competitive influences of cheatgrass (*Bromus tectorum*) on site restoration. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. 1994. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-50.

Ogg, Alex G., Jr. 1994. A review of the chemical control of downy brome. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. 1994. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 194-196.

Pechanec, J. F.; Hull, A. C., Jr. 1945. Spring forage lost through cheatgrass fires. National Wool Grower. 35: 13.

Pellant, Mike. 1988. Use of disk chain on southern Idaho's annual rangeland. In: 42d annual report, Vegetative Rehabilitation Equipment Workshop; 1988 February 21-22; Corpus Christi, TX. Missoula , MT: U.S. Department of Agriculture, Forest Service, Missoula Technology Development Center: 40.

Pellant, Mike. 1990. The cheatgrass-wildfire cycle—are there any solutions? In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 11-17.

Peters, Erin F.; Bunting, Stephen C. 1994. Fire conditions pre- and post-occurrence of annual grasses on the Snake River Plain. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. 1994. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 31-36.

Sparks, Steven. R.; West, Neil. E.; Allen, Edith. B. 1990. Changes in vegetation and land use at two townships in Skull Valley, western Utah. In: McArthur, E. Durant.; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV; Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 26-36.

Stark, R. H.; Toevs, J. L.; Hafenrichter, A. L. 1946. Grasses and cultural methods for reseeding abandoned farmlands in southern Idaho. Bull. 267. Moscow, ID: Idaho Agricultural Experiment Station. 36 p.

Stewart, G.; Hull, A. C., Jr. 1949. Cheatgrass (*Bromus tectorum* L.)—an ecological intruder in southern Idaho. Ecology. 30(1): 58-74.

U.S. Department of the Interior. 1991. Final Environmental Impact Statement for Vegetation Treatment on BLM Lands in Thirteen Western States. Casper, WY: U.S. Department of the Interior, Bureau of Land Management.

Whisenant, Steven G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. In: McArthur, E. Durant.; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV; Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 4-10.

Young, James A.; Tipton, Frosty. 1990. Invasion of cheatgrass into arid environments of the Lahontan Basin. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., comps. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV; Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 37-40.

Development of Native Seed Supplies to Support Restoration of Pinyon-Juniper Sites

E. Durant McArthur
Stanford A. Young

Abstract—Use of native plants for restoration and rehabilitation of disturbed or manipulated pinyon-juniper communities is increasing in response to desires of land managers and society in general. Seeds of native plants are becoming more available, but estimates and surveys show there is still more demand than available supply. Field grown seeds and warehousing do anticipate demand but are only partial solutions to the native plant seed shortage. Exotic, developed plant materials, especially Triticeae grasses and legumes, remain important resources for rehabilitation plantings. Private industry seed collectors, growers, and developers will be responsive to plant materials needs of land managers. Seed genetic identity and quality can be better assured through the seed certification process whether the seed is wildland collected or field grown.

After pinyon-juniper sites have been disturbed or depleted by natural or managed events such as prescribed or wildfire, chaining, or chopping, the rehabilitation and restoration of those sites often requires seeding. Seed for this purpose has traditionally been obtained by harvesting seed from native stands and from cultivated fields of mostly non-native plants (McArthur 1988; Meyer and Kitchen 1995; Monsen 1987; Plummer and others 1968; Roundy 1996). Seed suppliers, whether they be wildland seed collectors or those who grow various classes of non-selected common or developed plant germplasms, seek to respond to market needs (Plummer 1984; Young and others 1995).

Traditional objectives for pinyon-juniper rehabilitation were to provide stability to soils, and forage and cover for livestock and big game animals (Plummer and others 1968; Roundy 1996). The most important criteria for use of particular plant materials was their site adaptability and the resource values that they provided (Monsen and McArthur 1995). The early success in pinyon-juniper rehabilitation and conversion projects as well as other rangeland rehabilitation efforts were highlighted by the performance of exotic grasses, especially members of the Triticeae (wheatgrasses and their relatives), and legumes (rangeland alfalfas and clovers) (Asay and Knowles 1985a,b; Barnes and Sheaffer 1985; McArthur 1988; Plummer and others 1968; Roundy 1996; Rumbaugh and Townsend 1985;). Triticeae grasses and legumes remain the plants of greatest availability and primary choice for most pinyon-juniper rehabilitation plantings. However, more and more native plant materials (grasses, forbs, and shrubs) are becoming available (Carlson and McArthur 1985; McArthur 1988; Meyer and Kitchen 1995; Monsen 1987; Monsen and Stevens in press; Young and others 1995;).

In recent years there has been increasing interest in reconstructing natural plant communities and using site-indigenous and other regionally native plant materials (Allen and others 1997; Jordan and others 1987; Richards and others 1998; Roundy and others 1995). Governmental land management agencies (such as the U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management; Utah Department of Natural Resources, Divison of Wildlife Resources) have instituted policies to require, or at least encourage, the use of native plant materials in rehabilitation plantings (Richards and others 1998; Richard Stevens personal communication).

The practice of restructuring or recreating natural, preexisting plant communities has been termed "restoration" (Allen 1995; Jordan and others 1987). Rehabilitation implies a renewal of land productivity but a change in the ecosystem structure (Allen 1995). This paper reviews the status of the native plant seed industry in wildland rehabilitation and restoration. While we emphasize pinyon-juniper lands, our somewhat broader discussion includes other wildland plant community types.

Materials and Methods

We present survey information from the reclamation seed industry in two different formats. One of us (SAY) compiled a summary of market information for selected reclamation species emphasizing native plants and other conservation plant materials for presentation at the 1997 Utah Native Plant Forum. Data included current use, potential use, amount available as wildland collected seed, and price information for the Intermountain and Pacific Northwest Regions (Utah, Nevada, Idaho, Montana, Oregon, Washington). In this report we have included and updated much of that information.

The second source is a survey conducted by our colleague Richard Stevens of the Utah Division of Wildlife Resources, also for the 1997 Utah Native Plant Forum. This survey reported the volume of native seed sold in 1996 by five Utah seed companies. The volume of seed is given to indicate a trend and not meant to be definitive, although Stevens (personal communication) estimates these companies account for at least half of the native seed volume by Utah seed companies. The seed sold by these Utah seed companies was collected and sold both in and out of Utah.

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Results and Discussion

Market information estimates for 47 species from the Intermountain and Pacific Northwest regions show that potential use of these species—nearly 2.5 million lb pure live seed (pls)—far outstrips the current use (approximately 750,000 lb pls) and the volume available from harvest of wildland stands (approximately 370,000 pounds pls) (table 1). This information demonstrates that there is not enough seed collected nor available to be collected from wildlands to meet current demand, let alone potential usage, and that currently much of the demand is met from field-grown seed. The supply of native wildland-collected seed varies widely from year to year depending upon growing and collecting conditions, mainly weather. There is apparently a market for increasing field-grown seed for many species (table 2). The seed price estimates in table 1 emphasize this. Seed available from wildlands has higher value than current use value even though the volume of seed on wildlands is less than current use volume. This is because some high value wildland seed remains uncollected (table 2).

The five Utah seed companies that were surveyed sold a total of more than 500,000 lb of native seed in 1996 including more than 300,000 lb of shrub seed, nearly 200,000 lb of grass seed, and 35,000 lb of forb seed (table 3). Many of the species sold were the same as those in the Intermountain and Pacific Northwest area survey (table 2), but many additional species are also listed. The Utah seed companies sold seed of 29 native grasses, 39 native forbs, and 42 native shrubs (table 3).

We believe the increasing demand for native species for restoration and rehabilitation plantings can be best met when the principal users stockpile seed so seed will be available when needed, whether that need is generated by a planned site rehabilitation or restoration or an emergency situation such as wildfire rehabilitation. Two successful examples of seed stockpiling are the Utah Division of Wildlife Resources Seed Warehouse in Ephraim and the Bureau of Land Management Seed Warehouse in Boise, ID. These warehouses maintain large seed inventories (more than 200,000 lb) and a rich array of species. The Utah Division of Wildlife Resources has stockpiled native seed in its warehouse operation for more than 40 years. These seed resources have been used not only on Divison and other State lands, but on Federal and private lands as well. The Boise Bureau of Land Management seed warehouse has been servicing public land needs in Idaho and other Western States since 1991. The National Forests in Utah are considering establishing a native seed warehouse.

Table 1—Market information estimates for 47 selected reclamation species[a].

Factor	Current use	Potential use	Available for wildland collection
Pure live seed (lb/yr)	765,873	2,460,450	370,212
Dollar value	$3,232,749	$12,232,250	$3,261,417

[a]Summary of data from table 2. Financial values determined as mid-point values for use, availability, and price to grower (table 2).

We believe these public sector warehouses are needed for timely response to rehabilitation and restoration needs on public lands. Furthermore, we suggest that orderly stockpiling would greatly encourage consistent production from private sector seed collectors and growers who will continue to supply most of the seeds for publicly owned warehouses. We anticipate that private warehousing of seed will continue to serve as an adjunct to public warehousing.

As natural resource managers' objectives turn increasingly toward the maintenance and restoration of the genetic and ecological integrity of native ecosystems, native plant use will also increase. In response to this trend, more native plant materials are becoming available (tables 1-3). However, ecosystem function and service are also important. In some places, such as drastically disturbed sites, the genetic and ecological robustness of developed, available, and sometimes exotic plants may be needed. Plant germplasm collectors and developers and the seed industry will respond to land managers' needs in both restoration and general rehabilitation arenas if those needs are viewed as consistent market commitments.

Seed genetic identity and quality can best be assured if the seed is inspected and certified following the requirements and standards of the Association of Official Seed Certifying Agencies (AOSCA), whether the seed is wildland collected or field grown (Young 1995; Young and others 1995). If the seed is tagged by an official seed certifying agency, the buyer can have confidence about the seed quality (mechanical purity, germination, foreign material), source or site of origin (genetic purity and identity), and ecotypic or developed status of the seed lot.

Acknowledgments

We thank Richard Stevens and Steve Monsen for encouragement in preparation of this manuscript, Richard Stevens for sharing his survey data with us, and Ron Stevenson (Stevenson Intermountain Seed Company) for assistance in compiling market data. We also thank Jeanne Chambers, Stan Kitchen, and Richard Stevens for reviews and comment on an earlier version of this manuscript.

References

Allen, E. B. 1995. Restoration ecology: limits and possibilities in arid and semiarid land. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K., comps. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Ogden, UT: Gen. Tech. Rep. INT-GTR-315. U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 7-15.

Allen, E. B.; Covington, W. W.; Falk, D. A. 1997. Developing the conceptual basis for restoration ecology. Restoration Ecology 5: 275-276.

Asay, K. H.; Knowles, B. P. 1985a. Current status and future of introduced wheatgrasses and wildrye for rangeland improvement. In: Carlson, J. R; McArthur, E. D., eds. Symposium: range plant improvement. 1985 February 11-15; Salt Lake City, UT. Denver, CO: Proceedings, selected papers presented at the 38th Annual Meeting of the Society for Range Management: 109-116.

Asay, K. H.; Knowles, R. P. 1985b. The wheatgrasses. In: Heath, M. E.; Barnes, R. F.; Metcalf, D. S., eds. Forages, the science of grassland agriculture, 4th edition. Ames, IA: Iowa State University Press: 166-176.

Table 2—Market information estimates for Intermountain and Pacific Northwest regions for 47 selected reclamation species, in pounds of pure live seed (pls).

Species[a]	Current Use	Potential use	Avaliable wildland collected	Price to grower or collector[b]
	pls lb/yr			$/pls /lb
Species ≥ 10,000 lb/yr				
Small burnet[c,g]	50,000-200,000	300,000	0	0.40
Blue flax[d,g]	20,000-40,000	100,000	0	2.25-5.00
Western yarrow[d]	10,000-30,000	35,000-45,000	1,000-2,000	5.00-7.50
Antelope bitterbrush	5,000-20,000	35,000-45,000	5,000-30,000	5.00-8.00
Forage kochia[c,g]	25,000-40,000	100,000	40,000-60,000	7.00-12.00
Wyoming big sagebrush[e,f,g]	4,000-20,000	25,000	35,000	15.00-35.00
Fourwing saltbush[g]	40,000-80,000	100,000	100,000	2.50-6.00
Bottlebrush squirreltail	10,000-15,000	50,000-200,000	15,000	8.00-12.00
Western wheatgrass[g]	80,000-100,000	200,000	20,000-50,000	2.50-6.00
Bluebunch wheatgrass[g]	.20,000-50,000	75,000-300,000	5,000	2.00-5.00
Thickspike wheatgrass[g]	20,000-30,000	50,000	5,000	2.00-4.00
Basin wildrye[g]	25,000-50,000	75,000-100,000	10,000-15,000	3.00-7.00
Indian ricegrass[g]	20,000-40,000	50,000 100,000	5,000-20,000	2.00-5.00
Streambank wheatgrass[g]	20,000-30,000	50,000	0	1.60-5.00
Mountain brome[g]	30,000-100,000	300,000	5,000	1.00-2.00
Meadow brome[g]	20,000-50,000	100,000-200,000	0	1.50-2.50
Slender wheatgrass[g]	50,000-100,000	250,000-300,000	1,000	1.50-2.50
Species 1,000-9,999 lb pls/yr				
Arrowleaf balsamroot	500-1,500	2,500-3,500	500-2,000	8.00-9.00
Rocky Mountain Beeplant	500-2,500	3,000-5,000	3,000-5,000	8.00- 9.00
Palmer penstemon[g]	2,500-5,000	5,000-10,000	1,500-2,500	9.00-12.00
Rocky Mountain penstemon[g]	3,000-8,000	8,000-10,000	1,000-1,500	12.00-15.00
Common sunflower	2,000-5,000	10,000	10,000	3.00
Sweet anise	500-2,500	2,500-5,000	2,500-5,000	5.00-7.00
White-stemmed rubber rabbitbrush[e,f]	1,500-2,500	2,500	2,500	15.00
Basin big sagebrush[e,f]	1,500-3,000	3,000	10,000	10.00-20.00
Mountain big sagebrush[e,f,g]	2,000-5,000	6,000	10,000	15.00-30.00
Winterfat[g]	5,000-10,000	20,000	5,000-15,000	6.00-12.00
Sandberg bluegrass	200-2,000	25,000-100,000	3,000	8.00-12.00
Needle-and-thread grass	500-10,000	50,000-70,000	1,000-15,000	16.00-20.00
Species 100-999 lb pls/yr				
Blueleaf aster[e]	200-500	500-2,500	200-500	35.00-50.00
Pacific aster[e]	50-200	500-2,500	50-200	35.00-50.00
Sulfur flower buckwheat	100-200	500-2,500	300-500	25.00
Wyeth buckwheat	100-200	500-5,000	400-500	20.00
Gooseberry-leaf globemallow	500-1,000	2,000-4,000	200-1,000	25.00
Scarlet globemallow[g]	200-400	1,000-1,500	50-1,000	25.00-35.00
Munroe globemallow[g]	300-1,000	1,000-2,000	200-1,000	25.00
Showy goldeneye	500-1,000	1,000-2,000	200-500	20.00
Firecracker penstemon	100-500	1,500-2,000	100-200	30.00-40.00
Wasatch penstemon	200-1,000	1,500-2,000	100-500	15.00
Louisana sagewort	100-400	500-2,500	200-400	20.00-22.00
Oyster-plant salsify[c]	100-250	500-1,500	500-1,500	25.00
Utah sweetvetch[g]	500-1,000	5,000-8,000	500-1,000	20.00-25.00
Species < 100 lb/yr				
Gland cinquefoil	20-50	200-1,000	100-500	25.00
Canada goldenrod	25-75	500-2,500	25-300	25.00
Butterweed groundsel	10-50	200-2,000	10-100	25.00
Nuttal lomatium	25-100	500-2,500	50-200	14.00
Thurber needlegrass	25-100	10,000-50,000	3,000	10.00-20.00

[a]Species are divided into classes based on current use.
[b]Vendor price is some percentage above these figures, reflecting condition, warehousing, and other overhead costs and market conditions.
[c]Exotic or naturalized species.
[d]Circumboreal species.
[e]Seed is typically marketed at about 10 to 15 percent purity.
[f]Subspecies.
[g]Species or subspecies has released varieties and/or germplasm.

Table 3—Pounds of native seed sold in 1996 by five Utah seed companies.

Grass species	Pounds of seed	Forb species	Pounds of seed	Shrub species	Pounds of seed (bulk)
Thickspike wheatgrass	27,305	Western yarrow	8,443	Wyoming big sagebrush[c]	120,000
Western wheatgrass	23,616	Common sunflower	5,900	Fourwing saltbush	76,350
Basin wildrye	22,522	Blue flax	3,965	Mountain big sagebrush[c]	22,522
Mountain brome	19,202	Rocky Mountain beeplant	3,200	Basin big sagebrush[c]	20,230
Snake River wheatgrass	15,000	Lupine (several species)	2,686	Shadscale saltbush	14,250
Slender wheatgrass	14,400	Palmer penstemon	2,010	White-stemmed rubber rabbitbrush[c]	11,765
Streambank wheatgrass	11,850	California poppy	2,000	Antelope bitterbrush	6,047
Indian ricegrass	11,555	Desert globemallow	900	Winterfat	5,445
Sheep fescue	9,950	Arrowleaf balsamroot	625	Mountain rubber rabbitbrush[c]	5,350
Bluebunch wheatgrass	9,552	Utah sweetvetch	597	Gardner saltbush	4,200
Bottlebrush squirretail	7,865	Showy goldeneye	530	Douglas rabbitbrush	2,200
Green needlegrass	2,865	Munro globemallow	500	Woods rose	2,200
Sherman big bluegrass	2,500	Rocky Mountain Penstemon	500	Skunkbush sumac	1,820
Sideoats grama	2,000	Sweet anise	490	Green ephedra	1,605
Alkali sacaton	2,000	25 others[b] (2 - 410)	3,081	Low rabbitbrush	1,600
14 others[a] (10-1,202)	6,324			Nevada ephedra	1,255
				26 others[d] (10 - 955)	10,229
Total	188,506		35,427		307,068
Grand Total					531,001

[a]Sandberg bluegrass, sand dropseed, Idaho fescue, meadow foxtail, galleta, blue grama, tufted hairgrass, prairie June grass, needle-and thread grass, Letterman needlegrass, redtop, purple three-awn, alpine timothy, beardless wildrye.
[b]Blueleaf aster, Engleman aster, pacific aster, cutleaf balsamroot, columbine, cow parsnip, erigeron species, eriogonum species, farewell-to-spring, gaillardia, sticky geranium, gilia, gooseberryleaf globemallow, one-flower helianthella, Porter ligusticum, Louisiana sagewort, desert marigold, mules ear wyethia, Indian paintbrush, firecracker penstemon, Rydberg penstemon, thickleaf penstemon, Wasatch penstemon, Iseland poppy.
[c]Subspecies.
[d]Desert bitterbrush, roundleaf buffaloberry silver buffaloberry, chokecherry, Stansbury cliffrose, golden current, wax current, redosier dogwood, blue elderberry, red elderberry, Wyeth eriogonum, black greasewood, spiny hopsage, curlleaf mountain mahogany, true mountain mahogany, black sagebrush, silver sagebrush, fringed sage, sand sage, quail saltbush, mat saltbush, Saskatoon serviceberry, Utah serviceberry, mountain snowberry, Rocky Mountain sumac.

Barnes, D. K.; Sheaffer, C. C. 1985. Alfalfa. In: Heath, M. E.; Barnes, R. F.; Metcalf, D. S., eds. Forages, the science of grassland agriculture, 4th edition. Ames, IA: Iowa State University Press: 89-97.

Carlson, J. R.; McArthur, E. D., eds. 1985. Symposium: range plant improvement. In: Proceedings, selected papers presented at the 38th Annual Meeting of the Society for Range Management 1985 February 11-15; Salt Lake City, UT. Denver, CO: Society for Range Management: 107-220.

Jordan, W. R., III.; Gilpin, M. E.; Aber, J. D., eds. 1987. Restoration ecology, a synthetic approach to ecological research. Cambridge, UK: Cambridge University Press. 342 p.

McArthur, E. D. 1988. New plant development for range management. In: Tueller, P. T., ed. Vegetation science applications for rangeland analysis and management. Dordrecht, Netherlands: Kluwer Academic Publishers: 81-112.

Meyer, S. E.; Kitchen, S. G. 1995. First the seed: a restorationist's perspective. Hortus Northwest 6 (2): 4-8, 42-43.

Monsen, S. B. 1987. Shrub selections for pinyon-juniper plantings. In: Everett, R. L., comp. Proceedings—pinyon-juniper conference; 1986 January 13-16; Reno, NV. Ogden, UT: Gen. Tech. Rep. INT-215, U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 326-329.

Monsen, S. B.; McArthur, E. D. 1995. Implications of early Intermountain range and watershed restoration practices. In: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K., comps. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Ogden, UT: Gen. Tech. Rep. INT-GTR-315. U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 16-25.

Monsen, S. B.; Stevens, R., eds. In press. Restoring western range and wildlands. Ogden, UT: Gen. Tech. Rep. RMRS-GTR-xxx. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. 1968. Restoring big game range in Utah. Publication 68-3. Salt Lake City, UT: Utah Division of Fish and Game. 183 p.

Plummer, M. 1984. Considerations in selecting chenopod species for range seedings. In: Tiedemann, A. R.; McArthur, E. D.; Stutz, H. C.; Stevens, R.: Johnson, K. L., comps. 1983 May 2-6; Provo, UT. Ogden, UT: Gen. Tech. Rep. INT-172. U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 183-186.

Richards, R. T.; Chambers, J. C.; Ross, C. 1998. Use of native plants on federal lands: policy and practice. Journal of Range Management. 51: 625-632.

Roundy, B. A. 1996. Revegetation of rangelands for wildlife. In: Krausman, ed. Denver, CO: Society for Range Management: 355-368.

Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K. comps. 1995. Proceedings: wildland shrub and arid land restoration symposium. 1993 October 19-21; Las Vegas, NV. Ogden, UT: Gen. Tech. Rep. INT-GTR-315. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 384 p.

Rumbaugh, M. D.; Townsend, C. E. 1985. Range legume selection and breeding in North America. In: Carlson, J. R.; McArthur, E. D., eds. Symposium: range plant improvement. 1985 February 11-15; Salt Lake City, UT. Denver, CO: Proceedings, selected papers presented at the 38th Annual Meeting of the Society for Range Management: 137-147.

Young, S. 1995. Alternative germplasm release procedures for producing certified seed. Seed World 133 (8): 14-15.

Young, S.; Kitchen, S.; Armstrong, J. 1995. AOSCA approves certification guidelines for wild land collected seed. Seed World 133 (1): 20-21.

Species Compatibility and Successional Processes Affecting Seeding of Pinyon-Juniper Types

Scott C. Walker

Abstract—Introduced perennial grasses have long been used in rangeland revegetation efforts. These species have gained dominance in some communities. The competitiveness of these species have reduced native vegetative components. Through evaluation of long term ecological studies, the competitiveness of some introduced seeded species have become apparent. Our findings reveal that differences in species composition can be attributed to the competition of the seeded introduced species.

When restoring areas that have been inundated by pinyon-juniper trees, seeding is often necessary where desirable understory species are absent or too sparse to respond to treatment. Seeding efforts involved with pinyon-juniper treatment have been directed toward increasing forage production for livestock and restoring plant communities and wildlife habitat.

Seed mixtures have included various introduced and native grasses, forbs, and shrubs (Stevens 1983). Over the past 30 to 40 years, introduced grass species have dominated most seed mixtures. These grasses were selected for a number of reasons including availability of seed, ease of establishment, forage production, and soil stabilization characteristics. The compatibility of these exotic species with native herbs and shrubs is now becoming apparent through long term ecological studies. Many exotic species have competitive and aggressive establishment, and consequently have a direct adverse affect on native species and communities. These affects are often detrimental and have an adverse impact on natural functioning plant communities and ecosystems. Competition for limited resources may determine the presence, absence, or abundance of species within a community as well as their spatial arrangement (Pyke and Archer 1991). After reviewing research investigating competition in semiarid plant communities, Fowler (1986) concluded that competition does occur in these systems, involves different species, and is an important determinant of community structure. Rapid changes in plant communities occur on disturbed areas, such as chained and seeded pinyon-juniper sites (Stevens 1986; 1987).

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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Techniques have been developed that effectively remove trees while retaining the understory and creating the necessary seedbed. Plant research and development has resulted in considerable progress in improving availability of native grass, forb and shrub seed and in improving their establishment. These plant materials allow us to now go beyond revegetation to restoration. Ideally, ecologically speaking, our effort now is to restore sites and help return them back to a situation where natural processes can function.

Effects of Introduced Grasses

This paper will address the ideas of species compatibility. It is important to consider the effect that seeding has on the natural recovery of species that are released when an area is treated, and the influences of seeding exotics with natives. The following case studies demonstrate effects of introduced grasses on native and other seeded species.

Case Study 1—Gambel Oak Control by Intermediate Wheatgrass, Smooth Brome and Fairway Crested Wheatgrass (Plummer and Others 1970)

Large areas of Gambel oak were burned to remove overstory oak stems. These areas were then seeded to a mixture of intermediate wheatgrass (*Thinopyron intermedium*), smooth brome (*Bromus inermis*), and Fairway crested wheatgrass (*Agropyron cristatum*) in equal amounts at a total seeding rate of 12-15 lb per acre. A like area that burned was not seeded with the grass association.

Figure 1 shows the accumulative height of oak after 15 years on the area where, Fairway crested wheatgrass, intermediate wheatgrass and smooth brome were established as an understory after a burn. This is contrasted with an adjacent similar area where oak was burned but where no seeding occurred. The accumulated growth of oak on sites that were seeded has been maintained at an average height of about 40 inches and has remained open; whereas on nonseeded sites the oak has grown to an average height of 105 inches, and the clumps have again become impenetrable thickets. When well established, the seeded grasses have restricted the height regrowth of oak on treated sites by more than 60 percent.

Findings of this study were that, "After 14 years, it continues to be confirmed that competitive herbs can be seeded and established for controlling Gambel oak thickets, as well as thickets of other shrubs. Intermediate wheatgrass and smooth brome (two sod formers), and Fairway crested

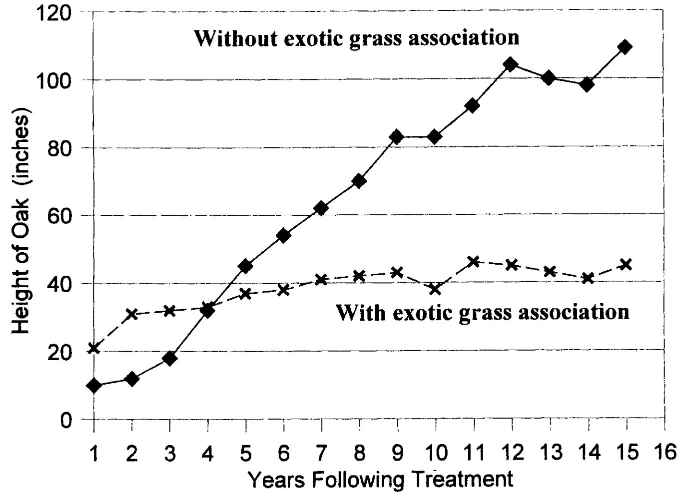

Figure 1—Mean accumulative height of Gambel oak plants in treatment areas with and without seeded exotic grass association.

wheatgrass have been found to be particularly useful for this purpose." Also, "Grazing by deer, as well as by livestock, appears to keep brush from growing beyond animal's reach, but most important is the competition from the established understory plants."

This study demonstrates that species interaction and competition can be beneficial depending on the desired outcome and management objective. It also shows how very competitive some introduced species can be. There was no information in the study to indicate how other plant species on the study area were affected. It is reasonable to assume that if these grasses were able to effectually reduce oak regrowth through competition for resources, then other understory species were likely adversely affected.

Case Study 2—The Competitive Influence of Seeded Smooth Brome (*Bromus Inermis*) and Intermediate Wheatgrass (*Thinopyron Intermedium*) Within Aspen-Mountain Brush Communities of Central Utah (Monsen And Others 1996)

Ecological relationships of smooth brome and intermediate wheatgrass with native species were investigated through comparison of seeded and nonseeded sites in aspen-mountain brush communities, on the Great Basin Research Area, Manti-La Sal National Forest. These sites were adjacent to each other, and vegetatively comparable prior to seeding. Within a 40-year period, the two sod-forming seeded grasses gained dominance and reduced native herbs and shrubs. Both introduced grasses are commonly planted to stabilize wildlands, but they are proving to be noncompatible with most native species and ultimately dominate seeded sites.

All lifeform groups (introduced grasses, native grasses, native perennial broadleaf herbs, and shrubs) showed a statistically significant difference in the percent ground cover values between the seeded and nonseeded areas. Fourty years after seeding the seeded areas showed a mean percent ground cover for introduced grasses was 33 percent, native grasses 1 percent, native perennial broadleaf herbs 11 percent, and shrubs 15 percent. In the nonseeded areas the mean percent cover for introduced grasses was 4 percent, native grasses was 17 percent, native perennial broadleaf herbs 21 percent, and shrubs 41 percent (fig. 2).

One hundred-nine species were encountered within the study sites. Of all species present, 86 were found in the seeded areas and 82 in the nonseeded areas, with 61 species common to both areas. Results of Sorensen's index of similarity, (Sorensen 1948) for all areas combined within a treatment, shows only a 41 percent similarity of species between the two treatments. This indicates the dissimilarity of the species composition between the two treatments, even though the number of species in each area is nearly equal. Prevalent species ranking by frequency value shows considerable difference between seeded and nonseeded areas (table 1). Smooth brome, intermediate wheatgrass and mountain big sagebrush (*Artemisia tridentata vaseyana*) were the most prevalent species in the seeded areas, while mountain snowberry (*Symphoricarpos oreophilus*), mountain big sagebrush and bluebunch wheatgrass (*Pseudoroegneria spicata*) were the most prevalent in the nonseeded areas.

Considerable difference in forb species occurrences and numbers were evident between treatments. The numbers of forb species between treatments were nearly equal with 58 in the seeded and 57 in the nonseeded area of these species 40 were common to both treatments. Native forb species accounted for a greater percent of the ground cover in the nonseeded than in the seeded area (fig. 2). This would indicate that native perennial forbs are doing better in the nonseeded area and did not fair well growing in combination with the exotic grasses

Considerable variation in summed frequency was evident between seeded and nonseeded areas (fig. 3). In the seeded

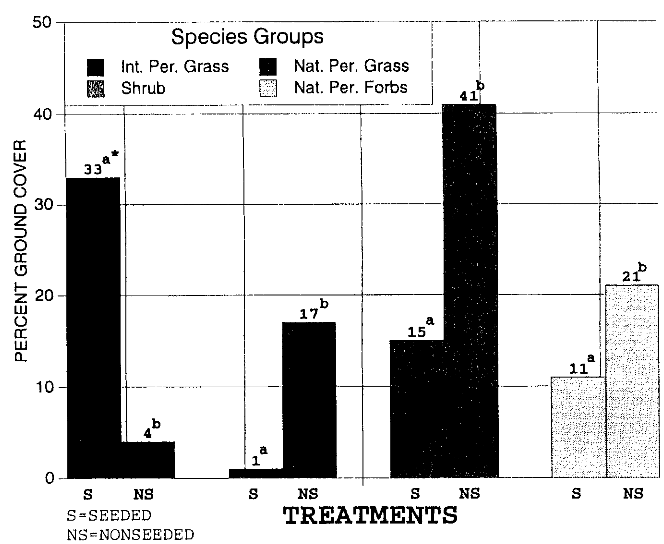

Figure 2—Percent ground cover of lifeform groups for seeded and nonseeded areas, 40 years after seeding. *Within species groups, columns with different letters indicate significant differences ($p < 0.05$).

Table 1—Ranking of most prevalent species for area seeded with introduced grasses and nonseeded areas.

Seeded Area	Nonseeded Area
1. *Bromus inermis*	1. *Symphoricarpos oreophilus*
2. *Thinopyron intermedium*	2. *Artemisia tridentata*
3. *Artemisia tridentata*	3. *Pseudoroegneria spicata*
4. *Lupinus sericeus*	4. *Bromus carinatus*
5. *Symphoricarpos oreophilus*	5. *Aster chilensis*
6. *Vicia americana*	6. *Astragalus convallarius*
7. *Agoseris glauca*	7. *Vicia americana*
8. *Aster chilensis*	8. *Eriogonum umbellatum*
9. *Agropyron cristatum*	9. *Stellaria jamesiana*
10. *Taraxacum officinale*	10. *Agropyron trachycaulum*

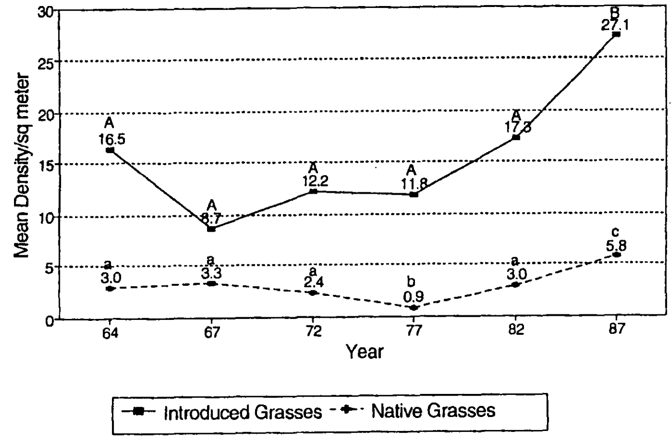

Figure 4—Average density of introduced and native grasses within the ungrazed treatment. Values with the same letter are not significantly different ($p < 0.05$).

area the introduced grasses were significantly more frequent than in the nonseeded area. Native grasses and shrubs were significantly more frequent in the nonseeded area than in the seeded areas. Though native forbs showed no significant difference between treatments as a group, there are difference in the species composition between treatments.

Species, cover, composition, and frequency differences between aspen-mountain brush communities seeded to smooth brome and intermediate wheatgrass in the 1950's and adjacent nonseeded areas, demonstrate the competitiveness and adverse influence of these seeded grasses on native species. Seeded and nonseeded areas were similar at time of seeding. Grazing pressure on these areas has been the same. Conclusions were similar to those of Rosentreter (1994), Davis and Harper (1990), and Walker and others (1995), in that differences in species composition can be attributed to the competition of the seeded species. Native grasses, forbs, and shrub species diversity, frequency, and cover are higher in the nonseeded areas. Few native grasses, forbs, or shrubs within the aspen-mountain brush communities in central Utah can compete with intermediate wheatgrass and smooth brome. These introduced grasses are proving to be noncompatible with most native species and ultimately dominate seeded sites. The concomitant loss of species diversity diminishes resource values.

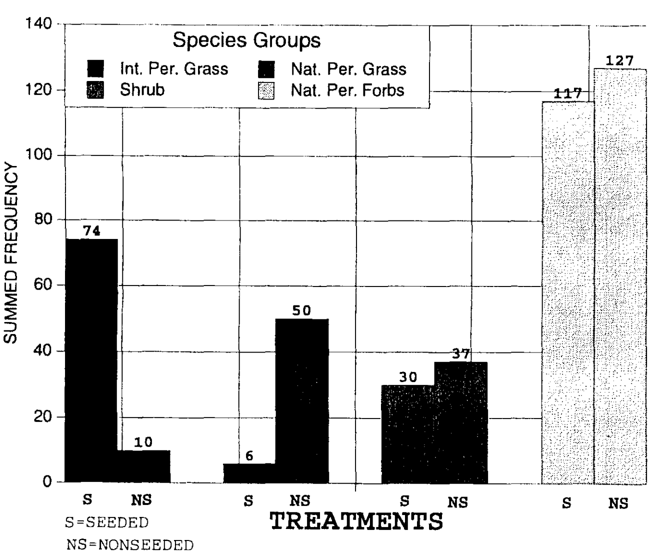

Figure 3—Summed frequency of lifeform groups for seeded and nonseeded areas, 40 years after seeding.

Case Study 3—Interaction Between Native and Seeded Introduced Grasses Through 23 Years Following Chaining and Seeding of Juniper-Pinyon Woodlands (Walker And Others 1995)

Three juniper-pinyon woodland sites in central Utah were evaluated over 23 years following chaining and seeding of introduced grasses under grazed and nongrazed conditions.

The density and production of herbaceous species was measured at intervals for 23 years in both the grazed and nongrazed treatments. In 1964, three to five years following initial treatment, introduced grasses had a five times greater density than the native grasses in the ungrazed areas (fig. 4). The density trend of the introduced grasses has continued to increase through 1987, while keeping the native grasses somewhat suppressed.

Under grazing pressure the introduced grasses have not increased in density at the same rate as in the ungrazed treatment. In the grazed treatment the introduced grasses have generally maintained at least twice the density as the natives (fig. 5). In the grazed treatment the introduced grasses are dominated by Fairway crested wheatgrass and intermediate wheatgrass. In the ungrazed treatment the introduced grasses are dominated by smooth brome and Fairway crested wheatgrass (table 2).

There has been a dramatic shift in the composition of the native species following seeding in both the grazed and ungrazed treatments. In 1964, both treatments supported a good compliment of a number of native grasses. Bottlebrush squirreltail (*Sitanion hystrix*), Indian ricegrass (*Oryzopsis hymenoides*), and bluebunch wheatgrass was

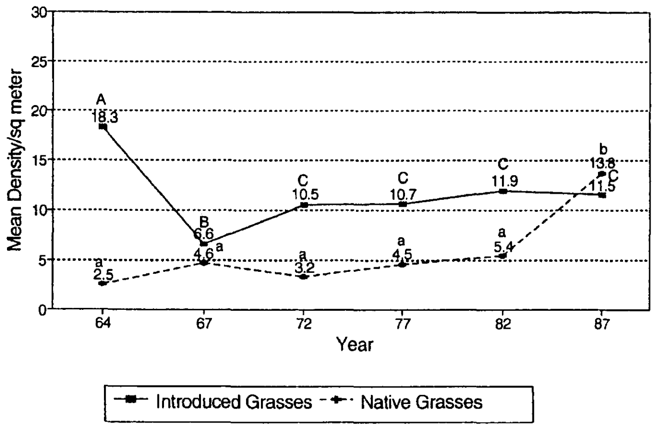

Figure 5—Average density of introduced and native grasses within the grazed treatment. Values with the same letter are not significantly different ($p < 0.05$).

well distributed throughout the areas (table 3). In 1987 the native grass composition shifted to, and is dominated by, a less productive sandberg bluegrass (*Poa secunda*) and western wheatgrass (*A. smithii*). The 1987 native grass component in the grazed treatment is comprised almost entirely (99 percent) of these two species (table 3).

Bottlebrush squirreltail and needle-and-thread (*Stipa comata*) responded favorably to removal of the juniper-pinyon, but succumbed to the more competitive species once they became established. Indian ricegrass and bluebunch wheatgrass are perennials that would be expected to respond favorably to tree removal. They both did, however, as the introduced species became firmly established, they were not able to compete with the aggressive exotics, with and without grazing. Western wheatgrass was able to compete somewhat with the introduced species, with or without grazing. Sandberg bluegrass, an opportunist, did well growing in association with western wheatgrass and the introduced species.

Table 2—Rank of introduced grasses by frequency and by density for grazed and ungrazed treatments. The rank is based on the average of three study areas, in the first data collection year (1964) and in the last data collection year (1987), showing species composition changes

Species	Rank by frequency	Frequency of occurrence	Rank by density	Density*** (per ha)
Ungrazed 1964				
Intermediate wheatgrass*	1	15	2	1,990
Fairway wheatgrass**	2	10	1	5,779
Smooth brome	3	5	4	565
Orchard grass	4	4	3	684
Russian wildrye	5	4	6	24
Bulbous bluegrass	6	3	5	24
				9,066
Ungrazed 1987				
Fairway wheatgrass**	1	15	2	5,913
Intermediate wheatgrass*	2	11	3	402
Russian wildrye	3	8	4	24
Smooth brome	4	5	1	11,745
				18,084
Grazed 1964				
Fairway wheatgrass**	1	15	1	5,360
Intermediate wheatgrass*	2	14	2	1,918
Smooth brome	3	10	3	1,091
Bulbous bluegrass	4	4	5	62
Russian wildrye	5	4	6	29
Orchard grass	6	3	4	67
				8,527
Grazed 1987				
Fairway wheatgrass**	1	10	1	10,635
Intermediate wheatgrass*	2	7	2	646
Russian wildrye	3	6	3	178
				11,459

*Combination of intermediate and pubescent wheatgrass.
**Combination of fairway and standard wheatgrass.
***Number of individual culms with rhizomatous species. Number of individual plants with bunchgrasses.

Table 3—Rank of native grasses by frequency and by density for grazed and ungrazed treatments in the first data collection year (1964) and in the last data collection year (1987), showing species composition changes

Species	Rank by frequency	Frequency of occurrence	Rank by density	Density[*] (per ha)
Ungrazed 1964				
Bottlebrush squirreltail	1	15	1	837
Indian ricegrass	2	11	2	598
Bluebunch wheatgrass	3	9	3	378
Western wheatgrass	4	4	4	148
Sandberg bluegrass	5	4	5	29
Needle-and-thread	6	2	6	19
				2,009
Ungrazed 1987				
Sandberg bluegrass	1	10	1	2,29
Western wheatgrass	2	9	2	1,512
Indian ricegrass	3	3	3	24
Bluebunch wheatgrass	4	2	4	19
Bottlebrush squirreltail	5	1	5	5
				3,856
Grazed 1964				
Bottlebrush squirreltail	1	15	1	723
Indian ricegrass	2	13	2	698
Sandberg bluegrass	3	5	4	72
Bluebunch wheatgrass	4	5	5	48
Western wheatgrass	5	2	3	101
Needle-and-thread	6	1	6	5
				1,647
Grazed 1987				
Sandberg bluegrass	1	10	1	9,989
Western wheatgrass	2	10	2	4,758
Indian ricegrass	3	5	3	75
Bluebunch wheatgrass	4	5	4	32
Needle-and-thread	5	1	5	22
Bottlebrush squirreltail	6	1	6	11
				14,887

[*]Number of individual culms with rhizomatous species. Number of individual plants with bunchgrasses.

Results show that after 23 years following the introduction of exotic grass species, the communities, though changing in density and cover, have not yet stabilized in plant dominance. The introduced grasses are increasing in density, cover, and production at a greater rate than are the native grasses that have shown a reduction in diversity.

Case Study 4—Long-Term Harmful Effects of Crested Wheatgrass on Great Plains Grassland Ecosystems (Lesica and Deluca 1996)

Lesica and DeLuca (1996) have done a comprehensive review of literature related to crested wheatgrass effects on Great Plains ecosystems. In summary:

Invasions by exotic plants are occurring at an increasing rate and are considered a serious threat to both agricultural systems as well as native communities (Drake and others 1989). Not only are exotics invading large areas, exotics have and are being planted extensively. Crested wheatgrass (*A. cristatum* and *A. desertorum*) is the most commonly planted exotic grass in western North America.

Crested wheatgrass has many desirable characteristics. These include, good forage yields, ease of establishment, good nutritional values, and it resists invasion by weeds. Although crested wheatgrass has desirable characteristics there are several often overlooked characteristics that may create a significant long-term decline in biological diversity and soil resource sustainability.

It is not uncommon to have considerable soil loss in crested wheatgrass stands. The strong competitiveness of crested wheatgrass creates a situation that results in high amounts of exposed soil. Grasslands with more exposed soil experiences higher rates of erosion (Wilson 1989; Dormaar and others 1995; McWilliams and Van Cleave 1960).

Perhaps a more serious effect on soil properties than the potential for increased soil erosion is the effect crested wheatgrass has on biochemical soil quality. Crested wheatgrass has a higher above-ground productivity than many native grasses. However, the below-ground biomass in the surface horizon is significantly lower (Dormaar and others 1995; Retente and others 1989; Smoliak and Dormaar 1985; Smoliak and others 1967). This lower below-ground biomass in crested wheatgrass reflects a reduction in both root detritus and root exudates that would otherwise be available for microbial use in the formation of soil organic matter. As a result, below-ground biomass under stands of crested wheatgrass has a higher carbon to nitrogen ratio than native grass species and only supplies about half as much organic N to the soil as does native grasslands (Biondini and others 1988; Klein and others 1987, 1988; Redente and others 1989). The small quantity and lower quality of organic matter in the upper soil horizons under stands of crested wheatgrass also results in a lower energy input to these soils as compared to native ranges (Dormaar and others 1978) and alters physical and biochemical processes in the soil. Stands of crested wheatgrass are associated with higher bulk density, fewer water stable aggregates, and lower levels of organic matter and nitrogen when compared to native grasses (Biondini and others 1988; Dormaar and others 1978; 1995; McHenry and Newell 1947; Redente and others 1989; Smoliak and others 1967). Crested wheatgrass provides the soil with a relatively high concentration of carbohydrates and little organic nitrogen (that is, the so-called "priming effect") as quantities of readily degraded carbohydrates in the presence of limited nitrogen often result in a net demand on soil organic nitrogen (DeLuca and Keeney 1993; Jansson and Persson 1982; Mortensen 1963). It has been suggested that these alterations to soil quality may prevent native species from invading crested wheatgrass monocultures (Klein and others 1988).

We presently lack the knowledge to know the long-term effects of crested wheatgrass. However, there is a growing body of knowledge that suggests that crested wheatgrass alters the environment in many undesirable ways. Further research into the changes in soils and plant and animal diversity associated with crested wheatgrass in the Great Plains as well as the Intermountain west are needed to assess its impact. Nonetheless, the continued conversion of native range and planting of crested wheatgrass in large stands as mono cultures or other exotic species seems ill advised.

Discussion

These four case studies help us understand that plant communities are continually changing in plant composition, density, and cover due to the effect directly caused by seeded species, precipitation cycles, and impacts from grazing or other disturbances. Introduced grasses have became more dominant in the communities, especially in the absence of grazing. The competitiveness of these grasses have caused a decline in native vegetation, reducing desirable species and changing plant composition. The data indicate that most native grasses do not appear to compete well with the species that were introduced. These results are Similar to those of Bock and others (1986) who reported that stands of exotic grasses support significantly lower variety and abundance of indigenous grasses. Davis and Harper (1990) report that planting a mixture of introduced and native species may produce artificial plant associations in which species may or may not be fully compatible with each other; and that it is difficult to maintain a stand of specified composition because each species responds differently to natural and imposed environmental factors that affect competitiveness.

There is an obvious shift in composition over time, the exotics are favored generally at the expense of native communities. Trends indicate that over a 30 or 40 year period of time introduced grasses are going to increase until they become dominant. For wildlife habitat, for biological diversity and for ecological integrity this scenario is not acceptable.

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References

Biondini, M.; Klein, D. A.; Redente, E. F. 1988. Carbon and nitrogen losses through root exudation by *Agropyron spicatum*. *A. smithii* and *Bouteloua gracilis*. Soil Biol. Biochem. 20: 4, 82.

Bock, C. E.; Bock, J. H.; Jepson, K. L.; Ortega, J. C. 1986. Ecological effects of planting African lovegrass in Arizona. Nat. Geogr. Res. 2: 456-463.

Davis, J. N., Harper, K. T. 1990. Weedy annuals and establishment of seeded species on a chained juniper-pinyon woodland in Central Utah. In: McArthur, E. D., E. M. Romney, S. D. Smith, P. T. Tueller, compilers. Proceedings-symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 72-79.

DeLuca, T. H.; Keeney, D. R. 1993. Glucose induced nitrate assimilation in prairie and cultivated soils. Biogeochem. 21:167-176.

Dormaar, J. F.; Johnston, A.; Smoliak, S. 1978. Long-term soil changes associated with seeded stands of crested wheatgrass in southeastern Alberta, Canada. In D. H. Hyder (ed), Proceedings of the first International Rangeland Congress, Society for Range Management, Denver, CO: 623-625.

Dormaar, J. F.; Naeth, M. A.; Willms, W. D.; and Chanasyk, D. S. 1995. Effect of native prairie, crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.) And Russian wildrye (*Elymus junceus* Risch.) On soil chemical properties. J. Range Manage. 48: 258-263.

Drake, J. A.; Mooney, H. A.; di Castri, F.; Groves, R. H.; Kruger, F. J.; Rejmanek, M.; Williamson, M. (eds.). 1989. Biological invasions: A global perspective. Wiley, Chichester, England.

Fowler, N. 1986. The role of competition in plant communities in arid and semiarid regions. Annu. Rev. Ecol. Syst. 17:89-110.

Jansson, S. L.; Persson, J. 1982. Mineralization and immobilization of soil nitrogen. In: F. J. Stevenson (ed.). Nitrogen in agricultural soils. American Society of Agronomy, Madison, Wisconsin. Vol. 22 pp. 229-252.

Klein, D. A.; Frederick, B. A.; Metzger, W. C.; Redente, E. F.; Trlica, M. J. 1987. Comparative soil microbial structural-functional relationships of introduced crested wheatgrass and native prairie communities. Pages L-2-1 to L-2-5. In: F. F. Munshower, S. E. Fisher, and P. E. Parady (eds.) Fourth biennial symposium on surface mining and reclamation on the Great Plains. Montana State University Research Unit Report 8704, Billings.

Klein, D. A.; Frederick, B. A.; Biondini, M.; Trlica, M. J. 1988. Rhizosphere microorganism effects on soluble amino acids, sugars and organic acids in the root zone of *Agropyron cristatum*, *A. Smithii* and *Bouteloua gracilis*. Plant Soil 110: 19-25.

Lesica, P.; DeLuca T. H. 1996. Long-term harmful effects of crested wheatgrass on Great Plains grassland ecosystems. J. Soil and Water Conservation: Vol. 51, no. 5 (Sept./Oct.): 408-409.

McHenry, J. R.; Newell, L. C. 1947. Influence of some perennial grasses on the organic matter content and structure of an eastern Nebraska fine-textured soil. J. Am. Soc. Agron. 39: 981- 994.

McWilliams, J. L.; VanCleave, P. F. 1960. A comparison of crested wheatgrass and native grass mixtures seeded on rangeland in eastern Montana. J. Range Manage. 13: 91-94.

Monsen, S. B.; Stevens, R.; Walker, S. C. 1996. The competitive influence of seeded smooth brome (*Bromus inermis*) and intermediate wheatgrass (Thinopyron intermedium) within aspen-mountain brush communities of central Utah. In: West, N. E., ed. Proceedings of the fifth International Rangeland Congress. July 23-28, 1995, Salt Lake City, Utah.

Mortensen, J. L. 1963. Decomposition of organic matter and mineralization of nitrogen in Brookston silt loam and alfalfa green manure. Plant Soil 19: 374-384.

Plummer, P. A.; Stevens, R.; Jorgensen, K. A. 1970. Highlights and accomplishments of game range restoration studies. Pub. No. 70-3. Utah State Division of Fish and Game. P. 26-29.

Pyke, D. A.; Archer, S. 1991. Plant-plant interaction affecting plant establishment and persistence on revegetated rangeland. J. Range Manage. 44(6): 550-557.

Redente, E. F.; Biondini, M. E.; Moore, J. C. 1989. Observations on biomass dynamics of a crested wheatgrass and native shortgrass ecosystem in souther Wyoming. J. Range Manage. 42: 113-118.

Rosentreter, R. 1994. Displacement of rare plants by exotic grasses, p. 170-175. In: Monsen, Stephen B.; Kitchen, Stanley G., comps. Proceedings-ecology and management of annual rangelands; 1992 May 18-21; Boise, ID Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 416 p.

Smoliak, S.; Johnston, A.; Lutwick, I. E. 1967. Productivity and durability of crested wheatgrass in southeastern Alberta. Can. J. Plant Sci. 47: 539-548.

Smoliak, S.; Dormaar, J. E. 1985. Productivity of Russian wildrye and crested wheatgrass and their effect on prairie soils. J. Range Manage. 38: 403-405.

Sorenson, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. Kong. Dan. Vidensk. Selsk. Biol. Skr. 5(4): 1-34.

Stevens, R. 1983. Species adapted for seeding mountain brush, big black and low sagebrush, and pinyon-juniper communities. In: Monsen, S. B.; Shaw, N., compilers. Managing Intermountain rangelands-improvement of range and wildlife habitats: Proceedings—1981 September 15-17; Twin Falls, ID; 1982 June 22-24; Elko, NV. Gen. Tech. Rep. INT-157. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 78-82.

Stevens, R. 1987. Thirty years of pinyon-juniper big game habitat improvement projects: what have we learned? In: R. L. Everett, ed. Pinyon-juniper conference: Proceedings; 1986 January 13-16; Reno, NV. Gen Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service Intermountain Research Station: 558-571.

Stevens, R. 1986. Population dynamics of two sagebrush species and rubber rabbitbrush over 22 years of grazing use by three animal classes. In: McArthur, E. D.; Welch, B. L., compilers. Proceedings—symposium on the biology of *Artemisia* and *Chrysothamnus*; 1984 July 9-13; Provo, UT. Gen. Tech. Rep. INT-200. Ogden UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 278-285.

Stevens, R. 1983. Species adapted for seeding mountain brush, big black and low sagebrush, and pinyon-juniper communities. In: Monsen, S. B.; Shaw, N., comps. Managing Intermountain rangelands-improvement of range and wildlife habitats: Proceedings—1981 September 15-17; Twin Falls, Id; 1982 June 22-24; Elko, NV. Gen. Tech. Rep. INT-157. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 78-82.

Walker, S. C.; Stevens, R.; Monsen, S. B.; Jorgensen, K. R. 1995. Interaction between native and seeded introduced grasses for 23 years following chaining of juniper-pinyon woodlands. In: Roundy, Bruce A.; McArthur, E. Durant; Haley, Jennifer S.; Mann, David K., comps. 1995. Proceedings: wildland shrub and arid land restoration symposium; 1993 October 19-21; Las Vegas, NV. Gen Tech. Rep. INT-GTR-315. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Wilson, S.D. 1989. The suppression of native prairie by alien species introduced for revegetation. Landscape Urban Plann. 17: 113-119.

Native Plant Solutions for Conservation Problems

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Abstract—The Bridger Plant Materials Center in Montana focuses on native species selection and establishment techniques for revegetation of rangeland, mineland, and other disturbed areas of the West. Work is carried out as a cooperative among several government and private organizations.

The Bridger Plant Materials Center (PMC) was established in 1959 by the USDA Natural Resources Conservation Service (NRCS) to help solve conservation problems in Montana and Wyoming. The land and facilities are owned by a nonprofit corporation consisting of all conservation districts in Montana and Wyoming and in turn leased to USDA-NRCS. Projects have focused on native species selection and establishment techniques for revegetation of rangeland, mineland, highly erodible sites, acid/heavy metal affected lands, wildlife cover/food, xeriscaping, and saline-affected soils. Research on native trees and shrubs has focused on the identification and testing of superior ecotypes for windbreak and shelterbelt applications in the Great Plains. In 1986, a cooperative agreement with the National Park Service was initiated to assist with the identification, collection, propagation, processing, and culture of indigenous species for revegetating roadsides. Assistance began in 1994 emphasizing the identification, propagation, and establishment of culturally significant plants of Native American tribes. As a service to the Montana Natural Heritage Program, germination and propagation techniques are being developed for "threatened" *Penstemon lemhiensis* and to the U.S. Fish and Wildlife Service for seed increase of "sensitive" *Gaura neomexicana* ssp. *coloradensis.*

Native plant species are collected from throughout Montana and Wyoming and evaluated at the Bridger Plant Materials Center or other appropriate remote sites. The seed of superior accessions (collections) is increased and then established in replicated plots. The superior material is increased and made available for field planting throughout Montana and Wyoming on private and public lands. These plantings are established under actual use situations and compared to commercially available germplasm for a particular conservation use. Once a plant is proven superior, seed is made available to growers for commercial production and sale. The Bridger PMC presently utilizes alternative release mechanisms, which ensure genetic integrity, while allowing plant materials to be released with a limited amount of testing. These alternatives are, from least tested to most tested: "source identified"—seed harvested from a native stand or collected and grown under cultivation; "selected"—germplasm that has genetic superiority or distinctive traits; "tested"—material that has been through multiple years, multiple site testing which statistically validates superior traits; and "cultivar"—material that has had purposeful genetic manipulation or extensive replicated and field testing.

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Evaluation of Plant Materials for Use in Reclamation of Disturbed Rangelands in Semi-Arid Areas of Northern Utah

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Abstract—Reclamation of degraded and disturbed rangelands in the arid west continues to be both desirable and difficult. At their best, reclamation practices and efforts often fail in their objectives due to harsh environmental conditions that tend to be difficult to predict. Development of species adapted to these harsh conditions improve reclamation success rates. The objective of this study was to test and select species that are adapted to two range site types in northern Utah. Between 20 and 24 species were used in replicated adaptability trials at two sites, sagebrush (*Artemisia* spp.)/grass and greasewood (*Sarcobatus vermiculatus*), located immediately southwest of Utah Lake in Northern Utah. Several species of both native and introduced grasses were evaluated as adapted to these sites, respectively. Alkar tall wheatgrass (*Elymus elongatus*) preformed well at the greasewood site, while crested wheatgrass (*Agropyron cristatum*) varieties established well at the sagebrush/grass site. A larger group of species performed well at the greasewood site than at the sagebrush/grass site.

Reclamation and revegetation of arid and semiarid rangelands are difficult processes complicated by severe environmental conditions. Natural recruitment in areas of low precipitation is limited to wetter years (Roundy and Call 1988; Allen 1995). Development of improved plant varieties which are better adapted to dry areas can increase success of rangeland revegetation (Asay and others 1985; Munda and Smith 1995).

Two vegetation types found in arid and semiarid areas of the Great Basin are sagebrush (*Artemisia* spp.)/grass and greasewood (*Sarcobatus vermiculatus*). Sagebrush/grass types have a long history of reclamation (Young and others 1979). Seeding strictly with native species met with little success, and use of introduced species became necessary (Young and others 1979). Crested wheatgrass (*Agropyron cristatum*) was one of the first introduced species successfully tested and used in adaptability trials. Kellar (1979), in a review of species selection and seeding methods for sagebrush/grass sites, stated that crested wheatgrass has been the most important grass in revegetating these sites. Other important sagebrush/grass species included intermediate and pubescent wheatgrasses (*Agropyron intermedium*), Siberian wheatgrass (*Agropyron cristatum*), Russian wildrye (*Elymus junceus*), and dryland alfalfa (*Medicago sativa*) (Kellar 1979).

Seedling establishment has proven difficult on greasewood sites, because of large amounts of salts in the soil (Forsburg 1953; Rollins and others 1968; Malcolm 1969; Sandoval and Gould 1978; Roundy and others 1983; USDA 1984; Roundy 1985). High concentration of salts can be toxic to plants, causing nutritional imbalances (Rollins and others 1968; Maas 1986), and reduced matric and osmotic potential of the soil (Sandoval and Gould 1978; Roundy 1985). In some greasewood sites the soils are sodic rather than saline (high salts but no excess of sodium). Sodic soils have a sodium adsorption ratio (SAR) greater than 13 and usually have a basic pH (Sandoval and Gould 1978; Jurinak 1981). Excessive sodium creates dispersed clay colloids in the soil which reduces infiltration of water into the soil (Rollins and others 1968; Sandoval and Gould 1978). Tall wheatgrass and basin wildrye (*Elymus cinereus*) varieties are among the few species which have proven to be successful on greasewood sites (Forsburg 1953; Fleck 1967; Rollins and others 1968; Malcolm 1969; McPhie 1973; Sandoval and Gould 1978; Roundy and others 1983; Roundy 1985).

A sagebrush/grass site and a greasewood site in northern Utah were selected to test the adaptability of 20 and 24 plant species, respectively. The objectives of this study were to 1) evaluate establishment of selected species on the respective sites and 2) evaluate the longevity of green tissue for the same species.

Study Site

The study area was located in northern Utah immediately southwest of Utah Lake. This area receives an average of 250 to 300 mm of precipitation per year with the majority coming as snow or winter rain. The mean annual air temperature varies between 7.2 and 11.1 °C, and the frost free period is between 100 and 140 days. Soil types in the general area range from silt clay loams to sandy loams with a slope between 0 and 5 percent.

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Table 1—Soil analysis for Sagebrush/grass and Greasewood sites.

Soil test	Sagebrush/grass	Greasewood
Nitrate-Nitrogen ppm N	9.54	3.32
Phosphorus ppm P	9.87	29.10
Potassium ppm K	1,065.60	688.00
Salinity-ECe mmhos/cm	1.15	2.10
Calcium ppm Ca	83.00	37.00
Magnesium ppm Mg	19.00	6.50
Sodium ppm Na	112.64	424.96
Sodium Adsorption Ratio (SAR)	2.89	16.90

Two range sites were used to evaluate the adaptability of several species. The first site (sagebrush/grass), a semi-desert gravelly loam range site (USDA 1993), was located 1 km north of Elberta, Utah and 2 km west of state highway 68. This was an upland site with current vegetation dominated by annual weedy species and interspersed shrubs and juniper trees. Analysis of these soils indicated a soil pH of 8.20, low levels of nitrogen and phosphorus, and high potassium levels (table 1). There were no problems with salinity or sodium on the site. Soil classification was Linoyer series, coarse-silty, mixed (calcareous), mesic Xeric Torrifluvents (USDA 1984).

The second site (greasewood), an alkali flat range site (USDA 1993), was located 7 km north of Elberta, Utah and 2 km east of state highway 68. This site was dominated by greasewood with a sparse understory of other annual forbs and grasses. A soil analysis indicated a pH of 8.40 and low levels of nitrogen, but high levels of phosphorus and potassium (table 1). There were no problems with salinity, but a medium sodium hazard existed, with the site having a SAR of 16.90 (Richards 1954). Soil classification was Manassa series, fine-silty, mixed (calcareous), mesic Xeric Torriorthents (USDA 1984).

Materials and Methods

At each range site the area was disked to remove the existing vegetation. The species to be tested were then seeded into a randomized four replicate complete block experimental design with 24 and 20 species in the sagebrush/grass and greasewood sites, respectively (table 2). Within each block, each species was planted in 10-row sections which were 3 m wide by 9 m long. Plots were seeded

Table 2—Plant Materials used at study sites.

Common name	Scientific name	Site planted
Oahe Intermediate Wheatgrass	*Agropyron intermedium*	Both
Luna Pubescent Wheatgrass	*Agropyron intermedium*	Sagebrush/grass
Nordan Crested Wheatgrass	*Agropyron cristatum*	Both
P27 Siberian Wheatgrass	*Agropyron fragile*	Both
Vavilov Siberian Wheatgrass	*Agropyron fragile*	Both
Ephraim Crested Wheatgrass	*Agropyron cristatum*	Both
Hycrest I Crested Wheatgrass	*Agropyron cristatum* X *desertorum*	Both
Hycrest II Crested Wheatgrass	*Agropyron cristatum* X *desertorum*	Sagebrush/grass
Douglas Crested Wheatgrass	*Agropyron cristatum*	Greasewood
Broadleaf Crested Wheatgrass	*Agropyron cristatum*	Both
Critana Thickspike Wheatgrass	*Elymus lanceolatus*	Sagebrush/grass
Secar Snakeriver Wheatgrass	*Elymus lanceolatus*	Sagebrush/grass
Bannock Thickspike Wheatgrass	*Elymus lanceolatus*	Sagebrush/grass
Goldar Bluebunch Wheatgrass	*Elymus spicatus*	Sagebrush/grass
NewHy Hybrid Wheatgrass	*Elymus hoffmanni*	Both
RSH Quackgrass Cross	*Elymus hoffmanni*	Greasewood
Alkar Tall Wheatgrass	*Elymus elongatus*	Greasewood
SL Hybrid Wheatgrass	*Pseudoroegneria spicata* X *Elymus lanceolatus*	Both
Magnar Great Basin Wildrye	*Elymus cinereus*	Both
Trailhead Basin Wildrye	*Elymus cinereus*	Both
Bozoisky Russian Wildrye	*Elymus junceus*	Both
Syn A Russian Wildrye	*Psathyrostachys juncea*	Both
Shoshone Beardless Wildrye	*Elymus trticoides*	Greasewood
Altai Wildrye	*Leymus angustus*	Greasewood
Regar Meadow Bromegrass	*Bromus riparius*	Sagebrush/grass
Paloma Indian Ricegrass	*Stipa hymenoides*	Sagebrush/grass
Spreador II Alfalfa	*Medicago sativa*	Both
Alfagraze Alfalfa	*Medicago sativa*	Greasewood
Remont Sainfoin	*Onobrychis viciifolia*	Both

with a John Deere flex planter at seeding rates of approximately 11 kg per hectare. The sagebrush/grass site was seeded in the fall of 1992, and the greasewood site was seeded in the fall of 1993.

In June of 1995, each plant species was rated for row uniformity and density on a scale from 1 to 10; 10 being the highest rating. Uniformity was an evaluation of plant spacing along the length of the row. Density was an evaluation of the relative number of plants per unit area. A stand performance index (SPI) was then calculated by multiplying the uniformity and density ratings.

The longevity of green foliage was also evaluated for each species. The greenness of foliage was evaluated at 1 to 4 week intervals through the growing season, beginning May 19 and ending August 10. A rating of 70 percent indicated that 70 percent of the foliage was green and 30 percent was dry.

Standard analysis of variance methods were used to compare species, and a protected LSD mean separation technique was used to distinguish performance between species (Ott 1988). A total of 29 plant species were seeded between the two sites, with some species being seeded at both sites (table 2).

Results

A wide range of density and uniformity ratings was found among plant species. The two ratings were tightly correlated for most species. The product of the density and uniformity ratings for each species was calculated, and used as a Stand Performance Index (SPI). Analysis of variance showed significant differences for stand performance among species ($p \leq 0.01$). Interaction between site and species was also significant ($p \leq 0.01$). Plant species were ranked in order from highest to lowest according to the Index for each site (tables 3 and 4). Siberian and crested wheatgrasses outperformed other species at the sagebrush/grass site. The top five varieties were P-27 Siberian, Ephraim, Hycrest I, Hycrest II, and Vavilov. These varieties scored significantly higher SPIs than the rest of the species. On the greasewood site, Alkar tall wheatgrass performed the best with a SPI almost 8 points higher than the other species, but it was not significantly higher than the other top 12 species (table 4). Remont sainfoin (*Onobrychis viciifolia*) was ranked the lowest at both sites, being in the statistically lowest group along with five other species at the sagebrush/grass site (table 3), and being significantly lower than all other species at the greasewood site. Significant interaction between site and species occurred because plants such as NewHy and RSH quackgrass cross were in the statistically highest ranked group at the greasewood site, while being in the statistically lowest ranked group at the sagebrush/grass site. Overall, a larger group of plant species performed better at the greasewood site than at the sagebrush/grass site. Sixty-five percent of the species seeded at the greasewood site were in the statistically highest ranked group, with only one species being in the statistically lowest ranked group. At the sagebrush/grass site only 21 percent of the species were in the statistically highest ranked group, while 25 percent were in the statistically lowest ranked group.

Plant species at the two sites began to show statistical differences ($p < 0.05$) in percent greenness by the middle of July. By the last collection date, August 10, the differences

Table 3—Species establishment at the Sagebrush/grass site.

Rank	Species	Density	Uniformity	Stand performance index
1	P27 Siberian Wheatgrass	9.03	9.00	81.3 a
2	Ephraim Crested Wheatgrass	8.59	9.17	78.9 a
3	Hycrest I Crested Wheatgrass	8.53	9.20	78.5 ab
4	Hycrest II Crested Wheatgrass	8.26	9.36	77.3 ab
5	Vavilov Siberian Wheatgrass	8.33	9.03	75.2 abc
6	Syn A Russain Wildrye	7.97	8.63	68.8 bcd
7	Broadleaf Crested Wheatgrass	7.87	8.33	65.6 cde
8	Bozoisky Russian Wildrye	7.47	8.17	61.0 def
9	Luna Pubescent Wheatgrass	7.30	7.97	58.2 efg
10	Bannock Thickspike	7.17	8.03	57.6 efgh
11	Nordan	7.20	7.50	54.0 fghi
12	Paloma Indian Ricegrass	6.77	7.63	51.7 fghij
13	Critana Thickspike Wheatgrass	7.03	7.00	49.2 fghij
14	Trailhead Basin Wildrye	5.97	7.97	47.6 hij
15	SL Hybrid Wheatgrass	6.63	6.83	45.3 ij
16	Magnar Basin Wildrye	6.10	7.10	43.3 j
17	Oahe Intermediate Wheatgrass	6.03	6.83	41.2 j
18	Spreador II Alfalfa	5.50	5.93	32.6 jk
19	Secar Snakeriver Wheatgrass	3.97	4.47	17.8 kl
20	RSH Quackgrass Cross	3.47	4.00	13.9 kl
21	NewHy	3.50	3.77	13.2 kl
22	Goldar Bluebunch Wheatgrass	3.00	3.57	10.7 l
23	Regar Meadow Bromegrass	1.97	3.17	6.2 l
24	Remont Sainfoin	0.83	0.93	0.8 l

Table 4—Species Establishment at the Greasewood site.

Rank	Species	Density	Uniformity	Stand performance index
1	Alkar Tall Wheatgrass	9.53	9.97	95.0 a
2	Vavilov Siberian Wheatgrass	8.83	9.83	87.7 ab
3	Bozoisky Russian Wildrye	8.73	9.93	86.7 ab
4	Nordan Crested Wheatgrass	9.03	9.53	86.1 ab
5	P27 Siberian Wheatgrass	8.67	9.83	85.2 ab
6	Hycrest I Crested Wheatgrass	8.27	10.00	82.7 ab
7	Syn A Russain Wildrye	8.57	9.27	79.4 abc
8	NewHy	8.50	9.20	78.2 abc
9	RSH Quackgrass Cross	8.67	8.93	77.4 abcd
10	Douglas Crested Wheatgrass	8.27	9.30	76.9 abcd
11	Trailhead Basin Wildrye	8.23	9.17	75.5 abcd
12	Broadleaf Crested Wheatgrass	8.13	9.27	75.4 abcd
13	Oahe Intermediate Wheatgrass	7.83	9.23	72.3 abcde
14	Critana Thickspike Wheatgrass	8.03	7.77	62.4 bcde
15	Shoshone Beardless Wheatgrass	7.03	7.63	53.6 cdef
16	Altai Wildrye	6.47	6.87	44.5 f
17	Spreador II Alfalfa	6.33	7.00	44.3 f
18	Magnar Basin Wildrye	6.00	6.80	40.8 f
19	Alfagraze Alfalfa	5.63	5.83	32.8 f
20	Remont Sainfoin	1.30	1.30	1.7 g

were quite evident (tables 5 and 6). There was much greater variation in greenness within species by August 10, making it more difficult to distinguish between species statistically. At the sagebrush/grass site on August 10, both varieties of Basin wildrye and Remont sainfoin had ratings of 80 percent green tissue or above. Table 5 shows that the first ten species stayed significantly greener longer than the rest of the species at that site. At the greasewood site, Remont Sainfoin received the highest rating on the last date, with the first 12 species listed on table 6 also being significantly higher than the other species at the site on August 10. By August 10, thirty-eight percent of the plants at the sagebrush/grass site were significantly lower than the rest of the species at that site with Vavilov Siberian wheatgrass receiving the lowest ranking. At the greasewood site, 30 percent of the species were in the statistically lowest ranked group, with Critana thickspike wheatgrass receiving the lowest rank on August 10.

Discussion

Different plant species have adapted to different types of environmental conditions, with some having a wide range of adaptation, and others having a narrow range. These adaptability trials indicated that the species evaluated represented a wide range of variation with respect to being adapted to these sites. Some species had strong establishment, while others had the ability to remain green into late summer. Some species did well in both areas, while others proved to be mediocre or poor in both categories.

Table 5—Percent green tissue remaining for species at the Sagebrush/grass site.

Rank	Species	July 19	Percent green tissue August 10
1	Magnar Basin Wildrye	89.0 abcd	81.5 a
2	Trailhead Basin Wildrye	85.7 cde	80.0 a
3	Remont Sainfoin	90.0 abc	80.0 a
4	RSH Quackgrass Cross	88.3 abcd	75.0 ab
5	Spreador II Alfalfa	88.0 abcd	73.3 ab
6	NewHy	84.3 def	72.3 abc
7	Goldar Bluebunch Wheatgrass	95.7 a	66.7 abcd
8	SL Hybrid Wheatgrass	94.0 ab	63.3 abcde
9	Secar Snakeriver Wheatgrass	90.0 abc	59.0 abcdef
10	Paloma Indian Ricegrass	64.3 i	55.0 bcdefg
11	Critana Thickspike Wheatgrass	83.7 cde	50.7 cdefgh
12	Regar Meadow Bromegrass	81.3 efg	49.3 defghi
13	Broadleaf Crested Wheatgrass	82.7 ef	48.3 defghi
14	Hycrest II Crested Wheatgrass	87.3 bcd	43.3 efghij
15	Hycrest I Crested Wheatgrass	81.7 efg	37.0 fghijk
16	Bannock Thickspike	89.3 abcd	34.0 ghijkl
17	Oahe Intermediate Wheatgrass	83.0 cde	33.3 ghijkl
18	Nordan Crested Wheatgrass	75.3 gh	30.3 hijkl
19	Luna Pubescent Wheatgrass	70.7 hi	28.3 ijkl
20	P27 Siberian Wheatgrass	87.7 abcd	26.7 jkl
21	Ephraim Crested Wheatgrass	78.7 fgh	21.7 jkl
22	Bozoisky Russian Wildrye	81.7 efg	18.7 kl
23	Syn A Russian Wildrye	87.0 bcd	15.7 kl
24	Vavilov Siberian Wheatgrass	82.0 efg	14.0 l

Table 6—Percent green tissue remaining for species at the Greasewood site.

Rank	Species	July 19	Percent green tissue August 10
1	Remont Sainfoin	89.0 a	75.0 a
2	Magnar Basin Wildrye	79.7 b	73.3 a
3	Alfagraze Alfalfa	95.0 a	70.0 ab
4	Trailhead Basin Wildrye	79.0 bc	70.0 ab
5	NewHy	76.7 bcd	67.7 ab
6	RSH Quackgrass Cross	73.7 bcde	67.3 ab
7	Alkar Tall Wheatgrass	79.0 bc	67.3 ab
8	Spreador II Alfalfa	79.0 bc	65.0 abc
9	Broadleaf Crested Wheatgrass	71.3 defgh	63.3 abc
10	Altai Wildrye	70.7 bcd	60.0 abc
11	Syn A Russian Wildrye	74.0 bcde	56.7 abc
12	P27 Siberian Wheatgrass	72.7 cdef	55.7 abc
13	Shoshone Beardless Wildrye	77.0 bcd	51.7 bc
14	Nordan Crested Wheatgrass	67.7 efghi	46.7 cd
15	Hycrest I Crested Wheatgrass	60.7 ijk	28.3 de
16	Vavilov Siberian Wheatgrass	55.3 k	28.3 de
17	Douglas Crested Wheatgrass	58.3 jk	26.7 e
18	Bozoisky Russian Wildrye	65.7 fghi	23.3 e
19	Oahe Intermediate Wheatgrass	65.3 ghij	19.0 e
20	Critana Thickspike Wheatgrass	62.3 ijk	11.0 e

At the greasewood site, Alkar tall wheatgrass showed good establishment, and also stayed green into August, having 67.3 percent green tissue remaining on August 10. It has been shown to stay green longer than other wheatgrasses (table 6; Asay 1995) which could be attributed to its extremely deep root system (Asay 1995). It was in the statistically highest ranked group for both stand performance and percent green tissue remaining. Tall wheatgrass is one of the foremost species used for revegetation on greasewood sites and is very important for reclamation purposes in these areas (Forsburg 1953; Fleck 1967; Rollins and others 1968; Malcolm 1969; McPhie 1973; Sandoval and Gould 1978; Roundy and others 1983; Roundy 1985).

Crested wheatgrass varieties established well on both study sites but did not remain green through the end of the summer. The performance on these sites corresponded with crested wheatgrass performance in other areas. Crested wheatgrass has been found to provide excellent spring forage, but quality declines rapidly (Welsh and others 1993; Asay 1995). Although the crested wheatgrass varieties which were used had low percent green tissue on the last collection date, they still remained green longer than expected from previous reports. This probably occurred because of the especially cool and wet spring and summer in 1995. This area received 229 mm of precipitation in May and 68 mm of rain in June, which equaled the long-term mean annual precipitation. Although crested wheatgrass varieties are not commonly planted for summer forage, its excellent establishment properties make it highly desirable for soil stabilization. For example, the first important use of crested wheatgrass occurred on the Great Plains, saving large tracts of soil during the dust bowl of the 1930's (Asay 1995).

Most of the wildrye varieties used in this study have histories of poor seedling vigor and poor establishment properties (Asay 1995). Bozoisky Russian wildrye and Syn A Russian wildrye were both selected for improved establishment and seedling vigor (Asay 1992), and did outperform the other wildryes receiving high scores on the Stand Performance Index (tables 3 and 4). Both basin wildryes had high percentages of green tissue throughout the summer at both sites (tables 5 and 6). At the sagebrush/grass site neither had strong establishment (tables 3 and 4), while at the greasewood site, Trailhead basin wildrye performed well, receiving an Index score of 75.5 and was in the statistically highest ranked group. Trailhead basin wildrye has been found to outproduce Magnar great basin wildrye under drought conditions (Asay 1995). Basin wildryes have proven to be important plant materials in revegetation of greasewood sites (Roundy and others 1983; Roundy 1985).

Thickspike wheatgrass varieties performed average to poor on both sites for stand performance. Critana thickspike, SL hybrid, and Bannock thickspike were not in the highest or lowest groups, but Secar snakeriver wheatgrass was in the statistically lowest group at the sagebrush/grass site. At the sagebrush/grass site, SL hybrid and Secar snakeriver wheatgrass were in the statistically highest group for percent green tissue remaining on August 10. Critana was average, and Bannock thickspike was in the statistically lowest group. Secar snakeriver wheatgrass has shown excellent drought tolerance in the past (Asay 1995). SL hybrid also has drought tolerance (Asay and others 1991).

Bluebunch wheatgrass performed very poorly at the sagebrush/grass site, being in the statistically lowest group for stand performance. On the greasewood site NewHy and RSH quackgrass cross were in the statistically highest group. It is not surprising that these two varieties would act similarly because they are both crosses between bluebunch wheatgrass and quackgrass (Asay 1992). RSH is the naturally occurring form of NewHy. It is also not surprising that they would do well on the greasewood site because they have high salt tolerance. Bluebunch wheatgrass was in the statistically highest group at both sites for percent green tissue remaining on August 10. This supports other findings that bluebunch wheatgrass is adapted to dry areas (Asay 1995).

Although Regar meadow bromegrass has shown rapid seedling establishment in other areas (USDA 1994), it was in the statistically lowest group for stand performance, receiving an index score of 6.2 at the sagebrush/grass site (table 3). It has also shown drought tolerance in other areas (USDA 1994), but received a marginal rating of percent green tissue remaining (table 5).

Paloma Indian ricegrass performed marginally in stand performance and percent green tissue remaining (tables 3 and 5). In other areas it has shown excellent stand establishment and relative drought tolerance (USDA 1994).

Although both varieties of alfalfa, Spreador II and Alfagraze, did not receive high Stand Performance Index scores, alfalfa would be a valuable plant to have in a species mix. Mature alfalfa plants can recover from heavy grazing, while seedlings have great difficulty recovering (Stevens and Monsen 1998). Alfagraze alfalfa is adapted to areas that are irrigated or have average annual precipitation higher than at these sites (Monsen and Horrocks 1996, personal communication), as such, it is not surprising that it did not exhibit high performance under extreme conditions.

Alfagraze probably should not be used in seeding mixes in these environments without irrigation. If Spreador II seedlings can be protected for 2 or 3 years, surviving plants should be long lived in the community (Stevens and Monsen 1998). The value of including a legume like alfalfa in a mix is that it greens up early and stays green longer than many grasses (Stevens and Monsen 1998).

Remont sainfoin is another plant which demonstrated poor establishment, but if it could be established, it would be valuable for grazing purposes. It greens up early and stays green long into the grazing season (Stevens and Monsen 1998). Remont Sainfoin remained green longer than almost all of the species at both sites (tables 5 and 6).

The high establishment and growth rate for many species on the greasewood site was unusual for such a site. Success could be attributed to high amounts of precipitation in the spring of 1995 (Roundy and others 1983; Roundy 1985). Another possible explanation, is that the site is sodic and not saline-sodic. Available water would not have been restricted by low matric and osmotic potentials as is often the case in saline soils (Rollins and others 1968; Sandoval and Gould 1978; Roundy and others 1983; Roundy 1985).

Conclusions

Reclamation projects can have many different objectives. The desired objectives of the project determines what plant species are used. If the objective is soil stabilization then crested wheatgrass would be a good species to use. If the objectives included lengthening the grazing season, then a species like alfalfa, which remains green through the summer, would be a better choice. Plant species used also depends on the site being reclaimed. For example, Trailhead basin wildrye had an Index score of 47.6 at the sagebrush/grass site while receiving a score of 75.5 on the greasewood site. Difference in soil type, water relations, and history of use can impact the site and which species are adapted.

Although objectives for an area will help determine which species should be planted, a mix of native and introduced grasses along with some shrubs has been shown to improve overall plant production in arid and semi arid areas (Roundy and Call 1988). Further studies could be performed to determine which mix of species grow best together, and to determine which species are preferred by grazing animals.

References

Allen, E. B. 1995. Restoration ecology: limits and possibilities in arid and semiarid lands. p. 7-15. IN: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K. (eds.) Proceedings: Wildland Shrub and Arid Land Restoration Symposium. INT-GTR-315 Intermountain Research Station Forest Service USDA, Ogden.

Asay, K. H. 1992. Breeding potentials in perennial Triticeae grasses. Hereditas. 116:167-173.

Asay, K. H. 1995. The wheatgrasses and wildryes: The perennial Triticeae. p. 374-394. IN: Barnes, R. B.; Miller, D. A.; Nelson, C. J. (eds.) Forages Vol. 1: An Introduction to Grassland Agriculture. Iowa State Univ. Press, Ames.

Asay, K. H.; Dewey, D. R.; Gomm, F. B.; Johnson, D. A.; Carlson, J. R. 1985. Registration of 'Bozoisky-Select' Russian wildrye. Crop Science. 25:575-576.

Asay, K. H.; Dewey, D. R.; Horton, W. H.; Jensen, K. B.; Currie, P. O.; Chatteron, N. J.; Hansen, W. T, II; Carlson, J. R. 1991. Registration of 'NewHy' RS hybrid wheatgrass. Crop Science. 31:1384-1385.

Asay, K. H.; Dewey, D. R.; Jensen, K. B.; Horton, W. H.; Maughan, K. W.; Chatteron, N. J.; Carlson, J. R. 1991. Registration of *Pseudoroegneria spicata* x *Elymus lanceolatus* hybrid germplasm. SL-1. Crop Science. 31:1391.

Asay, K. H.; Horton, W. H.; Hansen II, W. T. 1985. New grasses for intermountain rangelands. Utah Science. 119-123.

Asay, K. H.; Jensen, K. B.; Johnson, D. A.; Chatteron, N. J.; Hansen, W. T.; Horton, W. H.; Young, S. A. 1995. Registration of 'Douglas' crested wheatgrass. Crop Science. 35:1510-1511.

Bouton, J. H. 1992. America's Alfalfa Alfagraze. ABI, Shawnee Mission.

Bouton, J. H.; Smith, Jr., S. R.; Wood, D. T.; Hoveland, C. S.; Brummer, E. C. 1991. Registration of 'Alfagraze' alfalfa. Crop Science. 31:479.

Brough, R. C.; Robinson, L. R.; Jackson, R. H. 1977. The historical diffusion of alfalfa. Journal of Agronomy Education. 6:13-19.

Buman, R. A.; Monsen, S. B.; Abernethy, R. H. 1988. Seedling competition between mountain rye, 'Hycrest' crested wheatgrass, and downy brome. Journal of Range Management. 41:30-34.

Call, C. A.; Roundy, B. A. 1991. Perspectives and processes in revegetation of arid and semiarid rangelands. Journal of Range Management. 44:543-549.

DePuit, E. J. 1986. Western revegetation in perspective: past progress, present status, and future needs. P. 6-34. IN: Schuster, M. A.; Zuc, R. H. (eds.), Proc. High Altitude Revegetation Workshop No. 7 CWRR Information Ser. 58, Colorado State Univ., Fort Collins, CO.

Fleck, B. C. 1967. A note on the performance of *Agropyron elongatume* and *puccinella* in revegetation of saline areas. Journal of Soil Conservation. 23:261-269.

Forsburg, D. E. 1953. The response of various forage crops to saline soils. Canadian Journal of Agricultural Science. 33:542-549.

Haferkamp, M. R.; Adams, D. C.; Grings, E. E.; Currie, P. O. 1993. Herbage production and quality of RS2, a quackgrass (*Elytrigia repens* [L.] Nevski.) x bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh.] Love) hybrid. Proceedings of the XV International Grassland Congress: 207-208.

Hanson, C. H.; Barnes, D. K. 1973. Alfalfa. p. 136-147. IN: Heath, M. E.; Metcalfe, D. S.; Barnes, R. F. (eds.) Forages The Science of Grassland Agriculture. The Iowa State University Press, Ames.

Jurinak, J. J. 1981. Salt-Affect Soils. Department of Soil Science and Biometeorology, Utah State University, Logan.

Kellar, W. 1979. Species and methods for seeding in the sagebrush ecosystem. P. 129-163. IN: The Sagebrush Ecosystem: A Symposium. Utah State University, Logan.

Maas, E. V. 1986. Salt tolerance of plants. Applied Agricultural Research. 1:12-26.

Malcolm, C. V. 1969. Use of halophytes for forage production on saline wastelands. Australian Institute of Agricultural Science Journal. 35:38-39.

McPhie, G. L. 1973. Three successful salt tolerant plants. Southern Australian Journal of Agriculture. 76:5-8.

Munda, B. D.; Smith, S. E. 1995. Genetic variation and revegetation strategies for desert rangeland ecosystems. p. 288-291. IN: Roundy, B. A.; McArthur, E. D.; Haley, J. S.; Mann, D. K. (eds.) Proceedings: Wildland Shrub and Arid Land Restoration Symposium. INT-GTR-315 Intermountain Research Station Forest Service USDA, Ogden.

Ott, R. L. 1993. An Introduction to Statistical Methods and Data Analysis. Duxbury Press, Bellmont.

Richards, L. A. (ed.). 1954. Diagnosis and Improvement of saline and Alkali Soils. USDA Ag. Handbook 60, Washington, DC.

Rollins, M. B.; Dylla, A. S.; Eckert, Jr, R. E. 1968. Soil problems in reseeding a greasewood-rabbitbrush range site. Journal of Soil Water Conservation. 23:138-140.

Roundy, B. A. 1985. Emergence and establishment of basin wildrye and tall wheatgrass in relation to moisture and salinity. Journal of Range Management. 38:126-131.

Roundy, B. A. 1987. Seedbed salinity and the establishment of range plants. p. 68-81. IN: Frasier, G. W.; Evans, R. A. (eds.) Proceedings of Symposium "Seed and Seedbed Ecology of Rangeland Plants." USDA ARS, Tucson.

Roundy, B. A.; Call, C. A. 1988. Revegetation of arid and semiarid rangelands. p. 607-635. IN: Tueller, P. T. (ed.) Vegetation Science Application for Rangeland Analysis and Management. Kluwer Academic Publishers, Dordrecht.

Roundy, B. A.; Cluff, G. J.; Young, J. A.; Evans, R. A. 1983. Treatment of inland saltgrass and greasewood sites to improve forage production. P. 54-61. IN: Proc. Managing Rangelands Symposia, Twin Falls, ID and Elko, NV. USDA For. Serv. Intmnt. For. and Range Exp. Gen. Rep. INT-157. Ogden.

Sandoval, F. M.; Gould, W. L. 1978. Improvement Saline- and Sodium-Affected Disturbed Lands. p. 485-505. IN: Schaller, F. W.; Sutton, P. (eds.) Reclamation of Drastically Disturbed Lands. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison.

Stevens, R.; Monsen, S. 1998. Restoration of Western Range and Wildlands. USDA. FS. Rocky Mountain Research Station. In Press.

Stoddart, L. A.; Smith, A. D.; Box, T. W. 1975. Range Management. McGraw-Hill Book Company, New York.

USDA Agriculture Information Bulletin. 1982. Alfalfa for Dryland Grazing, Washington, DC.

USDA Forest Service. 1984. Viability of Seed Produced on Highly Sodic Coal Mine Spoils. Research Note INT-347, Ogden.

USDA Natural Resources Conservation Service and Idaho Agriculture Experiment Station. 1995. Notice of release of 'Bannock' thickspike wheatgrass.

USDA Soil Conservation Service. 1984. Soil Survey of Fairfield-Nephi Area Utah, Parts of Juab, Sanpete, and Utah Counties. National Cooperative Soil Survey, US Superintendent of documents, Washington, DC.

USDA Soil Conservation Service. 1994. Grass Varieties in the United States. Washington, DC.

USDA Soil Conservation Service. 1993. Utah Technical Guide, Salt Lake City.

Voigt, P. W.; Tishcler, C. R.; Young, B. A. 1987. Selection for improved establishment in warm-season grasses. p. 177-187. IN: Frasier, G. W.; Evans, R. A. (eds.) Proceedings of Symposium "Seed and Seedbed Ecology of Rangeland Plants." USDA ARS, Tucson.

Welsh, S. L.; Atwood, N. D.; Higgins, L. C.; Goodrich, S. 1993. A Utah Flora. Brigham Young University, Provo.

Young, J. A.; Eckert, Jr., R. E.; Evans, R. A. 1979. Historical perspectives regarding the sagebrush ecosystem. p. 1-13. IN: The Sagebrush Ecosystem: A Symposium. Utah State University, Logan.

Response of a Seed Mix and Development of Ground Cover on Northerly and Southerly Exposures in the 1985 Jarvies Canyon Burn, Daggett County, Utah

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Abstract—Response of a seed mix and recovery of plant and litter cover are compared for adjacent southerly (warm) and northerly (cool) exposures within a burn within the pinyon-juniper belt. Various plant species responded differently to the different exposures. Response of seeded and some nonseeded species are discussed. After 10 years, ground cover that provided protection against rain drop splash and sheet wash was 79 percent on the warm exposure and 97 percent on the cool exposure. Soil standards for cover should reflect different site specific capabilities as demonstrated on these two exposures.

Wildlands present a variety of ecological niches within many project areas with variation in exposure, gradient, slope position including drainage bottoms, change in geology and soils including amount of rock at the soil surface and in the soil profile, and other features. Seedings of burned areas and other projects are more likely to achieve desired objectives for cover, species diversity, forage supply over a greater part of a year, and higher production when they include a mix of species that can respond to site differences within the project area (Plummer and others 1968). At this study area, exposure is expected to be the major feature of difference in response of different plants.

Study Sites

The study sites are within the Jarvies Canyon Burn of 1985. This burn is in the Green River corridor north of the Flaming Gorge Dam in Daggett County, Utah, and about 3 miles northwest of the town of Dutch John and the Flaming Gorge Weather Station. Records from this weather station from 1957 through 1992 indicate annual precipitation of 12.50 inches of which 63 percent comes in the April through September period (Ashcroft and others 1992). The study sites are within the Uinta Mountain Section as defined by McNab and Avers (1994), and within a landtype composed of ridge and ravine topography underlain by Precambrian quartzitic materials and shales of the Uinta Mountain Group. Elevation of the burn ranged from 6,200 to 6,800 feet. The study sites were at about 6,700 feet.

Two general phases lie within the landtype. One phase is on northerly (cool) exposures where alder-leaf mountain-mahogany/bluebunch wheatgrass (*Cercocaprus montanus* Raf./*Elymus spicatus* [Pursh] Gould) communities with high plant diversity are seral to pinyon-juniper. The other phase is on southerly (warm) exposures where communities are often dominated by rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.), mountain big sagebrush (*Artemisia tridentata* var. *pauciflora* Winward & Goodrich), and grasses. These communities are also seral to pinyon-juniper. Gradient of the study site of cool exposure is about 15 percent, while that of the warm exposure is about 20 percent. On the warm exposures cheatgrass (*Bromus tectorum* L.) has proven to be a highly competitive plant. It was of much lower frequency on the cool exposure.

Prior to burning, the sites were dominated by mature stands of pinyon-juniper with canopy cover in excess of 50 percent on the cool exposure and somewhat less than this on the warm exposure. In the fall of 1985, 233 acres were burned by helitorch and aerial seeded in a cooperative project between the Utah Division of Wildlife Resources and the Ashley National Forest in which the Forest Service was responsible for burning and aerial application of seed, and Utah Division of Wildlife Resources supplied the seed mix (table 1). Both cool and warm exposures were burned, and intensity and spread of fire was sufficient to achieve essentially 100 percent mortality of pinyon and juniper within the perimeter of the burn.

The burn area had been closed to permitted livestock grazing since the early 1960's. Age and canopy cover of stands within the burn area indicate low presence of understory species through much of the 1900's. Permitted livestock use is

Table 1—Seed mix applied aerially to the burn in the fall of 1985.

Species	Seed per acre	Seeds per acre[a]
	lb	
Fairway crested wheatgrass	1	175,000
Intermediate wheatgrass	1	150,000
Lincoln smooth brome	3	213,000
Piute orchardgrass	2	1,308,000
Hard fescue	2	1,360,000
Ladak alfalfa	2	400,000
Small burnet	2	55,115
Yellow sweetclover	1	520,000
Mountain big sagebrush	1	2,575,940
Total	15	

[a]Determined from seeds per lb as given in Plummer and others (1968) and Stefferud (1948).

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expected to have been comparatively low at this site prior to the 1960's and none since that time.

The seed mix applied to the area included Fairway crested wheatgrass (*Agropyron cristatum* [L.] Gaertner), Intermediate wheatgrass (*Elymus hispidus* [Opiz] Meld.), Lincoln smooth brome (*Bromus inermis* Leysser), Piute orchardgrass (*Dactylis glomerata* L.), hard fescue (*Festuca ovina* var. duriuscula [L.] Koch.), Ladak alfalfa (*Medicago sativa* L.), Small burnet (Sanguisorba minor Scop.), Yellow sweetclover (*Melilotus officinalis* [L.] Pallas), and mountain big sagebrush (table 1). The moisture year that followed burning and seeding was favorable for establishment and growth of plants. In addition to the seeded species, cheatgrass and Japanese chess (*Bromus japonicus* Thumb.) became abundant enough to be significant in sampling at the sites. There were a few other native and introduced species of low frequency found on the sites.

Those of low frequency found in plots on the cool exposure were mostly natives. These were low penstemon (*Penstemon humilis* Nutt.), mountain dandelion (*Agoseris glauca* [Pursh] Raf.), and rockcress (*Arabis* L.). For the warm exposure, native species of low frequency found in plots were Ross sedge (*Carex rossii* Boott), tansy mustard (*Descurainia pinnata* [Walt.] Britton), narrowleaf goosefoot (*Chenopodium leptophyllum* [Moq.] Wats.), and hairy goldenaster (*Heterotheca villosa* [Pursh] Shinners). Introduced species of low frequency on the warm exposure were false flax (*Camelina microcarpa* Andrz. in DC.), and Russian thistle (*Salsola pestifer* A. Nels.).

Methods and Results

Rooted nested frequency (table 2) was determined in each of four nested plot sizes for all species at 100 sample points on each of the cool and warm exposures. Canopy cover of shrubs was determined on 500 feet of line intercept. Ground cover (tables 3 and 4) was determined from 400 point samples on each exposure. Methods for nested frequency, line intercept, and ground cover used in this study are outlined by U.S. Department of Agriculture, Forest Service (1993). Belt lines along which each of the above data sets were taken were permanently marked. Samples were taken

Table 2—Nested frequency scores for the two sites in 2 years based on potential score of 400.

Species	Warm exposure		Cool exposure	
	1991	*1996*	*1989*	*1996*
Fairway crested wheatgrass	159[a]	264[a]	166[a]	138[a]
Intermediate wheatgrass	32	26	35[a]	24[a]
Hard fescue	72[a]	148[a]	207[a]	277[a]
Piute orchardgrass	10	8	121[a]	90[a]
Lincoln smooth brome	56	57	137[a]	243[a]
Cheatgrass	30[a]	155[a]	0	0
Japanese chess	50[a]	77[a]	9	0
Ladak alfalfa	164[a]	145[a]	104	103
Yellow sweetclover	0	0	0	0
Small burnet	23	0	0	0

[a]The spread in scores for these species between years indicates significance at 80 percent probability (Chi Square = 1.642 with 1 degree of freedom).

Table 3—Development of ground cover as measured at 400 points on each the warm and cool exposures. Values shown are the number of points for each parameter of cover.

Site	Veg.	Litter	Moss	Rock	Pave.	Soil	Total
Warm exposure 1991	24[a]	117[a]	0	93[a]	47	119[a]	400
Warm exposure 1996	96[a]	184[a]	1	35[a]	39	45[a]	400
Cool exposure 1989	37[a]	211[a]	13[a]	25[a]	6	108[a]	400
Cool exposure 1996	182[a]	174[a]	22[a]	8[a]	1	13[a]	400

[a]The spread in scores for these values between 1991 and 1996 for the warm exposure and between 1989 and 1996 for the cool exposure is indicated to be significant at 80 percent probability (Chi Square = 1.642 with 1 degree of freedom).

Table 4—Development of ground cover (expressed as percent) following fire.

Site	Veg.	Litter	Moss	Rock	Pave.	Soil	Total
Warm exposure 1991	6	29	0	23	12	30	100
Warm exposure 1996	24	46	-	9	0	11	100
Cool exposure 1989	9	53	3	6	2	27	100
Cool exposure 1996	46	44	6	2	-	3	101

in 1989 and 1996 on the cool exposure and in 1991 and 1996 on the warm exposure. On the cool exposure, production (table 5) of above ground annual production (air dry weight) was measured in four different years in 10 random placed plots of 9.6 ft^2. No production measurements were taken on the warm exposure.

Dispersion of ground cover is indicated by quadrat frequency as well as nested frequency. In the 10th year after treatment, only one of 100 quadrats of 19.7 by 19.7 inches (50 by 50 cm) on the warm exposure did not have a perennial plant in it, and only eight of 100 nested plots of 9.8 by 9.8 inches (25 by 25 cm) did not have a perennial plant in them. By the 10th year, all 100 quadrats on the cool exposure had perennial plants in them, where only one of 100 nested plots of 9.8 by 9.8 inches did not have a perennial plant in it. The closely spaced plants with numerous fine stems indicate high value for dispersion of plants in relation to watershed protection.

Line intercept data showed no shrub cover on the warm exposure and rubber rabbitbrush crown cover of 0.3 percent in 1989 and 0.8 percent in 1996, and big sagebrush crown cover of 0 percent in 1989 and 1.8 percent in 1996.

Discussion and Management Implications

All seeded species except alfalfa and small burnet had higher frequency in 1989 on the cool exposure than they did in 1991 on the warm exposure. There are 2 years between these readings. However, greater establishment for all seeded species except alfalfa and small burnet is strongly indicated for the cool exposure. The difference in years supports this conclusion.

Lower production in 1989 was perhaps a function of precipitation of poor timing and low amounts. However, an obvious difference is the low production of alfalfa in that year

Table 5—Aboveground herbaceous annual production on the cool exposure.

Species	Pounds per acre air dry weight				Percent Composition by air dry weight			
	1989	*1991*	*1993*	*1996*	*1989*	*1991*	*1993*	*1996*
Fairway crested wheatgrass	247	372	145	186	29	24	7	13
Intermediate wheatgrass	30	62	41	113	3	4	2	8
Lincoln smooth brome	57	258	171	197	7	17	8	14
Piute orchardgrass	167	37	78	12	19	2	4	1
Hard fescue	310	279	701	316	36	18	34	22
Ladak alfalfa	50	526	911	591	6	34	44	41
Small burnet	0	3	4	0	0	0	0	0
Yellow sweetclover	0	0	0	0	0	0	0	0
Mountain big sagebrush	0	0	0	24	0	0	0	2
Totals	860	1541	2051	1439				

compared to the later years. Much of the higher production of later years is a function of maturation and greater production of alfalfa.

Variation in production and percent composition based on species production found at this site indicates problems for standards and monitoring based only on measurement of weight. Rather wide variations can be expected as a function of timing and amounts of precipitation and variations in temperature that are independent of management practices. A hard freeze in June, which has happened here, can greatly reduce production and change composition from that of other years with more favorable temperatures.

Ground cover provided by vegetation and litter increased significantly and bare soil decreased significantly with time as plants became established and produced litter. After 10 growing seasons, potential for cover providing protection against raindrop splash and sheet erosion (vegetation, litter, moss, and rock) is indicated to be 79 percent for the warm exposure and 97 percent for the cool exposure. Additional monitoring might show additional increase in ground cover on the warm exposure, but since percent ground cover on the cool exposure approached 100 percent, it can be considered at potential. The warm, dry conditions of the warm exposure indicates less than 100 percent as potential, and perhaps the 79 percent measured after 10 years is close to potential.

Soil standards for soil protection should include differences in potential ground cover for cool and warm exposures. The Decision Notice for the Environmental Assessment for Flaming Gorge Pinyon-Juniper Treatment (U.S. Department of Agriculture, Forest Service 1985) that applied to the Jarvies Canyon and other burns of the area included an objective to "Re-establish 70% ground cover in five years" after treatment. This standard seems fairly reasonable considering the information available on which to make the decision, and on the cool exposure this standard was met.

However, after 5 years, cover of vegetation, litter, and rock totaled 58 percent on the warm exposure, which was 12 percent below the standard. If pavement (12 percent) was considered effective cover, the standard would have been met. However, pavement (rock fragments less than 0.75 inches diameter) on these slopes is of questionable value for watershed protection. The data indicate more specific standards could be drafted for cool and warm exposures.

Also included in management goals and objectives of the environmental analysis was a standard to "produce a minimum of 300 lb per acre of desirable plant species on treated sites within five years". The data indicate this standard is far below the potential for at least the cool exposure. However, duration of high production is yet to be determined.

Evaluation and Management Implications for Different Species

Shrubs—The only shrubs found on the study sites were big sagebrush and rubber rabbitbrush. Shrubs were found only on the cool exposure and were of low frequency in all years samples were taken. Line intercept data showed rubber rabbitbrush increased from 0.3 percent crown cover to 0.8 percent from 1989 to 1996 while big sagebrush increased from 0 to 1.8 percent.

Additional monitoring over time will be needed to track the dynamics of shrubs, but this slight change indicates they will increase in time. Morphology and browsing preference by wild ungulates indicate both the seeded mountain big sagebrush and indigenous basin big sagebrush (*Artemisia tridentata* Nutt. *tridentata*) established after the fire. Mountain big sagebrush was closely hedged, while apparent plants of basin big sagebrush were hedged lightly or not at all.

Crested wheatgrass—Crested wheatgrass increased significantly from 1991 to 1996 on the warm exposure and decreased significantly from 1989 to 1996 on the cool exposure. By 1996 it was the most frequent species on the warm exposure and third most frequent species on the cool exposure. This species demonstrated high value for control of cheatgrass by rapid establishment and increase over time on the warm exposure. The decrease over time on the cool exposure indicates it is less competitive there. It also indicates it might be quite compatible with native bluebunch wheatgrass on cool exposures. Considering the portion of the seed mix in pounds as well as number of seeds, this species demonstrated comparatively high economic performance as well as ecological performance. Low amounts of crested wheatgrass in seed mixes for this area are indicated by low cost and high value for cheatgrass control. Davis and Harper (1990) documented an increase in crested wheatgrass in the third year following seeding in a juniper-pinyon chaining in central Utah. Their data indicated much lower establishment of crested wheatgrass than found at Jarvies Canyon.

Intermediate wheatgrass—Frequency of intermediate wheatgrass remained low through 1996 on both exposures where it decreased with time. This seems unexpected by comparison of nearby seedings where this species was seeded alone or as the major part of a seed mix where it rather quickly established solid stands. Performance in this seeding might indicate this is not so competitive when seeded in a mix. However, Davis and Harper (1990) documented results of seeding a mix in central Utah where intermediate wheatgrass was the most abundant seeded species. They also reported precipitation well above normal was concurrent with seedling establishment. The variable response of this species demonstrates the value of a diverse seed mix since it is unknown which species will do well in different seedings. This species often seems to establish in great abundance and become oppressively dominant or with low frequency following seeding. This "all or nothing" response in seedings indicates low desirability for this plant where diverse communities are desired. In the Jarvies Canyon seeding, seed of this species could have been replaced with that of bluebunch wheatgrass without putting watershed protection or cheatgrass control at risk.

Lincoln smooth brome—On the warm exposure, frequency of this species remained the same between the 5th and the 10th year post treatment. However, it increased dramatically on the cool exposure. The relatively low response of smooth brome on the warm exposure indicates low value for cheatgrass control. Compared to crested wheatgrass, hard fescue, and alfalfa, smooth brome was of low value for this purpose. It was slow starting on the cool exposure, which indicates low value for initial weed control there. It is also indicated to have comparatively low value for watershed protection in the critical, early years.

The data imply this species is trending toward dominance of the herbaceous community on the cool exposure, and perhaps it will drive community diversity downward. Although an increase in production of this species was measured between 1989 and 1996, production studies on the cool exposure indicate this will be a relatively low producing species at this site. Ladak alfalfa and hard fescue have produced considerable more herbage and thus litter for ground cover than has smooth brome in each of the 4 years production measurements have been made at the site since the fire.

The rhizomatous nature of smooth brome and intermediate wheatgrass is one value these plants provide that the other species do not. However, smooth brome showed comparatively little value for cheatgrass control and watershed protection in the critical early years, and it has an implied feature of driving community diversity downward.

Greater weight of seed of this species was applied than any another. Although numbers of seed applied might be a valid way to compare ecological performance, cost of seed is measured in terms of weight, not numbers of seed. This indicates poor economic performance in the early years of the seeding when cheatgrass control and soil protection are most critical. Data over the next decade might show the increase in frequency of this species is concurrent with lower production on the site. Its value for seeding in this setting appears to be low.

The native bluebunch wheatgrass does well on the cool exposures of this landtype. Although this species is not rhizomatous or is weakly rhizomatous compared to smooth brome, it is indicated to have high watershed values on similar nearby sites. Replacing smooth brome seed with that of bluebunch wheatgrass in seed mixes for this area is recommended.

Piute orchardgrass—Orchard grass showed essentially no value for cheatgrass control on the warm exposure. However, its quick establishment on the cool exposure followed by a significant decrease indicates high value there for initial weed control and for allowing other species to establish over time. Both frequency and production values indicate this is less aggressive over time than is smooth brome. Considering long-term diversity and greater presence of natives in the community, orchardgrass seems more appropriate in seed mixes for this area than does smooth brome.

Hard fescue—This was the only seeded species that increased on both the cool and warm exposures. However, it established with much higher frequency on the cool exposure. On the cool exposure this was the highest producing grass in 3 out of 4 years when production measurements were made. This appears to be an aggressive plant at these sites with the potential to drive communities to a lower diversity. Continued monitoring at this site is needed to evaluate the use of this species in future seedings. If it continues to increase concurrent with a decrease in other desired species, exclusion or much lower rates in the seed mix is indicated for future seedings. However, its increase on the warm exposure indicates high value for long-term control of cheatgrass. It remains green late in the fall and early winter when it is selected by elk (*Cervis canadensis*) and possibly by mule deer (*Odocoileus hemionus*).

Ladak alfalfa—This established quickly on both exposures. However, production data from the cool exposure indicate it is slower to mature into full production than some of the seeded grasses. However, it established with greater frequency on the warm exposure than on the cool exposure, which was not a feature of any of the seeded grasses, and by 1991 this was the most frequent species on the warm exposure. This indicates high value for reducing cheatgrass. Frequency of this species remained the same on the cool exposure but declined on the warm exposure. Frequency data indicate this species will not increase beyond the level of initial establishment. This indicates it will not become oppressive to other species, and that it will contribute to species diversity. Davis and Harper (1990) found Ladak alfalfa decreased in frequency in the second and third years after seeding, which indicates possible high establishment but also considerable mortality of seedlings and young plants.

After 1989, Ladak alfalfa produced more herbage than did any other species on the cool exposure. Ungulate use has been light, but alfalfa appears to be the most selected forage species by elk and mule deer at this site. Also, Smith (1992) recorded alfalfa to be highly selected by bighorn sheep (*Ovis canadensis*) within the Green River corridor. The potential of alfalfa for nitrogen fixation is an additional value of this plant. However, cheatgrass as well as other grasses can respond favorably to increased nitrogen. This feature implies a critical need to include aggressive perennial grasses with alfalfa in seed mixes to be used in areas where cheatgrass is highly competitive. Most features of this plant indicate high value for including it in seed mixes for the pinyon-juniper belt of the Green River corridor.

Yellow sweetclover—Although yellow sweet clover established from the seeding and put on a great show of tall plants in the first two to three growing seasons, it was not recorded in the plots by 1989, nor was it seen anywhere in the burn in that year. The flush of yellow sweetclover in the second growing season was great enough to be of concern to wildlife biologists who desired low stature of vegetation for high value bighorn sheep habitat. However, from 1989 to 1997, it was not seen anywhere in the burned area. In this setting, yellow sweet clover is indicated to be of value for quick establishment of cover with a rapid decline that will allow other species to replace it. Yellow sweetclover is often considered a highly invasive species. This has not been the nature of the plant in the general area of this study where its abundance and persistence are quite limited to roadsides and other frequently disturbed sites.

Small burnet—Small burnet was recorded at low frequency on the warm exposure in 1991. By 1996 it was not seen in the plots. It was not recorded in the plots on the cool exposure in 1989 or 1996. The performance of small burnet indicates value of this species is for quick establishment and rapid decline, which could allow for establishment of natives. However, comparison of its relatively high percent of weight of the seed mix with its relatively low performance indicates low economic value for this species when applied in a heavy seed mix (15 lb/acre) composed of highly competitive species. However, the number of seeds of this species was lower than any other in the mix, and the low performance is also likely a function of fewer seeds. It also seems important to note that no measurements were made until 5 years after treatment, and like yellow sweetclover, small burnet might have been abundant for 2 to 3 years. Davis and Harper (1990) recorded high establishment of small burnet in the first 3 years of a seeding in central Utah. Measurements in the fifth year might not reflect the early value of this plant in the seeding. Use of this plant in fire rehabilitation projects has been criticized on grounds that its value is for wildlife and not for rehabilitation. However, the nature of this plant to quickly establish and provide cover and then allow for increase of natives as it decreases indicates it is highly desirable for fire rehabilitation projects.

Japanese chess--Japanese chess increased on the warm exposure, but the increase was much less than for cheatgrass. It was found with low frequency in 1989 on the cool exposure, and it was not found there in 1996. Compared to cheatgrass, this introduced annual appears to be a mild competitor in the pinyon-juniper belt. Much focus on cheatgrass in literature with comparatively little coverage for this species indicates this is a general nature of this species.

Cheatgrass—Cheatgrass was not found in the plots on the cool exposure, but it increased significantly on the warm exposure. Frequency of cheatgrass on the warm exposure between the fifth and 10th years might be considered a negative indicator. However, the frequency of this winter annual can be expected to vary from year to year with variations in timing and amount of precipitation as well as winter-spring temperatures. Also, high frequency can be achieve by numerous, small, single-stemmed plants with few seeds. Where this growth form is a function of high frequency of vigorous perennial plants, cheatgrass is indicated to have a much subdued effect on plant community function. This was the common growth form of cheatgrass in the seeding.

However, the frequency data do indicate the ability of cheatgrass to persist even where perennial plants command most of the resources of a site even in the absence of livestock. Also indicated is the rapid increase in cheatgrass following the next disturbance. Also indicated is the potential increase of cheatgrass under management practices that reduce frequency or vigor of perennial plants.

Discussion

The various response of species in the mix indicates the importance of seeding a mixture of species on lands of diverse exposures. Species diversity in the early seral community was a function of the number of species included in the seed mix. Diversity of early seral communities that follow disturbance of closed stands of mature or old pinyon-juniper can be expected to be low and to be driven by cheatgrass and other weedy species, many of which are introduced. These features of pinyon-juniper communities strongly point to the need to develop a wide array of plant materials with the potential to compete with cheatgrass on a variety of exposures and many geological substrates and soil types. Concerns for diversity and native species indicate the need for development of native plant materials with the ability to establish quickly to reduce the influence of introduced, highly invasive species.

No species or mix of species is likely to eliminate cheatgrass on warm exposures, and reduction of its influence is a more realistic goal than eradication. Evidence is strong and growing that cheatgrass has altered many pinyon-juniper ecosystems to the degree that pure native plant communities are no longer a potential. The introduced species seeded at these sites represent some of the most capable plants known to be able to establish stands rapidly from a single seeding, which is important for cheatgrass control. Crested wheatgrass, alfalfa, and hard fescue, represent plant materials as capable or more capable of controlling cheatgrass in the pinyon-juniper belt than native grasses and forbs of this belt. To expect native species to provide better and especially complete control appears to be beyond reason.

The performance of Ladak alfalfa, crested wheatgrass, and hard fescue on the warm exposure demonstrates their value in seed mixes where suppression of cheatgrass is a goal. At this elevation and precipitation zone, smooth brome and orchard grass are indicated to be of less value for this purpose. It appears that neither smooth brome or intermediate wheatgrass (rhizomatous species) were needed for watershed protection or cheatgrass control. Seed of these species could have been replaced by seed of bluebunch wheatgrass without loosing ability of the seed mix to establish effective ground cover and provide cheatgrass control.

References

Ashcroft, G. L.; Jensen, D. T.; Brown, J. L. 1992. Utah climate. Logan, UT: Utah State University, Utah Climate Center. 125 p.

Davis, J. N.; Harper, K. T. 1990. Weedy annuals and establishment of seeded species on a chained juniper-pinyon woodland in central Utah. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tuller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 72-79.

McNab, W. H.; Avers, P. E. 1994. Ecological subregions of the United States: Section descriptions. Administrative Publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

Plummer, P. A.; Christensen, D. R.; Monsen, S. B. 1968. Restoring big-game range in Utah. Pub. No. 68-3. Ephraim, UT: Utah Division of Wildlife Resources, Division of Fish and Game. 183 p.

Smith, T. S. 1992. The bighorn sheep of Bear Mountain: ecological investigations and management recommendations, Provo, UT: Brigham Young University. 425 p. Dissertation.

Stefferud, A., ed. 1948. Yearbook of agriculture. Washington, DC: U.S. Department of Agriculture

U.S Department of Agriculture, Forest Service. 1985. Decision notice and finding of no significant impact and environmental assessment: Flaming Gorge pinyon-juniper treatment. Decision Notice and Environmental Assessment on file at: Ashley National Forest, Supervisors Office, 2060 study files, folder 6-1.

U. S. Department of Agriculture, Forest Service. 1993. Rangeland ecosystem analysis and management handbook. FSH 2209-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 4 ch.

Regrowth of 'Ladak' Alfalfa on Pinyon-Juniper Rangelands Following Various Timing and Types of Spring Use

Richard Stevens
Scott C. Walker
Stuart Wooley

Abstract—Drought tolerant alfalfa is the most abundantly seeded forb on Utah pinyon-juniper ranges. It is eagerly sought after by all classes of grazing animals. Generally, mule deer and elk utilize areas seeded to alfalfa during winter, early spring and fall, whereas, cattle and sheep generally use the same areas during mid spring to early summer and fall. Alfalfa in some seedings has been lost through year after year late May and June use. In order to properly manage and maintain alfalfa on rangelands it is imperative we know the effect of timing, type, and amount of use on regrowth and subsequent plant vigor. On a deer and elk winter and spring pinyon juniper range that had been chained and seeded 20 years earlier, sheep were grazed at differing periods. Grazing effect on alfalfa forage regrowth and seed production was evaluated. With grazing of alfalfa up to May 15, some regrowth of forage and seed production did occur. Little regrowth was evident when grazing occurred after May 15. Lack of regrowth does not allow alfalfa plants to maintain and replenish themselves and to produce seed.

For over 40 years, drought tolerant range alfalfa has been the most abundantly seeded forb on western pinyon-juniper ranges receiving over 25 cm annual precipitation (Rumbaugh and Townsend 1985; Stevens and Monsen In press). The most commonly seeded rangeland cultivar is 'Ladak'. The most persistent and best performing cultivars have been 'Ladak' and 'Nomad.' These cultivars have persisted on many seedings for over 28 years (Kilcher and Heinrichs 1965; Rosenstock and Stevens 1989), however on some seedings their persistence has been somewhat less. The decrease in density that occurred, has been a result of continuous heavy rabbit use and continual spring sheep and cattle use (Stevens and Monsen In press; USDA 1971).

Rangeland cultivars are especially well adapted to the sagebrush grass, pinyon-juniper, and mountain brush types. They have also been seeded and have done fairly well in the aspen, spruce-fir, and subalpine types (Stevens and Monsen In press). Once established, alfalfa can be very persistent and can produce adequate seed to maintain itself (Rumbaugh 1982). However, little reproduction has occurred from established stands on rangeland sites due to poor seed production and consumption of seed by rabbits, rodents, livestock and big game (Rosenstock and Stevens 1989). Rhizomatous forms do however spread vegetatively, even under arid conditions and grazing pressure. In fact, grazing has been shown to stimulate rhizome production (Rosenstock and Stevens 1989).

Drought tolerant alfalfa cultivars have not exhibited much regrowth or subsequent seed production following moderate to heavy spring use. Spring use could result in very few seeds being produced. Big game, livestock, and rodents readily consume seed heads in the fall. These two factors, combined with the fact that alfalfa seed requires seed coverage adversely affects sexual reproduction.

Alfalfa is sought out extensively by cattle, sheep, deer, elk, rodents and rabbits. Basal leaves can be green throughout winter months. New growth starts prior to snow melt and generally becomes available mid February to early March. Big game generally migrate off pinyon-juniper areas by mid May. Livestock grazing generally occurs from May through June. Fall use by big game and livestock most often starts in early October. It has been observed that when extended spring use occurs, there is little or no succulent forage available in the fall and that little if any seed is produced. Succulent fall forage is a key to healthy big game and for keeping big game out of cultivated fields.

Methods

Two hundred hectares of pinyon-juniper east of Ephraim, Utah were chained and seeded to a mixture of grasses, forbs, and shrubs in 1969. The area receives an average annual precipitation of 32 cm. 'Ladak' alfalfa was a major component (2.8 kg/ha) of the seeding. In 1989, 20 years after seeding, this study was conducted. Deer and some elk utilized the seeding throughout the winter and spring. Even with the late spring, a majority of the deer and all the elk had left the area by May 15. Sheep were allowed on the area May 15 through June 25. Eighteen baskets were set out on four different dates between September 10, 1989 and June 4, 1990 (total 72 baskets). Each basket was randomly placed over one to five alfalfa plants. Adjacent to each basket a like number of alfalfa plants were identified and marked. Baskets were round, rodent proof, and 1.5 m in diameter. Dates baskets were placed, moved and removed determined grazing periods. Grazing treatments were:

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Treatment	Date baskets on	Date baskets off	Grazing date
A	Sept. 10, 1989	Sept. 15, 1990	No use all year
B	May 15, 1990	Sept. 15, 1990	Spring deer and elk use to May 15
C	June 4, 1990	Sept. 15, 1990	Spring deer and elk use to May 15; and May 15 to June 4 sheep use
D	May 15, 1990	June 4, 1990	Spring deer and elk use to May 15 and June 4 to June 24 sheep use
Control	No baskets	No baskets	Year long use; sheep, deer, and elk

On September 15, 1990, identified alfalfa plants under baskets and adjacent to them were clipped to ground level. Number of stems with seeds were identified. Leaves and seeds were removed from stems. The length of each stem was determined. Stems, leaves, and seeds were air dried and weighed. Data was analyzed with one way ANOVA ($p < .05$).

Results

All elk and essentially all deer had moved off the area by May 15. When the sheep (ewes with lambs) were put in the area on May 15 alfalfa plants that had been available to deer and elk (Treatments B,C,D and Control) showed extensive use and averaged less than 20 mm in height. On June 24 when the sheep were removed, grazed alfalfa plants averaged less than 15 mm in height. No use occurred after June 24 to harvest on Sept. 15.

Timing of use significantly influenced the amount of regrowth that occurred. Plants that were not grazed all year (Treatment A) produced an average of 318 grams of stem, leaves, and seed (table 1). Plants only exposed to deer and elk use up to May 15 (Treatment B) produced significantly less (104 grams) regrowth than plants protected all year (Treatment A), and significantly more than those exposed to use after May 15 (Treatments C and D), and year long use (Control) (table 1). Ungrazed plants (Treatment A) produced produced more seed (111 grams) than plants that were grazed (treatments B, C, D, and Control) (table 1). Leaf and stem production accounted for the majority of the regrowth on grazed plants (table 1). If plants were grazed in the spring or year round grazed, little seed (0.7 to 14 grams depending on treatment) was produced (table 1).

Conclusions

'Ladak' alfalfa can and has been maintained in pinyon-juniper chainings and seedings for over 30 years. Year after year, continued early to late spring use by livestock has resulted in loss of alfalfa in some seedings.

When alfalfa is grazed into the spring, little regrowth takes place which is needed to maintain and replenish the

Table 1—'Ladak' alfalfa growth and regrowth. Average total leaf, stem and seed production, length of stems, and number of stems with seeds per plant on September 15 as influenced by five grazing treatments.

Grazing treatment	Total production (g)	Leaf production (g)	Stem production (g)	Seed production (g)	Stem length (mm)	No. stems with seed
A: No use all year	318^{A*}	77^{A}	130^{A}	111^{A}	287^{A}	5.10^{A}
B: Spring deer and elk use to May 15	104^{B}	38^{A,B}	52^{B}	14^{B}	197^{B}	0.95^{B}
C: Spring deer and elk use to May 15 and May 15 to June 4 sheep use	34^{C}	15^{B}	18^{C}	0.7^{B}	93^{C}	0.07^{B}
D: Spring deer and elk use to May 15 and June 4 to June 24 sheep use	48^{C}	19^{B}	26^{C}	3^{B}	100^{C}	0.18^{B}
Control: Year round use	35^{C}	14^{B}	14^{C}	1^{B}	59^{D}	.07^{B}

*Number within column followed by the same letter are not significantly different ($p < .05$).

plant through the summer, fall, and winter, and to produce seed for reproduction. Likewise, with no spring regrowth, little forage or seed is available for fall and winter use by big game and livestock.

This study demonstrates that grazing to May 15 significantly reduced subsequent regrowth of forage and seed production and use after May 15 reduced forage and seed production even further. Early and late spring grazing results in essentially no seed production. In order to maintain vigorous plants of drought tolerant alfalfa cultivars, it is recommended that spring grazing by livestock should not extend beyond May 15 and not occur in consecutive years.

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References

Kilcher, M. R.; Heinrich, D. H. 1965. Persistence of alfalfa in mixtures with grasses in a semiarid region. Canadian Journal of Plant Science. 46:163-167.

Rosenstock. S. S.; Stevens, R. 1989. Herbivore effects on seeded alfalfa at four pinyon-juniper sites in central Utah. Journal of Range Management. 42(6):483-490.

Rumbaugh, M. D. 1982. Reseeding by eight alfalfas populations in a semiarid pasture. Journal of Range Management. 35:84-86.

Rumbaugh, M. D.; Townsend, C. E. 1985. Range legume selection and breeding in North America. In: McArthur, E. D.; Carlson, J. R., eds. Proceedings selected papers presented at the 38th annual meeting of the Society for Range Management; 1985 Feb. 11-15, Salt Lake City, UT. Denver, CO: Society for Range Management. 137-147.

Stevens, R.; Monsen, S. B. In press. Alfalfa. In: Monsen, S. B; Stevens, R., eds. Restoration and revegetation of western ranges and wildlands. Rocky Mountain Research Station, Gen. Tech. Report.

U.S. Department of Agriculture. 1971. Management and use of alfalfa. In: Conservation Plant Handbook. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service.

Management Implications

Ecology and Management of Pinyon-Juniper Communities Within the Interior West: Overview of the "Management Implications Session" of the Symposium

Mike Pellant

Abstract—Categories of papers in the "Management Implications Session" were (1) ecological guidelines and thresholds, (2) collaboration, (3) rehabitation after wildfire, (4) weed management, and (5) miscellaneous management topics. The application of science, experience, and collaboration is a necessity for properly managing these diverse and ecologically complex ecosystems. Failure to undertake this task could result in woodland landscapes dominated by weeds and frequent and intense disturbance events.

A number of interesting and effective management strategies for pinyon pine (*Pinus* spp.) and/or juniper (*Juniperus* spp.) woodlands (hereafter referred to generically as woodlands) were presented in the "Management Implications" session of this symposium. I have attempted to synthesize the salient and innovative points from the 14 papers that were prepared for these proceedings. I also included one abstract in this synthesis from a symposium presenter who did not prepare a paper for these proceedings. This synthesis is a brief summary, and the reader is encouraged to review the individual papers cited for more detailed information. Finally, this review is couched by my experiences managing woodlands for the Bureau of Land Management (BLM) in southeastern Utah in the late 1970's.

Management of woodlands is affected by a wide variety of natural and anthropogenic influences. Management decisions must be considered in a scientific and political framework to implement management prescriptions effectively and to obtain a desired outcome. These decisions are based upon the land manager's experience and available science related to woodland management. Due to information gaps on some aspects of the ecology and restoration, woodlands management has been more of an "art" and less of a "science." These proceedings certainly provide much needed information (such as science and practical experience) to improve woodland management.

I have organized the papers in the "Management Implications" section into the following categories to facilitate their synthesis:

1. Ecological Guidelines and Thresholds
2. Collaboration
3. Rehabilitation After Wildfire
4. Weed Management
5. Miscellaneous Management Topics

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Ecological Guidelines and Thresholds

The five papers in this section provide managers with the framework to incorporate community ecology and the new "state and transition models" in developing and implementing management strategies for woodlands. All authors agree that woodlands are ecologically complex and vary greatly both spatially and temporally. Incorporation of science and research into management decisions is essential if resource issues and political controversy associated with woodlands are to be resolved.

Benchmarks or reference areas are one of the cornerstones to sound management of rangelands and woodlands. Miller and others described characteristics and values of old growth juniper and pinyon woodlands. Old growth woodlands are characterized by presettlement trees (established prior to 1870), which are typically present in open stands with understory species. Managers can benefit by recognizing and maintaining these woodlands given the diversity of plant and wildlife species that inhabit these areas and the recreational, cultural, and spiritual opportunities they offer. The authors recommended conducting inventories to identify and describe old growth woodlands and to closely evaluate fire suppression and prescribe fire policies in these areas.

Eddleman concurred with the previous assertion that a serious limitation in management of woodlands is the lack of information from benchmark or reference areas and inadequate research on postsettlement woodlands. He provided the following guidelines for the "ecological" management of woodlands:

1. Establish clear management goals and objectives.
2. Identify ecological problems on the area under consideration.
3. Inventory (tree age classes, understory vegetation, and ecological or functional status).
4. Evaluate landscape conditions around the area under consideration.
5. Implement management and restoration activities.

I would add a sixth element to this list, "Monitor and adjust management accordingly." It is also important to obtain and share information on the success or failure of management or restoration activities in meeting goals and objectives.

Tausch related the concepts of transitions and thresholds to the management of woodlands. He defined a threshold as "a significant change in the species composition or functioning of the community found on a site that usually results from some level of disturbance." A transition is the process of crossing a generally irreversible community threshold that is permanent unless major management actions are taken or a significant natural disturbance occurs.

It is important for managers to recognize thresholds and transitions in woodland management. Examples of "crossed" thresholds included sagebrush steppe vegetation that is invaded by and eventually dominated by woodland trees or sites where cheatgrass (*Bromus tectorum*) invades and dominates woodland sites following wildfires. Managers also need to be aware of the potential for certain plant associations to decrease and reach "dormant" thresholds. The threshold may be crossed following a disturbance (such as cheatgrass existing in the understory of woodlands susceptible to wildfires). There is also a spatial aspect to thresholds that must be considered in management. A disturbance in a surrounding area may influence or even "push" a nearby site over a threshold. For example, erosion and weed invasion after a woodland wildfire may impact surrounding areas causing them to become more susceptible to degradation after future disturbances.

Managers should recognize when a threshold is being approached for a woodland landscape unit and decide what, if any, management actions are required to reduce the probability of the threshold being crossed. The invasion of sagebrush steppe communities by juniper trees is an example of a plant community transition that will eventually result in a closed canopy woodland if management actions (such as prescribed fire) are not applied in a timely manner. If this threshold is crossed, accelerated erosion may occur, and the site potential may be changed to a degree that sagebrush steppe vegetation may no longer be adapted to the site.

Restoration activities—including woodland manipulations (chaining, burning, thinning, and so forth) and seedings with introduced species—should also be evaluated for transitions and thresholds. Such manipulations may meet short-term management objectives such as increased forage for herbivores, but they may also prove to be ecologically unsound. We need a better understanding of thresholds and transitions to implement appropriate management for almost all woodlands.

Miller and others described the threshold that is crossed as shrub steppe vegetation converted to a juniper woodland. Early indicators of such a conversion are the reduction in leader growth on dominant and understory trees and the loss of vigor and mortality of shrubs near large juniper trees. Once this threshold is crossed, fire potential is reduced, and loss of native species and accelerated erosion generally increases.

On low elevation rangelands (below 5,000 ft) exotic annual grasses, principally cheatgrass, may increase with poor livestock grazing management in juniper woodlands. It is essential that managers recognize the resource management implications of crossing this threshold and apply treatments to check the conversion in a timely manner. All of these actions must be considered in the context of the spatial and temporal heterogeneity that exists in woodlands across the landscape as well as the political, environmental, and budgetary issues influencing their management.

In the final paper in this section, Goodrich and Barber 1999 discuss the return interval for pinyon pine (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) following several wildfires that occurred about 100 years ago in northeastern Utah. They found a slow return rate of pinyon pine and Utah juniper for the first 40 to 50 years following the fires with an accelerated return rate thereafter. An estimated 150 to 200 years would be required to achieve preburn tree density for the Green River corridor of Utah. Therefore, a relatively small annual burning program would result in an adequate mix of seral stages on the landscape given this long woodland recovery period after fire.

Collaboration

Management of woodlands is becoming a controversial and contentious issue. Environmental groups are challenging management actions, especially chaining, on these woodlands. Concerns over the past management practice of large "block" chainings and reseeding introduced grasses has caused a heightened concern about any management action that results in a loss of woodlands.

Nelson and others described a collaborative process that was successfully used to implement chaining and seeding of pinyon-juniper woodlands in Spanish Fork Canyon, Utah. Early public participation in the planning process, clear and simple objectives, good interagency cooperation combined with nonagency partnerships, and follow-up monitoring all contributed to the successful chaining and seeding of small tracts of pinyon-juniper woodlands.

Goodloe described the value of integrated resource management in his paper in the "Restoration" session of this proceedings. He applied holistic livestock management and reintroduced fire on his ranch in New Mexico to reverse the effects of 80 years of fire suppression and year-long grazing responsible for the conversion of productive grassland communities to woodland species. He first thinned the tree stands and sold the wood as fenceposts, fuel wood, and Christmas trees. This treatment was followed by prescribed fire and reseeding with native grasses. Rotation livestock grazing systems now maintain these restored plant communities, which benefits livestock, wildlife, and recreation users, and stabilizes watershed values.

Native Americans also value and rely on the products from woodlands, and Miller reminds us that deeply rooted traditional values are associated with woodlands by various tribes. His agency (Bureau of Indian Affairs) is working with the tribes to manage these woodlands in a sustainable manner guided by tribal culture and tradition.

Rehabilitation After Wildfire

Two papers addressed rehabilitation efforts by the Bureau of Land Management (BLM) after wildfires in woodlands. Roberts described the financial and ecological impacts on public lands caused by the increasing frequency of woodland wildfires. In 1996, Utah BLM implemented nearly $9 million of rehabilitation projects on burned range and woodlands. Roberts identifies cheatgrass as the primary cause of the increased fire frequency. He is also concerned about the potential for other even more pervasive noxious weeds moving into these woodlands after wildfires.

MacDonald described the initial results of rehabilitation practices applied in 1996 on 102,100 acres of burned woodlands in south-central Utah. Aerial seeding followed by one-way anchor chaining resulted in better seeded species establishment than aerial seeding with no cover. Anchor chaining to cover seeds was controversial, yet the preliminary study results clearly demonstrate the value of seed coverage in ensuring that seeded species are successfully established.

The need for rehabilitation of woodlands will accelerate in the future given the increase of cheatgrass (and thus wildfires) in the understory or on the periphery of Western woodlands. Managers must give more consideration to the concept of thresholds in planning rehabilitation practices, especially in deciding whether to seed or allow natural recovery to occur, what seed mix to use (native, introduced, or a combination), and where seeding is necessary. The short-term and long-term trajectories of postfire plant communities, including weeds, will be greatly influenced by the decisions made during the rehabilitation planning process.

Weed Management

The role of cheatgrass and other weeds in the management of pinyon or juniper woodlands is the focus of the majority of the papers in this section. Two papers dealt with weed potential problems in planning woodland treatments and management of weeds before and after seeding. Svejcar cautions managers against automatically assuming that just because a weed is present, it will dominate the site if woodland species are removed. The response of weeds in woodland conversion projects is site specific and governed by the pretreatment plant community, susceptibility of the site to weed encroachment, and posttreatment management actions and climate. Svejcar suggests six steps to consider when planning any woodland conversion project and calls for the development of state and transition models to assist managers in making better decisions.

Goodrich and Rooks evaluated the effectiveness of a postfire seeding in reducing dominance of cheatgrass and musk thistle (*Carduus nutans* L.). They described the weed infestation that occurred after the 1976 wildfire in a pinyon-juniper woodland in northeastern Utah. Subsequently, a portion of the 1976 burn area was burned again in 1990 to reduce cheatgrass and reseeded to introduced grasses to compete with weeds that dominated the site after the original burn. The nonseeded area had 10 times more musk thistle plants than did the seeded area 6 years after the prescribed burn and seed treatment Cheatgrass frequency and vigor were also reduced in the seeding compared to the unseeded area.

Goodrich and Rooks also addressed the seeding of natives versus selected introduced species to exclude weeds in disturbed pinyon-juniper woodlands. They contend that until availability of native plant materials improves, competitive introduced species should be planted to prevent establishment and dominance of cheatgrass or other weeds after woodland treatments. They further caution against requiring only the use of "local natives" on large-scale restoration projects because costs and availability of seed could be too restrictive.

The potential for weed expansion after disturbance in many woodlands is high and should be a concern for managers. Early detection, aggressive treatment, and monitoring are a few of the required steps to minimize this threat to the integrity of Western woodlands. This task is one of the most challenging in regards to woodland management and will increase as disturbances such as wildland fires continue to increase and weeds adapt and evolve to new environments.

Miscellaneous Management Topics

Three presentations provided valuable information on the management of woodlands but did not logically fit into the previous organization or new categories. Rasmussen and others proposed the use of a helitorch to burn pinyon or juniper that has encroached in riparian areas. They speculate that if the treatment were done in the spring, and if the trees were individually ignited, then successful, albeit expensive, control could be obtained. Given the high resource values associated with riparian areas, further research or tests on this technique are warranted.

Stevens and others examined the effects of livestock grazing on dryland alfalfa planted in several woodland conversion projects near Ephraim, UT. Annual grazing after May 15 resulted in little alfalfa regrowth or seed production. Loss of alfalfa in the stand eventually occurred, reducing the diversity and forage value of the seedings. This study demonstrates the importance of considering short-term and long-term effects of livestock and wildlife grazing in the management of multispecies seedings after woodland conversion projects.

Eager described increasing mortality of pinyon pine throughout western Colorado and proposed some management actions to reduce these losses. Insect infestations and fungal root disease are the primary cause of the increased pinyon pine mortality. Human activity, primarily road, fence, and home construction, can cause tree damage by allowing the entry of insects or disease. Managers can minimize these outbreaks by scheduling disturbance treatments in cool weather and by promptly removing damaged trees or stumps from work areas.

Summary

These "Management Implications" papers all contribute to a better understanding of opportunities and constraints in managing Western woodlands. Managers should become more knowledgeable of the concepts of thresholds and the ecological implications of management actions they initiate or even the management actions that they don't take. Prescribed fire, chaining, and thinning are just a few of the woodland conversion tools that could be used to meet specific land use or management objectives. However, these treatments in conjunction with climate, livestock management, or weed invasion may "push" treatment areas across thresholds that may or may not be compatible with long-term management objectives (fig. 1).

Management in woodlands, especially controversial treatments such as chaining or seeding with nonnative plants, must be done collaboratively to minimize conflict and to

Figure 1—Utah juniper is invading a historical sagebrush steppe plant community that is now dominated by cheatgrass. A recent wildfire has burned into the area invaded by the juniper. Other noxious weeds are in the vicinity and have the potential to invade this disturbed site. What are the management implications and options in this situation?

ensure that decisions are made by stakeholders and not by our judicial system. Native Americans have many utilitarian and spiritual ties to woodlands that also need to be considered in any management strategy.

Wildfires have increased greatly in frequency and extent in certain areas dominated by woodlands in recent years. Rehabilitation after woodland fires is often necessary to prevent accelerated erosion and entry of invasive plants. Where seeding is required, every effort should be made to cover the seed mechanically to enhance the successful establishment of all seeded species. Rehabilitation planning should include an analysis of the potential thresholds that may be crossed given the practices proposed. Postfire livestock grazing, seeding with aggressive nonnative grasses, and not controlling noxious weeds all have the potential individually or in combination after fire to direct succession across a threshold to a new, undesirable stable state.

Perhaps the greatest threat to Western woodlands is the spread of weeds both invasive weeds (such as cheatgrass) and noxious weeds. Woodland treatment plans must include an evaluation of weed invasion potential in the posttreatment environment but not to the point where unfounded fear of a potential weed invasion precludes any manipulation or change in the management of woodlands. Where weeds are a threat after woodland disturbance, seeding competitive introduced grasses could reduce the threat. However, a better long-term goal is to increase the supply and availability of native plant materials that can both compete with weeds and provide the diversity and function of the historical woodland communities.

Implications of our actions, or lack of action, in managing woodlands may affect the Western landscape far into the future. The application of science, experience, and collaboration is a necessity for properly managing these diverse and ecologically complex ecosystems. Applied research, monitoring of management actions, and the sharing of local knowledge, information, and successes, as well as failures, are all critical for improving the understanding and proper management of Western woodlands. If we fail in this undertaking, woodland landscapes dominated by weeds and frequent and intense disturbance events may become an unwanted reality.

Transitions and Thresholds: Influences and Implications for Management in Pinyon and Juniper Woodlands

Robin J. Tausch

Abstract—Thresholds are important to understanding Great Basin ecology. Once a threshold has been crossed, the new community may have very different functional capabilities than the previous community. Management action needs to occur well before a threshold is crossed to be effective, and that action needs to reflect the scales of time and space in which the affected ecosystems and their thresholds function. Great Basin woodlands have at least three categories of thresholds, with two stages in the threshold process. The three categories of threshold differ in both the duration and timing by which the two stages of the threshold process occur. Depending on the community, more than one threshold may be involved in affecting community change at the same time. Thresholds interact between communities on landscape scales over the long term, often in response to climate change, and are most effectively managed on a landscape basis.

One of the most important aspects in understanding Great Basin pinyon-juniper woodland ecology is the concept of a threshold. The basic description of a threshold is a significant change in the species composition or functioning of the community found on a site that usually results from some level of disturbance. In the majority of instances, once the change has occurred returning the community back across the threshold may be very difficult or impossible (Laycock 1991; Tausch and others 1993; Westoby and others 1989). The community that is present after the threshold has been crossed is usually a new community that could have different functional capabilities than the previous community.

If a threshold is crossed managers must recognize, evaluate, and manage the new community based on its new range of functional possibilities (Tausch 1996). They also need to look at thresholds and their outcomes in time scales appropriate to ecosystems involved (Millar 1997). Techniques need to be developed to make it possible to recognize when a threshold is being approached well before it is crossed—when some form of corrective action may still possible to avoid the coming changes.

The prevailing climate is the primary influence on the ecosystem distribution and dynamics of a region (Betancourt and others 1993; Bailey and others 1994). Climate, its changes, and its modification by landform, probably plays major roles in the development and activation of thresholds. Climate and communities have interactions, including thresholds, that occur at many spatial and temporal scales.

In response to the past climate changes Great Basin vegetation has had repeated changes (Nowak and others 1994a,b; Thompson 1990), many probably involving thresholds. The dynamic and individualistic responses to climate change by plant species (Tausch and others 1993) may be involved in the existence and outcomes of thresholds. The threshold concept needs clarification and expansion in its application to pinyon-juniper woodland ecology. Such application of the threshold concept needs to better reflect the scales of time and space and associated changes in which ecosystems function. Most examples of thresholds published (Laycock 1991; Tausch and others 1993; Westoby and others 1989) focus mostly on the biotic aspects of the changes to vegetation that result from chronic disturbances. Abiotic changes that are discussed are generally those that are evident after the vegetation has been pushed across a threshold. An expanded view is that thresholds can have both abiotic and biotic aspects, with varying levels of interaction between them.

Thresholds in Great Basin Vegetation

For the woodlands of the Great Basin, there are at least three categories of thresholds that can be described. There are also two stages to the process for each of the threshold categories: (1) crossed or set, and (2) activated. There is also a quasi third stage (dormant) that can precede any of the three categories. The three categories, two stages, and one quasi category will be explained through the use of examples.

The first category of thresholds is brought about by some form of chronic impact that pushes the vegetation through a series of changes. At some point in those vegetation changes, and in the associated abiotic changes, a threshold is crossed. An analogous description is that the community is first bent until it is right at the edge of the breaking point. Then with one last push, it finally breaks. The vegetation description is that the changes resulting from an impact reaches a point where a threshold is first set, then activated, with the final vegetation changes immediately following. Here, the setting of the threshold, and its activation, occur almost simultaneously and is the type of threshold that has been most commonly recognized and discussed. This first threshold category has the criteria that a community has crossed a threshold only when the vegetation changes involved have

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largely, or entirely occurred. While this category of thresholds is present and important in the Great Basin, others are also present.

The second category of thresholds results from changes in a community that are subtle and not always obvious. These thresholds are often abiotically driven, but biotic factors may be involved. The change in composition that has occurred has its affect on the outcome of a disturbance. This threshold can be crossed without a major readily visible vegetation change immediately occurring. The vegetation change that has occurred has resulted in a community that I am defining as "set". The final vegetation change will occur after there has been some form of major disturbance, which is the trigger that activates the final vegetation change.

Although a community can appear to be unchanged without close examination, it is the type or the outcome of a disturbance, such as fire, that has been changed. The successional processes that follow the disturbance will involve new post-disturbance successional trajectories. The alteration of the community and its successional patterns may also result in the possibility of yet new forms of disturbance in the future. For this category, subtle changes in the initial floristics of a site that occur well before a disturbance may have the effect of both generating or setting a threshold and pushing the community across it. Final activation, however, only occurs after a disturbance.

A good example of this second category of threshold is the invasion of cheatgrass into a woodland site. Woodland dynamics largely remain unchanged, even with cheatgrass in the community, as long as there is no fire. However, if the site becomes dominated by cheatgrass and other annuals following the fire, then a threshold was crossed with the cheatgrass invasion. Following fire the woodland may have been lost, which is a very different outcome than would have occurred without the presence of cheatgrass.

The invasion or establishment of any new species into a community often involves the potential for new thresholds, particularly when they develop a dominant position in the community. A threshold should be considered to be present, and to have been crossed, whenever the amount of time passing between its being set or crossed, and its activation by a disturbance, does not change the outcome. Many Great Basin communities have probably already crossed such a threshold, but the full affect of introduced or other species that are responsible is as yet unknown. The outcomes of these introductions on the generation and activation of new thresholds can be expected to play out for some time.

The third category of thresholds recognizable in Great Basin woodlands is actually quite common, but these thresholds are even more infrequently recognized as such. For this category, there is some combination of biotic and abiotic factors that both set, and then activated, the threshold. The vegetation change that results is a permanent alteration in the successional dynamics of the community. However, this activation phase may take decades to reach completion. The alteration of the successional dynamics activates the progression to a new community. This type of permanent change in the successional trajectory of a community should be considered just as much the crossing of a threshold as the other examples, even though it may take a century or more for the full change of the activation stage to manifest itself.

The third category of threshold has similarities to the first category; the main exception is that the activation phase takes much longer. They may possibly represent opposite ends of a sort of a gradient of activation patterns and rates.

The majority of the woodlands in the Great Basin may have already crossed a threshold in this third category. In the late 19th century, at the end of the Little Ice Age, a series of changes occurred that generated an example of this threshold. Four of these changes were a reduction in fire frequencies (Gruell, this proceedings), heavy livestock grazing, the increase in atmospheric CO_2 (Farquhar 1997; Polley and others 1996; Tausch and others 1993) and a changing climate since the end of the Little Ice Age (Chambers and others 1998; Woolfenden 1996). Whatever the interaction of these factors, and any others that may have been involved, the majority of the potential woodland area in the Great Basin crossed a category three threshold. The outcome of this threshold has been the dramatic increase in the area and dominance of pinyon-juniper woodlands that has been progressing largely unrestricted over the last 150 years. Abiotic conditions and associated patterns of disturbance and succession that prevented this in the past are gone.

Both the second and third category thresholds may also be generated by the loss of key species. An example would be the loss of species of mycorrhizal fungi usually associated with a shrub-grass dominated community from increasing tree dominance, possibly in combination with crown fire (Klopatek and others 1988).

There is one more quasi stage, or possibly a fourth category, of proto or dormant threshold. This is a threshold that does not yet exist but most of the required precursors are in place, and if certain future dynamics occur, the threshold could potentially develop the remaining precursors to be set or crossed, and activated. History shows us that each change in vegetation sets up the conditions that interact with environmental changes to eventually trigger the next set of vegetation changes (Tausch, this proceedings). The examples of the woodland expansion, the introduction of annuals, and ongoing climate change described are causing community changes that are setting up the conditions for the eventual development of additional new thresholds. The potential for there to be new community patterns after these thresholds are crossed is high, particularly where exotic annuals are involved.

A community dominated by exotic annuals is essentially an open or unstable community waiting for the next invader. This is an example that represents a dormant threshold that cannot be generated, or set and activated, until after the arrival of the next species capable of invading the site. This invasion will happen, we just do not know when or what the species or the outcome will be until it happens. The community changes associated with the dominance of annuals is also leading to unknown changes in nutrient cycles and microbial processes for the sites and communities involved (Klopatek and others 1988). These soil changes could also contribute to the future development of new thresholds.

A second example of a dormant threshold is also present in many of the current woodlands that crossed the third category of threshold at the end of the Little ice Age. The altered successional changes that resulted are moving the woodlands toward yet another threshold. As larger and larger areas of these woodlands reach the point of crown closure, thereby becoming susceptible to catastrophic crown fire, they will have reached and then crossed a second formerly dormant category two threshold. The permanent vegetation changes will then wait only for the disturbance.

There appear to be two general ways environmental influences can bring any of these thresholds into existence—direct and indirect. The direct effects are most commonly reported in the literature and are usually involved with the first category of threshold. A disturbance directly impacts the vegetation, and the changes brought about pushes the community toward, and finally over, the threshold. Direct effects can work through biotic or abiotic mechanisms, may or may not be the final trigger activating the vegetation change.

Indirect effects appear to usually result from abiotic changes. An example of indirect effects is the fertilization effects of increasing atmospheric CO_2 and the differing responses to this increase between plant species (Farquhar 1997; Polley and others 1996). In many communities this indirect effect represents at least the presence of possible dormant thresholds. We do not know how each community is being affected, what thresholds are pending or already crossed, and what the resulting vegetation changes will be.

More than one threshold can also be involved at one time. As previously explained, Great Basin woodlands crossed a third category threshold in the late 19^{th} century. The activation stage of that threshold is still underway. On some sites there has been the introduction of cheatgrass, which has taken these sites across the second category of threshold. As the successional processes from the activation stage of the first threshold run their course, the dormant biotic threshold of susceptibility to catastrophic crown fire will be reached and set. When the next activation stage is triggered by fire, the outcome will be much different for many sites than if the cheatgrass were absent. Unless something changes the communities to alter those trajectories of change and their associated thresholds, the final activation by fire and conversion to an annual-dominated community will only be a matter of time.

Scale-related factors are important in defining ecosystem boundaries and the associated development and outcomes of thresholds. Interaction between regional and local scale topography, soils, associated species, environmental conditions, and disturbance types and frequencies can also cause major changes in the way sites respond to a disturbance, and thus affect both the presence and outcomes of thresholds. At each level in the nested structure of Great Basin ecosystems, a different aspect of climate and vegetation can be important in the development of thresholds.

How any system responds to the development and activation of thresholds is also at least partially related to how it interacts with surrounding systems. Changes occurring in other communities in the area around a particular community can result in the generation of a threshold, even if that community has had no change, for example a woodland on a steep slope with shallow soils. When the community on an adjacent site with deeper soils was non tree-dominated, fire intensity was insufficient to carry up through the woodland. If the adjacent community becomes tree-dominated, the heat generated by the next fire will be sufficient for the fire to carry up through the woodland on the adjacent slope.

Because of the environmental and topographic heterogeneity of the Great Basin, communities generally do not develop toward new thresholds at the same rate across a landscape. The thresholds that develop can differ from location to location, which may help prevent the simultaneous occurrence of the same change over a large area.

Over time, topographic-based site-to-site differences may have a tendency to break up large areas of uniform vegetation. An example of such an outcome is the high level of vegetation heterogeneity in chaparral in northern Baja, Mexico (Minnich and Chou 1997). As the areas experiencing a particular change become smaller, the mix of vegetation types and their associated successional stages may become more heterogenous over the landscape. The intermixing and interfingering of the mix of communities and associated successional stages that can develop increases landscape complexity. One way of describing it would be a dynamic fractal-like distribution across the landscape that is constantly changing. The outcome of thresholds becomes spatially more limited.

The pattern through history is that some environmental conditions seem to increase the development of landscape heterogeneity or complexity, and others seem to decrease it. There is an apparent shifting back and forth between community patterns of uniformity, or of more complexity. There appears to be some relationship between the types of community patterns present, the types and severity of the climatic changes, the associated disturbances involved, and the level of heterogeneity or homogeneity.

Management Implications

We know from history that the processes of change always continue through time (Nowak and others 1994a,b; Tausch and others 1993; Woolfenden 1996). Any of these changes in conditions can introduce new thresholds. Ecosystem management is the management of these changes and their associated thresholds as they are mixed over the landscape. Through management actions, we can slow or accelerate the trajectories of change, we can alter their direction, sometimes even reverse them, but we can never stop them. Every alteration we make, however, will affect the type, timing, magnitude, interaction, and outcome of future thresholds. The more effectively we can anticipate these changes resulting from our actions, the more effective ecosystem management will be.

If vegetation that has crossed a second or third category of threshold is not altered by direct intervention to change its structure or composition, the activation of the threshold by a disturbance will only be a matter of time. It will be desirable to attempt to treat some of these areas to possibly alter the outcome, which may or may not be easier to do before the activation stage has occurred. These treatments should be done based on the conditions existing on the entire associated landscape to maintain the diversity of the community, its successional stages, and their interconnectedness, and to help avoid the establishment of new, unwanted thresholds. The treatments used must incorporate the biological, topographic, and edaphic heterogeneity of the sites involved into their application. This is to preserve, and to take advantage of, the existing diversity—both biotic and abiotic.

Most of the existing treatments that have occurred so far in Great Basin woodlands have been, at least indirectly, and even if unknowingly, attempting to prevent the activation of, or alter the existence of, one or more of the described thresholds. Most the these treatments, such as chaining, have tended to ignore the biological, topographic, and edaphic heterogeneity of the treated sites. Usually they have been based more on a plowed-field type of model in their application. Large blocks have been treated as uniformly as possible over their entirety. Either no place within the treatment area is left unaffected, or a few token untreated islands are left isolated within the treatment. Also, on most of the acres that have been treated, the results are often inadequate. These treatments have sometimes provided a short-term slowing of the generation or activation of the targeted threshold. They have largely not changed the final outcome because they have not been based on the dynamics of the target communities and their thresholds.

The current level of uniformity over many areas of Great Basin woodlands may be one of the highest of the Holocene (Tausch, this proceedings). This uniformity appears to be the result of human activities over the last century and a half that have interacted with climate change to contribute to the simplification and homogenization of the landscape. It is basically the same outcome as observed in southern California chaparral where management activities have greatly increased their homogeneity in comparison to the chaparral across the border in northern Baja, Mexico (Minnich and Chou 1997). This homogenization has resulted from several impacts, including the introduction of exotic annuals, the many types of natural resource utilization patterns, fire suppression efforts, and the related increasing dominance of woody species. The increasing CO_2 content of the atmosphere, and atmospheric input of nitrogen into the system from air pollution, could also be contributing components. Such simplified, homogenized systems can be prone to the development of new thresholds. These thresholds can precipitate major vegetation and system changes that are new, or unique, to the ecosystems and species affected. Because of the homogeneity the changes can affect large areas simultaneously.

Past management activities have tended to apply similar procedures across the landscape on a piecemeal basis without adequate consideration of landscape variability or long-term consequences. As in other regions, this narrow focus has often contributed to ecosystem homogenization over large areas of the Great Basin. Such piecemeal management has also tended to have limited long-term success. Correcting these problems will require closer observation within the context of the greater temporal and spatial scales within which each site is imbedded. Unless such landscape level dynamics, and their long-term changes and interactions with thresholds, are a part of future ecosystem management, success will remain limited.

Identification of the controlling environmental factors is necessary to manage thresholds on the basis of landscape-level interactions over the long-term. For the Great Basin, much of the needed information on factors controlling community dynamics is absent. Additionally, different combinations of controlling factors can, in different locations, result in similar- appearing vegetation communities. These communities may have different thresholds and may respond differently to the same management or disturbance despite their similar appearance. Because our knowledge of causes is limited, we have often been left with only descriptions of the differences these causes have produced (Bailey and others 1994). The need to move beyond describing the outcomes after they have occurred, to being able to anticipate future changes, is probably our greatest challenge.

References

Bailey, R. G.; Avers, P. E.; King, T.; McNab, W. H. eds. 1994. Ecoregions and subregions of the United States. Map (scale 1:7,500,000). Washington, D.C: U. S. Department of Agriculture, Forest Service.

Betancourt, J. L.; Pierson, E. A.; Rylander, K. A.; Fairchild-Parks, J. A.; Dean, J. S. 1993. Influence of history and climate on New Mexico piñon-juniper woodlands. In: Aldon, E. F.; Shaw, D. W., coords. Proceedings, managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30; Santa Fe, NM. Gen. Tech. Rep. RM-GTR-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 42-62.

Chambers, J. C.; Farleigh, K.; Tausch, R. J.; Miller, J. R.; Germanoski, D.; Martin, D.; Nowak, C. 1998. Understanding long- and short-term changes in vegetation and geomorphic processes: the key to riparian restoration? In: Potts, D. F., ed. Proceedings of AWRA speciality conference, rangeland management and water resources. Herndon, Virginia, American Water Resources Association. TPS-98-1: 474p.

Farquhar, G. D. 1997. Carbon dioxide and vegetation. Science. 278: 1411.

Klopatec, C. C.; Debano, L. F.; Klopatek, J. M. 1988. Effects of simulated fire on vesicular- arbuscular mycorrhizae in pinyon-juniper woodland soil. Plant and Soil. 109: 245-249.

Laycock, W. A. 1991. Stable states and thresholds of range condition on North American rangelands: a viewpoint. Journal of Range Management. 44: 427-433.

Minnich, R. A.; Chou, Y. H. 1997. Wildland fire patch dynamics in the chaparral of southern California and northern Baja California. International Journal of Wildland Fire. 7: 221-248.

Millar, C. I. 1997. Comments on historical variation and desired condition as tools for terrestrial landscape analysis. In: Sommarstrom, S. ed. What is watershed stability? Proceedings of the Sixth Biennial Watershed Conference. 23-25 October 1996, Lake Tahoe, California/Nevada. University of California Water Resources Center Report No. 92: 105-131.

Nowak, C. L.; Nowak, R. S.; Tausch, R. J.; Wigand, P. E. 1994a. Tree and shrub dynamics in northwestern Great Basin woodland and shrub steppe during the late-Pleistocene and Holocene. American Journal of Botany. 81: 265-277.

Nowak, C. L.; Nowak, R. S.; Tausch, R. J.; and Wigand, P. E. 1994b. A 30,000 year record of vegetation dynamics at a semi-arid locale in the Great Basin. Journal of Vegetation Science. 5: 579-590.

Polley, H. W.; Johnson, H. B.; Mayeux, H. S.; Tischler, C. R. 1996. Impacts of rising CO_2 concentration on water use efficiency of woody grassland invaders. In: Barrow, J. R.; McArthur, E. D.; Sosebee, R. E.; Tausch, R. J., comps. 1996. Proceedings: shrubland ecosystem dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 189-194.

Tausch, R. J. 1996. Past changes, present and future impacts, and the assessment of community and ecosystem condition. In: Barrow, J. R.; McArthur, E. D.; Sosebee, R. E.; Tausch, R. J. Proceedings: shrubland ecosystems dynamics in a changing environment; 1995 May 23-25; Las Cruces, NM. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 97-101.

Tausch, R. J.; Wigand, P. E.; Burkhardt, J. W. 1993. Viewpoint: plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the Quaternary? Journal of Range Management. 46: 439-447.

Thompson, R. S. 1990. Late Quaternary vegetation and climate in the Great Basin. In: Betancourt, J. L.; VanDevender, T.; Martin, P. S. eds. Packrat middens: the last 40,000 years of biotic change. Tucson, AZ: University of Arizona Press: 200-239.

Westoby, M.; Walker, B.; Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management. 42: 266-274.

Woolfenden, W. B. 1996. Quaternary vegetation history. In: Sierra Nevada ecosystem project: final report to congress, Vol II, chap 4. Davis, CA: University of California, Centers for Water and Wildland Resources: 47-70.

Ecological Guidelines for Management and Restoration of Pinyon and Juniper Woodlands

Lee E. Eddleman

Abstract—An approach is suggested for developing general guidelines that in turn form the basis for site specific guidelines to be used in the management and restoration of pinyon-juniper woodlands. Guidelines are based on the establishment of goals, objectives and problem statements. This is followed by a structural and functional analysis of the land area under consideration for treatment. Finally a functional analysis relating the area under consideration to landscape as a whole is suggested.

At the outset it must be stated that this paper is intended to provide guidelines suitable for the determination of ecologically based management actions on pinyon-juniper woodlands. As such it may also be adaptable to other arid and semi-arid systems. It is purposefully ambiguous in some areas to avoid the quagmire of hard and fast rules.

Many problems arise in the development of site specific ecological guidelines for the management and restoration of pinyon-juniper woodlands. All attempts to do so are underlain by a set of assumptions that may or may not be correct and are driven by expectations, desires and objectives that may or may not be realistic in terms of either the supporting science or the available resources. Assumptions are likely based on social values, understanding of ecological theories and interpretation of ecological data, each of which need to keep as distinct as possible (Scarnecchia 1995 and Tausch 1996). As yet, we do not have comprehensive, whole system, ecological research on our arid land areas; at best we have partial research on a few areas. The manager is therefore faced with the formidable task of formulating suitable assumptions, developing reasonable objectives and applying guidelines in an appropriate manner from less than adequate research data, not so succinct and frequently conflicting ecological theories, shifting social values as well as observations and experience.

In spite of the lack of a comprehensive understanding of most arid ecosystems we are certainly not bereft of the basics. Ecological principles and guidelines applicable to the management and restoration of pinyon-juniper woodlands can be found in, or can be derived from, a variety of comprehensive publications including range management (Holechek and others 1998), grazing management (Heitschmidt and Stuth 1991), improvement of rangelands (Vallentine 1989) and improvement of game ranges (Plummer and others 1968). More specifically, Evans (1988) considered many ecological relations in developing strategies for management of pinyon-juniper woodlands for a variety of products and values, and Aldon and others (1995) provides a very useful checklist of critical questions that should be addressed prior to initiation of any management scheme in the pinyon-juniper type. In the actual application of guidelines the manager is faced with the question: does the guideline fit this particular piece of land and does it fit in the context of linked resource units?

Ecological guidelines should have broad scale applicability across the main pinyon-juniper woodland as well as juniper woodlands of the Northwest and southern Great Plains. Each site, the ecological site (U.S. Department of Agriculture 1997), is unique within itself and it is equally unique in its connectivity to surrounding sites. Connectivity has been defined as the degree to which patches of a given type are joined by corridors into a lattice of nodes and links (Wiens and others 1993). In woodlands connectivity could be considered as the degree to which a site is functional linked to other sites or landscape units of the system. This linkage is both spatial and temporal and is through mechanisms of emigration-immigration for materials such as water, sediment, nutrients, energy, flora and fauna (Schlesinger and others 1990, Tongway 1990 and Wilcox and Breshears 1995). Site specific internal attributes and external connectivity attributes require not only site-specific fine filter guidelines but also spatially and temporally scaled guidelines.

Establishment of guidelines for management and restoration of pinyon-juniper woodlands implies that standards exist and that we are capable of directing or redirecting ecological processes to attain those standards. Setting ecological standards is a distinctly human process and is therefore an arbitrary value judgement that shifts with shifting personal and societal values. We would like to think that pinyon-juniper woodlands have their own inherent ecological standards, and at certain temporal-spatial scales perhaps they do. Words such as natural and healthy pervade the literature and our concept of these words, as applied to a particular site, seem to provide the driving force for the establishment of standards. However, Lawton (1997) has pointed out that ecosystems change continuously at all timescales diverging more and more as we move back in time and Tausch (1996) points out that climate has continually changed in the past and it is likely to do so in the future. Lawton concludes that the true situation is that we have no benchmark virgin state that we can refer back to. Recognition of change and the processes associated with change should

In: Monsen, Stephen B.; Stevens, Richard, comps. 1999. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-9. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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allow us to formulate our site objectives and standards more realistically focusing on trajectories and functional standards (Lawton 1997, Tausch 1996).

If the above is true, then standards and guidelines developed around concepts of sustainability should be called into question and carefully evaluated, particularly as to their spatial-temporal scale. As noted above, it also may require that we focus our standards and guidelines on functional attributes of ecosystem components rather than composition of structural components. Key functional attributes should be the internal attributes of the ecosystem that control rate and magnitude of those processes that can lead to degradation or visa-versa to desired conditions. At the same time aspects of plant composition and other surface structures have been found to be useful indicators of site function (de Soyza and others 1997). Approaches suggested by the Committee on Rangeland Classification (National Research Council 1994) are a good step toward the application of functional ecology to determination and management of rangeland health and are applicable to pinyon-juniper woodlands.

Guidelines

Ecological guidelines useful in the management and restoration of pinyon-juniper woodlands have been placed to a degree in a question format. Questions best tend to force critical thinking considerably beyond the simple answers of yes and no and, hopefully, push responsible parties to find solutions from a variety of sources. Meaningful site-specific guidelines can be developed from a well thought out set of goals, objectives, problem statements, land area analyses and landscape analyses.

Goals and Objectives

Clear concise goals and objectives are required at the outset of any management or restorations action. Establishment of goals and objectives requires that the desired pattern and function of woodlands have been determined at both the landscape level and at the level of the unit of land, or land area, under consideration for management or restoration action.

Questions that need to be asked and answered include those below.

- What are the desired short-term and long-term ecological goals?
- What are the objectives and what is the spatial-temporal framework for measurement? (Literally how much per unit of space per unit of time)
- How do the goals for the land area under consideration fit within the goals for the landscape as a whole?
- What are the assumptions that underlie each objective?

Unless considerable thought is put into making sure these questions have been answered, conflicts and cross-purposes may not be identified and the reality of success may be illusive. Ecological goals for woodlands should include components of sustainability, productivity and a component of conservation of natural abiotic and biotic resources. Goals and objectives must be definable, achievable and measurable. They should provide a clear statement of the desired direction of change, if any, for soils, plants and animals, and identify desired future woodland conditions. The degree of success should be measurable on both temporal and spatial scales. Knowing the degree to which one's assumptions rely on social values, ecological theory, ecological data or observation and experience will help adjust confidence in reaching the goals and objectives.

As an example, for a particular land area the manager may set a goal of maximizing the infiltration of precipitation into soil storage at all times of the year. Short-term aspects might be focused on normal precipitation events during the growing season while long-term aspects might be focused on abnormal hydrological events year-round. Objectives could include reaching a condition of zero runoff during the growing season from rainfall events with intensities less than 25 mm per hour and totals less than 13 mm in a 10 year period.

Problem Statement

The next step in the process is to state precisely and clearly the apparent ecological problem as it exists on the land area under consideration. This statement should be as comprehensive as possible and based on field observation and as much site-specific and local information as is available. It should identify structural components that control rates and amounts of change and processes that appear associated with degradation. Degradation as used in this paper is the degree to which pattern and process have been altered and the land area under consideration rendered less favorable for the desired plant community or communities identified in the goals and objectives (modified from Tongway 1990).

As an example, a part of the problem statement may be that runoff is excessive as indicated by too much bare ground, an abundance of rills, long reaches for runoff and high sediment deposition on lower upland areas and drainage channels.

Land Area Analysis

Kind of Woodland

An inventory and analysis of the temporal and spatial nature of the woodland on the land area under consideration is needed since the kind of woodland presently on the land area determines in a large degree the management and restoration practices to be applied.

Questions that need to be asking and answered include those below.

- What is the age class structure of the trees?
- What is the size class-spatial structure of the trees?

Old woodlands have a variable number of very old trees present and the land area appears to have been in woodland for several hundreds of years. Pattern of plants, soils and animals, and processes, both biotic and abiotic, may appear spatially and temporally controlled by the tree component of the woodland. The tree component may appear to be stable; however in the last century degradation in these woodlands may be ongoing at several scales. Degradation may be due to a variety of causal factors including the addition of too many livestock and subsequent long-term overgrazing, particularly in the spring, and the removal or deletion of fire from the system.

New woodlands are those that have largely developed this century and there is not an indication they were previously present. These woodlands contain mature trees; the larger individuals may have recently begun to slow down their growth rates and mortality factors are not strongly in evidence. Patterns and processes in these communities may be largely under the control of the woodland. There is a relatively high probability that in many of the new woodlands tree densities will reach very high levels prior to mortality factors setting in, followed by a density decline to some lower level. The expansion and development of new woodlands is usually attributed to altered fire regimes, overgrazing by domestic livestock and optimal climate for establishment (Miller and Wigand 1994).

Degradation in new woodland communities may be due, firstly, to the trees themselves. In the above scenario we should expect both deletions and additions of flora and fauna to occur as woodlands move toward high tree densities. Altering the fire regime, continued over-grazing, additions of alien plant species and perhaps extreme climatic events, such as the drought of the 1930s, may also be contributing significantly to patterns and processes in young woodlands. Since young woodlands have largely developed in the absence of fire, fire, therefore, remains an unknown factor in the long-term development of woodland pattern and process.

Developing woodlands must also be considered as they are areas which are being newly invaded by trees but have not as yet reached the stage where pattern and process are dominated by trees. These future woodlands may be developing due to the removal of fire from the existing plant community. Overgrazing by domestic livestock and the addition of alien plant species may contribute to their development and to various degradation processes.

An example could be a young woodland with a broad spectrum of age classes. Older trees are roughly 100 years old, provide a 20 percent canopy cover and number 125/ha. In addition, smaller trees number 50/ha.

Understory Vegetation

The proportions and density of understory vegetation components must be determined on each functional unit within the land area under consideration in order to predict possible transitions in pattern and process to potentially new stable states.

Questions that need to be asked and answered include those below.

- What functional groups of understory plant species are present and what ones are absent?
- What plant species are missing that should be present and conversely what plant species are present that should be absent?
- Is the apparent vigor or health of the shrub species sufficient to maintain them in the community or has a threshold been crossed and extinction expected?
- Is the density of long-lived herbaceous and shrub species sufficient to respond to disturbance factors, both natural and man caused?
- What are the assumptions made in answering each question?

An example could be that shrubs are sparse, live plants have low leaf areas and recent high mortality is evident. Herbaceous plants are mostly annuals made up of early ephemeral forbs and scattered alien grasses. Some early spring species of perennial bunchgrasses and tap-rooted forbs, as well as scattered individuals of late spring, early summer and fall perennial forb and grass species are present. All perennial plants in interspace areas are small, widely spaced and appear to be of low vigor. Potential response of the understory to management or restoration actions appears possible, but long term.

Functional

The land area is the local area under consideration and may be made up of one to several ecological sites, or one to several distinct functional units. The area of interest must be delineated to assess functional attributes.

Questions that need to be asked and answered include those below.

- What distinct ecological sites, or functioning units, are present?
- What ecological factors currently dominate and control on-site pattern and process and how do they do so?
- To what degree and specifically how do trees individually and collectively control on-site pattern and process?
- What are the assumptions made to support the conclusions?
- What causal factors led to current site conditions?
- What is the degree of degradation?
- What ecological thresholds currently restrict transitions to goal oriented ecological conditions?
- What assumptions were made in answering each question?

Thinking in spatial-temporal scales will greatly aid in understanding how an area functions. Spatially scaled functional units suggested by Wilcox and Breshears (1995) or those suggested by Tongway (1990) and Anderson and Hodgkinson (1997) are very useful. Temporally scaled functions should at least include key seasonal aspects of moisture input, and plant growth and reproduction.

Woodland ecological sites may be mosaics or contain inclusions limited in area but significant in the functioning of the site at particular spatial or temporal scales. For example, areas of old growth trees on rock outcrops located within an otherwise seemingly uniform expanse of mature soils may be too small to separate out as distinct ecological sites, but they will function differently from the other parts of the site and, therefore, significantly contribute to site processes as a whole. Slight changes in topographic position may alter ecological functions, but given present ecological site classification protocol may be included in a single site. (Tongway 1990, Burke and others 1995, Herrick and Whitford 1995).

Basic processes of concern are those associated with the hydrologic cycle, nutrient cycle and energy flow. Also of primary concern are successional processes in the functional groups of plants and processes associated with functional structures for animal habitat (National Research Council 1994, U.S. Department of Agriculture 1997).

Identification of the causal factors of degradation to a particular land area is complex. Additionally, degradation of one area may be caused by treatments in other areas. This relationship is particularly evident in riparian systems (Briggs 1996), but is also true for most upland systems as well.

The degree to which certain ecological factors function as thresholds restricting transition to desire future conditions must be assessed (Laycock 1991, Reitkerk and van de Koppel 1997, Reitkerk and others 1997, Tausch and others 1995, Westoby and others 1989). Degree of tree dominance, present and potential dominance of invasive alien plant species, lack of plant species and individuals to respond, shallow soils, clayey or sandy textured soils, slopes receiving direct solar radiation all seasons of the year, surface soil loss, high surface water runoff and intense spring frost action may constitute some of the thresholds to be crossed. From the threshold assessment both treatment type and treatment magnitude can be estimated including management changes as well as additions and deletions of organisms and abiotic materials.

As an example, it could be determined that the land area under question should function to intercept and accumulate resources from the slopes above, but appears to be functioning as a source area, as well as a flow-through area for surface water. Secondly, it may be determined that runoff and interception dominate the initial hydrologic processes and that following precipitation events, transpiration by the trees and evaporation from the surface 6 cm of soil in interspace areas are the primary hydrologic processes. Thirdly, soil analysis may show the presence of eroded soil surfaces, deep, medium textured soils, generally well dispersed tree roots with the highest root mass just above and in a moderately developed clayey horizon at 35 to 50 cm.

Landscape Level Analysis

A complete spatially temporally scaled landscape level analysis relative to the land area in question is necessary to assure selection of the right treatment area and the right treatment and to prevent negative reactions off-site.

Questions that need to be asked and answered include those below.

- How does the landscape function as a whole?
- What are the links (connectivity) from the land area under consideration to adjacent and removed sites and functional units?
- How does the particular site or land area under consideration fit functionally into the landscape?
- As to the natural resources of the landscape, which areas are source-areas, which areas are flow-through-areas and which areas are run-on areas that intercept or accumulate resource materials?
- What reasons are there to believe that the area under consideration should function differently than it is?
- What are the assumptions made to support the conclusions?

Consideration of management units and treatment areas in isolation is no longer acceptable. It may be the case, for a particular area of land, that initial floristics and relay floristics are mechanisms determining composition of plant species over particular time scales. However, each area is linked to other areas in terms of a variety of critical resources that may strongly influence plant densities, vigor and energy values as well as rates and magnitude of processes.

In landscape analysis emphasis may need to be placed on water flow, paying particular attention to the physical and biological factors that control and dominate the water cycle. The spatial conceptual framework scales and functional units proposed by Wilcox and Breshears (1995) provide an excellent comprehensible starting point in landscape analysis, oriented as it is toward water flow in the system.

Adjustments in scales and functional units may be needed in other settings and where woodland management and restoration is of concern. Of critical concern is the ecological function of each land management area, ecological site and functional unit for which restoration treatments are proposed. The degree of movement and accumulation of critical resources is hypothesized to be the principle mechanism controlling threshold levels of response in arid and semi-arid systems (Anderson and Hodgkinson 1997, Burke and others 1995, Reitkerk and others 1997, Tongway 1990).

A patchwork land ownership is frequently encountered within a landscape making landscape level analysis critical. The land area under consideration may need to be managed or restored in such a way as to mitigate potentially degrading processes initiated up-slope and to prevent the area from being the focal point of processes which degrade down-slope areas.

An example could be a landscape analysis that reveals some of the water flowing over the surface is from slopes and plateaus above and most importantly surface water from off-site comes largely during snow-melt. Although the potential for accumulation of water and nutrients is considered as high, a question should arise as to altering management or initiation of restoration practices on the source areas above.

Management and Restoration Actions

Following the establishment of goals and objective and the completion of the structural and functional assessment of ecological factors, scaled from the functional unit up to the landscape, the problem statement needs to be revisited and revised, if necessary. Once this process is complete, site-specific guidelines of what, when, where and how can be addressed. Common actions considered in the management and restoration of pinyon-juniper woodlands, such as burning, mechanical removal, seeding and grazing should draw their ecological guidelines from a complete set of goals, objective and land analysis. If needed guidelines cannot be so derived, then some part or perhaps the whole set has deficiencies.

There are an endless number of questions that can be raised as to actions taken in ecological management and restoration of pinyon-juniper woodlands, however the ecological guidelines for each activity must be found in the goals, objectives and ecological land assessment.

For example, questions as to grazing by domestic livestock can be answered only by asking if it will function to meet goals and objectives for the land area given the present structural and functional condition of the resources of that land area.

More specifically, consideration of fall grazing requires that the prescribed grazing meet short term and long-term goals, objectives and that appropriate structural and functional resources in time and space are available to do so. For instance, using the examples above, fall grazing may be acceptable when the focus is on growing season capture of water, however, when winter and early spring hydrological events are considered, fall grazing may become unacceptable.

Consideration as to grazing rest time after additions of species by seeding should be guided by goals, objectives and land analysis. Desired direction, rate of change and area function should determine what, when, where and how grazing is to be initiated.

References

Aldon, E. F., Fletcher, R. and Shaw, D. 1995. A checklist for ecosystem management in southwestern Pinyon-Juniper. p. 125-129 In: Shaw, D. W., Aldon, E. F. and LoSapio, C., tech. coords. Desired future conditions for pinyon-juniper ecosystems; Symp. Proc., 1994, Aug. 12; Flagstaff, AZ. Gen. Tech. Rep. RM-258, Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 226 p.

Anderson, V. J. and Hodgkinson, K. C. 1997. Grass-mediated capture of resource flows and the maintenance of banded mulga in a semi-arid woodland. Australian Journal of Botany 45: 331-342.

Briggs, M. K. 1996. Riparian ecosystem recovery in arid lands. Univ. Arizona Press, Tucson. 159 p.

Burke, I. C., Elliott, E. T. and Cole, C. V. 1995. Influence of macroclimate, landscape position, and management on soil organic matter in agroecosystems. Ecological Applications 5: 124-131.

de Soyza, A. G., Whitford, W. G. and Herrick, J. E. 1997. Sensitivity testing of indicators of ecosystem health. Ecosystem Health 3: 44-53.

Evans, R. A. 1988. Management of pinyon-juniper woodlands. Gen. Tec. Rep. INT-249. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 34 p.

Heitchmidt, R. K. and Stuth, J. W. editors. 1991. Grazing management. An ecological perspective. Portland, OR: Timber Press 259 p.

Herrick, J. E. and Whitford, W. G. 1995. Assessing quality of rangeland soils: challenges and opportunities. Journal of Soil and Water Conservation. May-June: 237-242.

Holecheck, J. L., Pieper, R. D. and Herbal, C. H. 1998. Range management. Principles and practices. (3rd ed) Upper Saddle River, NJ: Prentice-Hall, Inc. 542 p.

Lawton, J. H. 1997. The science and non-science of conservation biology. Oikos 79: 3-5.

Laycock, W. A. 1991. Stable states and thresholds of range condition in North American rangelands: a view point. Journal of Range Management 44: 427-433.

Miller, R. F. and Wigand, P. E. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioScience 44: 465-474.

National Research Council 1994. Rangeland health. New methods to classify, inventory and monitor rangelands. National Academy Press, Washington, DC. 180 p.

Plummer, A. P., Christensen, D. R. and Monsen, S. B. 1968. Restoring big-game range in Utah. Pub. No. 68-3, Utah Division of Fish and Game. 183 p.

Rietkerk, M. and van de Koppel, J. 1997. Alternate stable states and threshold effects in semi-arid grazing systems. Oikos 79: 69-76.

Rietkerk, M., van den Bosch, F. and van de Koppel, J. 1997. Site-specific properties and irreversible vegetation change in semi-arid grazing systems. Oikos 80: 241-252.

Scarnecchia, D. L. 1995. Viewpoint: The rangeland condition concept and range sciences search for identity: a systems viewpoint. Journal of Range Management 48: 181-186.

Schlesinger, W. H., Reynolds, J. F., Cunningham, G. L., Huenneke, L. F., Jarrrel, W. M., Virginia, R. A. and Whiford, W. G. 1990. Biological feedbacks in global desertification. Science 247: 1043-1048.

Tausch, R. J. 1996. Past changes, present and future impacts, and the assessment of community on ecosystem condition. p. 97-101 In: Barrow, J. R., McArthur, E. D., Sosebee, R. E. and Tausch, R. J., comps. 1996. Proceedings: shrubland ecosystem dynamics in a changing environment. Gen. Tech. Rep. INT-GTR-338. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 275 p.

Tausch, R. J., Wigand, P. E. and Burkhardt, J. W. 1995. Viewpoint: plant community thresholds, multiple steady states, and multiple successional pathways: legacy of the Quaternary? Journal of Range Management 46: 439-447.

Tongway, D. J. 1990. Soil and landscape processes in the restoration of rangelands. Australian Rangelands Journal 12: 54-57.

U.S. Department of Agriculture 1997. National range and pasture handbook. Draft, Fort Worth, TX. Natural Resources Conservation Service, Grazing Lands Technology Institute.

Vallentine, J. F. 1989. Range development and improvements. 3rd edition. San Diego: Academic Press.

Werner, P. A. 1990. Principles of restoration ecology relevant to degraded rangelands. Australian Rangelands Journal 12: 34-39.

Westoby, M., Walker, B. and Noy-Meir, I. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management 42: 266-274.

Wiens, J. A., Stenseth, N. C., Van Horne, B. and Ims, R. A. 1993. Ecological mechanisms and landscape ecology. Oikos 66: 369-380.

Wilcox, B. P. and Breshears, D. D. 1995. Hydrology and ecology of Pinon-Juniper woodlands: Conceptual framework for field studies. p. 109-119 In: Shaw, D. W., Aldon, E. F. and LoSapio, C. (tech. coords.); Desired future conditions for pinyon-juniper ecosystems; Symp. Proc., 1994, Aug. 12; Flagstaff, AZ. Gen. Tech. Rep. RM-258. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 226 p.

Political Guidelines for Management and Restoration of Pinyon and Juniper Woodlands

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Abstract—In 1989 and 1990, on the heals of public protest against chaining of pinyon-juniper woodlands on public lands near Moab, Utah, the Uinta National Forest and Central Region, Utah Division of Wildlife Resources, were proposing to improve big game ranges in Spanish Fork Canyon through management of pinyon-juniper. Consideration of an array of treatments using various tools (such as prescribed fire and clear cutting) resulted in a proposal to create numerous small openings 5 to 60 acres in size, and seed these to provide additional forage and ground cover. Anchor chaining seemed to be the most practical and economical tool with which to accomplish this. Early public involvement quickly revealed strong support, and strong opposition, for pinyon-juniper treatment and specifically for chaining in upper Spanish Fork Canyon. This case-study describes the process used and experience gained in developing and planning this project. Elements are described which proved critical in enabling conflicts to be resolved, implementation to proceed, and the project to continue as a multi year effort.

In 1989, the Uinta National Forest and Central Region, Utah Division of Wildlife Resources (DWR), were searching for a way to enhance winter range for big game to partially compensate for habitat being lost to development along the southern portion of the Wasatch Front, adjacent to the communities of Provo, Springville, and Mapleton. Attention was focused on Spanish Fork Canyon because it contained considerable acres of winter and transitional range on public lands with potential for improvement. The canyon serves as a migrational corridor and it was believed that enhanced range there could "short stop" animals by holding them back from critical ranges along the Front in the fall and early winter. Overall pressure on the lower-elevation ranges could be reduced in most years and depredation on private lands reduced as well.

As biologists, hydrologists and ecologists from the two agencies looked for opportunities to improve winter range in the canyon, they identified considerable potential for increasing forage production on gentle to moderate slopes on soils derived from the Green River Shale. These sites were currently occupied by pinyon-juniper woodlands and provided extensive acres of good thermal cover but very little forage. Most of these sites were experiencing accelerated sheet erosion and gully development, believed to be due to large expanses with little ground cover. Openings in the woodlands were observed to be occupied by productive sagebrush and mixed mountain brush communities. However, these openings were very small, providing insufficient interruption of overland flow and offering little forage to wintering big game.

Specialists believed that soil productivity and precipitation were adequate to enable substantial increases in forage production in openings created in the pinyon-juniper woodland. The sites being considered were felt to be areas onto which the woodlands had expanded from adjacent "fire safe" sites. Heavy use by domestic sheep in the early part of the century had likely contributed to the loss of understory and accelerated the increase in tree density by reducing fine fuels which carry fire. Biologists looked for a way to create openings in the woodland, while maintaining critical thermal cover and travel corridors for big game and other wildlife. Ecologists wanted to be able to preserve older forests on steeper slopes and ridge tops, as well as healthy stands of shrubs scattered throughout the area. A tool was needed which could provide the control necessary to create a mosaic of openings within a matrix of pinyon-juniper woodland.

While specialists were conducting field surveys and investigating potential solutions, and preparation was being made to begin public interaction, local news broadcasts erupted with coverage of controversy over chaining of pinyon-juniper on public lands near Moab, Utah. At this same time, local sportsman's groups were pressuring the agencies to move forward with some sort of habitat enhancement work in Spanish Fork Canyon or allow them to commence winter feeding there. Both agencies preferred to pursue a long-term solution based on habitat improvement. Agency personnel were looking at possible tools to enable them to do just that—fire, clearcutting, and chaining.

Individuals involved in protests at Moab were contacted and invited to learn more about work being proposed in Spanish Fork Canyon. Public interaction proceeded with strong support for treatment, as well as strong opposition. Meetings, field trips, and more meetings were held. Analysis

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of alternatives continued. Personnel from both agencies agreed that chaining would provide the control needed to create the desired mosaic of habitat features. Fire could not be adequately controlled under conditions existing in the dense woodland to assure that necessary cover would be left. Clearcutting could accomplish the desired goals but the cost would be much greater.

Appeals were filed and negotiations undertaken. Both proponents and opponents worked hard to find solutions. Together with the agencies, they sought compromise that would allow the wildlife objectives to be met. It was agreed that a test would be performed: work was allowed to proceed using chaining as a tool to open no more than 350 acres in small patches. The work was to be a trial only, the results to be reviewed and evaluated before additional work would proceed. At the same time a small thinning would be made and the costs and outcome compared to the chaining.

Monitoring was established, work completed, and follow-up monitoring performed. Field reviews with both proponents and opponents were conducted and the outcome was favorable enough to opponents that appeals were not pursued further (Brocci 1994). Thinning proved to be less cost-effective than chaining (Chadwick and others 1998). Over the next five years, a total of more than 1,500 acres of pinyon-juniper habitat was treated in this manner. Forage production on south-facing slopes increased from less than 20 pounds per acre prior to treatment in 1990, to over 1000 in 1997. On north-facing sites treated that same year an increase from 500 to 1500 pounds per acre was recorded (USDA Forest Service 1997). Sediment loss was found to be five times greater and soil loss eight times greater on untreated (control) plots than on treated (chained and seeded) plots (Farmer 1995). Farmer found deer pellet groups to be twice as dense on treated plots, and elk five times as dense, as on adjacent untreated plots. Resource management objectives to provide additional forage for big game in upper Spanish Fork Canyon and to reduce erosion and soil loss on these same sites were accomplished.

Establishing Support and Developing Solutions

Following is an attempt to share what proved to be "critical elements" in the planning process for this project: things that we believe were important in enabling planning to proceed through controversy and disagreement, a one-year trial to be implemented, and implementation to then continue.

Objectives

Establishment of clear, honest and obtainable objectives proved critical in creating a working relationship with those opposed to the project, and provided the basis for developing support among potential proponents. In this particular case, the project objectives actually provided common ground among proponents and opponents. Agreement upon the purpose and need for the project provided a critical commonality among all involved, and allowed disagreement to focus on issues revolving primarily around methods.

Much of the area proposed for treatment in Spanish Fork Canyon does not lie within a grazing allotment. This eliminated an issue that has proved contentious in similar projects and, subsequently, agreement upon objectives came more readily. There was little debate over whether additional forage would benefit domestic livestock or wildlife. While our situation with respect to grazing issues was different than many projects involving treatment of pinyon-juniper, a host of other points of controversy and disagreement remained to be resolved, for example: method of treatment, visual impacts, consideration of historic and archaeological resources, use of natives vs. exotics in reseeding, and the potential for objectives to be met on sites selected for treatment. We believe that the steps outlined here could have been used to successfully address grazing issues as well.

Involvement in more recent projects has shown us the importance of avoiding laundry lists of objectives. While there are many secondary benefits resulting from any well-designed treatment, it is best to focus on what is actually driving the project in question. This allows for greater focus on pertinent issues and avoids the impression in some that the "deck" is being overwhelmingly "stacked" against any opposition. With a long list of objectives it becomes likely that objectives will conflict, i.e. providing for one will reduce the degree to which another can be accomplished. With even a short list of objectives, it may be necessary to prioritize. With our project, and just two primary objectives (to reduce runoff and erosion from the sites and improve winter and transitional-season forage for big game), compromise had to be made: it had to be decided whether to treat a maximum number of acres to meet watershed objectives, or treat a reduced number of acres to allow wildlife requirements to be met as well.

The importance of considering long-term as well as short-term needs, and to look at the problem and address the effects of potential solutions across a large area, became readily apparent. Appellants insisted that Utah DWR focus on maintaining sustainable populations of big game animals. These discussions ultimately lead to commitments to hold elk populations within current carrying capacities and to provide temporary reductions in the upper canyon until seedings were established. Appellants asked the Forest Service to expand the analysis area and extend the number of years of treatment considered. While this increased the complexity of the analysis and subsequently the amount of effort expended, it improved the overall quality of the analysis and increased opponents' confidence in it. Additionally, the planning work required in subsequent years of implementation was greatly reduced because of the extra effort spent in the beginning.

Public Input

It proved critical to involve the public throughout the planning process, and to continue this effort through implementation and monitoring. Not only is informing the public required by law (for Federal agencies and federally-funded efforts, under the National Environmental Policy Act), but the input provided can be valuable. The public must be involved early in the process, to provide an opportunity for input before a course is already charted. It may be necessary to actively seek out public input, both potentially in support of and in opposition to what is proposed. This reduces the risk that any unexpected issues will arise later in the process. As soon as debate was voiced in the media over projects near Moab, District Ranger Tom Tidwell sought out those individuals involved and invited their input on our project.

Tidwell worked to create open dialogue among the proponents, the opponents, and the agencies. He provided opportunities for the public to visit potential project sites and discuss concerns with the specialists designing the project. Through use of mediated debate, lead by a trained facilitator, proponents and opponents were able to talk directly rather than through agency personnel. Agreement on the fundamental needs driving the project provided common ground for the two groups. This made it possible to develop solutions by finding a balance in meeting each groups' concerns, while maintaining the ability to meet the agreed-upon objectives.

When some concerns could not be sufficiently addressed up-front, the agencies and involved public (both opponents and proponents) agreed to allow treatment to proceed for one phase (350 acres) and postpone any decisions regarding further treatment until this work could be evaluated. It was also agreed that a small thinning would be created to evaluate the costs and test the effects of that method relative to chaining. Monitoring was designed and implemented to address some of the specific concerns of opponents. For example, because the literature contained conflicting reports on the effects of chaining and seeding on reducing erosion, paired runoff plots were installed to compare effects on treated and adjacent untreated sites. Adequate monitoring, evaluating parameters of concern, was fundamental in demonstrating the value of the project and hence enabling work to continue.

Public input improved the outcome of the project in several ways. As previously mentioned, analysis of a project extending across a landscape and considering several years of treatment work, improved the decision making process and expedited planning work in subsequent years. Appellants strongly encouraged the Forest Service to use a seed mix containing primarily native species and it was agreed that a mix with approximately one-half native species would be used. The mix performed well and was used in subsequent years on this project. The Uinta National Forest has since increased its use of natives on all seeding projects. The establishment of monitoring to document runoff from treated and untreated areas, initiated because of concerns of opponents, has resulted in an entry in the scientific literature documenting dramatic results as well as an appropriate (and relatively inexpensive) method of evaluating effects at a scale appropriate for such projects.

Evaluate Options

Consideration of a full range of options, looking at all reasonable tools, was necessary to assure good decision-making and important in developing credibility and support for the final decision. It was important to fully assess the "no action" alternative. Analysis of the no-action should affirm the validity of the purpose and need for action. Alternatives should be developed which address concerns, but it is critical to then evaluate how well the alternative can address the objectives. When all parties agreed to the objectives, it became simple to reject alternatives that quelled specific concerns but did not enable accomplishment of objectives.

All reasonable alternatives should be fully assessed and given the same level of consideration. Experience has shown that more detailed analysis of some alternatives over others more likely results in suspicion than in strengthened support for that alternative. Each should be analyzed across a landscape and projected through a reasonable period of time to avoid the perception of a segmented, or piece-meal, analysis which does not fully reveal the cumulative effects of multiple years of work. This provided an appeal point in our case.

Careful Implementation

Care in implementation of the project, and in particular the close attention paid to detail in the design and layout of treatment units, built substantial support for the project. Criteria for unit design and layout were developed by experienced personnel from both agencies, assuring that project objectives would be met. Utah DWR biologists worked carefully to assure that adequate thermal cover would remain and that travel corridors would be provided. Forest Service hydrologists and ecologists worked together to determine which sites had the greatest capabilities for meeting erosion reduction and forage production objectives. Archeological surveys were conducted and protection provided for "eligible" sites. Implementation was closely supervised to assure that the desired outcome was achieved. Personnel (at least one biologist and several technicians) were on the sites with chaining and seeding contractors at all times.

Interagency Cooperation

Cooperation among interested agencies was very important to the success of the project. Both the Forest Service and Utah DWR provided funding and participated actively in all phases from planning to monitoring. Joint efforts in planning and design proved especially important in creating agreement and developing a sense of ownership in the project with agency personnel. The two parties worked together to develop support from the public, participated together in discussions with opponents, jointly pursued solutions and evaluated results. We feel this contributed considerably to the credibility of the project.

Nonagency Partnerships

Endorsement of the project by non-governmental organizations, especially groups willing to contribute funding or in-kind assistance, helped to build a broad base of support for the project. Partners' willingness to make a tangible contribution to the project by providing cash support and/or volunteering time and talents proved successful in drawing favorable attention to the project, and served as a vote of confidence. Funding provided by partners was critical in some years to enabling work to proceed. With continually shrinking budgets, being experienced by both state and federal agencies in recent years, such funding becomes increasingly important.

Partnerships create a responsibility for agency personnel to keep non-agency players informed. Circumstances often prevent these groups from participating in the day-to-day development and implementation of the project. This makes it important for the agencies to keep these groups informed as to the status of the project, by providing regular updates even in periods of little activity.

Dedication of Proponents and Opponents

It is important that all parties involved, both those who fully support the project and those who don't, are dedicated to spending the time necessary to fully explore issues and to remaining open to each other's ideas. This requires agency specialists and decision-makers to spend time with all groups involved, to listen to their concerns and ideas and explore these fully. Field reviews provided an excellent opportunity to accomplish this. This proved to be the best way to help the public develop an understanding of the project, while creating a forum for airing and discussing concerns and exploring ways to mitigate those issues. At a critical point when solutions were needed so that decisions could be made, mediated debate (discussed above) served a critical role in developing compromise and agreement.

Agency Decisionmaker Support

Excellent support and dedication by the deciding officer, in this case the district ranger, was without question one of the most critical components enabling compromise and collaboration to develop from disagreement. The district ranger first became intimately familiar with the project, it's purpose and need, its objectives and the proposed action. He then gave priority to spending time with the proponents and opponents, helping them to understand the agencies' proposal and then listening to and coming to understand their feelings about the proposal. He worked to build support for the objectives of the project, while remaining open to ideas and concerns. He was dedicated to finding solutions that enabled our objectives to be met, and skillful in dealing with controversy.

Our district ranger's insistence on remaining flexible and seeking solutions prevented an unsurmountable stalemate from developing. His willingness to accept opponents' request to implement a one-year trial, and their faith that he would stand behind that agreement, was an important turning point for the project. He worked with agency specialists to see that adequate monitoring was established so that the work could be properly and fairly evaluated. He maintained contact with the opponents throughout planning, implementation and assessment to assure that they understood how work was progressing.

Conclusions

Experience obtained through the development, implementation and monitoring of the Spanish Fork Canyon big game winter range enhancement project revealed a handful of factors that proved important in dealing with the controversy surrounding treatment of pinyon-juniper woodlands:

- develop clear, honest and obtainable objectives
- solicit and use public input, representing diverse points of view
- consider an array of options and alternatives
- establish interagency and partner support
- encourage proponents and opponents to dedicate the time needed to pursue solutions and create an open environment for exchange of ideas
- decisionmakers must dedicate the time and energy necessary to establish relationships with proponents and opponents, find common ground, and develop solutions
- use great care in planning (including design and layout), implementation and monitoring

While most or all of these items may be considered to reflect primarily common sense, we often see insufficient time and energy dedicated to them "up-front." Instead, an equal or greater investment is required to struggle through stalemates which develop when public involvement comes too late. Of course, such situations cannot always be avoided but prevention is a worthwhile goal.

We recognize that in the experience shared here, all conflicts were not resolved. Some opponents remained unhappy with the decisions made but chose not to commit the time necessary to pursue solutions. We are grateful to those who remained dedicated to the process of finding answers. Their contributions of energy and ideas enhanced the outcome of the project.

Acknowledgments

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References

Brocci, Jan. 1994. Rough times on the Wasatch Front—rejuvenating a winter range. Bugle. Spring: 44-54.

Chadwick, J. Holbrook. Thinning versus chaining: which costs more? In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel. (This proceedings). Proceedings: ecology and management of pinyon-juniper communities within the interior west. 1997 Sept. 15-18, Provo, UT. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Farmer, Mark E. 1995. The effect of anchor chaining pinyon-juniper woodland on watershed values and big game animals in central Utah. Unpublished thesis. Brigham Young University, Provo, UT. 46 p.

USDA Forest Service. 1997. Unpublished data summary. Uinta National Forest, Provo, UT.

Old-Growth Juniper and Pinyon Woodlands

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Abstract—The forestry, rangeland, and ecology communities have generally overlooked semi-arid old-growth woodlands. These ancient woodlands have some of the oldest trees in the Intermountain region, exceeding ages of 1,000 years. Old-growth are typically structurally more complex than postsettlement woodlands adding biological diversity to the landscape and providing an important source of habitat for many organisms. Mapping and inventorying old-growth woodlands are extremely important in developing management and land-use plans. Information is also needed on structure, function, gap dynamics, tree mortality, and succession following disturbance.

Old-growth juniper and pinyon woodlands in the West generally do not fit the typical image most people have of old-growth coniferous forests. In a recent symposium in the southwest, Swetnam and Brown (1992) stated; "Many peoples image of old-growth are the stately monarch trees with shafts of sunlight streaming down through tall, dense canopies. However, in the southwest, many of the old-growth stands do not fit this stereotype." Some of the oldest stands throughout the Intermountain West are low statured open semiarid woodlands composed of such species as bristlecone pine (*Pinus longaeva*), limber pine (*P. flexilis*), juniper (*Juniperus* sp.) and pinyon (*Pinus* sp.). Old woodlands usually differ in structure and function from postsettlement woodlands thus adding diversity at the community and landscape levels. Although considerable research has been conducted in old-growth for other conifer species, work addressing old-growth in juniper and pinyon woodlands is very limited. In addition, the concern over the rapid expansion of juniper and pinyon woodlands during this century has overshadowed the presence and values of these presettlement woodlands. Ancient woodlands are frequently overlooked in management plans and inventories where they are often lumped with postsettlement stands. Wildlife studies conducted in juniper or pinyon-juniper woodlands have also generally not separated post from presettlement stands.

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The intent of the paper is to describe old-growth as it relates to semiarid juniper and pinyon woodlands in the Intermountain West and briefly summarize their characteristics, variability, and some of the current work going on in these old stands. Specifically we will:

1. Describe old-growth and contrast juniper and pinyon stands with other coniferous stands.
2. Describe the values of old-growth juniper and pinyon woodlands.
3. Describe the different types of old-growth woodlands for western (*Juniperus occidentalis* spp. *occidentalis*), Utah juniper (*J. osteosperma*) and pinyon (*Pinus* spp).
4. Discuss management considerations for old-growth woodlands.

Old-Growth: A Generic Description

Old-growth work in the northwest United States has been focused on the more mesic heavily forested areas. In the Great Basin old-growth work is almost non-existent. The forestry, rangeland, and ecology communities have generally overlooked semi-arid old-growth woodlands. What is known about old-growth juniper and pinyon comes largely from anecdotal mentions in the literature, noting the occurrence of presettlement trees on rimrock, low sagebrush tablelands, and other fire resistant areas. Several attempts have been made to describe pinyon-juniper old-growth (Popp and others 1992, Mehl 1992) but little actual work has been conducted in these stands.

Old-growth forests are unique from younger forests in both structure and function (Mehl 1992, Kaufmann and others 1992). The U.S. Forest Service defines old-growth forests generically as ecosystems distinguished by old trees and related structural attributes. Their definition states that old-growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function (USDA Forest Service 1993). Structural features important in characterizing old-growth in the Intermountain West vary widely across forest type, climate, site conditions, and disturbance regimes (Kaufmann and others 1992).

Functionally, ecological interrelationships in old-growth forests are more complex than younger forests (Moir 1992). Old-growth ecosystems are characterized by having a component of old trees that have a biochemistry of secondary metabolic products, some of which may provide high resistance to insects and disease. Relative to younger trees, the oldest trees have approached their maximum size and have nearly ceased height growth, and the tree crowns may be in various stages of decline. On average, mortality and respiration offset the rate of production of new biomass, and net productivity of the ecosystem approaches zero (Kaufmann 1992).

Old-growth detrital food webs are usually more complex than found in earlier stages of stand development. Decay processes, some of which may involve nitrogen fixation, occur in snags, down logs, and dead portions of living trees. Arthropods and other microzoans occur in the forest litter and within decaying stems of old living trees, whose decay may involve nitrogen fixation. There may be mixed communities of cryptograms and associated invertebrates on tree branches and stems. The food web further includes fungal-small mammal relationships (Moir 1992).

Structural and functional complexity of old-growth ecosystems increases their biological value. Important values of these old stands include habitat for a variety of plant and animal species, climate reconstruction, pools of genetic resources (Kaufmann and others 1992), and wood for dating archeological sites. In addition, esthetic and spiritual values are frequently mentioned in relation to old-growth stands.

Old-Growth Juniper and Pinyon Woodlands

Old-growth characteristics listed above may not directly apply to semi-arid woodlands in the Intermountain West. However, like other conifer communities, old-growth semi-arid woodlands should be defined on the basis of tree age, and stand structure and function. Nonetheless little to no information is available on stand structure, rates of mortality and decomposition, gap dynamics, thinning, food webs, and nitrogen fixation for old-growth juniper and pinyon woodlands. Information relating old-growth woodlands to wildlife values is also limited since very few wildlife studies have described stand structure or separated old-growth from postsettlement woodlands.

Single Tree Perspective

A frequently asked question is; "What is an old-growth juniper or pine?" One age separation may be made on the basis of tree establishment occurring prior to and following Eurasian settlement. In the central and northern portions of the Great Basin, the rapid expansion of western, Utah juniper, and pinyon coincided with Eurasian settlement in the late 1860s and 1870s (Burkhardt and Tisdale 1976, Tausch and others 1981, Young and Evans 1981, Tausch and West 1988, Miller and Rose 1995). Woodland expansion for much of this region began in the 1870s. Based on the chronology of past events throughout the northern Great Basin we would define postsettlement trees as having established sometime after 1870 and presettlement trees establishing prior to 1870. However, old-growth can also be based on morphological characteristics of the tree, which develop slowly over time. As juniper and pinyon age, canopy morphology shifts from cone shaped to a rounded top. As age advances the tree may also develop a combination of the following characteristics; broad nonsymmetric tops, deeply furrowed bark (primarily juniper), twisted trunks or branches, dead branches and spike tops, large lower limbs, trunks containing narrow strips of cambium (strip-bark) (mostly in juniper), hollow trunks (rare in pinyon), large trunk diameters relative to tree height (in western juniper), and branches covered with a bright yellow green lichen (*Letharia* sp.) in both juniper and pinyon. Tree size, particularly height, is dependent upon site characteristics.

Tree age within the old-growth stand is an important index in assessing the stage of old-growth development (Swetnam and Brown 1992). Assessing stand age also determines the rarity or uniqueness of the woodland. Western juniper can easily attain ages exceeding 1,000 years (Miller unpublished data). The oldest living western juniper (*Juniperus occidentalis* ssp. *occidentalis*) currently reported is just over 1,600 years old. However, many old trees cannot be aged due to rotten trunk centers. Utah juniper can also exceed 1,000 years in age and pinyon can exceed 600 years (Tausch and others 1981).

A Woodland Perspective

At the community level, old-growth juniper woodlands should be described on the basis of the presence of old trees and structural characteristics such as standing and down dead, decadent living trees, cavities, and branches covered with lichens. The U.S. Forest Service definition based on such community structure characteristics has been applied to pinyon-juniper by the Rocky Mountain Region (Mehl 1992) and the Southwestern Region (Popp and others 1992) of the Forest Service. The resulting minimum structural attributes for this procedure are shown in table 1. In a narrative description, Popp and others (1992) stated, pinyon-juniper stands may consist of all ages or one age. Dominant trees are often 400 years old. Trees 800 to 1000 years old have been recorded. The trees can be single stemmed or have a sprawling multi-stemmed character. A few stands may have closed canopies with single or both tree species, with little or no understory, but most stands are open-grown with widely scattered trees of one or both species with a wide variety of understory vegetation. The pinyon-juniper type is climax, woodlands shifting to grasslands or shrub steppe only following disturbance, such as fire (Mehl 1992). In the absence of disturbance these communities will eventually return to pinyon-juniper woodland.

The above characteristics describing old-growth pinyon and juniper woodlands in the southwest and southern Rocky Mountains provide a good first attempt but are too generic and limited to appropriately fit all old-growth woodlands in the Intermountain West. Franklin and Spies (1986) state; a single set of attributes and quantities cannot classify all stands as either old or young. Old-growth juniper and pinyon woodlands occur across a wide range of parent materials, soils, aspect, slope, elevation, climate, and disturbance regimes (Kaufmann and others 1992). To account for some of this variation old-growth juniper and pinyon woodlands may be characterized into old-growth, woodland types. Woodland types would be separated out by such factors as ecological province, major landscape features including geology, parent materials, and landform. In addition to these physical parameters structural characteristics would also be used to classify old-growth woodland types.

Table 1—Minimum structural attributes used by the U.S. Forest Service in both the southern Rocky Mountain and southwestern regions to identify old-growth pinyon-juniper stands (derived from Mehl 1992 and Popp and others 1992).

Live Trees	
Tree per acre	30
Diameter at root collar	12 inches, with variation in diameter
Age	200 years
Decadence present	Yes, dead, broken, or deformed tops and/or bole or root rot
Number of tree canopies	Single story
Other	Upper canopy trees are slow growing Variation in tree diameter Basal area of 23 square ft/acre
Dead Trees	
Standing	
Number per acre	1
Diameter at root collar	10 inches
Down	
Pieces	2 per acre (10 ft long segments)
Diameter	10 inches
Canopy closure	
Total canopy cover	35 percent

Ecological provinces can provide a first separation in the classification of old-growth woodlands accounting for some of the heterogeneity across the Intermountain West. From eastern Oregon to southeast Nevada and into Utah rainfall distribution varies from almost all of it arriving in the winter to where up to a third or more of the annual precipitation comes in the summer. From north to south the environmental gradient varies from the cold deserts surrounded by coniferous forests in Oregon and Idaho to mountain slopes in the south that are surrounded by the Mojave Desert. The combination of these environmental gradients with the basin and range topography of the Great Basin, creates considerable environmental variation (West and others 1978). This environmental variation has been divided into ecological provinces (fig. 1) based on the floristic regions of Cronquist and others (1972), the Ecoregions described by Bailey and others (1980 and 1994), and soil-plant relationships in Oregon described by Anderson (1956). Ecological provinces differ somewhat in climate, topography, geology and soils, however, similarities and dissimilarities of vegetation between provinces are not always clear. Depending on management objectives further separation of old-growth woodlands is necessary.

We are currently working on a classification system for old-growth woodlands. In the proposed classification we consider; (1) community type, based on ecological province, landform, dominant shrub, dominant grass, soils, and topography (derived from West and others 1997), (2) tree age composition and structure, and (3) composition of the understory (fig. 2). The approach allows the composition of the understory and overstory to be evaluated separately but

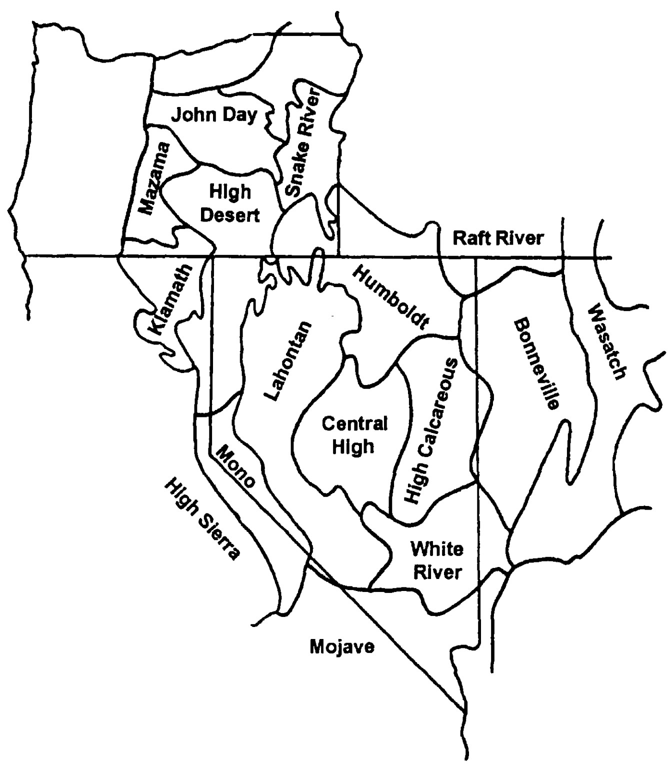

Figure 1—Ecological Provinces in the Intermountain West (derived from Anderson 1956, Cronquist 1972, and Bailey and others 1980, 1994).

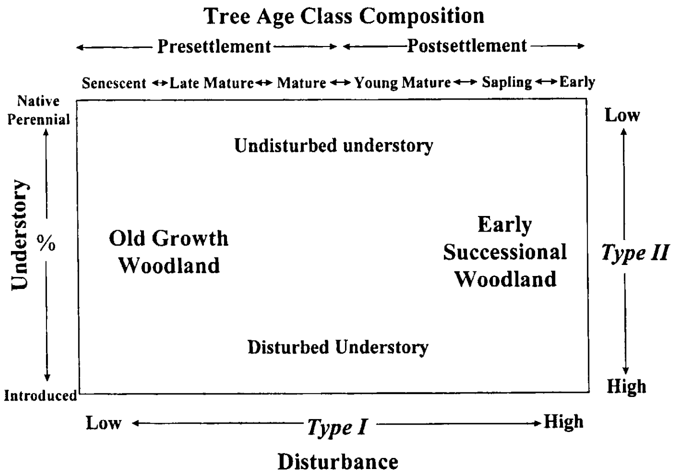

Figure 2—A conceptual model illustrating the range of possible conditions occurring within a juniper woodland type (modeled after Woodgate and others 1996). The horizontal axis represents composition of tree age classes. The vertical axis represents composition of understory species. Type I disturbances primarily affect the overstory age structure such as fire, cutting, land clearing, chaining. Type II disturbances influence understory composition and structure, such as grazing, off road vehicles, and land clearing.

combined for the classification. In central Oregon, old-growth woodlands are commonly found where the overstory canopy has changed little since settlement but the understory composition has been largely altered. The age of a stand, plotted along the horizontal axis, is based upon the proportion of tree age classes. Age classes currently proposed are presettlement; (1) standing dead, (2) senescent (>50 percent dead), (3) senescing 5-50 percent dead, (4) late mature (300+ yrs), mature (120-300 yrs); postsettlement, (5) young mature, (6) sapling (3-10 ft tall), and (7) juvenile (<3 ft tall). Abundance of down dead trees is also considered. (We are still working on age class definitions for western juniper). For mapping purposes, Woodgate and others (1996) suggested old-growth semi-arid stands in Australia consist of a minimum of 10 percent senescent trees and a maximum of 10 percent regrowth or young trees. For juniper woodlands that attain ages exceeding 1,000 years old it may be helpful to separate stands into several old-growth age classes. In western juniper, stands that are 150 to 300 years old may be structurally different than stands exceeding ages of 500 years.

Western Juniper (*Juniperus occidentalis* subsp. *occidentalis*)

This subspecies of western juniper is considered the northwestern representative of the pinyon-juniper woodland (Franklin and Dyrness 1973). The prehistoric record indicates the distribution and dominance of western juniper has greatly fluctuated during the past 5,000 years (Miller and Wigand 1994). Western juniper generally increased during periods of mild wet climate, declining with fire at the end of these wet periods. The pollen record indicates western juniper declined during the past 500 years prior to settlement. Old-growth stands in existence today are relicts of the extensive stands that characterized the landscape over the past 4,000 to 5,000 years. In contrast, stands that have established after the 1870s appear to be considerably more dense and to have developed under different environmental conditions than the presettlement stands which preceded them during the past 5,000 years.

In Oregon, estimates of less than 3 percent of the current 5 million acres of western juniper woodlands are characterized by trees >100 years old (USDI-BLM 1990). Although not well documented similar proportions of western juniper old-growth are probably found in northeastern California, northwestern Nevada, and southwestern Idaho. However, the proportion of pre- and post settlement trees varies across ecological provinces. Acreage of old-growth is not know since mapping and inventory of old-growth western juniper woodlands is limited throughout its range. In the southwest, the occurrence of old-growth woodlands is rare (Swetnam and Brown 1992).

Old-growth western juniper stands grow on soils derived from three major parent materials, located in six ecological provinces, the John Day, Mazama, High Desert, Snake River, Klamath, and Humboldt (fig. 1) Old-growth stand structure is typically uniquely different between the different provinces and parent materials. The igneous zone dominates most of the landscape in the High Desert and Klamath ecological provinces, and the Owyhee Plateau in the Humboldt province. Igneous rock is also the most abundant parent material in the southwestern portion of the Snake River province, where western juniper occurs. In these provinces old-growth juniper typically grows widely spaced on shallow, rocky, heavy clay soils, or rimrock supporting limited fine fuels to carry a fire. Juniper Mountain, in Harney and Lake Counties, is a unique example of dense old-growth woodlands growing on deep well-drained soils, which typically supports mountain big sagebrush steppe community types. Sedimentary soils, primarily found in the John Day province, support widely spaced old trees with little understory to carry fire. The aeolian sands in the Mazama and eastern edge of the High Desert provinces support the most extensive stands of old-growth western juniper woodlands.

Igneous Zone of the High Desert, Klamath, Humboldt, and Snake River Ecological Provinces

Presettlement juniper trees are typically found on rocky surfaces or ridges (fig. 3), and low sagebrush (*Artemisia arbuscula*) tablelands in the High Desert, Klamath, Humboldt, and Snake River Ecological Provinces (Vasek and Thorne 1977, West 1984, Miller and Rose 1995). The low sagebrush tablelands occupied by presettlement juniper trees (fig. 4) probably account for the greatest proportion of old-growth juniper across these provinces. Old-growth juniper probably accounts for less than 3 percent of the woodlands across these provinces. The dominant grass is

Figure 3—Ancient western juniper growing out of rock crevices covered by a few inches of soil.

typically *Poa sandbergii*, with *Festuca idahoensis* growing beneath the juniper tree canopies. These juniper low sagebrush tablelands often occupy extensive flats with less than 5 percent slope, although slopes can approach 30 percent. The rocky, shallow heavy clay soils are primarily of igneous (basalt, andesite, ryolite) origin. Although soils are shallow juniper roots often penetrate the fractured bedrock.

Tree canopy cover on the low sagebrush tablelands is highly variable and may approach 20 percent, but typically ranges below 5 percent. On the Devils Garden in northern California, 63 percent of trees aged ranged between 200 and 500 years old. The remaining 37 percent were older than 500 years (Miller unpublished data). However, many trees could not be aged due to rot. Tree densities in a majority of these low sagebrush tableland communities have increased during the past 100 years (Young and Evans 1981, Miller and Rose 1995, Miller and Rose submitted). Low presettlement tree densities in these communities can probably be attributed to limited tree establishment due to heavy clay soils, slow growth rates, and occasional fires. Lower CO_2 concentrations may have also attributed to slower rates of tree establishment prior to the 1900s (Farquhar, 1997). Occasional fires did burn across these low sagebrush Sandberg bluegrass community types (Young and Evans 1981, Miller and Rose submitted). In south central Oregon, two extensive presettlement fires burned across this type between 1700 and 1880 (Miller and Rose submitted). Mean fire intervals of 80 to 100 years were probably adequate to create a stand of widely scattered juniper trees. However, single tree lightening fires were probably more common occurrences across the juniper low sagebrush tablelands.

On the deeper igneous soils fire limited the development of old-growth western juniper woodlands (Miller and Wigand 1994). These soils typically support mountain big sagebrush steppe communities. Mean fire intervals between 12 and 25 years occurred in these shrub steppe communities (Houston 1973, Burkardt and Tisdale 1976, Martin and Johnson 1979, Miller and Rose submitted). However, Juniper Mountain located east of Alkali Lake in central Oregon is an exception (fig. 5) This site may serve as a model as to what most of the mountain big sagebrush type would have looked liked if fire had played a minor role in the sagebrush ecosystem. Preliminary work indicates the age of overstory trees range between 350 and 600 years. Understory trees 3 to 5 ft tall were between 100 and 200 years old. This is the only old-growth stand we have measured throughout the range of western juniper that meets the criteria of canopy cover (≥30 percent) defined by the U.S. Forest Service. On the north and northeast aspects tree canopy cover ranged between 35 and 50 percent. On south and southwest aspects tree cover ranged between 20 and 35 percent. Shrub cover accounted for less than 1 percent of the understory cover. Dominant herbaceous species were Idaho fescue (*Festuca idahoensis*) on the north aspects and Thurber needlegrass (*Stipa thurberiana*) on the south aspects.

Sedimentary soils in the John Day Ecological Province

Very little work has been conducted on old-growth juniper on these soils. The majority of these soils occupied by old-growth western juniper occur in the John Day province with limited amounts occurring in the High Desert and

Figure 4—Juniper low sagebrush Sandberg bluegrass tablelands. Tree canopy is usually sparse and trees are widely scattered.

Figure 5—Dense ancient western juniper woodland growing on the north aspect of Juniper Mountain, in eastern Oregon. Soils are deep loamy Argixerolls and Haploxerolls. Tree canopy cover varies from 40 to 60 percent.

Figure 6—Ancient western juniper tree growing on sedimentary soils in central Oregon.

Klamath provinces (fig. 1). These soils usually support a very low density of trees and sparse understory incapable of carrying fire (fig. 6). The accumulation of both down and standing dead and decadent trees on many of these sites indicates the presence of very old stands. Tree ages on these soils exceed 1,000 years. Dead trees may remain standing for hundreds of years. These old-growth stands probably account for less than 3 percent of the juniper woodland component.

Aeolian Sands in the Mazama and Western High Desert Ecological Provinces

The aeolian sand region is located in the Mazama and northwestern portion of the High Desert Ecological Provinces, just east of the Cascade Mountain range (fig. 1) This region supports the most extensive stands of old-growth western juniper woodlands (fig. 7). These old woodlands probably account for over 10 percent of the juniper woodlands in the Mazama Province. Soils in the Mazama Province are strongly influenced by Mazama pumice. In the northwest corner of the High Desert Province, sources of wind blown sands are primarily from Pleistocene lake beds, and Mount Mazama and Newberry Craters pumice. Stand structure varies across these provinces but are generally open with tree canopy cover typically ranging between 10 and 15 percent. Live tree density ranged between 15 and 25 per acre, standing dead ≤6 per acre, and down dead 1 to 7 per acre. Very slow decomposition rates allow for an accumulation of dead wood on these sites. Burned stumps and standing weathered trees can persist for hundreds of years. Tree ages are variable ranging between 200 and >1,000 years. Currently we have aged several trees ranging between 1,200 and 1,600 years old. Fires are typically small, burning single to several trees within a stand. However, old fire scars on these landscapes indicate occasional extensive fires burning in these stands. Idaho fescue, western needlegrass (*Stipa occidentalis*), and bluebunch wheatgrass (*Agropyron spicatum*) (primarily on the west and southwest aspects) frequently dominate the understory. However, in the Bend and Redmond area which lies below 5,000 ft, rabbitbrush (*Chrysothamnus* sp.) and cheatgrass (*Bromus tectorum*) will dominate the understory on sites that have been overgrazed or mechanically disturbed.

Figure 7—Old woodland growing on aeolian sands. Tree canopy cover is 15 percent and dominant understory grass is Idaho fescue or western needlegrass.

Wildlife Values

It is important that future wildlife work describes both woodland structure and stand age. Old-growth woodlands are typically more structurally complex than postsettlement woodlands. More than 80 species of animals use living trees with decay, hollow trees, snags and logs in the interior Columbia River Basin (Bull and others 1997). Although this report excluded juniper species, our breeding bird surveys show old-growth western juniper woodlands provide important habitat for many bird species. Preliminary results from our songbird surveys indicate an increase in cavity nesters in old-growth compared to postsettlement woodlands. Densities of cavity nesting mountain blue birds, red- and white-breasted nuthatches have been consistently greater in old stands. Some of our highest mountain blue bird counts also occur in shrub steppe communities adjacent to old-growth stands. Our lowest counts have been recorded in closed postsettlement stands. At this time we have no information on cavity densities or minimum tree ages where cavities are typically found. However, the greatest number of cavities typically occurs on trees greater than 400 years. Wood rats also commonly nest in the hollow trunks of western juniper. In addition to wood rats, the abundance and diversity of small mammals is typically greater than in postsettlement woodlands (Willis and Miller, this symposium).

During the winter a large abundance of frugivores, including western and mountain bluebirds, cedar waxwings, American robins, and townsend solitares have been reported in the extensive juniper stands in central Oregon in the Mazama Province (Contreas 1997). These stands are predominately open old-growth woodlands, with 15 percent or less canopy cover supporting good crops of juniper berries. Dense woodlands produce very few berries (Miller and Rose 1995). We have observed heavy berry crops on trees over 500 years old growing in relatively open stands. Tree density appears to have a greater effect on the potential berry production than tree age.

Western Juniper (*J. occidentalis* subsp. *australis*)

This subspecies of western juniper, found in the Sierra Nevada Mountains south of about 40 degrees north Latitude (High Sierra Ecological Province, fig. 1), is seldom present in woodlands. This subspecies, usually found on rocky and shallow soil areas, is typically associated with various montane conifer communities. Old junipers tend to be common in these open, mixed conifer forests. There are at least two relatively large areas where the sierra juniper is associated with singleleaf pinyon in woodland communities. One of these sites is in the lower drainage of the east and west forks of the Carson River east and south of Markleeville, California. These woodland areas are almost exclusively on rocky and shallow soil sites that have apparently greatly reduced fire frequency. Large areas of these woodlands, and possibly the majority, are old-growth communities dominated by large, old pinyon and juniper. The prehistoric record for these woodlands is unknown but because of their locations they may to be of relatively recent (late Holocene) origin.

Extensive singleleaf pinyon, western juniper (southern subspecies) woodlands also occur near the southern end of the Sierra Nevada Mountains. These are on large areas of rolling topography along the south fork of the Kern River, mostly the east side, from about Chimney Peak north to near Kennedy Meadows. Scattered occurrences of these woodlands may also be present along the east slopes of the Sierra Nevada Mountains above Owens Valley. Unlike stands further north, these are typical post-settlement woodlands dominated by younger trees, and their appearance resembles woodlands found throughout much of western Nevada. The proportion of old-growth in this location is unknown, but appears to be very limited. The prehistoric record of these woodlands is also unknown but appears to be largely of post-European settlement age.

Pinyon-Utah Juniper

Woodlands of the Great Basin of Nevada, western Utah, and eastern California cover a large land area (about 8 million hectares, 18 million acres) of considerable environmental complexity (Tueller and others 1979). The distribution, dominance, and species composition of these woodlands has seen even greater fluctuation over the last 5,000 years than the northern subspecies of western juniper. Pinyon, for example, was absent from most of Nevada and Utah during the Pleistocene and migrated into the area during the Holocene (Nowak and others 1994a,b). For some areas in western and northern Nevada, pinyon has been present for less than 2,000 years. The structure of the woodlands, and the overstory-understory competitive patterns are often different when pinyon is present than when it is absent.

Throughout the last 5,000 years woodland dominance has widely fluctuated and, following reduction during an extended drought, was slowly expanding over about a 400 year period prior to the mid nineteenth century (Wigand and others 1995). The rapid expansion that has occurred during the last century to century and a half (Tausch and others 1981, Tausch and West 1988) may be the largest of the Holocene. This expansion is continuing.

The environmental and topographic heterogeneity of provinces in the Great Basin of Nevada and Utah is generally greater than the provinces further north and east (fig. 1) Even though the ecological provinces of Nevada and Utah share many similar environmental conditions, there is a higher level of heterogeneity within as well as between, provinces (West and others 1979, West and others, in press). Soils are also highly variable, again both within and between provinces. Overall, the quantity of old-growth present is similar to the northern subspecies of western juniper, probably representing about 3 to 5 percent of the total woodland area. This is an approximation because past inventories have not distinguished between pre- and post settlement sites. For some ecological provinces the total may be higher.

There is some commonality between old-growth woodlands across provinces. However, the amount of old-growth present, woodland structure, where woodlands occur, and the environmental conditions that support these woodlands vary between provinces. There are two general conditions in which old-growth most commonly occurs in the Great Basin of Nevada and Utah. The first of these categories are old-growth locations with shallow soils, rocky conditions, and steep topography that were relatively fire safe prior to recent tree expansion. These physical factors reduced the occurrence of fire allowing for some form of old-growth structure to develop. However, these combination of site factors occur over a wide range of elevation, topography, and environmental conditions that affect the structure, function, and appearance of the associated old-growth woodlands. As a result, this is the most variable category of old-growth woodlands found in the region. With the recent expansion of the woodlands many of these old-growth locations are now succumbing to crown fires carried by the increased density of younger trees (Gruell, this symposium).

The second type of site resulting in old-growth woodlands are sites where disturbances such as fire occur with some regularity but fuel levels are generally low enough to allow some tree survival, particularly for juniper forming communities similar to savanna in structure. These are generally lower elevation areas with relatively level to rolling terrain that prior to the recent tree expansion were open savannas with scattered older trees. Although the environmental heterogeneity is less than for the first type of site, considerable variation in conditions still exits within this category. The amount present also varies between ecological province. Here also the recent tree expansion, plus the increasing presence of invading annuals, is changing fuel conditions leading to the increasing loss of this type of old-growth by wildfire.

High Desert and Mono Ecological Provinces

These two provinces comprise the mountain ranges immediately east of the Sierra Nevada-Cascade Mountain chain and west of the Lahontan basin (fig. 1). Precipitation in this province comes almost entirely in the winter. With the exception of a few scattered locations of singleleaf pinyon at the far south end, the woodlands of the High Desert Ecological Province contain only juniper (West and others 1978). In Oregon it is the northern subspecies of western juniper. In the south of the High Desert Province Utah juniper dominates the woodlands. By contrast, the Mono Ecological Province is dominated by singleleaf pinyon, and over large areas the woodlands contain only singleleaf pinyon (West and others 1978, West and others, in press). Old-growth woodlands of both categories occur throughout both of these provinces. Although rare, some very old (1,000 years old plus) juniper old-growth woodlands are present in the Mono Ecological Province.

The fire-protected category of old-growth sites appears to be more common than sites in the savanna category. Some large areas of old-growth juniper woodland occur on high mountain areas in the High Desert Ecological Province in Nevada that contain a good understory dominated by bluebunch wheatgrass (Tausch and others 1995). Large areas of old-growth pinyon woodlands, but with less understory (Robin Tausch and Robert Nowak, unpublished data), are found growing in similar environmental and topographic conditions in the Mono Ecological Province. In both provinces old-growth probably represents less than five percent of the total woodland area, but more locally its representation can be higher.

Lahontan Ecological Province

The Lahontan Basin is an open, low elevation area that extends north south through western Nevada from the Oregon border south to the Mojave Desert. Precipitation comes almost entirely in the winter. Woodlands on the mountain ranges in the northern half of this province are mostly Utah junipers, although scattered locations of western juniper and pinyon are present (Charlet 1996). In the southern portion the woodlands are either singleleaf pinyon dominated, if it is present, or have only Utah juniper. Two notable examples of mountain ranges with woodlands containing only juniper are the Pilot and Cedar Mountains east of Mina, Nevada. Mountain ranges to the immediate north, south, east, and west are pinyon dominated. As pinyon migrated into this Province in the mid Holocene the Pilot and Cedar Mountains.

Although both categories of old-growth woodlands occur in this ecological province, the savanna type is probably the most common. This occurs because of the aridity of the region from the rain-shadow of the Sierra Nevada Mountains, and the generally low elevations compared to surrounding provinces. Even in the higher elevation portions of the mountain ranges present, the woodlands are often more open with generally scattered trees. Maybe 10 percent of the woodlands in this province are old-growth. Essentially all the rest are post-settlement in age.

High Central and High Calcareous Ecological Provinces

These two Ecological Provinces, overall, represent the highest elevation areas of the Great Basin of Nevada and Utah. Some valley floors in the area exceed 7,000 ft and many of the highest peaks exceed 10,000 ft, with the highest over 13,000 ft (West and others 1978). Geology of the High Central Ecological Province is mostly of igneous origin. Limber Pine is the only other relatively common conifer in the area. Geology of the High Calcareous Ecological Province is mostly of sedimentary origin with a high abundance of limestone and dolomite present. This latter province has several species of conifer that are common in addition to pinyon and juniper (Charlet 1996).

Juniper was probably very restricted in its distribution, and possibly absent in much of the area, during the Pleistocene. Pinyon was entirely absent, not arriving in the area until or after about 6,000 years B.P. (Nowak and others 1994a,b). The majority of the old-growth in these two provinces is in the first category, and found most often on steep mountain slopes, generally with south and west aspects. This old-growth is predominantly pinyon dominated or pure pinyon. Some isolated locations of juniper old-growth are present on these upper elevations. Some Rocky Mountain junipers are scattered through the High Calcareous Ecological Province. This species often occurs along stream channels and in the highest elevations of the woodlands. Savanna type old-growth on the Bajadas and lower foothills are predominantly juniper dominated or only juniper is present. Old-growth of any type is rare, probably less than three percent of the total. All types of old-growth are increasingly at risk for loss by wildfire from both the recent increase in tree density and dominance, and the increasing prevalence of exotic annuals, particularly cheatgrass.

Bonneville Ecological Province

The Bonneville Basin is the eastern equivalent of the Lahontan Basin in the west. During the Pleistocene this basin had the largest lake in the region, Lake Bonneville. Shadscale desert covers large areas, isolating the mountain ranges that are present. This area is also rainshadowed by the higher mountains to the west. Summer precipitation increases in importance eastward across the region. The majority of the woodlands in this area have a high presence of juniper. Extensive areas of juniper savanna are present, and a large part of it is old-growth. Most of the old-growth is in the savanna category. Old-growth in the first category has rare occurrences on the higher mountains in the region. On average, the oldest pinyon and juniper in the Great Basin of Nevada and Utah are generally found in this province (Tausch and others 1981). Old-growth may exceed 10 percent of the total woodland area in this province. In the eastern half of the province hybrids between singleleaf and Colorado pinyon are present.

Humboldt and Raft River Ecological Provinces

Both of these provinces represent a transition zone of generally decreasing elevation between the high basin and range topography to the south, and the Snake River Plains to the north. Woodlands in the Humboldt Ecological Province are almost exclusively juniper, mostly Utah to the south and western juniper to the north (West and others 1978, Charlet 1996). The scattered pinyon that are present in the Humboldt province are only along the southern fringe of the area. The southern half of the Raft River Ecological Province has large areas of woodlands with mixed singleleaf pinyon and juniper. In the northern half the woodlands contain only juniper.

Old-growth Utah juniper is rare in these provinces, probably less than three percent of the total. The majority of the rest of the woodlands are post-settlement in age. Both categories of old-growth are present but their relative abundance needs to be determined.

White River Ecological Province

This province is a transition of decreasing elevation southward from the higher mountains and valleys of eastern and central Nevada down to the Mojave Desert. The southeastern portion of this province can get about a third or more of its rainfall in the summer. Woodlands are found from the upper elevations of the mountains down to, and in some places in the eastern half, out onto the valley floors. Further west woodlands are more confined to the mid to upper elevations of the mountain ranges. Both categories of old-growth woodlands are present within this province. Large areas of former savanna on the valley floors and foothills have seen a strong increase in tree density from the recent expansion. Many of these areas are now experiencing intense crown fires that consume both the pre- and the post-settlement trees.

The highest mountain ranges have areas of old-growth on steep, rocky slopes. The south ends of the White River and Lahontan Ecological Provinces represent some of the most environmentally variable woodlands in the region. They have the highest diversity of plant species in woodlands of the Great Basin of Nevada and Utah (Tueller and others 1979, West and others 1978). This apparently results from their position of transition between the high mountains and valleys to the north and the Mojave Desert to the south. Climatic fluctuations throughout the Pleistocene and the Holocene has resulted in the migration of many plant species through these provinces (Nowak and others 1994a,b).

Wasatch Ecological Province

This province includes the west slopes of the Wasatch Front and the mountain ranges immediately to the west. Woodlands in this province have considerable floristic affinity with the Wasatch and Rocky Mountains. Most of the pinyon present is Colorado pinyon with the presence of some hybrids with singleleaf (possibly California) pinyon in the western edge of the province. Pinyon is also present primarily in the southern half of the province. Juniper is the most common tree in the woodlands of the northern half.

Old-growth is limited in this province, probably less than two percent of the total. The majority of what is present is probably in the first category of sites that are relatively safe from fire.

Mojave Ecological Province

Woodlands in this province exist on the upper elevations of the higher mountain ranges that are like islands scattered through a sea of desert. The lowest valley elevations in the continental United States occur in this province, such as, Death Valley. Rainfall is almost exclusively in winter. Some of the valley locations in this province were refuges for singleleaf pinyon during the Pleistocene (Nowak and others 1994a,b). Despite the overall aridity of the region, all except the lowest elevations tend to be dominated by singleleaf pinyon. In addition to Utah juniper the highest ranges, such as the Spring and Sheep Ranges, also have scattered locations of Rocky Mountain juniper in their woodlands. Old-growth of both the fire safe and savanna categories is present throughout the region. Old-growth tends to be more common on lower elevation ranges than higher elevation ranges where the recent tree expansion has been more dominant. The savanna type of old-growth may also be more common. Overall, the amount of old-growth is low, but unknown. A large part of this province is within the boundaries of the Nevada Test Site.

Management Considerations

Before we can address how we should manage old-growth woodlands in the Intermountain West we must ask the question what should these old-growth stands be managed for? Old-growth juniper and pinyon woodlands make up a small percentage of the juniper and pinyon woodland. They are structurally and topographically more complex than the younger more abundant woodlands, adding biological diversity to the landscape and providing an important source of habitat for many organisms. Many of these stands are also very esthetically pleasing providing recreational, cultural and spiritual opportunities. Kaufmann and others (1992) states; "old-growth provide us with a tremendous opportunity for retaining or enhancing biological features unique to old-growth ecosystems." We should evaluate fire policies influencing these old stands including both fire suppression and let burn. Recent changes in overstory and/or understory can alter the response of these communities to fire. However, continued fire suppression in some woodlands may increase the potential for large stand replacement fires. Fuel woodcutting also appears to be a rather wasteful use of this limited resource, unless cutting is designed to remove postsettlement trees and restore presettlement stand structure.

Studies are needed to determine and describe the range of old-growth characteristics throughout the Intermountain West. Mapping and inventorying old-growth woodlands is extremely important for developing management and land-use plans. Development of and old-growth woodland classification system used in inventories would prove helpful in developing management plans. We also need information on gap dynamics, tree mortality, and succession following disturbance. This information will allow us to predict how woodlands respond to disturbance. It will also allow us to evaluate pre- and postsettlement changes in community structure and composition that have occurred in old-growth stands, define desired future conditions, and develop management programs to restore or maintain old woodlands. Old-growth woodlands can not be managed on a single tree basis but only at the community and landscape levels to be successful. These old stands are an important landscape component in the Intermountain West, supporting many plant and animal species, and interacting with adjacent plant community types.

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References

Anderson, E.W. 1956. Some soil-plant relationships in eastern Oregon. Journal of Range Management 9:171-175.

Bailey, R.B. and others. 1994. Ecoregions and subregions of the United States. Map USDA Forest Service, Washington D.C.

Bailey, R.B. 1980. Description of the Ecoregions of the United States. USDA Forest Service Misc. Publication 1391.

Bull, E.L. C.G. Parks, and T.R. Torgersen. 1997. Trees and logs important to wildlife in the interior Columbia Rive Basin. USDA Forest Service General Technical Report PNW-GTR-391.

Burkhardt, J. W., and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 76:2-484.

Charlet, D.A. 1996. Atlas of Nevada conifers: a phytogeographic reference. University of Nevada Press, Reno, NV 320p.

Contreras, A. 1997. Northwest birds in winter. Oregon State University Press, Corvallis, OR.

Cronquist, A., Holmgren, A.H., Holmgren, N.H., and Reveal, J.L. 1972. Intermountain Flora: Vascular Plants of the Intermountain west, USA. Volume I: Geological and botanical history of the region, its plant geography and a Glossary. New York Botanical.

Farquhar, G.O. 1997. Carbon dioxide and vegetation. Science 278:1411.

Franklin, J.F. and C.T. Dyrness. 1988. Natural vegetation of Oregon and Washington. Oregon State University Press.

Franklin, J.F. and T.A. Spies. 1986. The ecology of old-growth Douglas-fir forest. Oregon Birds. University of Oregon Press, Eugene, OR. Garden and Hafner Publishing Co., Inc. New York.

Gruel, G. 1998. This symposium. Pre- and Post- settlement patterns and outcome of fire in pinyon/juniper woodlands. In: Houston, D. B. 1973. Wildfires in northern Yellowstone National Park. Ecology 54:1109-1117.

Kaufmann, M.R., W.H. Moir, and W.W. Covington. 1992. Old-growth forests: What do we know about their ecology and management in the southwest and Rocky Mountain regions. In: Old-Growth Forests in the Rocky Mountains and Southwest Conference, Portal, AZ.

Martin, R. E., and A. H. Johnson. 1979. Fire management of Lava Beds National Monument. Pages 1209-1217. In: R. E. Linn, ed. Proceedings of the First Conference of Science and Research in the National Parks. USDI National Parks Service. Transactions Proc. Serial No. 5.

Mehl, M.S. 1992. Old-growth descriptions for the major forest cover types in the Rocky Mountain region. In: Old-Growth Forests in The Rocky Mountains and Southwest Conference, Portal, AZ.

Miller, R. F. and J. A. Rose. 1995. Historic expansion of Juniperus occidentalis (western juniper) in southeastern Oregon. Great Basin Naturalist 55:37-45.

Miller, R.F. and P.E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioScience 44:465-474.

Miller, R.F. and J.A. Rose. (submitted). Fire history and *Juniperus occidentalis* Hook. encroachment in Artemisia steppe. American Midland Naturalist.

Moir, W.H. 1992. Ecological concepts in old-growth forest definition. In: Old-Growth Forests in the Rocky Mountains and Southwest Conference, Portal, AZ.

Nowak, C.L., Nowak, R.S., Tausch, R.J., and Wigand, P.E. 1994a. A 30,000 year record of vegetation dynamics at a semi-arid locale in the Great Basin. Journal of Vegetation Science 5:579-590.

Nowak, C.L., Nowak, R.S., Tausch, R.J., and Wigand, P.E. 1994b. Tree and shrub dynamics in northwestern Great Basin woodland and shrub steppe during the Late-Pleistocene and Holocene. American Journal of Botany 81:265-277.

Popp, J.B., P.D. Jackson, and R.L.Basset. 1992. Old-growth concepts from habitat type data in the southwest. In: Old-Growth Forests in the Rocky Mountains and Southwest Conference, Portal, AZ.

Swetnam, T.W. and P.M. Brown. 1992. Oldest known conifers in the southwestern United States: temporal and spatial patterns of maximum age. In: Old-Growth Forests in the Rocky Mountains and Southwest Conference, Portal, AZ.

Tausch, R.J., West, N.E., and Nabi, A.A. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management 34:259-264.

Tausch, R.J., and West, N.E. 1988. Differential establishment of pinyon and juniper following fire. American Midland Naturalist. 119:174-184.

Tausch, R.J., and N.E. West. 1988. Differential establishment of pinyon and juniper following fire. American Midland Naturalist. 119:174-184.

USDA Forest Service. 1993. Interim old growth definition. Region 6.

USDI-BLM. 1990. The juniper resources of eastern Oregon. USDA, Bureau of Land Management, Information Bulletin, OR-90-166.

Tausch, R.J., Chambers, J.C., Blank, R.R., and Nowak, R.S. 1995. Differential establishment of perennial grass and cheatgrass following fire on an ungrazed sagebrush-juniper site. In: Roundy, B.A., McArthur, E.D., Haley, J.S., and Mann, D.K. Compilers. Proceedings, wildland shrub and arid land restoration symposium, 1993 October 19-21, Las Vegas, NV. Gen. Tech. Rep. INT-GTR-315. USDA Forest Service, Intermountain Research Station: 252-257.

Terry, R.G., Tausch, R.J., Nowak, R.S., Shulka, N.C., Lahood, E.S., and Keim, P. In press. Genetic structure and relationships among populations of Utah (*Juniperus osteosperma*) and western (*Juniperus occidentalis*) juniper: evidence from nuclear ribosomal and chloroplast DNA. Great Basin Naturalist.

Tueller, P.T., Beeson, C.D., Rausch, R.J., West, N.E., Rae, K.H. 1979. Pinyon juniper woodlands of the Great Basin: Distribution, flora, vegetal cover. USDA Forest Service, Intermountain Research Station, Ogden Utah. Research Paper INT-229.

Vasek, F.C. 1966. The distribution and taxonomy of three western junipers. Brittonia. 18:350-372.

Vasek, F.C. and R.F. Thorne. 1977. Transmontane coniferous vegetation. Pages 797-832. In: Barbour, M.G. and J. Major eds. Terrestrial vegetation of California. California Native Plant Society. Special Publication No. 9.

West, N.E., Tausch, R.J., Rae, K.H., and Tueller, P.T. 1978. Phytogeographical variation within juniper-pinyon woodlands of the Great Basin. In: Intermountain Biogeography: A symposium. Great Basin Naturalist Memoirs 2:119-136.

West, N.E., Tausch, R.J., Rae, K.H., and Southard, A.R. 1979. Soils associated with pinyon-juniper woodlands of the Great Basin. In: Youngblood, C.T. (Ed.). Forest Soils and land use. Proceedings North American Soils Conference, Colorado State University, Fort Collins Co. Pp. 68-88.

West, N.E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. Pages 1301-1332. In: Developing strategies for rangeland management. National Research Council/National Academy of Sciences. Westview Press, Boulder, CO.

West, N.E., Tausch, R.J., and Tueller, P.T. In press. A management-oriented classification of pinyon-juniper woodlands of the Great Basin. General Technical Report, USDA Forest Service, Rocky Mountain Research Station, Ogden UT.

Wigand, P.E., Hemphill, M.L., Sharpe, S.S., and Patra. S. 1995. Great Basin semi-arid woodland dynamics during the late Quaternary. In: climate change in the Four Corners and adjacent regions: Implications for environmental restoration and land-use planning. U.S. Department of Energy, Grand Junction CO. Pp. 51-70.

Woodgate, P.W., B.D. Peel, J.E. Coram, S.J.Farrell, K.T. Riman, and A.Lewis. 1996. Old-growth forest studies in Victoria, Australia concepts and principles. Forest Ecology and Management 85:79-94.

Young, J.A., and R.A. Evans. 1981. Demography and fire history of a western juniper stand. Journal of Range Management. 34: 501-506.

Conversion of Shrub Steppe to Juniper Woodland

Rick Miller
Tony Svejcar
Jeff Rose

Abstract—Juniper woodlands are frequently treated generically in management, wildlife studies, and environmental issues. Western juniper grows on a broad variety of soils and terrain, creating a high degree of spatial variability in stand structure and function. Stand heterogeneity can also be attributed to temporal or successional differences in shrub steppe conversion to juniper woodlands. During conversion a threshold is crossed which moves the shrub steppe community to a new steady state driven by different ecological processes. It is important to recognize both spatial and temporal heterogeneity when evaluating habitat suitability, predicting potential resource problems related to stand development, developing management plans, and setting priorities.

Over 8 million acres of sagebrush steppe are in various stages of conversion to western juniper woodlands (*Juniperus occidentalis* spp. *occidentalis*) in the semi-arid Intermountain Northwest (Miller and Wigand 1994). The rapid conversion of shrub steppe to western juniper woodlands (Burkhardt and Tisdale 1976, Young and Evans 1981, Miller and Rose 1995) has occurred across a wide variety of sagebrush communities, soils, and topography since the 1880s. The combination of spatial and temporal diversity creates a vast array of structurally different juniper communities, many of which are changing. Juniper woodland function and structure changes across different soils, landscape positions, and stages of development. During woodland development, low densities of trees in the early phases of encroachment add structural heterogeneity to shrub steppe community types. However, as woodlands continue to develop, tree function changes with size, distribution, and density. As woodland function and structure shift across varying landscapes and stages of development there are significant affects on community composition, diversity, and associated soils. Wildlife habitat suitability is also altered across time and space.

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Juniper woodlands have often been treated generically during the development of management plans, defining wildlife values, and debates relating to the benefits or problems of these communities. The illusion of a homogeneous landscape is created as tree canopies close. The majority of wildlife studies and inventories in the Intermountain West have not considered the wide variation of structure and function of woodlands across community types and in different successional stages. Spatial and temporal heterogeneity generally have not been taken into account when considering the impacts of woodland development on erosion, loss of understory, or plant diversity. It is very important to identify the community type, stage of woodland development, and thresholds for developing management plans, setting priorities, determining the best management tools to use, evaluating wildlife habitat values, and determining the effects of no action.

This paper will present preliminary results and discuss several concepts relating to the conversion of shrub steppe communities to western juniper woodlands. Specific objectives are to: (1) describe the different phases of shrub steppe conversion to juniper woodland, (2) discuss thresholds that are crossed during the conversion of shrub steppe to woodland, and (3) describe the affects of spatial variability on woodland development.

Study Area

The conversion of shrub steppe to juniper woodlands was studied in both the High Desert and Klamath ecological provinces of eastern Oregon and northeastern California (fig. 1). Climate is cool and semiarid, characteristic of the northern Great Basin. Annual precipitation in the western juniper woodland zone typically ranges from 12 to 16 inches. Most of the moisture is received as snow in November, December, and January and as rain in March through June. Summers are usually dry. Soils in these two provinces are primarily derived from igneous materials such as basalt, andesite and ryholite. The largest area of woodland conversion is in mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*) and low sagebrush (*A. arbuscula*) steppe communities. However, western juniper encroachment also occurs in basin big sagebrush (*A. tridentata* spp. *tridentata*), bitterbrush (*Purshia tridentata*), mountain mahogany (*Cercocarpus ledifolius*), aspen (*Populus tremuloides*), and riparian communities.

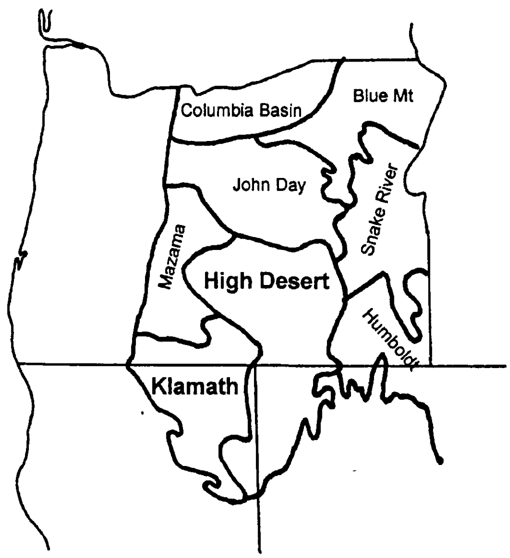

Figure 1—Ecological provinces in the Intermountain northwest region where western juniper occurs (derived from Anderson 1956 and Bailey et al. 1994).

Methods

Plant community composition, and soils were measured in a 160 macroplots, 60 x 45 m, across the two ecological provinces. We collected a representative sample of community types characterizing this region within the western juniper belt in different stages of woodland conversion. Juniper cover was measured along three 60 m line intercepts within each macroplot. Tree density was recorded in three 60 x 6 m rectangular plots. Shrub cover was measured along three 30 m line intercepts and density determined in 30 x 2 m plots. Both density and cover of herbaceous species were recorded in 0.20 m^2 plots placed at 3 m increments along the three 60 m transects. Soils were described for each macroplot and samples collected for textural analysis. Elevation, aspect, and slope were also measured.

Discussion

Temporal Change

Several thresholds may be crossed as juniper woodlands develop. Once a threshold is crossed the probability of a community returning to a previous state is very low. The conceptual model in figure 2 illustrates the conversion of shrub steppe communities to juniper woodland in the absence of fire. The perennial forb-grassland and shrub steppe communities are a fire driven system. During the early phases of woodland development, transition is reversible.

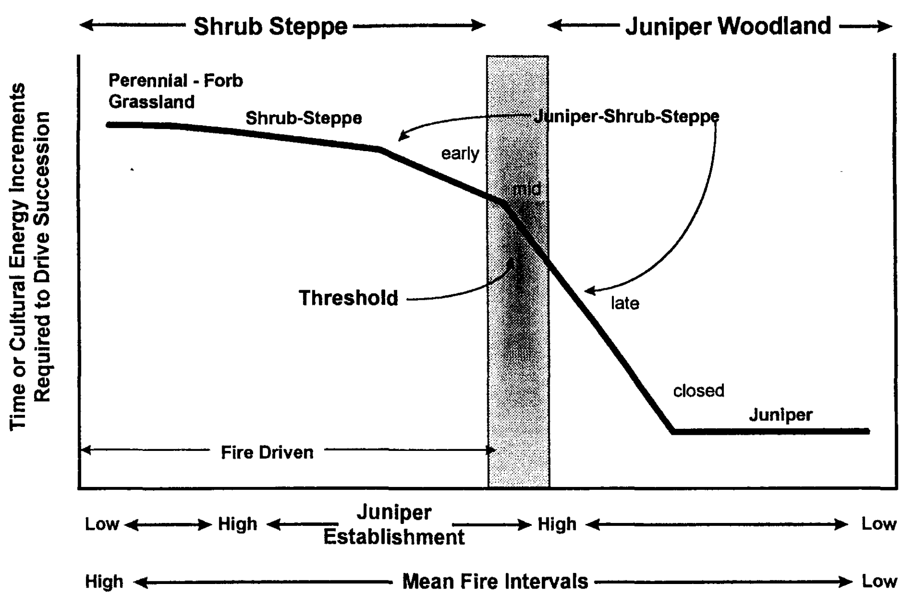

Figure 2—Conceptual diagram of changes in a shrub steppe community in the absence of fire (modeled after Archer 1989). In the absence of fire the abundance of shrubs decline as juniper trees gain dominance. The threshold has been crossed when understory fuels drop to a level where fire is unlikely to carry through the stand or generate enough heat to kill trees > 10 ft tall. The probability of the woodland crossing the threshold and reverting back to shrub steppe is very low in the absence of a major disturbance or very costly inputs.

However, by mid to late stages of transition a threshold is crossed where the reversal to shrub steppe communities is unlikely. Shrubs begin dying out as woodlands approach mid development, in mountain big sagebrush community types. As shrubs decline in the understory the probability of a fire event intense enough to kill large juniper trees rapidly declines.

Presettlement fire return intervals in mountain big sagebrush were frequent enough to maintain shrub steppe community types. Fire return intervals in these communities usually ranged between 10 and 25 years (Houston 1973, Burkhardt and Tisdale 1976, Martin and Johnson 1979, Miller and Rose in press). Trees less than 10 ft tall are easily killed by fire (Bunting 1984). It usually requires 40 to 50 years for a western juniper to attain this height in mountain big sagebrush community types (Miller and Rose 1995). The maximum hazard function (100 percent probability that a fire will occur within a defined time period) prior to 1880 was 45 years in a mountain big sagebrush community type in south central Oregon (Miller, unpublished data). However, the maximum hazard function for many newly formed juniper woodlands is 1,000 years. In low sagebrush-Sandberg bluegrass (*Poa sandbergii*) community types tree establishment and growth rates are limited in the shallow heavy clay soils. One fire every 100 to 150 years were adequate to maintain a widely scattered stand of juniper in these communities.

The state of woodland transition can be identified by structural characteristics of the woodland (table 1). Tree canopy cover and density alone have limited value as indicators of stand closure (the point where the site is fully occupied by juniper) since tree abundance is highly variable across community types. Sites with naturally low productivity will reach stand closure at lower juniper canopy cover and density than a more productive site. However, tree growth characteristics and shrub vigor are good indicators of the early stages of stand closure. Leader growth on dominant and understory trees is probably the best indicator for degree of stand closure for the site. The reduction in leader growth on trees less than 10 ft tall is due to intra-specific competition from larger neighboring trees. Prior to stand closure shrubs begin dying near the base and directly adjacent to large juniper trees. Shrubs begin thinning in the inner space during the early phases of stand closure (late-mid to early late woodland development), about the same time as understory tree leader growth becomes suppressed. At this stage of juniper woodland development shrub steppe community characteristics in the understory quickly change. During the later stages of woodland development tree recruitment declines due to changes in seed production and community structure. As intra-specific competition between trees increases, seed production declines and the ratio of male:female trees increases. This reduces seed rain from within the stand although birds, the primary seed dispersers of juniper berries, can easily bring in seed from outside sources. However, micro sites provided by shrubs for juniper seedling establishment decline during the later stages of woodland development. Shrubs are an important structural component for the germination and establishment of juniper seedlings (Miller and Rose 1995).

Crossing the threshold in juniper woodlands results in a significant reduction in the role of fire. On many sites, crossing the threshold may result in a loss of native herbaceous species (fig. 3), the potential loss of surface soil, and the loss of mast crops for wildlife. However, site factors such as soil depth and texture, the presence of shallow hardpans, slope, and aspect influence the effects of juniper competition on understory vegetation and soils. Grazing and fire suppression are the two primary management activities that have influenced junipers' interaction with the herbaceous understory. Below about 5,000 feet in elevation, poor grazing management can hasten the abundance of exotic

Table 1—Structural characteristics that change during the conversion of mountain big sagebrush community types to fully developed western juniper woodlands.

Characteristics (Post settlement stands)	Early	Mid	Late	Closed
Leader growth (Dominant trees)	Good terminal and lateral growth	Good terminal and lateral growth	Good terminal growth, reduced lateral growth	Good to reduced terminal growth, lateral growth absent
Tree Canopy	Open, actively expanding cover ≤ 5 percent	Actively expanding, cover 6 to 20 percent	Canopy expansion greatly reduced, cover 21-35 percent	Canopy expansion stabilized, cover > 35 percent
Crown Lift (Dominant Trees)	Absent	Absent	Lower limbs beginning to die (for productive sites)	Lower limbs dead (for productive sites)
Potential berry production	Low	Moderate to High	Low to Moderate	Nearly absent
Potential Tree Recruitment	High	High	Reduced	Nearly absent
Growth (Understory trees)	Good terminal and lateral growth	Good terminal and lateral growth	Greatly reduced terminal and lateral growth; reduced ring growth	Leader growth absent, some mortality, limited ring growth
Shrub Layer	Intact	Nearly intact to dying canopies around dominant trees	≥ 40 percent dead	≥ 85 percent dead

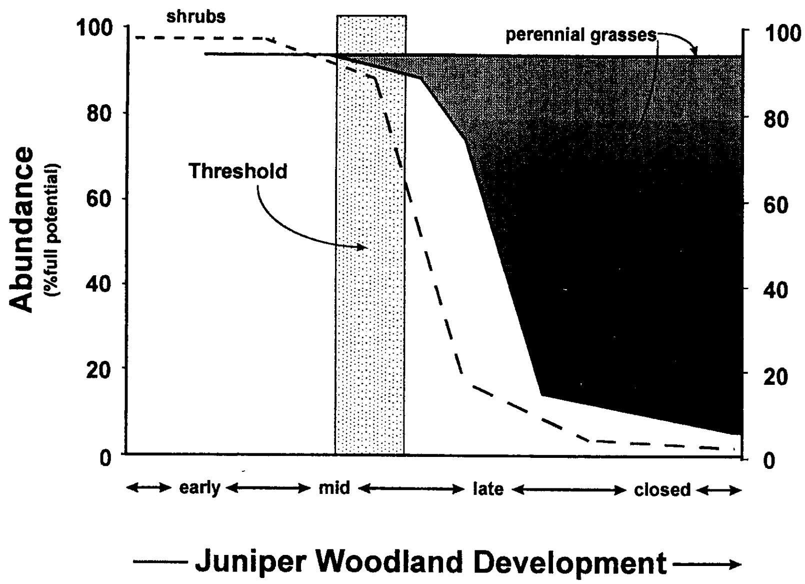

Figure 3—Conceptual model illustrating the change in abundance of perennial grasses and shrubs during the conversion of shrub steppe to juniper woodland. The affect of juniper woodland succession on grass abundance is variable, dependent upon site factors (soils, aspect, etc.). The shaded area between the perennial grass line, during mid to closed stages of woodland development, illustrate the different levels of grass abundance that occurs across different sites.

annuals. Above 5,000 feet exotic annuals are less abundant, but poor grazing management can reduce herbaceous cover and increase the amount of bare ground. The loss of soil during woodland conversion is particularly acute on south slopes that have been improperly grazed.

As woodlands develop, the threshold of habitat suitability for certain wildlife species is also crossed. Horned larks, vesper sparrows, brewers sparrows, sage thrashers, and sage grouse decline during the mid to late stages of woodland development (Eastern Oregon Agricultural Research Center unpublished data). The lowest abundance of mountain bluebirds occurred in closed juniper stands in contrast to the highest counts that occurred in open old growth juniper woodlands, and sagebrush steppe communities adjacent to old growth woodlands.

Spatial

Western juniper occurs across a wide array of soils within the two provinces including Durargids and Haplargids commonly characterizing the low sage community types, and Druixerolls, Argixerolls and Haploxerolls in the mountain big sagebrush community types. Soil suborders vary from aridic, lithic, typic and pachic and soil temperature regimes range from mesic to frigid. Soil textures vary from 80 percent clay content on juniper low sage tablelands to 80 percent sand in the aeolian sand region. Soil depths vary from zero on fractured rock to deep Haploxerolls commonly found on mountain big sagebrush/snowberry (*Symphoricarpos oreophilis*)/Columbia needlegrass and aspen community types.

Western juniper occurs across a large number of plant community types in the High Desert and Klamath ecological provinces (table 2). Plant community structure in fully developed woodlands varies across and within community types. Tree canopy cover measured within community types for fully developed woodlands ranged between 20 percent in low sagebrush/Sandberg bluegrass to over 90 percent in aspen community types (fig. 4). Vertical lines in figure 4 are anticipated ranges of maximum juniper cover within different community types based upon our observations. Tree numbers were also highly variable in fully developed woodlands across community types (fig. 5). Density of mature trees varied from 50 per acre in low sagebrush to over 300 per acre in mountain big sagebrush/Columbia needlegrass. In mountain big sagebrush community types with clay to clay loam soils and argillic horizons, average densities of mature trees typically ranged between 120 to 200 per acre. Tree densities were usually over 250 per acre on deep loams with weak to absent argillic horizons. These productive community types are typically positioned on northerly aspects. Densities of mature juniper trees in aspen stands converted to juniper woodland were over 700 per acre.

We are currently analyzing the herbaceous cover data across the plots to determine the relationship of juniper and environmental variables on understory composition and structure. A consistent response across all plots is the decline in mountain big sagebrush with the increase in western juniper (fig. 3). However, preliminary results indicate the response of perennial grass and forb cover to juniper cover is inconsistent across and within community types. The shaded area in Figure 3 represents the full range of

Table 2—Plant community types commonly invaded by western juniper in the High Desert and Klamath ecological provinces in southeastern Oregon and northeastern California.

Dominant shrub	Co-dominant shrub	Dominant grass
Low sagebrush		Sandberg bluegrass
Low sagebrush		Bluebunch wheatgrass
Low sagebrush		Idaho fescue
Basin big sagebrush		Basin wildrye
Basin big sagebrush		Thurber needlegrass
Mountain big sagebrush		Thurber needlegrass
Mountain big sagebrush		Bluebunch wheatgrass
Mountain big sagebrush		Idaho fescue
Mountain big sagebrush		Columbia needlegrass
Mountain big sagebrush	Bitterbrush	Thurber needlegrass
Mountain big sagebrush	Bitterbrush	Bluebunch wheatgrass
Mountain big sagebrush	Bitterbrush	Idaho fescue
Mountain big sagebrush	Snowberry	Idaho fescue
Mountain big sagebrush	Snowberry	Columbia needlegrass
Curleaf mountain mahogany		Idaho fescue
Aspen		

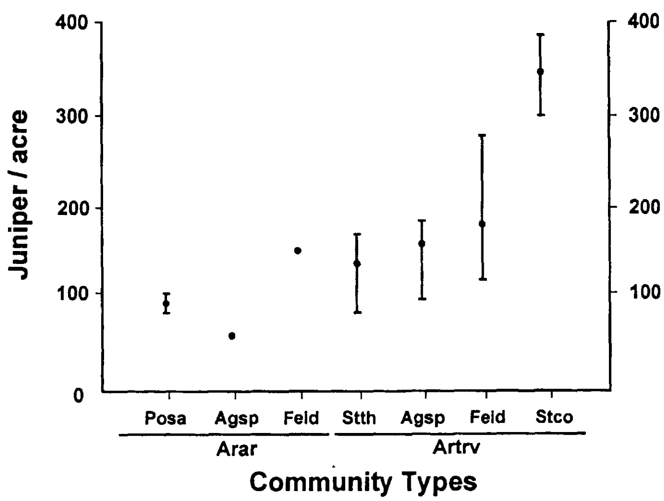

Figure 4—Percent juniper canopy cover for fully developed woodlands across different community types. Communities were designated as fully developed woodlands based on the criteria in table 1. Each point represents one 60 x 45 m plot. Vertical lines drawn through the points are anticipated ranges of maximum juniper canopy cover for each community type.

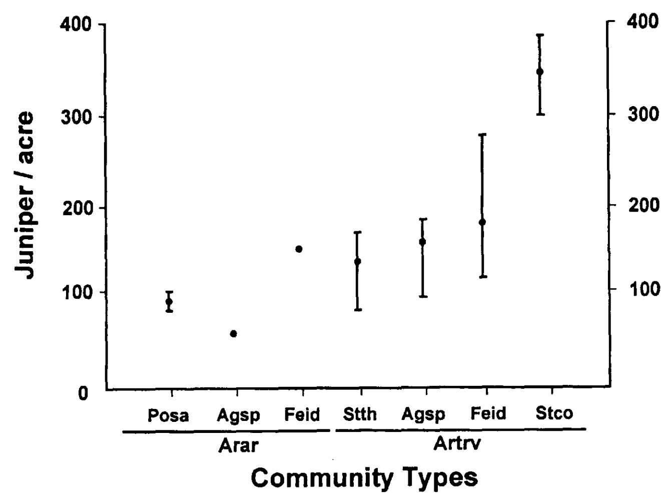

Figure 5—Density of mature juniper trees (near full height) for fully developed woodlands across different community types. Criteria in able 1 were used to determine stands that were fully developed woodlands. Points are means and lines represent range between maximum and minimum points occurring on plots within types.

changes in perennial grass abundance influenced by juniper woodland development across different sites. As mentioned previously, site variables appear to influence the impact of increasing juniper cover on perennial grass cover. Perennial grass cover was little affected by increasing juniper dominance on deep well-drained soils. This situation is most common on north aspects with deep clay loam to loamy Pachic Argixerolls and Pachic Haploxerolls characterized by mountain big sagebrush/Idaho fescue (*Festuca idahoensis*) and mountain big sagebrush/Columbia needlegrass community types. However, herbaceous cover was greatly reduced in community types with restricted cemented ash layers. Herbaceous cover was reduced to 2 percent on a mountain big sagebrush/Thurber needlegrass (*Stipa thurberiana*) site growing on clay loam soils 14 to 16 inches deep, underlain by a thick, cemented silicic ash layer of rhyolite and rhyodacite composition (Bates et al. in press). Following release from tree competition, perennial herbaceous cover on this site increased 300 percent in the first two years. On other mountain big sagebrush/Thurber needlegrass community types, total herbaceous cover in closed woodlands was typically less than half compared to cover values in the early stages of woodland development. In pinyon-juniper woodlands an inverse relationship between tree canopy cover and understory cover and biomass have been reported (Jameson 1967, Clary 1971, Clary and Jameson 1981, Tausch et al. 1981, Pieper 1990). For western juniper it appears this relationship is dependent upon certain site variables.

Conclusions

Western juniper occurs across a broad variety of soils and terrain creating a high degree of stand heterogeneity in structure, composition, function, and varying effects on ecological processes such as hydrology and nutrient cycling. Stand variability can also be attributed to varying stages of woodland development since western juniper expansion is relatively recent (within the last 120 years). As shrub steppe communities are converted to juniper woodlands community structure, composition, function, processes, and wildlife habitat suitability are altered. During conversion a threshold is crossed which moves communities to new steady states driven by different ecological processes. Once a threshold has been crossed it becomes significantly more difficult to return communities to previous states. The identification of spatial and temporal heterogeneity in western juniper woodlands is extremely important when evaluating potential resource problems, determining wildlife habitat values, developing management plans, and setting realistic goals and time frames.

References

Anderson, E. W. 1956. Some soil-plant relationships in eastern Oregon. Journal of Range Management 9:171-175.

Archer, S. 1989. Have southern Texas savannas been converted to woodlands in recent history? The American Naturalist 134: 545-561.

Bailey, R. B. and others. 1994. Ecoregions and subregions of the United States. Map USDA Forest Service, Washington DC.

Bates, J. D. 1996. Understory vegetation response and nitrogen cycling following cutting of western juniper. Ph.D. Dissertation, Oregon State University, Corvallis.

Bunting, S. 1984. Prescribed burning of live standing western juniper and post-burning succession. Pages 69-73 in T.E. Bedell, compiler, Oregon State University Extension Service. Proceedings of western juniper short course. October, 15-16, Bend, Oregon.

Burkhardt, J. W., and E. W. Tisdale. 1976. Causes of juniper invasion in southwestern Idaho. Ecology 76:2-484.

Clary, W. P. 1971. Effects of Utah juniper removal on herbage yields from Springerville soils. Journal of Range Management 24: 373-378.

Clary, W. P. and D. A. Jameson. 1981. Herbage production following tree and shrub removal in the pinyon-juniper type of Arizona. Journal of Range Management 26:70-71.

Houston, D. B. 1973. Wildfires in northern Yellowstone National Park. Ecology 54:1109-1117.

Jameson, D. A. 1967. The relationship of tree overstory and herbaceous understory vegetation. Journal of Range Management 20:247-249

Martin, R. E., and A. H. Johnson. 1979. Fire management of Lava Beds National Monument. Pages 1209-1217 in R. E. Linn, editor. Proceedings of the First Conference of Science and Research in the National Parks. USDI National Parks Service. Transactions Proc. Serial No. 5.

Miller, R. F. and J. A. Rose. 1995. Historic expansion of *Juniperus occidentalis* (western juniper) in southeastern Oregon. Great Basin Naturalist 55:37-45.

Miller, R. F., T. J. Svejcar, and N. E. West. 1994. Implications of livestock grazing in the Intermountain sagebrush region: plant composition. Pages 101-146 in M. Vavra, W. A. Laycock, and R. D. Pieper, editors. Ecological Implications of Livestock Herbivory in the West. Society for Range Management, Denver, Colorado, USA.

Miller, R. F., and P. E. Wigand. 1994. Holocene changes in semiarid pinyon-juniper woodlands. BioScience 44:465-474.

Miller, R. F., and J. A. Rose. (1998). Fire History and *Juniperus occidentalis* Hook. encroachment in Artemisia steppe. Journal of Range Management (submitted).

Tausch, R. J., N. E. West, and A. A. Nabi. 1981. Tree age and dominance patterns in Great Basin pinyon-juniper woodlands. Journal of Range Management. 34:259-264.

Young, J. A., and R. A. Evans. 1981. Demography and fire history of a western juniper stand. Journal of Range Management. 34:501-506.

Return Interval for Pinyon-Juniper Following Fire in the Green River Corridor, Near Dutch John, Utah

Sherel Goodrich
Brian Barber

Abstract — Colorado pinyon (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) are returning, following three fires, in the Green River corridor, Daggett County, Utah. It will take several decades to over a century before pinyon-juniper will dominate plant communities following fire. Recognizing this interval can facilitate planning and management for a diversity of successional stages across the landscape of the Green River corridor. The long return interval indicates a rather small burning program could sustain diversity. The long return interval indicates long-term benefits and thus higher economic return for burning compared to treatments of shorter return interval for pinyon and juniper.

The Green River corridor in Daggett County, Utah, represents the northern limit for Colorado pinyon (*Pinus edulis* Engelm.) near the Utah-Wyoming line. North of the Green River corridor, Colorado pinyon is uncommon and it is known to extend only a few miles into Wyoming. Utah juniper (*Juniperus osteosperma* [Torr.] Little) extends well into Wyoming where it forms stands without Colorado pinyon. In the Green River corridor, the two species commonly grow together, but Colorado pinyon often replaces Utah juniper over time especially on cool aspects where to some extent it is able to regenerate under its own shade or at least in small openings created by the death of old trees. In the Green River corridor as elsewhere in their range, Colorado pinyon and Utah juniper have great capacity to drive plant community dynamics. Without disturbance they displace other communities and form close stands across nearly all soil types and all geologic substrates within the thermal belt to which they are well adapted. Management of pinyon-juniper areas can be facilitated by an understanding of the return interval of these highly competitive plants following fire or other disturbance. Return of pinyon and juniper in three burns in the Green River corridor indicate the return interval following fire.

The three burns are at Mustang Ridge (13 ha or 32 acres), Dripping Springs (56 ha or 138 acres), and Dutch John Canyon (82 ha or 203 acres). The burn at Dripping Springs was aerially seeded with a mix of grasses of which crested wheatgrass established throughout the burn. The other two burns were not seeded. These burns are all within a radius of 4.8 km (3 miles) of the town of Dutch John where mean annual precipitation at the Flaming Gorge Weather Station is 31.75 cm (12.50 inches) (Ashcroft and others 1992).

Methods and Results

A search of files at the Supervisor's Office, Ashley National Forest, Vernal, UT, indicated the Mustang Ridge fire burned about 1950 (Plummer 1965, 1972; Webster 1972), and the Dripping Springs fire burned in 1959 (Plummer 1965). The burn in Dutch John Canyon was older. It was not included in notes by Plummer or Webster cited above. This burn was visited in 1996, and a search was made for fire scars on pinyon trees that had survived the fire. A number of fire-scared pinyon trees were found. Cross sections were taken by chain saw from three of the scared trees. One tree was near the bottom of the canyon. One was from about mid-slope on the east side of the canyon, and the other was taken from near the top of the east side of the canyon. All were from the margin of the burn. No live, scared trees were found toward the center of the burn. This was a stand replacing fire with few or no survivors except at the margin of the burn. Also, cross sections of a few trees that had obviously regenerated since the fire were taken between ground level and about 30 cm (1 foot) above ground level.

With the aid of a 7-30 power binocular scope, annual rings of the cross sections were counted. Rings from the scar outward to the cambium were used to indicate the year of the fire. Ring counts from the three scared cross sections indicated the fire had burned 101, 102, and 103 years before 1996. These dates were close enough together to consider a single burn for the area of just over 100 years ago. Growth of the trees might have been suppressed for a year or two following the fire. However, the fire is indicated to have burned in the 1890's. Procedures for dating the fire from annual rings of trees with fire scares is similar to those discussed by Arno and Sneck (1997). Annual rings from cross sections indicated live trees within the burn were 30 to 95 years old. There were smaller trees present than the one dated at 30 years, but the 95 year old tree was one of the largest ones in the burn. Since the cross section was taken above ground level, this tree was somewhat older than 95 years. It was adjacent to the burnt stump of a large tree burned in the fire. It is highly unlikely that it was a survivor from the fire. This tree also indicates the fire to have been in the 1890's.

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Return of trees to these burns was determined by measurements, ocular estimates, and by photographs. Counts in six 1.83 by 50.78 m (0.0093 ha) plots in 1997 indicated between 287 and 358 trees per hectare in some places in the Mustang Ridge Burn. However, these plots indicated only 71 to 143 trees per hectare were over 1 m tall. The large number of seedlings and small trees indicate a much greater dominance of pinyon-juniper in the next few decades. In some areas of the Dripping Springs and Mustang Ridge burns, tree density was less than five trees per hectare at 38 and 47 years postfire, respectively. After about 100 years, density of trees in the Dutch John Canyon Burn varied from few to many per hectare depending on location within the fire. Size and age structure of these trees indicated recruitment of all ages within the burn. Overall canopy cover of pinyon and juniper was less than 1 percent 38 years post fire at Dripping Springs, about 2 percent 47 years postfire at Mustang Ridge, and between 5 and 15 percent about 100 years postfire at Dutch John Canyon.

Discussion

A slow return rate is indicated for the first 40 to 50 years with an apparent accelerated rate in later years. A slow rate of return is also indicated by Despain (1987) in the first 20 to 30 years following burning and seeding in Arizona. Also, Ronco (1987) suggested stand density of pinyon-juniper does not increase appreciably until 45 years after disturbance. The successional patterns of the Green River corridor appear similar to the model of Erdman (1970) which shows shrub/open tree communities at 100 years postfire.

Nearly all pinyon-juniper trees within the perimeter of these fires were killed. There were a few islands of survivors in the Dutch John Canyon fire on rocky outcrops and at topographic breaks. It appears that few seeds of either species survived the fires, or they failed to germinate or at least failed to establish. However, the 95 year old tree that had regenerated in the burn indicates at least a few trees established soon after the fire. Return of trees to the burns appears to be a largely a function of seed spread from the edge of the burns, and as indicated by Balda (1987), they are heavily dependent on birds to disperse their propagules. This appears to be a major factor in return of these trees to the center of large burns. Also, the few trees that establish soon after fire appear to be a source of seed within burns. This discussion is most applicable to burns over 8 ha (20 acres). Return of pinyon and juniper to smaller burns and especially the margins of burns could be more rapid. Huber and others (these proceedings) found a stand with crown cover of pinyon-juniper at about 60 percent. This appeared to be at the margin of a small burn of about 140 years old where seeding establishment was rapid.

Return of trees to the burns at Dripping Springs, Mustang Ridge, and Dutch John Canyon indicates it will take 100 years or more for plant communities to progress to a shrub/open tree status. Also indicated is 150 to 200 years to achieve preburn density of trees and greater than 200 years to achieve mature and old stages of succession. For north-central Arizona, Tress and Klopatek (1987) estimated 215 years to complete a sere in pinyon-juniper woodlands. Erdman (1970) indicated 300 years from fire to climax forest. Barney and Frischknecht (1974) found woodlands well developed 85 to 90 years after fire in the Great Basin. However, well developed in this case seems to apply to young stands with aspect dominance but not the end of a sere.

Management Implications

The burns reported in this paper and other wildfires and prescribed burns of the Green River corridor were stand replacement fires. Underburning does not seem a realistic option. The stands are difficult to burn until conditions are severe enough to create crown fires. Recognizing the return interval for pinyon-juniper after stand replacement fires can facilitate management of landscapes where certain levels of different successional stages are desired across a landscape. Under a draft concept of "properly functioning condition," Amundson and others (1996) indicated a proper landscape mix of successional stages for pinyon-juniper woodlands in the Intermountain Region of the Forest Service as follows: 10 percent grass/forb, 10 percent seeding/sapling, 20 percent young forest, 20 percent mid-aged forest, 20 percent mature forest, and 20 percent old forest. For the Green River corridor, it appears that it would require a fire frequency of greater than 200 years to achieve closed, mature pinyon-juniper stands in burns of greater than about 8 ha (20 acres). Fire interval would have to exceed 100 years to achieve and maintain scattered trees in plant communities. Fire intervals of 10 to 30 years would not allow for succession beyond a grass/shrub stage in which trees over 1 m tall would be mostly excluded.

The rate of succession indicates maintenance of earlier successional stages can be achieved with a small annual burning program. For a 8,100 ha (20,000 acre) landscape with a fire interval of 100 years, only 80 ha (200 acres) of burning per year could maintain the landscape in early to mid-seral stages. If 40 percent of the landscape was desired with mature and old stands, an average of 50 ha (120 acres) of burning per year is indicated to maintain this condition. The long return interval greatly facilitates economic return for prescribed fire, and it indicates a relatively small burning program to achieve a desired mix of successional stages.

References

Amundson, J.; Ogle, K.; Winward, A. H.; and others. 1996. Properly functioning condition. Draft Process - Version. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 31 p.

Arno, S. F.; Sneck, K. M. 1977. A method for determining fire history in coniferous forest of the Mountain West. Gen. Tech. Rep. INT-42. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 28 p.

Ashcroft, G. L.; Jensen, D. T.; Brown, J. L. 1992. Utah climate. Logan, UT: Utah State University, Utah Climate Center. 125 p.

Balda, R. P. 1987. Avian impacts on pinyon-juniper woodlands. In Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 525-533.

Barney, M. A.; Frischknecht, N. C. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. J. Range Manage. 27: 91-96.

Despain, D. W. 1987. History and results of prescribed burning of pinyon-juniper woodland on the Hualapai Indian Reservation in Arizona. In Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 145-151.

Erdman, J. A. 1970. Pinyon-juniper succession after natural fires in residual soils of Mesa Verde, Colorado. Brigham Young University Science Bulletin Biological Series 11. Provo, UT: Brigham Young University. 24 p.

Huber, A.; Goodrich, S.; Anderson, K. These proceedings. Diversity with successional status in the pinyon-juniper/mountain mahogany/bluebunch wheatgrass community type near Dutch John, Utah. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Plummer, A. P. 1965. Correspondence on file at: U.S. Department of Agriculture, Forest Service, Ashley National Forest Supervisors Office, Vernal, UT; 2060, study folder 6-8.

Plummer, A. P. 1972. Correspondence on file at: U.S. Department of Agriculture, Forest Service, Ashley National Forest Supervisors Office, Vernal, UT: 2060, study folder 6-8.

Ronco, F., Jr. 1987. Stand structure and function of pinyon-juniper woodlands. In Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 14-22.

Tress, J. A., Jr.; Klopatek, J. M. 1987. Successional changes in community structure of pinyon-juniper woodlands on north-central Arizona. In Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 80-85.

Webster, R. P. 1972. Environmental analysis report, Dutch John habitat improvement. On file at: U.S. Department of Agriculture, Forest Service, Ashley National Forest Supervisors Office, Vernal, UT; 2060, study folder 6-8.

Implications of Weedy Species in Management and Restoration of Pinyon and Juniper Woodlands

Tony Svejcar

Abstract—A survey of the literature was done to determine if the presence of a weedy species is a short-term annoyance or a long-term threat on pinyon-juniper lands. The conclusion is that situations differ with no "cookbook" solutions for managers. Six-step guidelines will help managers find answers for site-specific questions.

Rangeland weeds have attracted an increasing level of attention during recent years. There is concern over potential weed problems that may result from woodland (juniper or pinyon/juniper) conversion projects. In spite of the interest in both rangeland weeds and woodland conversion projects, I found surprisingly little research that specifically addresses weed problems in woodlands. Much of the work was more focused on control of woody species rather than the weeds that might follow restoration efforts. Young and others (1985) pointed out that juniper control methods would influence subsequent weed control/revegetation options in the understory. If standing dead trees were left in place (for example, using herbicides or fire) there are physical limitations to the use of weed control and seeding equipment. For example, in a formerly dense woodland the dead canopy might make it impossible to use ground-seeding equipment.

Cheatgrass (*Bromus tectorum* L.) has probably received more attention than any other weedy species that occurs in woodlands. So I will try to summarize the literature results for this species. In this paper I will: 1) present some of the reasons why woodland conversion projects pose the risk of weed invasion, 2) discuss the role of cheatgrass in woodland conversion, and 3) suggest several planning steps where weeds are considered in a larger ecological context.

Why Should Weeds be a Concern?

Woodland tree species, junipers in particular, are very effective at using soil resources. Using field data in conjunction with a simulation model, Angell and Miller (1994) estimated that western juniper would use about 44 percent of the total precipitation in a year that received 32.0 cm (12.6 inches). They assumed the site was stocked at 75 trees per ha (30 per acre) and that the leaf area index was 1.6. The effect of the juniper stand was to reduce precipitation available to other species to about 18 cm (7 inches). Seventy-five trees per hectare is not a particularly dense juniper stand. These authors point out that juniper may also intensify drought effects during dry years, and create site-water deficits early in the growing season. These conclusions were confirmed by Bates and others (1998), who found that soil moisture and nitrogen availability were much higher in cut woodlands, compared to those uncut. In a pinyon (*Pinus monophylla* Torr. & Trem) woodland, Everett and Thran (1992) found that about half of the total site N was contained in above-ground tree biomass and half in soil. Thus, the pinyon sequestered a major portion of site N, which would no longer be available to other species.

The fact that woodland trees use a good deal of the resources on a site actually provides a degree of protection against weed invasions. Unfortunately, the tree dominance also tends to reduce the diversity and productivity of understory species (Bates and others 1998). The potential risk to woodland conversion projects is that an opportunistic weedy species will take advantage of the additional resources more quickly than desirable species (either existing or seeded species). The challenge is to determine whether the presence of a weedy species is a short-term annoyance or a long-term threat.

Cheatgrass and Others

As mentioned earlier, there is more research information available on cheatgrass than on any other weedy species associated with North American woodlands. Much of this research has dealt with vegetation dynamics after a woodland fire. Barney and Frischknecht (1974) identified a weedy annual stage that peaked within 3 to 4 years after a fire, followed by several stages with differing mixes of perennial grasses, forbs, and shrubs. The change in cheatgrass cover values was dramatic ranging from 12.6 percent in 3-year-old burns to less than 1.0 percent in burns older than 22 years. A similar pattern was identified by Erdman (1970) in southwestern Colorado. The pattern may be similar with chaining. Working in central Utah, Davis and Harper (1990) measured a high density of both cheatgrass and burr buttercup (*Ranunculus testiculatus*) immediately after chaining on a pinyon juniper site. However, by the third year after chaining, the density of both species had declined by 85 percent or more compared to the initial year values. In this

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study, the density of seeded perennials increased over the 3-year period. Evans and Young (1985) measured a dramatic increase in standing crops of cheatgrass (from near zero to 1400 kg/ha) after controlling juniper with picloram pellets. Cheatgrass frequency declined in the treated areas over a 7-year period, but there was a continual increase in frequency of medusahead (*Taeniatherum asperum*).

There is a body of research that shows weedy annuals, cheatgrass in particular, can increase immediately after woodland trees are killed, whether it be by fire, chaining, or herbicides. Much of the research indicates that this response will be transient, or that it may not even occur. For example, Barney and Frischknecht (1974) point out that the annual stage may be by-passed in areas that have good cover of perennial herbaceous species prior to burning. In central Oregon, Quincey (1984) stratified fire response of juniper woodlands into dry and moist sites. Dry sites contained cheatgrass prior to burning, and the increase persisted for 20 years in some cases. On the moist sites, perennial grasses dominated the unburned vegetation with little cheatgrass present. The moist sites did not have a fire-induced increase in cheatgrass. These results suggest that responses to woodland conversion projects will be site-specific and depend heavily on the initial floristics of each plant community (Everett and Ward 1984, Koniak 1985).

Although cheatgrass is the weed species mentioned most frequently in the literature, it certainly is not the only weed of concern in woodlands. There is presently an on-going invasion of diffuse and spotted knapweeds (*Centaurea diffusa* and *C. maculosa*, respectively) in upland sites and Russian knapweed (*C. repens*) in the moister sites (Lee Eddleman, personal communication). There are many other alien species that have the potential to invade woodlands.

Principles and Planning

There are many variables that interact to influence the threat weeds pose on any given piece of rangeland. Every situation will be different and few "cookbook" answers will be available. However, there are general principles that will prove useful and every manager can develop site-specific information that will aid their future decisions; this approach is really adaptive-management.

I would suggest everyone become familiar with the old ecological concepts of relay floristics and initial floristics. An orderly succession of plant communities is the basis of relay floristics. Each seral plant community relays the site to the next (see Barbour and others 1980, or other plant ecology texts for a more detailed discussion). The successional sequence is considered well defined and repeatable. In contrast, the implications of initial floristics is that succession of plant communities is not so easily defined and may not be repeatable (Barbour and others 1980). A number of factors may influence the course of succession. There is a degree of chance in which species are present on a site, which migrate quickly to the site after a disturbance, the type of year immediately following disturbance, etc.

There may be elements of both initial and relay floristics that apply to any given situation. For example, there may be an annual phase that gives way to perennials over time (relay), but the annual phase may not occur if cheatgrass isn't a major component of pre-burn vegetation (initial floristics). In a study of post-burn succession in pinyon-juniper stands, Everett and Ward (1984) suggest that elements of both relay and initial floristics were evident. There may be multiple successional pathways (Everett and Ward 1984) and successional patterns may vary among different sites (Koniak 1985). This led Koniak to conclude that it will be necessary to characterize a site (elevation, soil type, post-burn climate) and the disturbance (severity and timing) if community response is to be predicted.

With appropriate planning and monitoring, land managers will be in a position to make informed decisions about woodland manipulation projects. Weeds should be considered within this larger framework. I would suggest the following six steps for a starting point:

1. *Develop clearly defined objectives.* What are the land management goals for the site? What is the problem and what will be gained from a particular woodland treatment? Be as specific as possible.
2. *Describe the site.* Parameters, such as land area, tree density, tree age, species composition, slope, aspect, soil depth, elevation, prior management, should be used in the decision-making process. The nature and initial floristics of a site may give clues as to the risk of weed dominance.
3. *List the available management options.* These will vary from one area to another, and by land ownership. These options should be evaluated for cost and effect on plant succession (next item).
4. *Consider how proposed treatments might influence the primary causes of succession.*
   a. *Site availability for colonization.* What sites (actually microsites) might favor occupation by invader species? How will changes in density of woodland trees influence site availability? Different management tools have varying impacts, for example, prescribed fire will have a different effect on site availability than will cutting. Maybe a goal could be to reduce tree density to make sites available for other species, rather than total conversion of a woodland.
   b. *Species availability.* What species are on site or within easy dispersal distance? Are there species that tend to appear on a particular site after treatment (even if they are not obvious prior to treatment)? Do any of the species listed pose a major weed risk? Are species present that might close the site to weed invasion?
   c. *Species performance.* Are there site characteristics such as slope, soil texture, soil depth, aspect, that might favor a weedy species of concern? In many areas, drier south-facing slopes appear more susceptible to invasion by weedy species than do north-facing slopes.

A more detailed discussion of successional weed management can be found in Sheley and others (1996).

5. *Prescribe site management after woodland management.* Will seeding be necessary? Keep in mind that residual native species often respond favorably to woodland manipulation, even on sites that appear depleted. Is the site to be grazed, and if so, what type of management will be necessary to allow recovery of understory species?

6. *Develop a follow-up monitoring plan.* How will adaptive management be accomplished if we don't keep track of our successes and failures? It is worthwhile setting goals for monitoring what you hope to accomplish. What is an appropriate monitoring system and time frame? How will the information be summarized and interpreted? Were weeds a problem?

Although it is not specific to weeds, Aldon and others (1994) have developed an ecosystem management checklist for pinyon-juniper communities.

Closing Thoughts

Many of the decisions made on rangeland must be site-specific, yet often site-specific information is not available. This is unfortunate because there are often treatments that have been applied in any given area, but no system was in place to evaluate the results and pass them along to future land managers. There is a need for ways of assembling fairly complex information into a simple format. One option is to use some form of the state-and-transition model initially proposed by Westoby and others (1989). This model is really a means of organizing information for use in management. Svejcar and Sheley (1995) suggested that state-and-transition models, and the primary causes of succession (site availability, species availability, and species performance), can be molded into a framework that would better integrate research and management. State-and-transition models could be developed using ecological principles, research results, and local knowledge. The site-specific monitoring data could then be used to evaluate and refine the state-and-transition models. Gaps in information would serve to prioritize research needs.

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References

Aldon, E. F., R. Fletcher, and D. Shaw. 1994. A checklist for ecosystem management in southwestern pinyon-juniper. U.S. Department of Agriculture, Forest Service, General Technical Report RM-258:125-130.

Angell, R. F. and R. F. Miller. 1994. Simulation of leaf conductance and transpiration in *Juniperus occidentalis.* For. Sci. 40:5-17.

Barney, M. A. and N. C. Frischknecht. 1974. Vegetation changes following fire in the pinyon-juniper type of west-central Utah. J. Range Manage. 27:91-96.

Barbour, M. G., J. H. Burk, and W. A. Pitts. 1980. Terrestrial plant ecology. The Benjamin/Cummings Publishing Company, Menlo Park, CA.

Bates, J. D., R. F. Miller, and T. Svejcar. 1998. Understory dynamics in cut and uncut western juniper (*Juniperus occidentalis* ssp. *occidentalis*) woodlands. J. Range Manage. (submitted).

Davis, J. N. and K. T. Harper. 1990. Weedy annuals and establishment of seeded species on a chained juniper-pinyon woodland in central Utah. In: Proceedings-Symposium on Cheatgrass Invasion, Shrub Die-off and Other Aspects of Shrub Biology and Management. USDA Forest Service Gen. Tech. Rep. INT-276:82-79.

Erdman, J. A. 1970. Pinyon-juniper succession after natural fires on residual fires of Mesa Verde, Colorado. Brigham Young Univ. Sci. Bull. Biol. Series 11:1-24.

Evans, R. A. and J. A. Young. 1985. Plant succession following control of western juniper (*Juniperus occidentalis*) with picloram. Weed Sci. 33:63-68.

Everett, R. L. and D. F. Thran. 1992. Above-ground biomass in N, P and S capital in singleleaf pinyon woodlands. J. Environ. Manage. 34:137-147.

Everett, R. L. and K. Ward. 1984. Early plant succession on pinyon-juniper controlled burns. NW Sci. 58:57-68.

Koniak, S. 1985. Succession in pinyon-juniper woodlands following wildfire in the Great Basin. Great Basin Nat. 45:556-566.

Quincey, S. D. 1984. Fire and grazing effects in western juniper woodlands of central Oregon. M.S. Thesis, University of Washington, Seattle.

Sheley, R. L., T. J. Svejcar, and B. D. Maxwell. 1996. A theoretical framework for developing successional weed management strategies on rangeland. Weed Tech. 10:766-773.

Svejcar, T. J. and R. L. Sheley. 1995. A conceptual framework for integrating natural resource management and research. Proceedings, Fifth International Rangeland Congress, Salt Lake City, Utah: 547-548.

Westoby, M., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. J. Range Manage. 42:266-274.

Young, J. A., R. A. Evans, and C. Rimbey. 1985. Weed control and revegetation following western juniper (*Juniperus occidentalis*) control. Weed Science 33:513-517.

Factors Affecting the Health of Pinyon Pine Trees (*Pinus edulis*) in the Pinyon-Juniper Woodlands of Western Colorado

Tom J. Eager

Abstract—Mortality of pinyon pine has recently been on the increase throughout western Colorado. Black stain root disease (*Leptographium wageneri*) is a significant source of mortality for pinyon trees in infested stands. The pinyon ips (*Ips confusus*) is also an important factor in these stands. These mortality agents often act in concert, affecting large areas within the pinyon-juniper stands. Recent increases in human activity, most prominently road building and home construction, have increased the impact of the pathogen-insect complex. Efforts are underway to determine management activities which may reduce undesired mortality of pinyon pine trees.

The pinyon-juniper forest type covers extensive areas of the southwestern United States. In the Four Corners Region over 14.9 million ha (37.2 million acres) are contained in this warm, lowland cover type. There is a total of 1.8 million ha (4.7 million acres) of pinyon-juniper forest lands in Colorado, the majority of which are on the western slope of the Continental Divide, bordering the Red Rock region of the Colorado Plateau.

The pinyon-juniper woodlands of Colorado have long been an important component of the forested landbase. In presettlement times, these areas served as the homelands of several indigenous native groups, the trees themselves providing fuel, materials for shelter, habitat for hunting and foraging in addition to supplying an important component of the diet, specifically pinyon nuts (seeds).

Since the time of settlement, this forest type has been utilized in a variety of ways adding forage production and recreation to the list of uses. While the economic value of these lands has been regarded as being rather low in the past, increasing human populations and the development of an infrastructure able to sustain habitation of these harsh lands has increased the rate of development, particularly the construction of homes.

This increase in the human population within the pinyon-juniper forest has been accompanied by an awareness that mortality of the pinyon pines is increasing at an unprecedented rate. Exclusion of disturbance events such as fire has caused a homogenization of stand characteristics, particularly age-class structure, and has resulted in forest stands which tend to be older and more advanced in the successional pathways of this cover type. The combined factors of increased human activity and an older, more successionally advanced condition are believed to be responsible for this increase in pinyon mortality.

A number of different insects and diseases are specifically responsible for the increased mortality, the combined effects of these agents is being called pinyon pine decline. The actions of these various agents are being considered as a whole since the contribution of the various factors can vary greatly between sites. Additionally, these individual disturbance factors have not been studied well enough to separate their effects. There are a number of secondary insects and diseases affecting the health of pinyon pines, but the primary agents responsible for pinyon pine decline in Colorado appear to be black stain root disease (*Leptographium wageneri*) and pinyon ips (*Ips confusus*).

Ips Bark Beetles (*Ips confusus*, Scolytidae:Coleoptera)

Bark beetles are well-known causes of damage and mortality in nearly all species of woody plants. The majority of bark beetles live and mine within the bark and wood of hosts, spending most of their lives within this cryptic environment. The genus *Ips* is a particularly prominent group of bark beetles due to their habit of attacking a number of economically important timber species. Ips beetles are ranked high in terms of destructiveness to various species of pines and spruce. Most species of *Ips* have a restricted host range, for the most part they attack only a few closely related host trees. This is true of the pinyon ips, *Ips confusus*, which attacks both *Pinus edulis* and *P. monophylla* throughout their ranges.

In general, pinyon ips act as a recycling and thinning agent in stands of pinyon pine. They attack and feed upon broken, fallen and dying trees, and are important factors in stand dynamics and nutrient pathways. However, when populations reach high levels in a given area, these beetles can be responsible for widespread mortality of otherwise healthy trees.

Pinyon ips are cylindrical beetles, 3.5 to 4.0 mm in length and are reddish-brown to black in coloration. A distinguishing feature of the *Ips* genus is the pronounced concavity at the rear end (declivity) of the elytra (wing covers) of the adult, which is margined on each side with 3 to six toothlike spines. *Ips confusus* can be recognized by the pattern of 5 spines on each side of the elytra margins.

Pinyon ips become active as temperatures warm up in the spring, beetle flight occurs on warm, sunny afternoons. Adult males leave overwintering sites and fly to potential hosts to initiate attack. The male beetles begin chewing an entrance hole in the host tree and this activity produces the signs of bark beetle attack, boring dust and pitch. The production of pitch is the host tree's way of defending itself.

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If a host tree is to avoid colonization by the beetles, it must have an ample supply of pitch with which to entrap and force the beetles out of their attack sites. In turn, ips beetles must overcome the defenses of potential hosts if they are going to successfully produce brood. The attacking beetles coordinate their attacks on potential hosts by producing pheromones which concentrate large numbers of beetles on a specific host tree. Pheromone production by the initial beetles attracts additional males as well as females which assist in the attacks. This phenomenon of "mass attack" concentrates enough beetles to overcome the tree's defenses.

The attacking beetles are assisted in their efforts to overcome the host's defenses by means of a symbiotic fungus, *Ceratocystis* sp. The adult beetles have small structures on their bodies in which they carry these fungal spores, and as the attack proceeds, these spores are released beneath the bark. The spores germinate, and the fungal mycelium begins to grow into the sapwood of the host tree, cutting off the host tree's vascular system and girdling it. The growth of this fungus is responsible for the characteristic blue staining in the wood of a tree attacked by bark beetles.

As increasing numbers of beetles arrive at the host, the males are able to establish small chambers beneath the host's bark. *Ips confusus* is a polygamous species and three females usually respond to each male. After mating, each female begins to construct an elongate gallery which extends away from the central male chamber. The construction of these galleries produces another characteristic sign of beetle activity, the gallery pattern. In the case of the pinyon ips, the gallery pattern takes the form of an inverted "Y", with the mating chamber at the center of the three "arms" which each female has constructed. Each female then lays between 25 to 40 eggs in small niches along these galleries. The eggs hatch in about a week and the larvae begin tunneling beneath the bark, feeding upon the host phloem. After several molts beneath the bark, the larvae form a pupal chamber and undergo the final metamorphosis to the adult stage. Adults remain beneath the bark for a short time and then emerge to attack new host trees. There can be from 2 to 5 generations per year, depending upon the elevation and climate. As temperatures cool in the autumn, beetles seek out overwintering sites in the duff layer or beneath the bark of host trees.

Black Stain Root Disease (*Leptographium wageneri*)

Black stain is the common name of a fungus which causes a vascular wilt of coniferous trees. While other strains of this fungus which cause black stain in Douglas-fir and ponderosa pine in the far West are relatively well-understood, black stain root disease in pinyon has not been intensively studied. Black stain root disease was first noted in 1942 in Mesa Verde National Park. James Mielke began investigating the cause of pinyon pine mortality which had previously been ascribed to bark beetles. Mielke's work determined that bark beetle activity was secondary to black stain root disease as a cause of mortality. This work also noted the spread of the disease via root to root contacts (Wagener and Mielke 1961).

Symptoms of black stain root disease are usually first manifested in the foliage of the host tree crown. Infected tree needles become shorter and chlorotic and terminal growth is reduced. These general conditions become increasingly acute until the death of the host tree ensues in a relatively short period of time (as little as 2 to 3 years following initial infection). In addition, the disease predisposes the infected tree to attack by other damaging agents. Once a host has died, the fungus does not survive long and pinyon seedlings often reestablish in old black stain centers.

Black stain can be identified by its distinctive coloration as well as the pattern and location of the staining. As the fungus spreads through the vascular system of an infected tree, it leaves a characteristic black to chocolate-brown stain or streaks of stain in the sapwood of the roots and/or root crown. Removal of bark in the area of the root crown and roots should reveal the characteristic coloration in infested trees. A second key characteristic is the pattern of the staining. Black stain appears in arc-like patterns in the sapwood of infested material when viewed in cross-section. This signature is in contrast to the pattern left by the bark beetle fungal symbiont, *Ceratocystis* sp. Blue stain appears as wedge shaped markings, in addition, the silvery-blue coloration appears throughout the length of the bole.

Trees killed by black stain generally occur in groups or "centers". This pattern of mortality is a result of the local spread of the disease by root to root contact. Once established in a new root, the fungus colonizes the distal portions of the root and then grows towards the root crown. After infecting the root crown the fungus spreads throughout the remaining uninfected roots.

Long distance spread of black stain, resulting in the establishment of new centers has also been observed. In the case of Douglas-fir and ponderosa pine black stain, insect vectors, particularly root-feeding weevils, have been shown to vector the disease. However, in the case of pinyon pine, insect vectoring has not yet been proven. Like their "cousins", the bark beetles, wood-feeding weevils are attracted to wounded and damaged host tissues. Their attraction to injured plant tissue makes them a favorable vector for the disease.

Diagnosis of a black stain infestation center can be difficult, the symptoms may be obvious for only a short period of time. After the death of an infected host, the fungus survives only a relatively short period of time. A number of trees may need to be examined before positive identification of the disease can be made, usually those trees which have very recently or soon will be dead provide the best possibility for detection.

Pinyon Decline

Forest management groups from throughout the Four Corners region have noticed an increase in the reporting of pinyon pine mortality over the last several years. While some of this mortality is being reported for the first time due to lack of previous monitoring, it is evident that actual mortality has increased significantly. This mortality is caused by a number of different agents in different locales, but the majority of the cases involve pinyon ips and black stain root disease. These organisms frequently act in concert, causing widespread areas of mortality.

The bark beetles appear more as opportunists, taking advantage and colonizing trees weakened by black stain root disease or other disturbance factors. When a sufficient supply of susceptible host trees are available, numbers of beetles can reach fantastic levels, and the population can swell out to attack many otherwise healthy trees. An outbreak will decline over time, but often not before a large area has been affected and many trees have been killed.

Black stain can be a major source of mortality in pinyon pine, but local spread of the disease occurs at a limited pace. In contrast, long distance spread of the disease can cause widespread mortality over large areas. The spread of the disease appears to be exacerbated by the activities of wood or root feeding insects. These insects are attracted by wounded or damaged host tissues and can compound other forms of stand disturbance.

Both the insect and the fungus are encouraged by stand disturbance. Trees under stress serve as a food source for bark beetles. The spread of black stain may be accelerated by the activities of vectors which thrive on damaged or stressed host trees.

The rapid increase of human activity in the pinyon-juniper woodlands of western Colorado has in some cases created conditions favorable to black stain and pinyon ips. Direct wounding of trees, damage to root systems, and improper treatment of cut trees and slash has created a large source of potential host material. House, road and utility line construction frequently damage pinyon pines and allow the rapid increase of mortality agents. Since many of these trees are valuable as landscape plants, the death of even a few is undesirable. On a landscape scale, dead trees may increase fuel loads and pose a threat due to wildfire. Outbreaks of these mortality agents also interfere with other management objectives. The relatively slow growth of vegetation associated with the pinyon-juniper woodland further increases the impact of widespread mortality.

Conclusions

The best prospects for reducing the impacts of pinyon decline is by maintaining the forest in as vigorous a condition as possible. Variability of stand conditions within a forest reduces the risk of widespread mortality due to one or two factors. Sanitation of stands by prompt removal of damaged host material reduces a potential source of food for damaging agents. Over the long run, reintroduction of prescribed fire will reduce biomass and fuel loads. In other areas, thinning and harvesting can help achieve desired stocking levels and stand conditions.

Two simple tactics that individual land managers can utilize are proper slash management and timing of activities. Removal or treatment (burning, burying, debarking, or tarping can be used under various circumstances) of potential host material (including stumps, logs, and large branches) can reduce the potential for increased mortality due to bark beetles. Scheduling potentially disruptive activities in pinyon-juniper stands during the cooler winter months can also reduce the risk of mortality. Activities should be as non-disruptive as possible, but working in cooler weather (roughly late November to early March in western Colorado) while the insects are inactive will allow time for managers to sanitize the stands following activity. In addition, timing of activities during the winter months allows the trees to "recuperate" a bit before the bark beetles and weevils become active in the spring.

There are many gaps in the information base regarding pinyon pine decline. As the value of these lands continues to escalate these questions will become increasingly important. Information on the stand factors which increase susceptibility to pinyon decline and the longevity of the influence of black stain within infested areas will be necessary for effective long-term management of these stands. The role and identity of vectors of black stain, and the influence of secondary organisms such as other insects, fungi and nematodes also needs investigation.

Public information will be an important part of any effort to reduce pinyon mortality. A better understanding of the natural environment under which these trees evolved is necessary. Many trees are literally "killed with kindness": drowned by water, overfertilized, or paved around. Others are strung with fences and wires, cut and trimmed indiscriminately, or otherwise mistreated. Managers need to consider the trees under their care as part of a larger woodland. They need to work beyond their property lines and consider pinyon-juniper stands as a crucial component of the landscape.

Reference

Wagener, W. W.; and J. L. Mielke. 1961. A staining-fungus root disease of ponderosa, Jefferey and pinyon pines. Plant Disease Reporter. 45 (11) : 831-835.

The Budgetary, Ecological, and Managerial Impacts of Pinyon-Juniper and Cheatgrass Fires

Thomas C. Roberts, Jr.

Abstract—The 1996 fire season illustrated the potential impacts of wildland fires on the Bureau of Land Management (BLM) administered lands through numerous western states. During the 1996 fire season, over six million acres burned in the United States through unplanned ignitions (wildfires). Over two million acres burned on BLM administered acreage, with over three hundred thousand of them having Emergency Fire Rehabilitation (EFR) projects implemented on them with project costs of over $21 million, over a three year period. Many of these fires were on lands dominated by pinyon-juniper or cheatgrass vegetation community types. These fires are indicative of fuel loads and fire conditions that lend themselves to unplanned or planned ignition and commensurate ecological implications. Pinyon-juniper and cheatgrass fires, as often happen on BLM managed lands are expensive to rehabilitate, disruptive to the workforce and local land users, and at times contentious in methods used for rehabilitation. This paper will describe the budgetary, ecological, and managerial implications of these wildland fires and their rehabilitation within the BLM, using the 1996 fire season as an example.

The Bureau of Land Management (BLM) administers approximately 270 million acres of public land, with about 170 million in the lower forty eight states. Wildfire is a planned and budgeted program, with a programmed budget and workforce, that although in the most part seasonal, is obligated in its tasks, training and commitment. As performed in the BLM, Emergency Fire Rehabilitation (EFR) is funded under the Fire Operation and Suppression Accounts, and performed on an as needed basis. As such, training and support, until recently have been a low priority, with very few full time personnel and limited training. However, during the 1996 fire season, over six million acres burned across the country, including over two million on BLM administered lands, rehabilitation projects were implemented on over three hundred thousand acres with costs of over $21 million, spread over a three year period. The states of Idaho and Utah were particularly heavily hit with large expensive fires in each state. The fires caused millions of dollars of unbudgeted expenditures to be planned, requested and budgeted. Utah alone needed almost $9,000,000, with Idaho, Nevada and Oregon also needing significant amounts of funding. These amounts significantly exceeded the usually budgeted amount of $5,400,000 necessitating the request for supplemental funding through the Department of Interior. While to some extent, an obligated budget like Social Security or Medicare, it is not without scrutiny or concern that such large increases are made by the BLM.

Indeed there is and has been a large amount of discussion and concern about the appropriate level of rehabilitation or "restoration", or to some observers, reclamation, that needs to be done after a fire. These discussions well illustrate not only a person's fiscal philosophies, but their philosophies about the role of government in ecological matters. It is likely that as the 1996 and 1994 fire season are averaged with lower cost years, the average cost for the Emergency Fire Rehabilitation program will increase, and this is without anticipated increases in burned acreage, that may be in the future.

The ecological impacts of the pinyon-juniper and cheatgrass fires are particularly significant in Idaho, Nevada, and Utah, which have had a considerable number of fires in the last twenty years. In an era when the "health" of the land is often a subject of discussion, the impacts of these fires and their results have the potential for omission, when their impacts have both positive and negative possibilities. The pinyon-juniper community type has in common with the invasive annual, cheatgrass, the fact that they affect both the sagebrush-grass and salt desert shrub types where elevation or precipitation patterns permit. As such they affect a number of states including California, Colorado, Idaho, New Mexico, Nevada, Oregon, Wyoming and Utah. The implications of the management of the pinyon-juniper type are changing in visibility and ecological importance because of a number of reasons. The pinyon-juniper community type covers a large area, a diversity of uses and values, and the results of management decisions will be noticed whether those decisions are by intent or default. Fire and fire rehabilitation have a particularly large role in the management of this ecotype. Concurrently, this administration is encouraging the use of fire or the reinstatement of fire into ecosystems where it has been absent.

There are a number of considerations that are necessary to avoid ecological problems in the reinstatement of fire, including the presence of cheatgrass or other invasive plants on a site to be burned or one that has burned, and the lack or presence of a desirable understory prior to the fire. There are many areas dominated by pinyon-juniper or becoming dominated by them that may need appropriately applied fire or lack of aggressive suppression, should a wildfire start, but unless they have a desirable understory, either a funding source is necessary to reseed with desirable plant species or prescribed fire postponed until a funding source located, or in the case of wildfire, Emergency Fire Rehabilitation funds

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may be appropriately used to fund a rehabilitation project. Basically, fire rehabilitation funded with EFR funds may be done to reduce soil erosion, protect private property and life, and to deny the entry or expansion of weeds. It is not meant to be a restoration account, although possibly desirable, site restoration is not the primary goal of the EFR program.

However, as stated above, fire and fire rehabilitation can be powerful tools in land management in the BLM. There are presently about 45,000,000 acres dominated by pinyon-juniper trees under administration of the BLM (USDI, 1993) and an estimated 75,000,000 acres with cheatgrass or with the potential for the presence of cheatgrass (Pellant and Hall, 1994). The ecological problems related to these fires have been documented by many including, Bunting, (1994), Billings, (1994), and others. Bunting (1994), found that the fire free interval of juniper dominated areas to be as long as fifty years and suggests a number of scenarios to explain the present situation, and ecological impacts of fire in the juniper type in the Great Basin. Indeed, the apparent conflicting needs of ecosystems dominated by juniper or pinyon and juniper, and the necessity to control fire in sagebrush or shadscale ecosystems that are at risk because of the presence of cheatgrass have been documented by Pellant (1994), Roberts (1994), and others. Probably most telling is Billings (1994) where he states that "Cheatgrass in the Great Basin area has become abundant enough to provide fuel for disastrous and extensive fires". Roberts (1994) reported on the resource impacts of a ten year history of fire in the Salt Lake District of the BLM, consuming nearly 500,000 acres of rangeland documenting differences between sites before and after fires and the impacts due to the presence of cheatgrass. Whisenant (1990) reported on the decreased fire frequencies in the Snake River Plains of Idaho, again due to the presence of cheatgrass. As illustrated above, the ecological implications related to fire and the pinyon-juniper community type are integral to questions related to the presence or absence of cheatgrass.

The managerial challenges are final and possibly the most limiting to these intertwined ecosystems. Again, using Utah as an example, the fires of 1996 caused an expenditure of over 425 workmonths in rehabilitation projects on the burned over acreage, much of it juniper or cheatgrass dominated. Although half of those workmonths were accomplished by temporary labor, the other half was work done by full time permanent employees, including range conservationists, wildlife specialists, botanists, engineers, equipment operators, archaeologists, surveyors, public affairs officers, and numerous others. Unfortunately, the use of solicitors and even the BLM's Resource Advisory Council because of the use of chaining, a controversial method of burying seed (in Utah), was necessitated because of legal challenges and ultimately a Temporary Restraining Order prohibiting the Utah BLM from completing one project. Idaho also had difficult questions relating to fires near Boise. The Eighth Street Fire, just inside Boise City limits was human caused, burning up through dry cheatgrass and shrub vegetation though publicly and privately owned land to be stopped on the Boise National Forest. The choice of rehabilitation techniques, in this case terracing, caused a furor in Boise, which threatened to shut down the project. Ultimately, it is probable that result was less than first proposed, but more than desired by many. It was a fire and rehabilitation project that will be monitored for a number of years. It also had significant impacts on the workforces of Boise District (BLM) and Boise National Forest, while drawing upon the concerned volunteers of Boise City. While costing millions of dollars as did the projects did in Utah, it involved much less land, and many more people and more jurisdictions, including the BLM, U.S. Forest Service, state and county governments, and private land owners.

In conclusion, the problems or challenges caused by pinyon-juniper vegetation and fires, and cheatgrass are many and will continue. The dilemma caused by fire exclusion and the concomitant increase in juniper dominated land is countered by the cheatgrass presence and its problems. A potential problem that may make cheatgrass look benign are the secondary invasive weeds such as medusahead-rye, yellow starthistle, diffuse knapweed, and rush skeleton weed, weeds that have been found on the Eighth Street fire, and some of the Utah fires. These are weeds, particularly yellow starthistle and diffuse knapweed, that have little or no forage producing capacity, have the same site dominating capabilities of cheatgrass, and sharp thorns that destroy the site's recreational desirability also. The 1997 fire year was a light to moderate fire year, with adequate moisture for a high fuel buildup and carryover into next season, indicating that 1998 could be as difficult or worse than 1996.

In a positive note, the BLM and Forest Service have increased their training and in the BLM's case revised its EFR Handbook to reflect a broader approach to fire rehabilitation. There has also been a great amount of discussion and evaluation of Post-Fire rehabilitation policies and directions, being done at the Departmental Level, at the Department of Interior. It is likely that this review will examine the policies and funding authorities being used by Interior agencies, and BLM in particular.

This review may also have some impacts on the Forest Service. In the short run, the agencies are committed to an increased level of communication and coordination on training, and when necessary, project planning and implementation. It can be expected, however, that continuing discussions or concerns will remain as to funding authorities and philosophies for fire rehabilitation, and how far that approach can be extended towards vegetation restoration on the burned site. It should be anticipated, however, that as discussed above, there will likely plenty of rhetorical and physical fuel to continue some of the controversies relating to management of the pinyon-juniper ecosystem and its adjacent ecosystems, particularly as the discussions relative to ecosystem "health" continue.

References

Billings, W.D. 1994. Ecological Impacts of Cheatgrass and Resultant Fire on Ecosystems in the Western Great Basin. In: Monson, Stephen B. and Kitchen, Stanley G., comps. Proceedings—Ecology and Management of Annual Rangelands; General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah: 22- 31.

Bunting, S.D. 1994. Effects of Fire on Juniper Woodland Ecosystems in the Great Basin. In: Monson, Stephen B. and Kitchen, Stanley G., comps. Proceedings—Ecology and Management of Annual Rangelands; General Technical Report INT-GTR-313, USDA Forest Service, Intermountain Research Station, Ogden, Utah: 53-56.

Pellant, M, and Hall, C. 1994. Distribution of Two Exotic Grasses on Intermountain Rangelands: Status in 1992. In: Monson, Stephen B. and Kitchen, Stanley G., comps. Proceedings—Ecology and Management of Annual Rangelands; General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah: 109-113.
Roberts, T.C., Jr. 1994. Resource Impacts of Cheatgrass and Wildfires on Public Lands and Livestock Grazing. In: Monson, Stephen B. and Kitchen, Stanley G. comps. Proceedings—Ecology and Management of Annual Rangelands; General Technical Report INT-GTR-313. USDA Forest Service, Intermountain Research Station, Ogden, Utah: 167-170.
USDI, Bureau of Land Management, 1993. Forests: Our Growing Legacy, Bureau of Land Management, Washington, DC, 20240.
Whisenant, S.G. 1994. Changing Fire Frequencies on Idaho's Snake River Plains: Ecological and Managerial Implications; In: McArthur, E.D.; Romney, E.M.; Smith, S.D.; Tueller, P.T., comps. Proceedings—Symposium on Cheatgrass Invasion, Shrub Die-off and Other Aspects of Shrub Biology and Management; General Technical Report INT-GTR-276. Ogden, Utah, USDA Forest Service, Intermountain Station: 4-11.

Control of Weeds at a Pinyon-Juniper Site by Seeding Grasses

Sherel Goodrich
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Abstract — An area seeded to perennial grasses and an adjacent nonseeded area both within a burned Colorado pinyon/Utah juniper (*Pinus edulis* Engelm./*Juniperus osteosperma* [Torr.] Little) community provided an opportunity to contrast frequency of plant species in the two treatments. Lower frequencies for cheatgrass (*Bromus tectorum* L.) and yellow salsify (*Tragopogon dubius* Scop.), which are introduced annuals, were found in the seeded area. Abundance of musk thistle (*Carduus nutans* L.), a noxious weed in Utah, was found at much reduced density and frequency where the burn had been seeded compared to where the burn had not been seeded. Higher frequency for squirreltail (*Elymus elymoides* [Raf.] Swezey), which is a native perennial grass, was found in the seeded area compared to the nonseeded area. Management implications include the need for advanced collection and storage of seed to supply the need for seeding large burns to prevent dominance of cheatgrass and other invasive weeds in these burns.

Introduced weedy plants present a formidable challenge to the management of native plant communities. Indeed cheatgrass (*Bromus tectorum* L.) seriously challenges the concept of maintaining native plant communities in some areas such as on the Snake River Plain and valleys and foothills of the Great Basin. Once established it is perpetuated by high fire frequencies by which it is able to exclude sagebrush and other native species (Peters and Bunting 1994). Some other introduced plants are also highly competitive including those on noxious weed lists of various states such as musk thistle (*Carduus nutans* L.). Control of these species has become a major concern where they now dominate thousands of acres and result in great economic loss (Leistritz and others 1996; Whitson and others 1991).

While some of these species are competitive at higher elevations in aspen and spruce-fir belts, cheatgrass is generally not. However, the thermal belt of Colorado pinyon (*Pinus edulis* Engelm.) and Utah juniper (*Juniperus osteosperma* [Torr.] Little) is prime habitat for cheatgrass. Coupled with the nature of pinyon-juniper to greatly oppress native understory species and outlive the seed banks of these species (West and Van Pelt 1987), the explosive ability of cheatgrass to increase after disturbance (Young and Evans (1978) presents a scenario in which it is difficult to apply a concept of native plant communities. Disturbance is usually a matter of "when" more than of "if." When disturbance comes to mature and old stands of pinyon-juniper they are left wide open to the invasion of cheatgrass and other invasive weeded species by the general lack of native understory species that is a function of pinyon-juniper stand closure (Everett 1987; West and Van Pelt 1987).

With an expanding human population of increasing mobility, the spread of weeds can be expected to remain at high levels and probably increase. This scenario has and will continue to complicate the maintenance of native plant communities. Applying a concept of wilderness or natural areas where disturbance by humans is hopefully omitted, will not always adequately address this challenge. Some of these plants have shown ability to enter and increase on sites where disturbance by man is minimal.

Kindschy (1994) reported the presence and increase of cheatgrass in southeastern Oregon's Jordan Crater Research Natural Area that has been protected from human activities including livestock grazing. Tausch and others (1994) found cheatgrass has displaced native perennial species on Anaho Island in Nevada despite a general absence of human-caused disturbance and fire. They attributed the increase to the competitive ability of cheatgrass. Young and Tipton (1990) cited two works from southeastern Washington that documented observations of cheatgrass successfully inserting itself into climax perennial grass/shrub communities that had been protected from fire and grazing for as long as 50 years. They proposed the idea of cheatgrass spreading in a biological vacuum created by grazing may be somewhat misleading or overstated. Goodrich and Gale (these proceedings) reported high frequency of cheatgrass on two sites with little apparent use by non-Native Americans or their livestock that are within 2.4 and 5.6 km (1.5 and 3.5 miles) of this study site. Knight (1994) reported the cheatgrass problem is not restricted to land managed for livestock, and he gave an example of an increase of cheatgrass following fire in Little Bighorn Battlefield National Monument in southern Montana. He suggested that managing vegetation of a National Monument so it reflects presettlement conditions is a goal that may be impossible once certain introduced species become established.

In addition to the ability of cheatgrass to invade some native plant communities without disturbance, the reality of the modern world includes international travel, high speed freeways, and a maze of other paved and dirt roads. Vehicles are a major means by which seeds are spread. Within a day, modern travel can carry seeds not only across major drainages but across oceans. It is common for seeds from vehicles to be deposited in disturbed areas where there is comparatively high probability for establishment. Northam and

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Callihan (1994) examined five exotic annual grasses of recent introduction to the inland Pacific Northwest. Their work indicates the introduction of alien species continues and their dispersal has been enhanced by human transportation technology. The seeds of musk thistle and some other weedy species are highly adapted to transport by wind. This feature also indicates a continuing spread of these species. The ability of invasive weeds such as cheatgrass to spread and greatly alter ecosystem function indicates high priority for dealing with these species.

Features and Recent History of the Study Location

The study site is within the North Skull Creek Burn of 1976, in the Green River corridor near Flaming Gorge in Daggett County, Utah, about 6 miles northwest of the town of Dutch John, within the Uinta Mountain Section as defined by McNab and Avers (1994). Annual precipitation at the Flaming Gorge Weather Station (near Dutch John) is 31.75 cm or 12.50 inches (Ashcroft and others 1992). The study site is within a landtype composed of ridge and ravine topography underlain by Precambrian quartzitic materials and shales of the Uinta Mountain Group. Within the landtype there are two general phases. One phase is on northerly exposures where alder-leaf mountain-mahogany/bluebunch wheatgrass (*Cercocarpus montanus* Raf./*Elymus spicatus* [Pursh] Gould) communities of high plant diversity are seral to pinyon and juniper. The other phase is on southerly exposures where communities of rubber rabbitbrush (*Chrysothamnus nauseosus* [Pallas] Britt.), sagebrush (*Artemisia* L,) and grasses are seral to pinyon-juniper. On the southerly exposures cheatgrass has proven to be a highly competitive plant. It is less competitive on the northerly exposures.

History of the site included livestock grazing up to about 1972. Livestock grazing was not permitted at this study site from before the burn of 1976. Although livestock had grazed the area in earlier decades, age and crown closure of trees prior to burning indicate little forage production inside the stand prior to European settlement. Livestock would not have been highly attracted to the site due to distance to water as well as low forage production. A stock watering pond had been constructed near the site, but it rarely held water.

The burn site is at 2,134 to 2,256 m (7,000 to 7,400 ft) elevation on a southerly exposure with gradients of 10 to 50 percent. The study site within the burn is on gradients of 10 to 20 percent. The burn was not seeded following the 1976 fire. The decision not to seed reflects the attitude that without livestock, native plants would occupy the site after burning. However, occupation of dense stands of pinyon and juniper had exceeded the life span of seed banks for most species. Response of native plants was low. Within a decade cheatgrass dominated the site. Other introduced plants became abundant including musk thistle, which is included on noxious weed lists for several Western States. The aggressive nature of this plant allows it to spread rapidly forming extremely dense stands that crowd out other species (Whitson and others 1991).

The site was serving as a source of weed seed to spread to other areas. It was prescribed burned again on June 27, 1990, when cheatgrass seed was mature but had not yet shattered. The prescription was intended to reduce cheatgrass long enough to facilitate establishment of seeded species. The burn was aerial seeded in fall 1990 with a mixture of grasses and forbs. However, parts of the burn were missed in the seeding, which allowed a comparison of adjacent seeded and unseeded areas. The seed mix included aggressive, introduced grasses such as crested wheatgrass (*Agropyon cristatum* [L.] Gaertner), intermediate wheatgrass (*Elymus hispidus* [Opiz] Meld.), orchardgrass (*Dactylis glomerata* L.), and smooth brome (*Bromus inermis* Leysser).

Methods

Six growing seasons after the 1990 burn and seeding, five 30.5 m (100 ft) belt lines were established in each of the seeded and nonseeded areas of the burn along which samples were taken in 100 frequency plots. Rooted nested frequency for all species present was determined in each of four nested plot sizes at each of the 100 plots as outlined by U.S. Department of Agriculture, Forest Service (1993). The method allowed for a score of 400 for each species. Scores for the more frequent species are shown in table 1. Also the number of musk thistle plants were recorded in 0.91 by 30.5 m (3 by 100 ft) macro plots along each of the belt lines for a total sample area of 0.0139 ha (0.0344 acres).

Results

There were 26 and 270 musk thistle plants in the five macro plots for the seeded and nonseeded areas, respectively, or 1,871 and 19,424 plants per ha (756 and 7,849 per acre) in the seeded and nonseeded areas, respectively. Six growing seasons postseeding, the nonseeded area supported 10 times more musk thistle plants than did the seeded area.

Nested frequency scores were significantly higher in the nonseeded area than in the seeded area for cheatgrass, musk thistle, yellow salsify (*Tragopogon dubius* Scop.), and Canada

Table 1—Nested frequency scores for eight species. Based on a potential score of 400

Plant species	Seeded area	Nonseeded area
Cheatgrass	309	347
Musk thistle	6	44
Yellow salsify	66	126
Canada thistle	0	28
Squirreltail[a]	178	133
Crested wheatgrass[a]	75	5
Intermediate wheatgrass[a]	66	3
Orchard grass[a]	76	6
Smooth brome[a]	49	0
Other annuals and biennials	1	26
Other herbaceous perennials[a]	97	79

[a]Herbaceous perennial species excluding Canada thistle.

For all species of this table, the spread in scores between the twp areas is indicated to be significant at 80 percent probability (Chi Square = 1.642 with 1 degree of freedom).

thistle (*Cirsium arvense* [L.] Scop.). Scores were higher in the seeded area for squirreltail (*Elymus elymoides* [Raf.] Swezey) and for crested wheatgrass, intermediate wheatgrass, orchardgrass, and smooth brome (table 1).

Discussion

Reduced frequency of weedy species was found in the seeded area. With the exception of Canada thistle, perennial, herbaceous species had higher frequency scores in the seeded area. The seeded and nonseeded sites were adjacent to each other and conditions were very similar at each site. However, some species could have been more abundant at one site than the other prior to treatment. This is most likely for squirreltail and Canada thistle. The invasive nature of cheatgrass indicates it had near equal frequency across the two sites prior to treatment. Musk thistle and yellow salsify are annual or biennial weeds with highly mobile seeds. The high mobility of the seeds and annual or biennial habit of these plants indicate these two species can be expected to have equal distribution in the seeded and nonseeded areas. Although Canada thistle has highly mobile seeds, there seems to have been little recruitment of this perennial species by seed since the second burn. Persistence and advance of this species is expected to be largely a function of its robust rhizomes. This plant is expected to have been most common in the unseeded area prior to seeding. The difference in scores for this species is not expected to be a function of seeding.

Much of the reduction of the introduced annual and biennial plants including cheatgrass appears to have been a function of seeding perennial grasses. The difference in nested frequency scores for cheatgrass between the seeded and unseeded areas might appear too small for an obvious shift in dominance of this species to a greatly reduced position in the community. However, comparison of the total scores for perennial herbaceous species between the two areas indicates the wide difference in the communities. Total scores for perennial herbaceous species excluding Canada thistle were 541 for the seeded area and 226 for the unseeded area. Difference in cheatgrass between the seeded and unseeded sites goes beyond frequency. Size of cheatgrass plants was also reduced in the seeded area. Davis and Harper (1990) also reported reduction of weedy plants concurrent with establishment and increase of seeded species at a juniper-pinyon site in central Utah.

Management Implications

The explosively invading, highly competitive nature of cheatgrass (Pyke and Novak 1994; Harris 1967; Hironaka 1994; Nasri and Doescher 1995a,b; Young and Evans 1978; Evans and Young 1978) and especially on southerly exposures (Monsen 1994) might have been expected prior to the 1976 burn at North Skull Creek. However, much of the literature dealing with the competitive ability of this plant has come since that time. The decision not to seed following the 1976 fire seems to reflect the perception of that time that the native flora would dominate the site in the absence of livestock. However, the ability of cheatgrass to drive community dynamics goes beyond the influence of livestock grazing as discussed at the first of this paper. On some sites, it is a better competitor for soil moisture than are some widespread, highly successful native, perennial grasses including bluebunch wheatgrass (Harris 1967; Hironaka 1994; Pyke and Novak 1994) and Idaho fescue (*Festuca ovina* var. *ingrata* Hackel ex Beal) (Nasri and Doescher 1995b).

The ability of cheatgrass to drive plant community dynamics on pinyon-juniper sites as well as sagebrush sites presents a formidable challenge to maintenance of native plant communities. It is becoming increasing apparent that in some places plant communities will not be as they were before the advent of cheatgrass and other Eurasian introductions. South-facing slopes of pinyon-juniper ecosystems are one of these places. Super dominance (West and Van Pelt 1987) that comes with long-term occupation of pinyon-juniper trees of high percent crown closure leaves a depauperate understory that is essentially unable to respond after fire with the rapidity needed to compete with cheatgrass. Closed stands of pinyon and juniper are often quite effective in keeping cheatgrass at low levels. However, cheatgrass has inserted itself into these stands and has become wide spread in the pinyon-juniper ecosystem. Young and Evans (1978) found density of cheatgrass plants increased from 10/m^2 the first year after fire to 10,000/m^2 by the third year. Fire in dense stands of pinyon-juniper sets the stage for this kind of cheatgrass response. Fire in woodlands is more often a matter of "when" than "if." Eventually, many stands burn and are then exposed to cheatgrass and other weedy, introduced species.

Response to this situation includes doing nothing in which case, dominance of cheatgrass is strongly indicated by its past performance. Seeding can greatly decrease the influence of cheatgrass, but this is not likely to exclude it. Currently some of the most competitive plant materials for which seed is available in quantities sufficient to respond to large fires are of Eurasian origin. In recent years seeding these species has become increasingly objectionable because of their origin. However, this presents a dilemma of "choose your alien." The choices are a dominance of the annual cheatgrass or a mixture of perennial species of which some of the most likely to compete with cheatgrass are of Eurasian origin.

This dilemma points to the urgent need to develop native plant materials that are more competitive with cheatgrass. Until such materials are developed and of sufficient quantity to respond to large fires, introduced species such as those used in the 1976 North Skull Creek Burn seem to provide an alternative to cheatgrass. For 1996, Roberts (these proceedings) reported over 6 million acres burned in the United States through unplanned ignitions with over 2 million of these acres on lands administered by the Bureau of Land Management where over 300,000 acres were included in Emergency Fire Rehabilitation projects. Many of these fires were on lands dominated by pinyon-juniper and cheatgrass communities. Over 200,000 acres of pinyon-juniper-cheatgrass range burned in central Utah in 1996. The scale of these projects went far beyond availability of seed of native species.

The concept of using seed of local, native plants only to preserve pure local ecotypes without contaminating their gene pools has become an issue for rehabilitation projects. This concept might be practical for small projects and especially outside the ecological range of cheatgrass and other highly aggressive, invasive species. However, the scale of fires of 1996 demonstrates the futility of demanding seed of local natives only for use in seeding large burns. The ability of cheatgrass to increase from 10 to 10,000 plants per square m from the first to the third year postfire (Young and Evans 1978) demonstrates the need to apply seed in the year of the burn. This requires advanced storage of seed for rehabilitation projects. The critical need for advanced storage and early application of seed will be difficult to supply under a concept of "on site" collected seed of "pure" local natives. This concept is plagued by the uncertainty of specific sites of future fires. It is also difficult to apply after locations of fires are known. After fire, it is too late to collect abundant seed from the specific site. The year in which a fire burns can be a poor year for seed in areas adjacent to a burn.

Cheatgrass and other aggressive introduced weedy plants seriously challenge the concept of maintaining some native plant communities including many within the pinyon-juniper belt. Responding to these weedy plants might require looking beyond our traditional fascination with native plant communities, and especially if that fascination is based on a concept of "pure native" where "pure" implies native communities of local gene pools without influence of outside forces.

American isolation from the Old World, if it ever existed, stopped in 1492. The incidence of introductions and distribution of plants as a function of travel and Eurasian occupation has increased greatly since than time. Some of the introductions are simply better competitors in some environments than are natives. Or at least these introductions are aggressive enough to insert themselves into and maintain themselves in native plant communities that then are no longer native in a pure sense. Knight (1994) has suggested that management of vegetation so it reflects pre-European settlement conditions is a goal that may be impossible once certain species become established. His suggestion combined with the catastrophic and large-scale change induced by cheatgrass and other weedy species in the Great Basin (Billings 1994) and Snake River Plain (Peters and Bunting 1994) vividly portray the potent ecological force of cheatgrass.

Standards for plant communities within the pinyon-juniper belt based only on natives and especially only local natives could reflect more romanticism than realism. We agree with Young's (1994) evaluation that: "The inherent variability in bluebunch wheatgrass and related native species is a vital part of the cheatgrass range restoration picture. If the genotypes cannot be found in bluebunch wheatgrass populations, which can compete with cheatgrass, then range restoration is dependent on: (1) reestablishment of high-technology weed control systems, (2) hybridization of bluebunch wheatgrass with relatives such as quackgrass (A. repens) [*Agropyron repens* L.] that are not native, followed by selection for competitive ecotypes, or (3) accept exotic hybrids that are competitive."

At the North Skull Creek Burn, native plants, in the absence of livestock, did not prevent cheatgrass dominance or an abundance of musk thistle. The seeding at the North Skull Creek Burn demonstrates the ability of crested wheatgrass and other introduced perennial grasses to reduce cheatgrass and musk thistle to subordinate positions in plant communities. These highly successful plant materials are the product of hundreds of years of selective breeding for high seed production, ease of harvest, vigorous germination, rapid establishment, high production, and other features. Establishment of these species and reduction of cheatgrass indicates a reduced fire frequency that can facilitate increased of sagebrush and other native species including pinyon and juniper. Fire frequency typical of cheatgrass dominated lands is commonly too high to allow for the return of native woody species.

In response to fires of 1996, many thousands of pounds of seed of introduced species were used not because managers prefer them over natives, but because seed of suitable natives was not available. It is not the intent of this paper to recommend continued use of introduced species for seedings. However, until large quantities of seed of native species with the ability to compete with and suppress cheatgrass are available, the introduced species seeded at North Skull Creek Burn provide an alternative to cheatgrass dominance. This and the relatively low cost of seed of these species will continue to appeal to those faced with the reality of large burns in cheatgrass-prone areas.

Quantities of native seed adequate to supply the need following large fires in fire seasons such as 1996 can be facilitated by the methods that have put seed of introduced species in abundant supply. Selecting for high seed production, ease of harvest, vigorous germination, and rapid establishment and advanced harvest and massive storage of seed to be used in regional areas and not necessarily local areas might not fit well into a pure, local, native concept. However, the challenge presented to such a concept by cheatgrass and other aggressive, introduced , weedy species seems catastrophic. This challenge has been met by selection and marketing that has put seed of successful, perennial, introduced species in abundant supply. Similar selection and market development of native species is strongly indicated as a vital part of rangeland restoration including control of noxious weeds and other highly invasive species.

References

Ashcroft, G. L.; Jensen, D. T.; Brown, J. L. 1992. Utah climate. Logan, UT: Utah State University, Utah Climate Center. 125 p.

Billings, W. D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 22-30.

Davis, J. N.; Harper, K. T. 1990. Weedy annuals and establishment of seeded species on a chained juniper-pinyon woodland in central Utah. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tuller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 72-79.

Evans, R. A.; Young, J. A. 1978. Effectiveness of rehabilitation practices following wildfire in a degraded big sagebrush-downy brome community. J. Range Manage. 31: 185-188.

Everett, R. L. 1987. Plant response to fire in the pinyon-juniper zone. In: Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 Janurary 13-15; Reno NV: Gen. Tech. Rep. 152-157. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 152-157.

Goodrich, S.; Gale, N. These proceedings. Cheatgrass frequency at two relic sites within the pinyon-juniper belt of Red Canyon. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Harris, G. 1967. Some competitive relationships between Agropyron spicatum and Bromus tectorum. Ecological Monographs. 37: 89-111.

Hironaka, M. 1994. Medusahead: natural successor to the cheatgrass type in the northern Great Basin. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 89-91.

Kindschy, R. R. (1994). Pristine vegetation of the Jordan Crater Kipukas: 1978-91. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 85-88.

Knight, D. H. 1994. Mountains and plains: the ecology of Wyoming landscapes. New Haven, Conn., Yale University Press. 338 p.

Leistritz, F. L.; Bangsund, D. A.; Leitch, J. A. 1996. Economic impact of leafy spurge on grazing and wildlands in the Northern Great Plains. In: Quimby, C., moderator; Busby, F., facilitator. Proceedings of the alien plant invasions symposium; 1995 January 17: BLM/OR/WA/PT-95/048+1792. U.S. Government Printing Office; Region No. 10: 15-21.

McNab, W. H.; Avers, P. E. 1994. Ecological subregions of the United States: Section descriptions. Administrative Publication WO-WSA-5. Washington, DC: U.S. Department of Agriculture, Forest Service. 267 p.

Monsen, S. B. 1994. The competitive influences of cheatgrass (Bromus tectorum) on site restoration. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-50.

Nasri, M.; Doescher, P. S. 1995a. Effect of competition by cheatgrass on shoot growth of Idaho fescue. J. Range Manage. 48: 402-405.

Nasri, M.; Doescher, P. S. 1995b. Effect of temperature on growth of cheatgrass and Idaho fescue. J. Range Manage. 48: 406-409.

Northam, F. E.; Callihan, R. H. 1994. New weedy grasses associated with downy brome. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 211-212.

Peters, E. F.; Bunting, S. C. 1994. Fire conditions pre- and post-occurrence of annual grasses on the Snake River Plain. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 31-36.

Pyke, D. A.; Novak, S. J. 1994. Cheatgrass demography—establishment attributed, recruitment, ecotypes, and genetic variability. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 12-21.

Roberts, T. C. These proceedings. The budgetary, ecological, and managerial impact of pinyon-juniper and cheatgrass fires. In: Monsen, Stephen B.; Stevens, Richard; Tausch, Robin J.; Miller, Rick; Goodrich, Sherel, comps. 1998. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proc. RMRS-P-000. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Tausch, R. J.; Svejcar, T.; Burkhardt, J. W. 1994. Patterns of annual grass dominance on Anaho Island: implications for Great Basin vegetation management. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 120-125.

U. S. Department of Agriculture, Forest Service. 1993. Rangeland ecosystem analysis and management handbook. FSH 2209-21. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 4 ch.

West, N. E; Van Pelt, N. S. 1987. Successional patterns in pinyon-juniper woodlands. In: Everett, R. L., compiler. Proceedings-pinyon-juniper conference; 1986 January 13-16; Reno, NV: Gen. Tech. Rep. INT-215. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 43-52.

Whitson, T. D.; Burrill, L. C.; Dewey, S. A.; and others. 1991. Weeds of the west. The Western Society of Weed Science in cooperation with the Western United States Land Grant Universities Cooperative Extension Services. 630 p.

Young, J. A. 1994. History and use of semiarid plant communities—changes in vegetation. In: Monsen, S. B.; Kitchen, S. G., compilers. Proceedings—ecology and management of annual rangelands; 1992 May 18-21; Boise, ID. Gen. Tech. Rep. INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 5-8.

Young, J. A.; Evans, R. A. 1978. Population dynamics after wildfires in sagebrush grasslands. J. Range Manage. 31: 283-289.

Young, J. A.; Tipton, F. 1990. Invasion of cheatgrass into arid environments of the Lahontan Basin. In: McArthur, E. D.; Romney, E. M.; Smith, S. D.; Tueller, P. T., compilers. Proceedings—symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U. S. Department of Agriculture, Forest Service, Intermountain Research Station: 37-40.

Use of the Helitorch to Enhance Diversity on Riparian Corridors in Mature Pinyon-Juniper Communities: A Conceptual Approach

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Abstract—As pinyon-juniper have increased their dominance throughout the Great Basin, other perennial plants have declined in abundance. Riparian areas traditionally have the greatest biodiversity found in the region. The increase of pinyon-juniper can generally be attributed to a change in the disturbance regime. To increase the plant diversity found in the riparian areas pinyon-juniper plants must be removed, but traditional methods, such as individual tree cutting, chaining, or herbicides, are not practical or acceptable in many cases. Fire has generally not been thought of as a viable alternative. A helitorch, with a fan nozzle, could be used to follow the riparian corridor and burn out pinyon-juniper trees when leaf moisture is lowest and weather conditions would restrict fire spread to just those trees where the fuel has been placed. Burned areas could be used to break up fuel continuity associated with mature pinyon-juniper communities. This would allow land managers to work with small areas to (1) break up fuel bed structure, (2) reestablish desired plants in both riparian and upland areas, and (3) enhance and restore plant diversity found in the Great Basin and Intermountain West.

Pinyon-juniper communities have encroached into many new areas because of altered disturbance regimes in the Great Basin. This has primarily been due to changes in fire return intervals. In addition, occurrence of exotic annuals now make these communities susceptible to being invaded and dominated by these annuals once a disturbance occurs. This is particularly apparent on large-scale fire disturbances because of the difficulty often encountered in revegetation. Within the riparian corridors the loss of plant diversity and the increased erosion potential following large disturbances can lead to numerous negative consequences. Disturbances need to be gradually reintroduced into these systems. This would allow reestablishment of diverse species that could provide a seed source to aid in the recovery of the plant communities following larger disturbances.

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Currently there are several disturbance practices available to treat riparian zones including mechanical, individual tree cutting, herbicides, and broadcast burning. All have distinct advantages and disadvantages, One approach that has not been considered is the use of a helitorch during periods when precise ignition placement and speed could be used to limit the scale of the fire and reduce soil disturbance.

The helitorch has been developed to burn large complex units on forest and rangelands. It has been successful on these large units where hand ignition was not practical or safe (Masters and others 1986). This ignition tool has been very successful in treating redberry juniper (*Juniperus pinchottii*) communities (McPherson and others 1985) and Utah Juniper (*J. osteosperma*) (Brad Barber personal communication). However, the successful use of this ignition technique requires people with experience and the desire to burn large units, which limits its application (Masters and others 1986). This technique provides a very precise placement of the ignition pattern to develop sufficient heat to overcome many of the fuel discontinuities associated with rangeland fuels. While many have tried to use the helitorch, often the size of the units are not sufficient to be cost effective (Rasmussen and others 1988). In addition, many land managers felt that large units were often logistically impractical to treat.

While this ignition technique is associated with large units it also has the capability to deal with smaller areas for specific objectives. We propose that many of the riparian corridors in the Great Basin where pinyon-juniper has become a dominate at he expense of the original riparian vegetation can be effectively restored using prescribed fire ignited with a helitorch. This can be done by precise placement of the fire and modifying the fire prescription to allow the fire to stay within the original riparian corridor. Non-sprouting juniper and pinyon could be removed which would allow riparian vegetation to reestablish. Because of weather conditions at time of burning few personnel would be needed for containment which would reduce the cost of the burn. An added benefit would be to break up fuel continuity associated with mature woodlands. This practice could also be used to enhance fire manage capabilities especially if the associated ridges were burned in the same manner.

Attempts of using spring burns in mature pinyon-juniper communities have been difficult because of the limited number of days that occur when weather conditions at this time in the season promote the desired spread of fires and amount of herbaceous fine fuel needed to carry the fire is often lacking. However, ignition of individual trees has been successful when the ignition source was placed directly on the tree foliage (personal communication Stan Miller). Bunting and others (1976) found juniper readily ignited when leaf moisture was below 45 percent. Low moisture levels normally occur in the summer, but may also be encountered in the spring. Spring leaf moisture of Utah juniper in Cache County, Utah has been recorded as less than 40 percent in March and April. The ability to ignite individual trees appears to be related the leaf moisture of the juniper during this period of the year.

Factors that limit the use of prescribed fire during the winter spring periods in the Great Basin can also be used to effectively burn small areas for the specific objectives. Reestablishment of a variety of communities in the riparian areas and uplands could be accomplished using this technique. In addition reducing continuous fuel beds by strategically placing corridors in the riparian areas and ridges could reduce the spread of wildfires. Instead of promoting large fires with 50 to 80 percent burn coverage, prescribed fires can be limited to those trees where the fuel is placed. Fire spread could be minimized by selecting the appropriate weather conditions. This would limit the disturbance to small areas that can be effectively restored with desired plant species.

The helitorch provides an ignition source that could effectively ignite sufficient trees along a corridor (riparian or ridge) during the spring period. Since the rate of fire spread is not the driving factor in developing prescription for burning, weather constraints would be greatly relaxed. A fire prescription could be developed which would increase the number of days that burning could be used. An additional advantage would be the increased availability of equipment which is normally not being used for fire suppression during this period.

A modified helitorch with a fan nozzle was used to ignite 1000-4000 ha units in West Texas (Masters and others 1986). The helicopter flew at 60-90 km/hr, 30-50 m above the surface. This resulted in a 10 m swath with burning fuel in very m^2. To ensure sufficient fuel lands on individual trees and increase the precision of fuel placement the helicopter would probably have to slow down. We would suspect from experience that 10 to 30 km/hr may be sufficient. This would increase the amount of fuel/m^2. Table 1 provides an initial prescription range that would allow individual trees to ignite but limit fire spread. Research would have to be conducted to refine the prescriptions and the most desired speed and height needed to ignite the trees along a desired corridor. In most cases we suspect several passes of the helitorch would be required to create the desired corridor width.

Table 1—Proposed possible weather conditions in the Winter/spring that could be used to develop fire prescriptions to burn corridors in mature Pinyon-Juniper communities in the Great Basin.

Weather conditions	Winter/Spring
Temperature (F)	40-80
Wind (mph)	0-10
Relative humidity (percent)	10-50
Cloud cover (percent)	<25
Juniper leaf moisture (percent)	<45

This approach while unconventional offers several advantages over existing methods of treatment managers can use to restore narrow corridors in pinyon-juniper communities.

1. It has the potential to limit soil disturbance compared to most mechanical techniques and summer fires.
2. Allows managers to work with small areas to increase the success of establishing desired plant community (diversity), which can then be used as a seed source when other disturbances occur.
3. Can be used in remote rough sites.
4. Can be incorporated in the large scale fire management plans to break up fuel bed structure and help in wildfire suppression.
5. Application would be rapid though it is doubtful planning costs would change.

Before this approach is used research or tests would need to be established to refine the prescriptions and decrease the risk of failures by burning under the wrong conditions.

References

Bunting, S. A., C. M. Britton, H. A. Wright, and C. M. Countryman. 1976. Ignition temperature and leaf moisture relationships in Juniper. Fire Mange. Notes. 37: 143-146.

McPherson, G. R., R. A. Masters, and G. A. Rasmussen. 1985. Prescribed burning a chained redberry juniper community with a helitorch. Fire Manage. Notes. 46: 7-10.

Masters, R. A., G. A. Rasmussen, and G. R. McPherson. 1986. Prescribed burning with a helitorch on the Texas rolling plains. Rangelands. 8: 173-176.

Rasmussen, G. A., G. R. McPherson, and H. A. Wright. 1988. Economic comparison of aerial and ground ignition techniques for rangeland prescribed fires. J. Range Manage. 41: 413-415.

Wildfire Rehabilitation in Utah

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Abstract—The magnitude of the fire problem on arid rangeland in Utah was addressed, and effectiveness of common fire rehabilitation practices was compared. In lower elevations, and over much of Utah's arid environment, cheatgrass and other weedy species readily invade burned areas when the site specific reseeding mixture used is not planted (drilling) or covered (chaining). Aerial seeding followed by single chaining to cover the seed proved to be a very effective method of establishing perennial vegetation, maintaining species diversity, and inhibiting the spread of weedy species. It was noted that old seedings, containing fire resistant and fire tolerant species of vegetation, remained green longer into the fire season, and made natural fire-breaks, thereby helping to contain the wildfire.

Land administered by the Bureau of Land Management (BLM) in Utah is generally arid, receiving 8-12 inches of precipitation per year. Acres of BLM land burned by wildfire has increased from 4,549 acres in 1991, to 308,457 acres in 1996 as shown in the following tabulation:

Year	BLM acres burned
1991	4,549
1992	7,439
1993	11,928
1994	116,021
1995	127,900
1996	308,457

The increase in number of acres burned is due in part to the invasion of introduced winter annuals such as cheatgrass (*Bromus tectorum*), and past fire suppression activities. Cheatgrass not only changes the fire frequency of a site, but also the fire volatility, intensity and extent of the area likely to burn in the future.

Objective

The purpose of the Emergency Fire Rehabilitation program is to: Protect life, property, soil, water and/or vegetation resources; Prevent unacceptable on-site and off-site damage to the watershed (erosion control); Reduce invasion and establishment of undesirable or invasive species of vegetation, and; Facilitate meeting Land Use Plan objectives. The purpose of this study was to compare various treatment methods of wildfire rehabilitation for meeting the stated objectives, keeping in mind the cost associated with each method of treatment.

Methods and Results

In all seeding methods, mixtures of grasses, forbs and shrubs that are adapted to the site were used. Exception: On some sites with State listed noxious forbs, a mixture of native and introduced grasses adapted to the site was used. Forbs and shrubs will be seeded after the noxious weed problem is controlled by spraying.

Precipitation following the seeding was above normal, and winter temperatures were warmer than normal. Results described, therefore, are from the best possible climatic conditions to be expected in the area.

Natural Revegetation, No Seeding (Control Area)

Control areas were examined to determine their natural recovery. In higher elevations where sufficient moisture and a diverse population of perennial vegetation exists, these areas recovered sufficiently to protect the watershed, especially on the north and east facing slopes. Response of native vegetation was not as good on south and west facing slopes, which are typically drier.

Below 6,000 ft elevation, and in much of Utah's arid environment, cheatgrass and other weedy species readily invaded the burned areas. These areas did not respond naturally with sufficient perennial vegetation to protect the watershed from wind and water erosion, and weed invasion.

Seed by Aerial Application Only Without Covering the Seed

Seed was flown over 102,100 burned acres in the rehabilitation area. Of this number, 55,200 acres were aerial seeded only, with no disturbance to the soil. These areas were then compared with areas that were not seeded (control areas), areas where seed was planted by drill, and with areas that were seeded and then chained to cover the seed.

While a small percent of the uncovered seed germinated and became established, it was not in sufficient quantity to protect the soil from erosion. In areas of high winds, the seed was blown to unburned islands, and roadside gullies. There it was covered with topsoil lost from the site due to wind erosion. The seed became established in these disturbed areas. Pedestaling of the exposed plant roots, showed that up to four inches of topsoil was lost due to wind erosion in some areas that had been seeded, where the seed was not covered.

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Seed by Aerial Application Followed by Chaining to Cover the Seed

The seed mixture was flown on the treatment area, followed by one-time chaining to cover the seed. In addition, in some areas, seed dribblers were placed so that shrub seeds were planted by the action of the heavy equipment in areas being chained. In 1996, some areas suitable for drilling seed were aerial seeded instead because of the vast acreage needing immediate treatment following wildfire. More than twice as many acres could be covered per day, by using this method.

Covering the seed with one-time chaining, proved to be very effective in establishing perennial vegetation to protect the site from wind and water erosion. This seeding method helped establish and maintain species diversity, and inhibit the spread of cheatgrass and other weedy species.

Drill Seeding

Sixteen thousand one hundred fifty acres were seeded by rangeland drills. Most exhibited a high germination response, the exception being the sand dunes at Little Sahara Recreation Area. In most cases, drilling effectively planted the seed mix, and inhibited the spread of cheatgrass and State listed noxious weeds.

Discussion

Study plots have been identified for long term monitoring of the treatment areas, by BLM and by the U.S. Forest Service Shrub Laboratory. Observations discussed below pertain to results of rehabilitation, the first year following treatment.

Natural Revegetation

In higher elevations (above 6,000 ft) where sufficient moisture and a diverse population of perennial vegetation exists, reseeding is often not needed, especially on the north and east facing slopes. However south and west facing slopes, which are typically drier, would likely benefit from seeding.

Below 6,000 ft elevation, and over much of Utah's arid environment, cheatgrass and other weedy species readily invade burned areas. The dominance of cheatgrass shortens the fire cycle, and increases the volatility and extent of the fire. Also because cheatgrass does not catch and hold snow like a diverse perennial stand of vegetation, the site becomes drier (desertification). On sites dominated by cheatgrass, the normal revegetative process is interrupted resulting in loss of native perennial species, and lack of diversity.

Dense stands of pinyon-juniper often lack a diverse understory. When wildfire removes the canopy, there is not sufficient perennial seed available in the soil to protect the site from wind and water erosion.

Aerial Seeding Without Covering the Seed

This method did not result in adequate perennial vegetation to protect the watershed. Invasive introduced weeds such as cheatgrass and State listed noxious weeds readily invaded the sites. In areas with highly erosive soils, wind and water erosion is evident. It was also determined aerial broadcast seeding without covering the seed was not cost effective over large areas in Utah's arid environment.

Aerial Seeding Followed by Chaining to Cover the Seed

This method of covering the seed proved to be a very effective in establishing perennial vegetation on areas with slopes and gullies, rocky outcrops, and areas with dead tree stumps and debris. This treatment is highly effective in protecting the site from wind and water erosion. These seedings helped establish and maintain species diversity, and inhibit the spread of cheatgrass and other weedy species.

Aerial seeding followed by one-time chaining to cover the seed also proved to be a practical and relatively inexpensive method to use when large acreage needs to be treated (over 300,000 acres of BLM land burned in 1996). With this method, 250 acres could be treated per day, as compared to drilling the seed at 100 acres per day.

Drill Seeding

Areas that were seeded by drilling had the highest germination response. But drilling could only be used on level areas free from obstacles. Therefore drilling wasn't possible in pinyon-juniper sites, rocky outcrops, and areas with washes or channels, and on slopes.

Additional Benefits of Seeding

Where wildfire burned into old seedings, it's advance was slowed or stopped in that direction, in spite of strong winds. The seedings, which contain fire resistant and fire tolerant species of vegetation, remain green longer into the season. There are numerous examples where old seedings make natural fire-breaks, thereby helping to contain the wildfire.

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References

Clary, Warren P. Plant density and cover response to several seeding techniques following wildfire. Research Note INT-384, 6 pp. U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Everett, Richard; Clary, Warren. Fire effects and revegetation on juniper-pinyon woodlands. Rangeland fire effects: a symposium, Boise, ID. 1984 November 27-29. Idaho State Office, U.S. Department of Interior, Bureau of Land Management, Boise, Idaho. 1985. (33-37).

Farmer, Mark E.; Harper, Kimball T.; Davis, James N. 1997. The influence of anchor-chaining on watershed health in a juniper-pinyon woodland in central Utah. In: Ecology and management of pinyon-juniper communities within the interior west symposium; proceedings; 1997 September 15-18; Provo, UT.

Monsen, Stephen B.; Pellant, Mike. 1997. Seeding burned shrublands by aerial broadcasting and anchor chaining. 1997. In: Ecology and management of pinyon-juniper communities within the interior west symposium; proceedings; 1997 September 15-18; Provo, UT.

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