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Guidelines for Prescribed Burning Sagebrush-Grass Rangelands in the Northern Great Basin

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RESEARCH SUMMARY

This report is primarily designed for those with limited fire experience who want to begin a program of prescribed fire in sagebrush-grass vegetation. The guidelines outline procedures and considerations for planning and conducting prescribed fires in such vegetation. Fire effects information is summarized by the major series of sagebrush species as described in recent habitat type classifications for the northern Great Basin, Snake River Plains, and Columbia River Basin. An annotated bibliography of literature published since 1980 on fire-sagebrush-grass vegetation is appended. The report recommends monitoring techniques to be used for evaluating effects of prescribed fire, a step that is becoming increasingly important in land management. Procedures for evaluating effects on plant cover, plant density, species composition, plant mortality, and biomass production are included.

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INTRODUCTION

Use of prescribed burning for managing sagebrush-grass ranges has increased dramatically in recent years. Consequently, many land managers are interested in starting or expanding prescribed burning programs. Often these people have had only limited fire experience. These guidelines are not a substitute for experience. But they will result in better planning and scheduling of fires and increase the probability of achieving objectives.

The guidelines outline some procedures and considerations required when planning and conducting prescribed fires in sagebrush-grass ranges and monitoring the effects of these fires. The literature on sagebrush-grass fire effects is summarized briefly and a comprehensive bibliography of sagebrush-grass fire literature published since 1980 is included in appendix B.

The sagebrush-grass range region is extensive and includes portions of all 11 Western States. The climatic patterns and vegetation composition vary considerably throughout this vast region. In the southern portion, sagebrush-grass vegetation is influenced by the desert grassland and hot desert shrub vegetation. Consequently, sagebrush communities may contain substantial amounts of warm season grasses. In the eastern portion, sagebrush-grass ranges gradually merge with vegetation characteristics of the short grass plains and mixed grass prairie. The vegetation and climate of these sagebrush areas will vary considerably when compared to the cool season sagebrush-grass ranges of the northern Great Basin and Columbia River Basin.

These guidelines are based, in large part, on the authors' experience in applying prescribed fire to sagebrush-grass ranges in the northern Great Basin and Columbia River drainage. Because of variation in both environmental conditions and plant community composition, these guidelines should not be indiscriminantly applied to sagebrush-grass communities in the southern Great Basin and east of the Continental Divide. Many principles and considerations required to conduct prescribed fires, however, apply throughout the sagebrush-grass region.

FIRE EFFECTS

Recent reviews of fire's effect on the major plant species that comprise sagebrush-grass communities include those of Wright and others (1979), Lotan and others (1981), and Wright and Bailey (1982). In addition to fire's effect, a general review of sagebrush ecological literature was recently written by Tisdale and Hironaka (1981) and has been summarized in a symposium proceedings compiled by McArthur and Welch (1986). Blaisdell and others (1982) provide a summary of the most important literature that may be helpful in managing sagebrush-grass ranges, including the use of prescribed fire. Harniss and others (1981) have published a computerized bibliography of selected sagebrush species. This paper will not include a review of fire on particular species but will include a list of the major references that include information on these species published since 1980 (appendix B).

Most current literature does not integrate the importance of vegetation classification systems with fire effects on the various species involved. Blaisdell and others (1982) do stress the importance of habitat types to land management treatments. This review will utilize the habitat type concept of vegetation classification as described by Daubenmire (1952). Daubenmire's approach has many distinct advantages over other classification systems (Hironaka and others 1983). Classifications have been developed for portions of the northern half of the sagebrush region (Hironaka and others 1983; Mueggler and Stewart 1980; Schlatterer 1972; Zamora and Tueller 1973) and classifications for other areas are being developed. It has long been realized that sagebrush-grass vegetation is complex and the response to fire and other factors varies considerably between geographic areas and subspecies. A knowledge of plant species response after fire, combined with an appreciation of the importance of habitat type, gives one a greater ability to predict fire response. Better results are obtained when fire is used on areas receiving more precipitation than the mean for that taxonomic unit. The habitat type also can be utilized as a framework to develop a data storage-retrieval system in which to catalog new information (Hironaka and others 1983). This section includes a discussion of two other factors that may greatly affect fire response—ecological status (range condition) and season of the fire.

Habitat Type

Early vegetation maps used by the land management agencies classified all sagebrush-grass vegetation into a single classification unit. Later work separated sagebrush vegetation into tall and low sagebrush types. In recent years the classifications have become more refined. Much of the refinement was made possible by advances in the taxonomy of the sagebrushes themselves (Beetle 1960; Beetle and Young 1965; Winward and Tisdale 1977). Vegetation classification systems are becoming increasingly sophisticated as land management becomes more intensive. This enables researchers to explain observed differences in vegetation response to fire and other disturbances on the basis of habitat type.

More recently, attempts have been made to develop a system of classification for seral communities within a habitat type (Hann 1982; Schott 1981). This seral classification will be an important sequel to the habitat type classification (Hironaka and others 1983). It is of particular interest for those planning prescribed fires because most communities are disturbed to some degree and many are seral to climax conifer or other vegetation. Prescribed fire is frequently used as a tool to maintain seral communities, which are more desirable for some land management objectives.

The ecological relationships of the northern portion of the sagebrush-grass region have been reviewed (Hironaka 1979; Hironaka and others 1983; Johnson 1979; Tisdale and Hironaka 1981; West 1979). The following discussion will consider the ecological role of fire in these communities. The habitat types will be grouped by the dominant sagebrush present (Series Level). Discussions at the habitat type level would be more precise, but information is not available on fires at this level. However, significant variations that are known will be included (table 1).

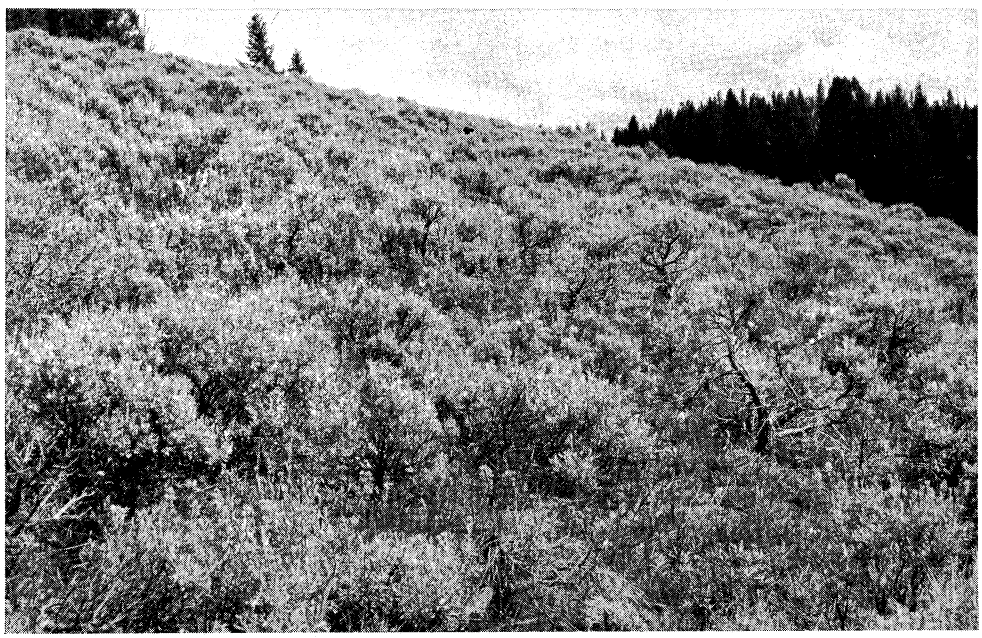
Mountain Big Sagebrush Series—This subspecies occurs on the most mesic and usually highest elevations of the three subspecies of big sagebrush. As a result this

Table 1—Environmental characteristics and general fire response of sagebrush grasslands grouped at series level of classification

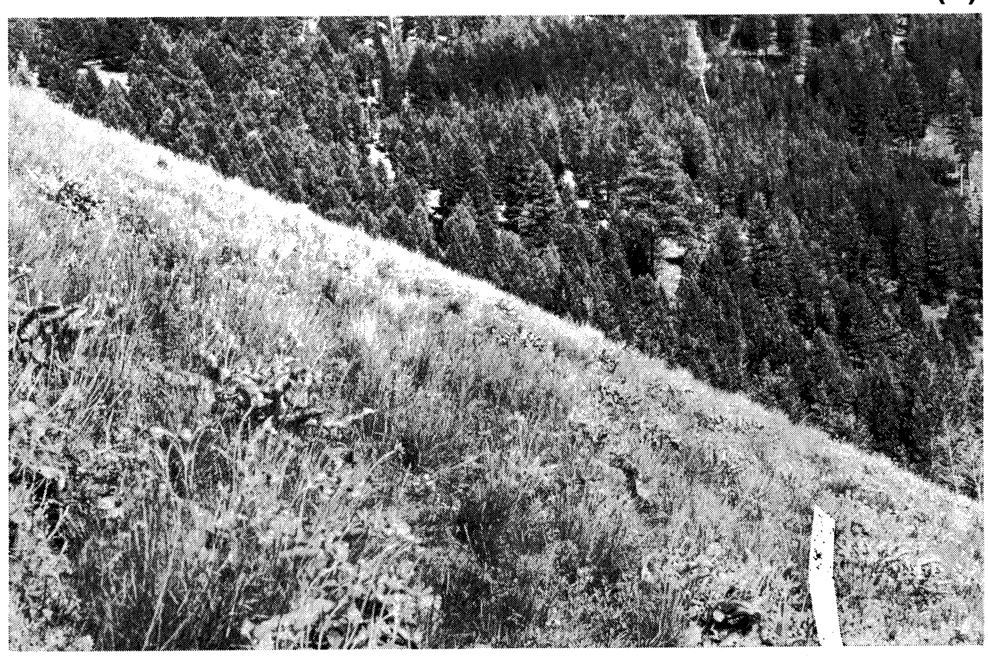
Series	Precipitation	Environmental characteristics and fire response
	Inches	
Mountain big sagebrush	12-20	Very productive sites; seeds of sagebrush establish readily; sage may return to preburn condition within 15 to 25 years; community contains high diversity of perennial forbs; herbaceous productivity usually enhanced by burning.
Species "X" (form of mountain big sagebrush)	>12	Annual grasses frequently important component of community; frequently burned by wildfires at current time; shrubs may be removed from community by repeated wildfires.
Basin big sagebrush	10-18	Most extensive areas now cultivated due to deep soils; many sites depleted of perennial grasses and invaded with cheatgrass; favorable response to fire occurs if adequate understory is present.
Wyoming big sagebrush	7-12	Most arid series; slow sagebrush reinvasion after fire; perennial depleted in many warmer habitat types and replaced with cheatgrass; few perennial forbs present in any range condition; invasion by rabbitbrush may be problem following fire; difficult to burn due to low sagebrush cover and low fine fuel loading.
Threetip sagebrush	11-16	Resprouts but varies considerably regionally; horsebrush and rabbitbrush often present and become a problem following fire.
Silver sagebrush		Minor importance in Great Basin but extensive east of Continental Divide; sprouter, particularly on spring burns; located on fertile, well-drained sites capable of producing over 2,000 lb/acre herbaceous material.
Dwarf sagebrushes	variable	Low fine fuel loadings make burning difficult; can sometimes be used as fire breaks; many sagebrush species in this group are preferred forage species.

series is one of the most productive of the sagebrush types (fig. 1). It is not known to resprout following fire. Mountain big sagebrush, however, is well adapted to becoming established following fire. The seeds germinate more readily following a light heat treatment than if untreated (Chaplin and Winward 1982). The plants also grow rapidly and may reach reproductive maturity within 3 to 5 years. The combination of these two factors favors the rapid reestablishment of a new stand of sagebrush. Sagebrush may return to preburn density and cover within 15 to 20 years following the fire. Establishment after severe fires may proceed more slowly, and sagebrush may not dominate the area for 30 years (Blaisdell and others 1982).

Bitterbrush is often found in communities within the mountain big sagebrush series. It is normally a decumbent form and is moderately adapted to spring and fall fires in this series. Survival averaged 45 percent for bitterbrush within mountain big sagebrush communities in the Northern Rocky Mountains (Bunting and others 1984). Most of the other shrub species found within this series also resprout (Hironaka and others 1983).



(A)



(B)

Figure 1—Representative areas of the *Artemisia tridentata tridentata/Festuca idahoensis* h.t. in central Idaho. (A) A stand that has not been burned for at least 50 years. (B) An area that was prescribed-burned in the fall 4 years earlier.

If rabbitbrush occupies a site, it usually resprouts following fires. It does not, however, seem to increase in density in most instances as has been observed in other sagebrush communities. Horsebrush in this series follows the same pattern as rabbitbrush.

The herbaceous component of the mountain big sagebrush series is among the most productive of all the sagebrush communities. Many communities within this series are also rich in species number of both grasses and forbs. Kuntz (1982) found that the herbaceous component changed little following spring prescribed burns. Vegetation was dominated by perennial forbs for the first 2 to 3 years. After that the grasses dominated and probably will continue to do so until sagebrush reestablishes. Minor changes in density were observed for grasses and forbs following spring fires. The greatest changes were increases in the productivity of the individual plants occupying the site at the time of the fire (Kuntz 1982).

"Species X" is a form of mountain big sagebrush (Winward and Tisdale 1977) found primarily in western Idaho and eastern Oregon. It is restricted to a narrow zone where the annual precipitation exceeds 12 inches, the elevation is less than 4,500 feet, and the summers are relatively warm (Hironaka and others 1983). It is easily confused with basin big sagebrush because of similarities in growth form and stature of the shrubs.

The response of the "species X" communities to fire is more similar to basin big sagebrush than the other mountain big sagebrush communities. Bitterbrush, when found in "species X" communities, is of the columnar form and is severely reduced by fire (Bunting and others 1984). The perennial grasses such as Idaho fescue and bluebunch wheatgrass seem to be more sensitive to fire, and the community frequently has a larger component of annual grasses present. This probably reflects the warmer and drier climate this type has as compared to the other mountain big sagebrush communities.

Many of the "species X" communities are on relatively steep slopes. Combined with the dominance of cheatgrass and medusahead in the understory and the potential for human and lightning-caused fires, this steepness has resulted in much of the original area being repeatedly burned. These frequently burned areas are dominated by annual grasses. Sagebrush and bitterbrush have been significantly reduced. Most burned areas have not shown great increases in rabbitbrush, although it is often present.

Basin Big Sagebrush Series—The majority of the historic area of this series is currently under intensive agricultural cultivation and is now restricted primarily to field edges, swales, and along water drainage ways in areas dominated by other sagebrush species. It does not resprout (Blaisdell 1953), and repeated fires have eliminated it from many of the remaining sites (Pickford 1932).

The basin big sagebrush series is usually found on productive sites, and the sagebrush canopy coverage may exceed 60 percent (Neuenschwander 1980). The fuels are normally adequate to carry a fire. Two common problems have been observed with this series in relation to prescribed burning. The part of this series still remaining occurs topographically in areas preferred by livestock. Herbaceous utilization by livestock is often greater than the surrounding vegetation types. Fire will intensify the use in these areas, particularly if adequate areas of surrounding vegetation are not also burned. After the fire, the loss of sagebrush protection may result in a decrease in density of these grasses even though perennial grasses are increasing in productivity and density on upland areas.

A second problem may exist in communities in the warmer dry portions of the basin big sagebrush series. The understory of these areas is frequently dominated by cheatgrass. The cheatgrass will increase following a fire (Countryman and Cornelius 1957) making establishment of perennial grasses difficult.

When adequate stands of perennial grasses such as bluebunch wheatgrass or Great Basin wildrye occur on the site, favorable increases in productivity often result unless the fire is extremely severe. In addition to increased productivity, substantial increases in herbaceous forage availability may result due to the decreases in density and canopy coverage of sagebrush following fire in the older stands (fig. 2).

Wyoming Big Sagebrush Series—This series occurs on the most arid areas within the range of big sagebrush. Annual precipitation may average less than 7 inches in some habitat types (Hironaka and others 1983). The low productivity and resultant lack of fine fuels of these areas often make prescribed burning difficult. The coverage of Wyoming big sagebrush seldom exceeds 25 percent, and this may contribute to the difficulty in getting a fire to carry through many communities of this series.

Cheatgrass predominates in lower successional stands of the Wyoming big sagebrush series in western Idaho, northern Nevada, and Oregon. An abundance of cheatgrass increases the likelihood of fire in these areas and many have been burned repeatedly by wildfires. This has resulted in a conversion to nearly pure stands of cheatgrass (fig. 3). While burning in this series will remove brush, it will not provide more perennial grass where cheatgrass has become dominant. The annual grass stage is relatively stable with bottlebrush squirreltail being the primary perennial grass to increase on the more arid sites. Once an area burns and becomes dominated by cheatgrass, the risk of wildfire becomes much greater (Hironaka and others 1983) and the likelihood of conversion back to perennial grasses by natural regeneration is greatly diminished. Cheatgrass rarely is present in large amounts in Wyoming big sagebrush communities in eastern Idaho.

Wyoming big sagebrush will establish readily from seed if seed is available. Slow growth, however, reduces the rate at which it recovers as compared to the other big sagebrush subspecies. Repeated fires will eliminate the onsite seed source and reinvasion into these areas will be extremely slow.

Rabbitbrush may become a problem on areas that are repeatedly burned, but this varies considerably within Wyoming big sagebrush series. Rabbitbrush resprouts readily throughout this series, but establishment from seed is not as common in eastern Idaho and Wyoming as it is farther west. Repeated fires in western Idaho have resulted in very dense stands of rabbitbrush (fig. 4).

Species diversity is much lower in the Wyoming big sagebrush series as compared to the mountain sagebrush

(A)

(B)

Figure 2—(A) Basin big sagebrush with an understory of Great Basin wildrye. Many of the mature sagebrush plants were older than 40 years. (B) A similar community prescribed-burned during the fall 4 years earlier. The wildrye has remained vigorous and productive.

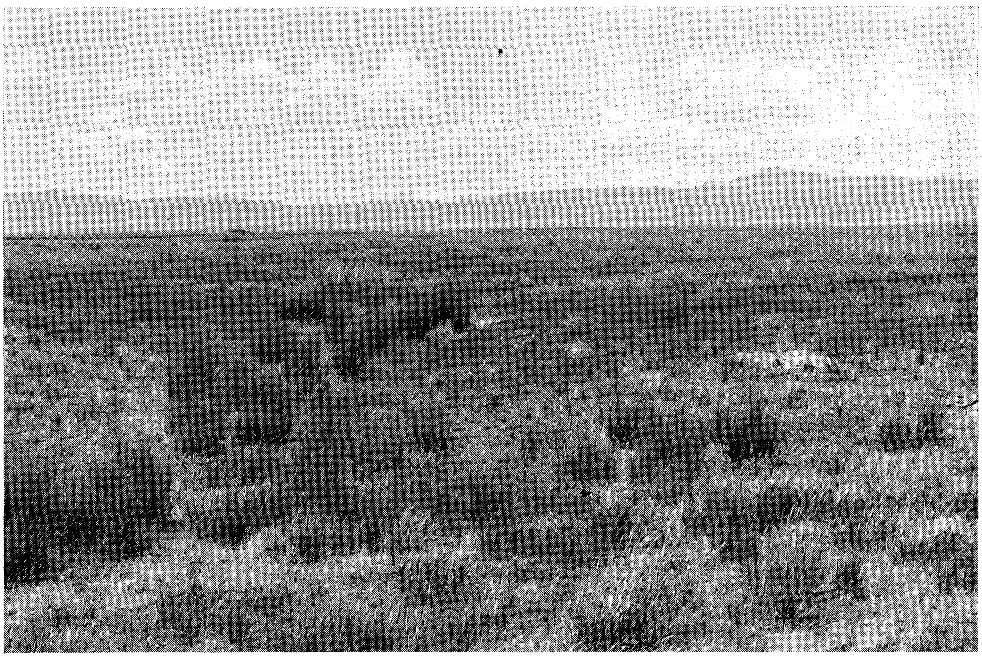


Figure 3—Annual grass community dominated by cheatgrass on the lower Snake River Plains. Sites with seral stages of big sagebrush that are burned by either prescribed or wildfires often become dominated with annual grasses. Great Basin wildrye (foreground) has survived this high-severity wildfire.

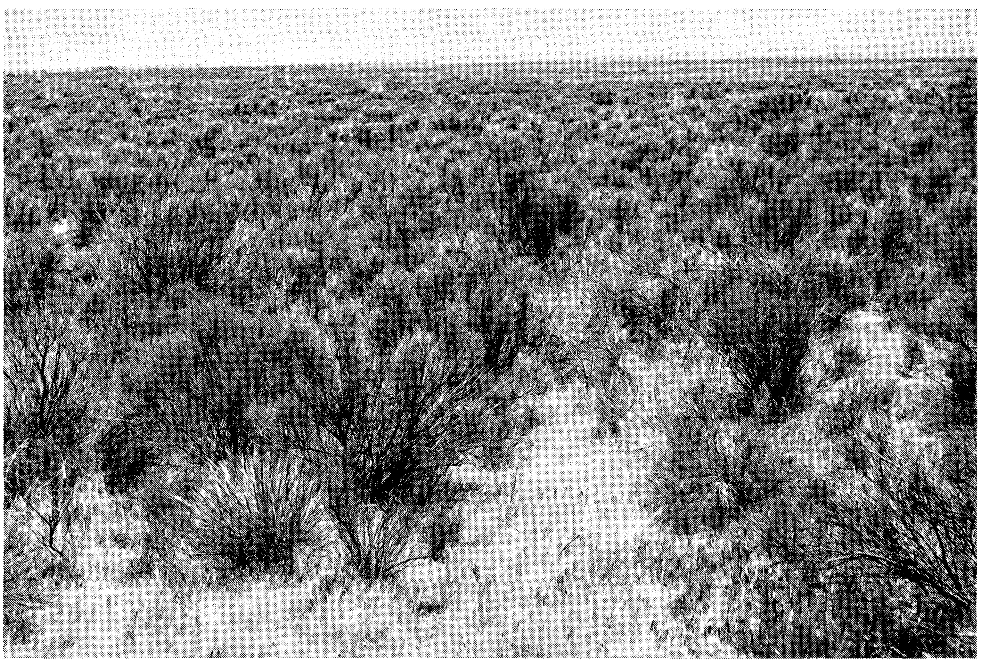


Figure 4—Rubber rabbitbrush may become dominant on sites that are burned repeatedly, such as this site on the lower Snake River Plains. It resprouts readily and becomes established from seed after disturbance. Resprouting and seedling establishment varies greatly, however, over the wide range of the species.

series. This is particularly true for perennial forbs. Normally these communities do not have many perennial forbs present in the unburned condition, and this component does not increase as a result of fire. Consequently, the potential for increasing perennial forb production with fire is much less than with many other sagebrush types (fig. 5).

(A)

(B)

Figure 5—Representative sites of areas classified as *Artemisia tridentata wyomingensis/Agropyron spicatum* h.t. (A) A site that has not been disturbed for over 50 years. (B) A site that was prescribed-burned in the fall 3 years previously. This community is dominated by bluebunch wheatgrass; few perennial forbs increase as a result of the fire.

The perennial grasses found in this series are in general more sensitive to fire than the same species associated with the more mesic subspecies of big sagebrush. Bluebunch wheatgrass and Great Basin wildrye are the most adapted to fire of the perennial grass species naturally occurring in this series and generally recover quickly to preburn biomass productivity levels. Thurber's needlegrass is one of the grass species least adapted to fire and is usually severely reduced following fire (Wright and others 1979). Sandberg bluegrass may suffer high initial mortality due to the fire but seems to reproduce readily from seed in following years.

Threetip Sagebrush—This series of sagebrush communities is restricted in area and located primarily in eastern Idaho, eastern Oregon, Wyoming (Beetle 1960), and southwestern Montana (Morris and others 1976). Climatically threetip sagebrush occupies a position between the Wyoming and the mountain big sagebrush series (Hironaka and others 1983). In most respects the herbaceous component is also intermediate in its response to fire. There are, however, some factors that are different enough to warrant noting.

Threetip sagebrush has been reported to be a prolific resprouter (Beetle 1960; Morris and others 1976; Pechanec and others 1965). This ability varies, which is evidence that several ecotypes exist (Hironaka and others 1983). In our experience, those populations in eastern Idaho seem to have the greatest resprouting potential. Populations in the central portion of Idaho's Snake River Plains (area west of the Craters of the Moon National Monument) have low resprouting ability. Populations in eastern Oregon have moderate resprouting potential. The southwestern Montana populations resprout readily.

Threetip sagebrush communities often include rabbitbrush and horsebrush. Both associated shrubs resprout and establish from seed readily following fire. The presence of rabbitbrush and horsebrush indicates that fire has played an important role in this series (Hironaka and others 1983). Resprouting and seedling establishment of these species certainly needs to be considered when planning prescribed fires in these communities.

Cheatgrass is present in many areas of threetip sagebrush series. But it seldom becomes a problem following fire or other types of disturbance (Hironaka and others 1983).

Silver Sagebrush Series—Little information is available on the response of this series. Silver sagebrush is of minor importance in the Great Basin but is more extensive east of the Continental Divide (Beetle 1960) and may dominate areas of eastern Montana (Morris and others 1976). Silver sagebrush was noted to be a sprouter (McArthur and others 1979) but apparently can be controlled by fire in some areas of its range (Wright and Bailey 1980). Blaisdell and others (1982) referred to silver sagebrush as an occasional respouter following fire. White and Currie (1982) found that on the Great Plains it resprouted vigorously on spring burns, but that fall burns resulted in greater mortality and low vigor of resprouts. Spring burns, however, increased production of western wheatgrass and bluegrasses more than fall burns.

Dwarf Sagebrushes—This group includes black sagebrush, stiff sagebrush, low sagebrush, and others. These species normally occur on shallower and less productive sites than the taller sagebrush species. Due to low productivity, these sites are difficult to burn and can frequently be used as natural firebreaks. Dwarf sagebrush habitat types seldom have fuel loadings capable of carrying a fire (Blaisdell and others 1982). Care must be taken, however, in above average production years because they may be capable of carrying a fire at this time. All species are easily killed by fire. Mortality of bunchgrasses seems to be low on burned areas we have observed, but the low site potential limits the increase in herbaceous production. Dwarf sagebrush species are often preferred forage plants for livestock and wildlife (Beardall and Sylvester 1976). Consequently, prescribed burning cannot be recommended widely in these communities.

Ecological Status

One of the most important factors involved in determining the response of an area to fire is the preburn plant composition. Numerous studies have indicated that the initial stages of secondary succession following fire are dominated by plants that were present prior to the burn and which survived the fire (Armour and others 1984; Connell and Slatyer 1977; Kuntz 1982; Lyon and Stickney 1976). The surviving vegetation influences postfire succession in two ways. First, surviving plants occupy space in the community, preventing the establishment of others. Second, they produce the seed which influences the availability of propagules that will establish on the unoccupied sites (Cattelino and others 1979; Horn 1975a, 1975b).

Sites considered for range improvement are usually those that have high potential but are currently producing considerably below that potential. These sites will have the greatest potential for improvement (Vallentine 1971). But this is usually not the best criteria for selecting sites to prescribe burn if increased perennial grass production is an objective. As previously discussed, these sites may be difficult to burn because of the lack of fine fuels (fig. 6). If burned, the areas may have few if any desirable perennial forage species present, and consequently the recovery may be slow unless seeds are supplied artificially. It has been observed that herbaceous productivity following herbicide treatment is unsatisfactory when perennial grass density is less than one plant per 10 ft^2 in sagebrush-grass vegetation (Hyder and Sneva 1956). Similar densities are probably necessary for adequate response following prescribed burning.

Selection of areas with moderate coverages of sagebrush (10 to 15 percent) and in high fair to good ecological status will respond favorably in most situations. Sites in low seral ecological status are more rapidly reoccupied by sagebrush seedlings, more susceptible to annual plant invasion, and respond to a lower percentage increase of herbaceous production following sagebrush removal than those sites in mid or high seral ecological status (Hyder and Sneva 1956; Hedrick and others 1966).

The amount of sagebrush that results in reduced herbaceous production varies by site and sagebrush species. Sagebrush coverages of 10 to 15 percent will reduce herbaceous production significantly (Tisdale and others 1969).

A brief inspection of the site prior to burning will determine whether or not desirable plants are present in a density that will allow good postfire response. In some areas sagebrush coverages greater than 15 percent are desirable for certain species of wildlife (Klebenow 1972). In these instances one may decide to permit sagebrush coverage to increase to higher levels before considering burning to regenerate the stand. If so, remember this may slow the reestablishment of perennial plants following the burn. It should also be noted that the maximum potential cover of sagebrush varies considerably by species and site (table 2).

Season of the Year

Considerable work has been done on the effects of burning at different seasons (see summary by Wright and Bailey 1982). In general cool season grasses such as bluebunch wheatgrass are least detrimentally affected by fall fires, and warm season grasses such as blue grama are least affected by spring burns. In areas where the two occur together, the season of burning will favor one type of grass over the other (Gartner and Thompson 1972; Schripsema 1977; Wright and Bailey 1982). Seasonal effects are related to the phenological stage of the plant. These stages may vary regionally, yearly, and with elevation.

In the northern portion of the sagebrush range, the effect of season is less clear. Most communities in the northern Great Basin have no warm season grasses, so this aspect is of less consequence. The reported results of spring versus fall burns are mixed (Kuntz 1982; Wright and Klemmedson 1965; Wright and others 1979). In our experience, the perennial herbaceous species are most resistant if they are burned when completely dormant. In much of the Great Basin, spring fires are frequently not feasible due to the abundant moisture in late winter and spring. By the time the fuels dry out sufficiently, the new herbaceous growth is too advanced. This raises the fuel moisture to a point that fire will not carry through the combined living and dead fuels. If fires do occur, perennial grasses may incur high mortality. In eastern Idaho and Montana, however, proper fire conditions may occur in late winter (February-March). Fire response of herbaceous vegetation on these burns has been positive (Kuntz 1982). When the burns are delayed until after winter dormancy is broken, the effects can be much different, particularly on the fire-sensitive species such as Idaho fescue (Beardall and Sylvester 1976).

The same situation may occur in the fall. For instance, on the Owyhee Plateau, sufficient precipitation may occur in late summer or early fall to cause a fall green-up. Burning after this occurs seems to cause as much or more plant mortality as burning in the late summer when the plants are dormant.

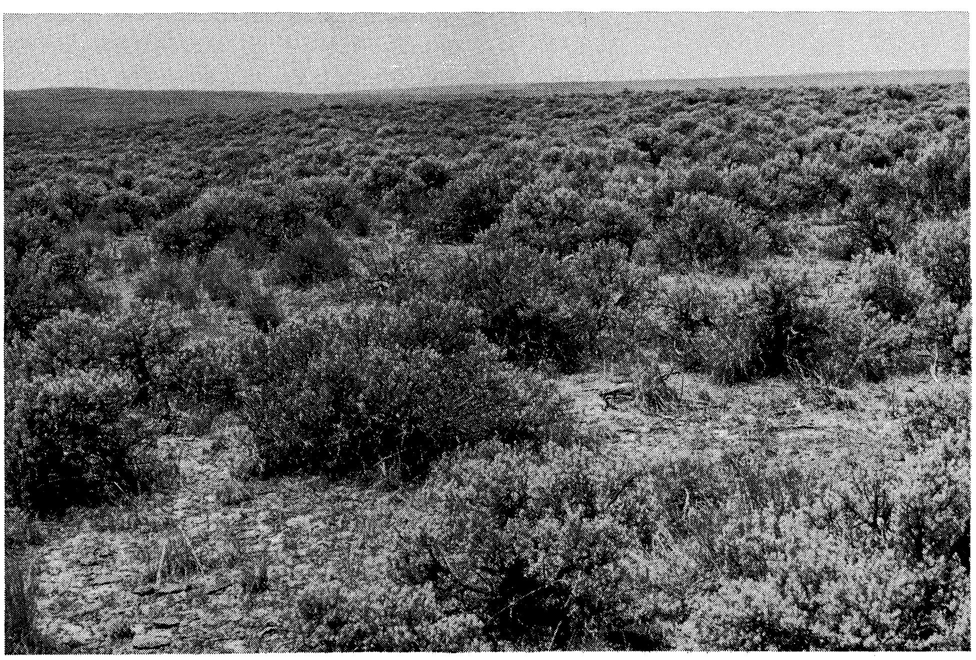


Figure 6—A site classified as an *Artemisia tridentata wyomingensis/Agropyron spicatum* h.t. that contains little fine fuel in the understory. A community such as this would be difficult to burn and would not produce enough perennial grass forage to justify the cost of burning.

Table 2—Mean percent coverage for species of sagebrush by series for the northern Great Basin and Columbia River drainage; cover is estimated by the use of line-intercept method except as noted

	Source of data and State							
	Eckert 1957 (Oregon)	Sheehy 1975 (Oregon)	Champlin 1982 (Oregon)	Winward 1970 (Idaho)	Clifton 1981 (Idaho)	Kuntz 1982 (Idaho)	Hironaka[1] (Idaho)	Daubenmire 1970[2] (Washington)
				Artemisia tridentata ssp. *wyomingensis*				
Mean	11	10		18	18		15	
Range	6-15	(approx) —		8-23	—		5-23	
n	13	3		13	20		48	
				Artemisia tridentata ssp. *tridentata*				
Mean		13		24			9	15
Range		—		19-30			5-13	2-38
n		3		2			6	37
				Artemisia tridentata ssp. *vaseyana*				
Mean	7	12	10	22		26	25	
Range	5-11	(approx) —	6-13	15-41		12-38	18-37	
n	7	3	8	21		15	17	
				Artemisia tridentata ssp. *vaseyana* f. "*xericensis*"				
Mean		10					8	
Range		—					2-13	
n		3					7	
				Artemisia tripartita				
Mean							11	21
Range							7-27	10-34
n							23	7
				Artemisia cana				
Mean		28						
Range		—						
n		3						
				Artemisia arbuscula				
Mean	15	11					13	
Range	8-19	(approx) —					6-20	
n	10	3					10	
				Artemisia nova				
Mean		12					23	
Range		—					7-29	
n		3					26	
				Artemisia rigida				
Mean							26	21
Range							7-60	10-34
n							26	7

[1]Unpublished data of M. Hironaka, University of Idaho.
[2]Coverages estimated with canopy coverage method (Daubenmire 1959).

Fires during early and midsummer are potentially the most damaging to plants. Bunting and others (1984) found that the mortality of bitterbrush was greater when the fires occurred in summer as compared to fall and spring. This is probably true for many other species, too. Repeated summer fires will often deplete a sagebrush-grass community of perennial grasses (Wright and Klemmedson 1965).

OBJECTIVES FOR PRESCRIBED BURNING

The objectives in using prescribed fire in the management of sagebrush-grass vegetation vary considerably, depending upon the vegetation and the particular resource that is being managed. But more than a single objective often can be achieved with a single burn (table 3).

The most common objectives of prescribed fires in sagebrush-grass vegetation are reduction of sagebrush cover and subsequent increase in herbaceous production. Harniss and Murray (1973) reported that by the third year following a fire grass and forb production on burned sites was greater than that on unburned sites, and this increased productivity continued for more than 10 years. After 30 years the mountain big sagebrush was beginning to become well established again and herbaceous production had declined to the unburned level. It has been found that minor amounts of sagebrush may affect herbaceous productivity. As sagebrush cover was reduced from 15 percent (untreated) to 8 and 0 percent, understory dry matter production increased from 194 lb/acre to 253 and 830 lb/acre, respectively (Tisdale and others 1969).

Herbaceous productivity, however, may not always increase following fire. On a mountain big sagebrush site in central Idaho, no significant increase had occurred during the first 3 years following fire. Sagebrush canopy cover on the site averaged 15 percent. The potential increase may be related to a number of factors, including plant vigor, subsequent growing conditions, site productivity, and sagebrush cover prior to treatment.

In some situations the objective may be not only to increase herbaceous productivity but also to increase the production of desirable forbs. Forbs are often seasonally important in the diets of many animals such as elk, pronghorn antelope (Miller and Vavra 1982), and domestic sheep (Stoddart and others 1975). Fire has been successful in achieving this in many situations. But not all sagebrush communities have equal potential for forb response. For example, Wyoming big sagebrush communities normally have small amounts of forbs, regardless of the ecological condition or successional stage.

Fire can prevent the invasion of other species into sagebrush-grass vegetation. In many areas sagebrush communities are being invaded by conifers such as juniper, Douglas-fir, and ponderosa pine. As these conifer stands develop, the productivity of the understory herbaceous species is reduced (Arnold and others 1964; Barney and Frischknecht 1974), making control of coniferous species often desirable.

Sagebrush may reach a size and density that physically impedes access of animals to the understory plants of the community. This may be common in communities of taller sagebrush species such as basin big sagebrush or with the species that may develop high coverages such as silver sage or mountain big sagebrush.

Mature sagebrush plants decline in productivity and become decadent with age. Because sagebrush is an important component in the diet of wildlife species, the establishment of young vigorous plants is a factor in wildlife management.

Table 3—Potential objectives for prescribed burning sagebrush/grassland vegetation

Objective	Duration of treatment	Citation
	Years	
Reduce sagebrush cover:		
mountain big sagebrush	15-25	Harniss and Murray 1973; Kuntz 1982
Wyoming big sagebrush	25-50	Blaisdell and others 1982
threetip sagebrush	10-20	
Increase herbaceous productivity	3-30	Harniss and Murray 1973; Wright and others 1979; Blaisdell and others 1982
Increase forb productivity	1-10	Harniss and Murray 1973
Increase sagebrush productivity		Hironaka and others 1983
Increase habitat diversity and edge effect (ecotone)		Lyon 1978
Reduce invasion by conifers		Wright and others 1979; Gruell and others 1986
Alter herbivore distribution		Klebenow and Beall 1977; Lowe and others 1978
Enhance palatability and nutrient value		Hobbs and Spowart 1984; Seip and Bunnell 1985
Seeding pretreatment		Monsen and McArthur 1985

The diversity of habitats available for wildlife is often a concern to management agencies. Successive fires have the potential to create mosaics of varying successional stages within an area (Lyon and others 1978). This increase in the diversity of habitats (beta diversity) and increase in the diversity of species present (alpha diversity) can often be a primary objective in prescribed burning in sagebrush-grass vegetation.

Prescribed fire has also been used as a control measure for sagebrush prior to seeding rangelands by aerial broadcasting or drilling. In addition to controlling sagebrush, the fire also consumes the majority of the woody biomass, improving access for equipment.

PLANNING PRESCRIBED FIRE

Development of Objectives

The initial step in considering the use of a prescribed fire is to identify the factor that is limiting productivity. For example, the grazing allotment may be limited by the forage available in just one unit. If the forage production of that unit were increased, the use of the entire allotment would be improved. Or perhaps the scarcity of forbs renders an area of limited use to one or more species of wildlife. If forb production were increased, the potential habitat for these species would be improved.

Once a limitation is identified, alternatives to improve the situation may be considered. Prescribed fire may often be one of these alternatives. Prescribed burning should not be a substitute for good range management. A problem rooted in inappropriate range management practices may not be corrected by vegetation treatment. In these instances management should be altered prior to application of prescribed fire. A preferred alternative will then be selected based on an onsite evaluation by a multidisciplinary team that considers economic, environmental, and other considerations. The authors assume that this portion of the planning process has occurred and that prescribed fire has been selected as the preferred alternative.

An important initial step in the fire plan development is focusing general objectives into specific objectives for a particular fire. The difference between a fire plan and a fire prescription should be noted. The fire plan is designed to direct practitioners through the planning sequence and includes such aspects as site characteristics, management objectives, and expected fire effects. The fire prescription specifies the environmental conditions, the desired fire behavior, and the accomplishment to be achieved by the fire (Fischer 1978). More specific objectives are necessary to determine the specific location and habitat type, and the characteristics of the fire desired, such as season, fire intensity, fire severity, and size of the area to be burned. Frequently, objectives such as "to improve wildlife habitat" or "to control sagebrush" are listed. General objectives such as these give little guidance to people developing a fire plan or the means to evaluate the success of achieving the objectives.

To overcome this problem, very specific objectives are sometimes developed for some fire plans. An example might be "to increase the production of bluebunch wheatgrass 200 lb/acre." The difficulty presented here is the considerable time commitment for intensive monitoring needed to determine whether or not the objective was achieved. It is important that objectives set be both realistic and attainable. (See Evaluation and Monitoring.) Site-specific objectives have been defined as:

A clear, concise statement of what is to be accomplished which:

(1) allows a reasonable opportunity for success;
(2) has an acceptable time frame for determining results;
(3) contains a measurable factor that determines the degree of success.

It is desirable to state objectives concisely enough to give guidance to those planning, conducting, and evaluating the fire, but at the same time, be reasonable in what this requires in evaluating the fire's success or failure. A desirable objective in this case would be "to increase herbaceous production 50 percent by the end of 3 years."

Frequently, more than one objective may be achieved with a single fire. A prescribed fire may initially increase forb diversity and production for pronghorn and later increase perennial grass for livestock. Problems arise when objectives conflict in the type of fire needed or the type of area to be burned. For example, if a burn is designed to provide greater amounts of herbaceous forage for elk in early spring, south-facing slopes may be burned on ridges free of snow early in the spring. But if a second objective is to increase production of grasses for cattle, the location and size of the burn may need to be changed. In some cases objectives may need to be prioritized.

Selection of Fire Area

Selection of the area to be burned will dictate how the fire can be conducted, characteristics of the fire, and whether it achieves its objectives. Areas with more than 1,500 lb/acre of fine fuels may be burned with a wide variety of fire prescriptions. Those with less than 500 lb/acre will be able to sustain fire only under warm temperatures and low relative humidities. The narrow range of potential burning conditions may limit achievement of objectives. As discussed earlier, the composition will affect the response of the area to the fire and may also limit the potential of fire to meet objectives.

The planning team needs to look at the proposed site, discuss its potential and any constraints or problems, and agree that the proposed objective can be met by use of prescribed fire. On many sagebrush-grass sites, fuel quantity is marginal for large fires (greater than 50 acres) under normal prescribed burning conditions. Beardall and Sylvester (1976) report that sagebrush in Nevada is difficult to burn if the herbaceous fuels are less than 600 lb/acre. But wildfire may occur on areas with less than 300 lb/acre (Wright and Bailey 1982). Sagebrush canopy coverage will compensate for the lack of fine fuels to some degree. Britton and Ralphs (1979) doubted that successful prescribed fires could be conducted on areas with less than 20 percent canopy coverage of sagebrush. Brown (1982) suggested that with 20 percent sagebrush cover, it would be necessary to have a minimum of 300 lb/acre of cured fine fuel and 10 mi/h of wind for successful fire spread. These minimum values preclude the use of fire in many areas of sagebrush-grass vegetation (table 2).

Areas with sagebrush coverages greater than 30 percent may burn even though the fine fuels are less than 300 lb/acre. This may occur if the sagebrush coverages are high and the fire can burn primarily through the sagebrush canopies. Postfire response of perennial grasses and forbs may not be as defined, however, unless adequate populations of preferred species populate the burned site.

The minimum amount of cured fine fuel needed varies with the type of species that comprise this component. Fine fuel primarily composed of tall perennial bunchgrasses such as needle-and-thread must be present in greater quantity than if the fine fuel is composed of annual grasses such as cheatgrass. The smaller particle size and even distribution of the annuals create a more uniform fuel bed enabling the fire to carry across areas with very low fine fuels.

Other factors that determine whether or not an area will burn include topography, slope, windspeed, sagebrush canopy moisture levels, and sagebrush height. As height and slope increase, the maximum distance that a flame is able to ignite fuels on a horizontal plane also increases ("fire reach," as defined by Neuenschwander 1980). This reduces the amount of sagebrush cover and fine fuels needed compared to the same type of fire in shorter sagebrush and/or on level terrain. The increased height of sagebrush may not necessarily contribute to fire spread, however, if it has a growth form with few lower branches.

Rough topography and slope also channel wind and create situations of upslope and downslope winds. These in turn increase the effective windspeed and enable one to burn at a lower average windspeed and lower fuel loadings than one can on level terrain.

The majority of the sagebrush fuels will be alive and therefore more moist than the fine fuels, which will probably be dormant at the time of burning. The big sagebrush subspecies remain physiologically active throughout most of the year (Campbell and Harris 1977; DePuit and Caldwell 1973; Fernandez and Caldwell 1975). Immediately following significant precipitation (0.25 inches or greater), we have noted increased moisture content in sagebrush foliage. Canopy moisture will reach or exceed the moisture of extinction, preventing the sagebrush from contributing to the fire spread. The fine fuels will dry out more quickly than foliage; therefore it may be possible to burn the fine fuels beneath the sagebrush plants. If sufficient fine fuels are present, it may be possible to kill the sagebrush plants, but they will not contribute significantly to fire behavior. Dry sagebrush canopies are necessary to burn sites with marginal fuels.

In addition to amount of fuels, one must consider fuel arrangement and continuity. Many sites, particularly those where fuel is marginal, are broken by areas with little fuel or vegetation types that produce little fine fuel (fig. 7). Such fuel patterns frequently prevent the spread of the fire over a large area and may be advantageous or disadvantageous, depending on the type of burn that is desired. Fuel discontinuity will, however, increase the cost per unit area burned and reduce the acreage that can be burned during a single burning period.

Preparation of a burning plan involves establishment of primary and often secondary control lines. The costs of the fire and the risks of escape can be significantly reduced if the area selected offers roads and natural breaks

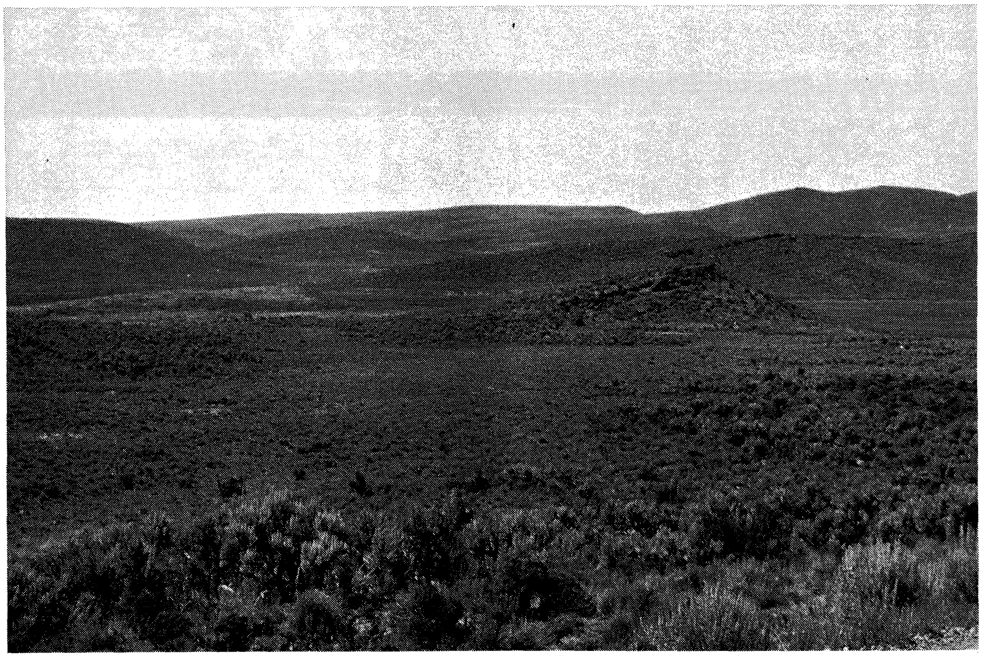


Figure 7—Vegetation types such as *Artemisia arbuscula/Festuca idahoensis* h.t.'s produce low amounts of fine fuels and may serve as firebreaks. The big sagebrush communities that are mixed with low sagebrush communities, such as above, may be burned with only minor fireline preparation. But caution is advised during years when above-average grass production may carry fire.

such as ridges, drainage ways, talus slopes, and less flammable vegetation types (fig. 8). The primary costs of prescribed burning are often associated with establishment of control lines.

Prescribed burns often require some type of special management before and following the fire. Any changes in management must be considered at the time of site selection. This management must be coordinated for all resource uses. For example, a fire designed to increase spring forage for deer may not require special management. If livestock have access to the burn, however, the full benefits of the prescribed fire may not be realized and negative impacts may occur unless management of the livestock is included in the plan.

Season of the Year

The season during which a tract is burned influences both the feasibility of burning and subsequent effects. The abundant precipitation renders burning impractical during late winter and spring throughout most of the northern sagebrush-grass region. By the time the previous year's

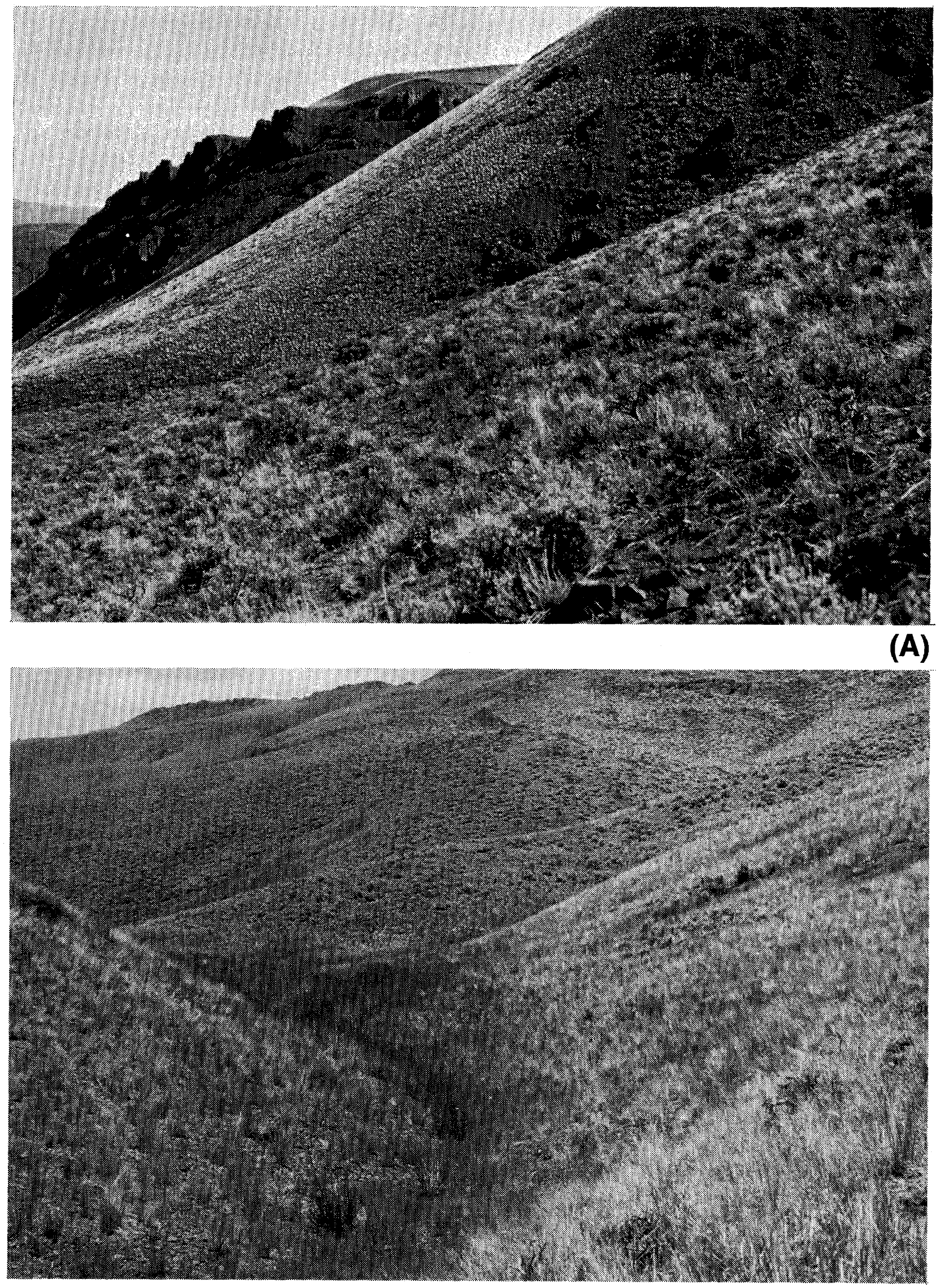


Figure 8A and B—Topography can often be utilized as firebreaks to minimize fireline preparation.

herbaceous fuels dry out, herbaceous plants have broken dormancy and have begun to produce green material. Range burning is unfeasible or undesirable at this time of year.

Burning during the fall is more common throughout most of the northern Great Basin. As a general rule, fall will offer more suitable burning days than spring. Because fine fuels and sagebrush canopies are drier, it is possible to burn sites that have less fuel. Some problems may be encountered, however. Areas such as the Owyhee Plateau may start to receive intermittent precipitation during this time of year. This often results in a fall green-up and an increase in the canopy moisture of sagebrush. Either occurrence will decrease the likelihood of conducting a successful burn when fuels are marginal.

Many managers are now considering conducting prescribed fires in late summer when the perennial grasses are dormant. By starting earlier, they can maximize the number of burning days available to them. In addition, the drier conditions may enable them to burn areas with lower accumulations of fuel. Starting earlier also enables managers to utilize seasonal personnel for prescribed burning projects. It must be recognized, however, that burning during the summer includes a greater probability of fire escape than burning during wetter and cooler seasons and the effects on the plant community may also differ.

In some areas, however, such as eastern Idaho and eastern Montana, late winter and early spring may favor prescribed burning. Drier weather and greater fine fuel loads of this region make burning at this time of year effective and economical. Burning sagebrush-grass vegetation that is mixed with forest vegetation can safely be attempted without firelines in these areas. The forests and drainages will retain the snow and make effective fire breaks. Fires conducted during late winter are often of low severity and tend to be small and patchy (Gruell and others 1986). This may be ideal to meet some objectives but may make burning large continuous acreages difficult.

Due to high moisture and snow-compacted fuels, spring fires are usually smaller and contain more unburned patches than fall fires. This may be either an advantage or a disadvantage, depending on the objectives of the project. Throughout most of the northern sagebrush-grass range, it is difficult to burn effectively in either spring or very late fall. Weather and fuel moisture will meet prescriptions (see page 9) on relatively few days.

Prescribed burns during spring or late fall should be considered special projects. The fires will be limited in size and effectiveness and should be compatible with objectives. Generally, sites with south and southwest aspects and at least moderate slope will be the most advantageous locations. Usually, fine fuels must be more abundant than during a drier season to achieve similar results.

During the spring, snow lines and increased fuel moisture on varying aspects adjacent to the proposed treatment area may aid in fire control and reduce overall cost. The limited burn size, however, may increase the amount of time and personnel required for ignition. In many cases, this results in higher average costs per acre. During these seasons, the limited days in prescription also often result in failure to achieve objectives.

Your particular geographic area should be studied to determine how many days will be in prescription on the average. If only a few days are likely to be in prescription, then modification of the plan may be necessary. United States Weather Service records and RX WTHR/RX BURN programs (Bradshaw and Fischer 1981a, 1981b) will be useful in obtaining and analyzing this information.

Size of Prescribed Fires and Fire Mosaics

The proposed size of a prescribed fire needs to be carefully considered during the planning process. The total acreage burned has a considerable effect on the postfire response of the vegetation. Wild and domestic animals are drawn to recently burned areas (Komarek 1969; Kramp and others 1983; Lyon and others 1978), resulting in greater utilization of the burned area than the surrounding vegetation. Water availability on the burned site may also concentrate utilization. Sufficiently large areas should be burned, so that browsing and grazing does not adversely affect the plants on the site.

Consideration should also be given to the amount of area that can be burned in a single burning period (normally 4 to 6 hours). Time will be needed to widen out firebreaks and ignite the unit. Sufficient time should be allowed for the unit to burn out prior to burning conditions becoming too cool and/or wet at night or too severe. In continuous fuels this limits the maximum size to about 500 to 2,000 acres when hand firing, and 1,000 to 3,500 acres when aerial ignition is used. Areas larger than this can be divided into smaller units. For noncontinuous fuels, the size of the individual fires is limited by variations in fuel loads.

Economics is also a factor in determining size of prescribed fires. The costliest portion of conducting prescribed fires is establishing and burning out fire lines. The smaller the size, the greater will be the perimeter per unit area. Over very large areas the need for (and costs of) additional personnel and equipment may outweigh the economics of burning larger units unless adequate natural barriers can be located.

Many prescribed burns are conducted with the objective of increasing the diversity of successional stages within an area or creating a fire mosaic. To do so, the size of the individual burned area should be small, usually less than 40 acres. Creating a mosaic of burned and unburned areas is relatively easy on sites with noncontinuous fuels and relatively high fuel moistures by careful selection of ignition pattern and weather conditions. Conditions are chosen in which only the sites with greater amounts of fuel will burn. As fuels become very noncontinuous and the topography becomes dissected, it is difficult to achieve a burn that is not a mosaic in spite of any fuel moisture relationships. A problem may arise, however, in areas where fuel loadings are high and more continuous. Without natural fuel breaks, an extensive system of fire lines may have to be established to restrict the fires to the desired size. This often makes the prescribed burn economically unfeasible. In these cases a compromise must be made between numerous small burns and a single large burn.

Rest and Deferment

There is a great deal of disagreement concerning the need for rest and deferment of grazing livestock on prescribed burns. The amount of nonuse necessary after the fire varies considerably with the vegetal composition, site conditions, and objectives of the burn and therefore may contribute to the controversy.

In almost all situations in the northern sagebrush-grass region, the prescribed burn area must be rested the year prior to the fire to permit the fine fuels to accumulate. Even light grazing often removes enough fuel to make fire spread difficult. Light grazing will break fuels continuity because animals will utilize preferred species and preferred sites first.

Land managers have often permitted light grazing in the spring, depending on fall regrowth to produce the fine fuels necessary for burning. In most instances regrowth was not sufficient. As a result, fires were patchy, or would not burn at all. There is some indication, however, that light grazing could be used to produce a patchy burn and create a mosaic in continuous fuels.

The amount of nonuse required after the fire depends upon many factors. Those prescribed burns that have a primary objective of increasing herbaceous production for livestock require some nonuse. Wright and others (1979) suggest that the area be ungrazed for two growing seasons in order to allow the perennial plants to recover from the fire. Currently, many land managers rest the burns the first year following the fire and then defer the second year. Grazing the established plants after dormancy in the fall probably has little effect on the plant if it is not utilized heavily. Resting the burned areas a year prior to the fire and for 2 years after the fire often makes it difficult to continue using traditional grazing systems. More use is shifted to unburned pastures, and consequently these may suffer during this time.

The ecological status of the burned unit affects postfire management. Pastures that have an adequate density of desirable plants present after the fire need only be ungrazed until those plants regain vigor. Areas with less than desired plant densities require postfire management that will maximize seed production and seedling establishment.

Other burn objectives need little or no special postfire livestock management. For example, an area was burned to enhance early spring forage for elk. The site was a south-facing slope near the crest of a high ridge. Due to the lack of water and steepness, livestock did not frequent the site. Grazing was deferred the year following fire so no adjustment in the grazing system was necessary. Because of improved palatability of forage cattle use increased on the burned site but did not become significant.

Prescription Development

Developing the fire prescription can determine to a large measure the probable success or failure of the fire. General procedures for planning prescribed fires have been developed by Fischer (1978) and Martin and Dell (1978). Special factors need to be considered when planning burns in sagebrush-grass and other vegetation types that produce low amounts of fine fuels.

The ranges in three weather factors suggested by numerous sources (Britton and Ralphs 1979; Wright and Bailey 1982; Wright and others 1979) are:

relative humidity 15-35 percent
temperature 60-85 °F
midflame wind 4-15 mi/h

Gruell and others (1986), and Bushey (1986) discuss fire prescriptions in relation to fuel conditions and prescribed fire objectives.

In sagebrush-grass fuels, the single most important prescription element is windspeed. Greatest changes in flame lengths and rate-of-spread came from changes in windspeed. Hence, considerable attention needs to be given to this element in both planning and implementing a burn. Additional factors to be included are (1) period of time since last significant precipitation, (2) atmospheric stability, and (3) the location and possible arrival of weather fronts. When the relative humidity is greater than 30 percent, the temperature is less than 60 °F, and the midflame windspeed is less than 4 mi/h, it is unlikely that fire will spread satisfactorily unless fine fuels exceed 600 lb/acre. When the relative humidity is less than 15 percent and the temperature is greater than 85 °F, fire control becomes more difficult. Windspeeds greater than 15 mi/h not only create fire control problems but also limit the effectiveness of fire within the burn area. At high windspeeds, the lateral spread of the fire is limited, and long narrow stringers of burned areas result. In some cases, these winds may actually blow the fire out (Neuenschwander 1980). In our experience, burning during windspeeds greater than 15 mi/h has never aided achieving a more continuous burn on an area.

As discussed earlier, fuel quantities, topographic conditions, and burn objectives may require that the prescription be modified within general limits. With small amounts of fine fuels and/or sagebrush cover, lower relative humidity (12 to 25 percent) and higher temperatures (75 to 85 °F) will be needed to enable the fire to spread. When fine fuels exceed 1,500 lb/acre, days with cooler temperatures, lower windspeeds, and higher relative humidities may be used to achieve a successful burn. Slope will increase the rate of spread significantly as graphically shown in Albini's (1976) nomographs. Brown (1982) estimated that a 30 percent slope will increase the rate of spread twofold to threefold over a level area and that a 50 percent slope will increase the rate of spread fourfold to sevenfold. More importantly for prescribed burning, steeper slopes will often enable the fire to carry across areas that would not burn if they were level by increasing the effective fire reach. Slope does not significantly affect the general range of temperature and relative humidity. Slope does, however, reduce the need for wind, and allow areas with lower fuel loads to be burned effectively. Even slopes of 10 to 15 percent may significantly affect fire rate-of-spread. See Albini (1976), Brown (1982), and Rothermel (1983) for further information on predicting fire behavior.

Other factors may also require deviation from the general fire prescription conditions. If burned and unburned mosaic is an objective, a prescription with cooler and moister weather conditions may be used. Conversely, significant amounts of green herbaceous growth (live fuels) increase the average moisture content of the fine fuels, and a prescription requiring higher temperatures and lower relative humidities is needed.

Rate-of-spread, fire intensity, and flame length can be estimated by Rothermel's fire behavior model (1972) and by Albini's nomograms (1976). Rothermel's models have recently been adapted for use within a set of interactive computer programs for minicomputers (BEHAVE System, Burgan and Rothermel 1984; Andrews 1986) and personal microcomputers (PC/BEHAVE, Cooney 1986). These technical aids provide rapid evaluation of site specifics or NFFL fuel models, and predict fire behavior.

A program module for the Hewlett-Packard HP-71B calculator providing fire danger and fire behavior computations is also available for use in the field (Burgan and Susott 1986; Susott and Burgan 1986). This module replaces a similar one using the Texas Instrument TI-59 (Burgan 1979). Fire behavior models are primarily used for wildfire situations, to predict free-running headfires in a uniform environment. Although these models were not designed for prescribed burns, where fire behavior is influenced by ignition pattern, those who understand the models can use them to predict behavior of a prescribed burn. These computer programs are also useful in determining the need for suppression forces. If the fire behavior and spotting potential is great, the need and placement of suppression personnel and equipment becomes critical.

Other measurements of burning conditions have been developed and used in some situations. Fine fuel moisture has been used, but it is strongly correlated to relative humidity and temperature, which are far easier to obtain. Ten-hour time-lag moisture, which can be taken onsite with fuel moisture sticks, gives an index of the moisture of the 0.25- to 1.0-inch dead fuels. Although this size class of fuels is not abundant in sagebrush-grass vegetation, it may be used as a general index to the "dryness" of the system. Our experience shows that 10-hour time-lag moisture should be less than 10 percent and preferably near 8 percent. When the 10-hour time-lag is less than 7 percent, the sagebrush twigs and branches are completely consumed by the fire. More research needs to be done on the application of this index to rangeland burning. The moisture content of the current year's growth of sagebrush is an index to the flammability of these plants. Results have been highly variable, but preliminary data indicate that the moisture content should not exceed 110 percent of dry weight for most situations.

Many prescriptions call for a significant amount of rainfall to occur prior to the fire's ignition. Although this may enhance resprouting of some shrubs such as bitterbrush (Blaisdell and Mueggler 1956), it may also create undesirable effects. In many areas of the northern Great Basin and Columbia Basin, late summer and early fall are characterized by warm dry weather. Precipitation does not often occur until the general high pressure over the area breaks down. Once this happens, periodic showers occur and cooler temperatures predominate until winter. A situation is created where the weather seldom gets into the general range of sagebrush burning prescriptions. This is particularly critical in areas with marginal fine fuels (and less topographic relief) where conditions on the drier and warmer end of the general range are needed. Many prescribed fires end up being very patchy and small or have had to be postponed because wet conditions prevailed after this precipitation occurred. The need for precipitation prior to burning to achieve the desired fire effects and the likelihood of adequate burning conditions afterward should be critically assessed before writing the fire prescription.

Other Factors To Be Considered

During the planning process a number of other factors should be considered to maximize the probability of a successful burn. Most sagebrush-grass vegetation must be rested prior to burning to allow fine fuels to accumulate. This is a management cost that cannot be recovered unless the grazing system included a rest for that area at that time. The possibility of a year occurring where conditions are not optimum for burning as described in the plan should be considered. It is well known by those conducting prescribed burns that all years are not equal and that we have so-called "good years" and "bad years." Bad years may include years during which the precipitation is so limited that the fine fuels are significantly less abundant than expected. They may also be years wherein precipitation occurs throughout the summer and the herbaceous fuels never cure completely prior to winter. In other years, the fall rains may begin earlier than expected and the fuels never dry sufficiently.

These conditions may result in fires that achieve far less than desired. A manager is faced with choosing between three options:

1. Rest the area a second year and postpone the fire for 1 year;
2. Due to allotment limitations one cannot delay the fire for 1 year and consequently the fire may be postponed indefinitely;
3. Decide to burn under current conditions, realizing that the objectives will not be met as successfully as hoped.

Option 3 may result in less area being burned than desired if conditions are too wet. Less than desirable mosaics of burned and unburned vegetation may also result. The consequences of each alternative should be considered and guidance given to the personnel charged with conducting the fire.

The same type of reasoning must take place in regard to a single day. Most of the fire prescriptions for sagebrush-grass vegetation are very similar in the required weather conditions. As more and more fire projects are planned each year, the number of days in which fires can be conducted may become a limiting factor. This situation can be alleviated in several ways. More personnel can be trained to conduct prescribed burns, allowing more than one burn to be conducted on a given day. The conditions under which fires are prescribed may be expanded. This may involve (1) beginning the prescribed burning earlier in the summer, or (2) burning on days when conditions are less than optimal.

Both choices have included within them certain costs and risks. Burning under hotter and drier conditions increases the risk of escape and the need for suppression

Table 4—Suggested timetable/checklist for prescribed burning

Activity	Date to be completed
Development of burn plan	Year prior to burn
Sample monitoring plots	Growing season prior to fire
Install RAWS unit in field	
Reserve fire equipment, firing and holding crews	
Weather and fuel moisture monitoring	Begin 10 days prior to burn or as required
Prepare firelines	End of growing season prior to fire or immediately before fire
Inspection of firelines	Post-fireline preparation
Inspection of fire equipment, water sources to be used in fire	
Determine firing and holding burn pattern	Day prior to burn
Review burn plan with all personnel	Day of burn
Notify local fire departments	Day of burn
Monitor weather	Hourly day of burn
Sample vegetation and other monitoring plots	Yearly or as required
Evaluation of burn plan	Postburn

forces. Burning earlier in the summer may require wildfire suppression personnel who may not be as available for prescribed burning. Many plant species may not respond as favorably when burned during midsummer as during late summer and early fall. Burning under cooler and wetter conditions results in patchy, small burns and requires more personnel for ignition. Each situation may result in not fully achieving the objectives of the burn and add to the cost of the project. These possibilities should be considered well in advance of the fire so that personnel conducting the burns can deal with situations as they arise.

Prefire Activities

A number of other tasks need to be accomplished prior to the burn. In most areas other agencies need to be notified, and a burning permit may be required. The surrounding agencies, landowners, and fire departments should be notified of the date of the burn. This should prevent an alarm being issued to a fire suppression group.

A timetable-checklist should be developed for the project. This would cover the prefire jobs, who is to do them, and the completion dates. Typical duties would be the establishing of monitoring plots, prefire weather and fuels data, securing and testing of equipment, training of personnel, and notification of others (table 4).

Prefire Crew Briefing

An onsite briefing should be conducted prior to ignition. This is necessary for the success of the fire and safety of the personnel. The more complex the fire is and the larger the fire crew needed, the more the briefing is necessary. At this briefing the overall plan is outlined on a map so everyone understands the entire project. Each individual should be assigned a specific job. At this time an individual is designated to record periodic weather observations. If photographs or data are to be taken, such chores should be assigned to specific individuals. All personnel should be checked out on equipment they are to operate.

Personnel in charge of holding firelines need to be aware of critical points along the fire perimeter. The contingency plan in case of fire escape must be outlined. Location of water sources should be identified for all engine operators. Finally, escape routes for all personnel must be clearly identified.

The briefing must cover communication among personnel, which is often a major problem during the burn. The briefing must also cover actions in case of changing weather conditions. Unpredicted fronts may significantly affect weather. In addition, large fires may generate their own wind (Schroeder and Buck 1970). Contingencies for such events should be outlined to the crew.

EVALUATION AND MONITORING

Usually, the project will be evaluated to determine if it achieved objectives, and to foster improvement in planning implementations of other burns. Evaluations may vary from highly subjective and qualitative observation to sophisticated quantitative monitoring. The degree of evaluation required depends on the specificity of the objectives of the burn and the availability of data from the area.

As objectives become more specific, the evaluation becomes more painstaking. For example, it is much more difficult to determine whether or not the annual production of bluebunch wheatgrass increased by 100 lb/acre following a prescribed fire than it is to determine whether there has been a 50 percent increase in herbaceous production. Although the sampling methodology is similar, the sampling intensity required is much less in the latter case. The availability of pertinent data may also affect the monitoring needs. In some situations information may be available so that only sampling of general trends will be necessary. In other situations, no literature or administrative studies may be available and more detailed sampling would be necessary.

Regardless of the monitoring effort needed, a number of requirements remain. For most types of data, the most efficient sampling procedure utilizes a permanent sample site. This reduces the amount of variability included within the site. The site should be sampled prior to the burn treatment in order to further account for between-site variability. By taking prefire measurements it is possible to detect smaller changes with lower sampling intensity than one can by randomly sampling burned and unburned vegetation after the fire has occurred. The establishment of a permanent site does not necessarily imply that the sampling microplots are permanently located. This will be addressed in more detail under the various sampling methods. The monitoring effort should be tailored to the objectives of the plan. Many monitoring programs involve studies that are not related to the objectives. Although the information may be useful, its collection adds to costs.

When sampling vegetation, a control or an untreated sample plot should be established and sampled at the same time as the treated plots. An untreated plot is needed to separate the effect of the yearly weather variation from the effect of the burn on the vegetation. It is essential that the environmental conditions of the untreated area reflect those of the burned area. Therefore, it is important to select sites that are as similar as possible in vegetation composition, soil type, and grazing impact. Sampling in subsequent years should also fall within the same general phenological timeframe as the original sampling. Untreated plots are particularly important when benefits of the prescribed fire will not be realized for more than 5 years after the site is burned. In these situations the untreated vegetation may also change significantly over time.

It is suggested that the agency's standard sampling procedure for determining range trend (vegetation change) be used if possible. This method can then be modified or added to in order to assure that the appropriate data needed are collected. Use of the agency's standard method simplifies documentation and provides for an additional range trend data point should it be needed in the future. Individuals or agencies without a standard procedure may want to adopt a method with which they are familiar.

Types of Vegetation Data

Vegetation characteristics that can be sampled are rather limited in number. The basic vegetation parameters are descriptors of a plant community and primarily include basal cover, foliar cover, species density, and species biomass. Frequency is another vegetation characteristic related to abundance. These methods have been described by Brown (1954), Mueller-Dombois and Ellenberg (1974), Pieper (1978), and Cook and Stubbendieck (1986). In addition to the basic vegetation descriptors mentioned above, it may also be necessary to monitor direct fire effects such as plant mortality and characteristics related to fire behavior such as fuel moisture.

We are not recommending inclusion of all types of data in a monitoring system. The amount and type of data needed vary, depending upon the prescribed burn objectives, the data available from other sources, the extent of the proposed burn, the value of the resources involved, and ability of the interested agency to commit funds and personnel. The following sections are intended to recommend procedures that have been utilized in the past to evaluate prescribed burns. These methods, when correctly applied, have supplied data of appropriate precision for land management purposes. Whenever possible, we encourage collection of both vegetal and fuel data on the same transects or plots.

Plant Cover—Plant coverage values can be used as an effective indicator of dominance in a community because they allow comparisons between species of varying growth forms (Mueller-Dombois and Ellenberg 1974). There are two basic forms of coverage: basal cover and foliar cover. Basal cover is a vertical projection of the root crown area onto the ground surface while foliar cover is the projection of the entire aerial portion of the plant. Foliar cover of herbaceous plants is more sensitive to changes caused by season, climate, and grazing than is basal cover. Basal cover is rarely estimated for shrubs because it inadequately reflects the importance of these species. Basal cover is also not usually estimated for annuals and single-stemmed or rhizomatous species because the unit basal area is smaller.

The most widely accepted method of determining coverage of herbaceous plants is through the use of point-intercept (Mueller-Dombois and Ellenberg 1974). Usually multiple points are taken at sample locations at a given interval along a tape. The point frame developed by Floyd and Anderson (1983) has been shown to give good results in sagebrush-grass vegetation, particularly for foliar coverage (fig. 9 illustrates a cross hair point frame). Basal coverage is more labor intensive. It is often preferable to obtain an estimate of basal cover from a more easily obtained characteristic such as frequency (discussed later).

Line-intercept is an efficient method for sampling shrub aerial coverage (Canfield 1941). The length of the individual lines required may vary but normally exceeds 25 feet in length. The lines should not be so long that they cross vegetation or soil types. Line-intercept has also been used with some success for herbaceous vegetation. It may be applied fairly well to sampling bunchgrasses but is very tedious and time consuming when sampling rhizomatous grasses or very small plants (Floyd and Anderson 1983). Different length lines are usually required to sample shrub and bunchgrass species. To solve this, only a portion of the total line length will be used to sample the herbaceous species. For the sake of consistency between observers, it is better to sample from one edge of the canopy to the other (fig. 10 shows line-intercept method). Only large gaps (greater than 8 inches) in the canopy are subtracted. Subtraction of small areas reduces replicability and adds to sampling and recording time required. Line-intercept and canopy coverage estimation (Daubenmire 1959) of shrub cover provide comparable results. But line-intercept is preferred where levels of high precision and confidence are required (Hanley 1978).

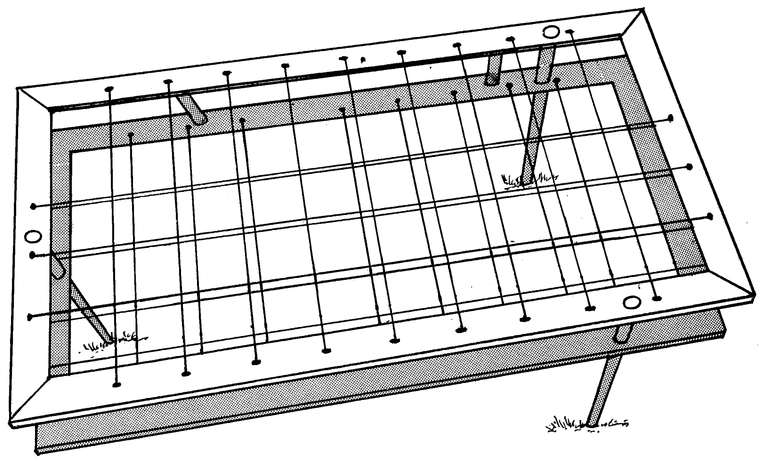


Figure 9—Point-sighting frame for estimating herbaceous foliar cover.

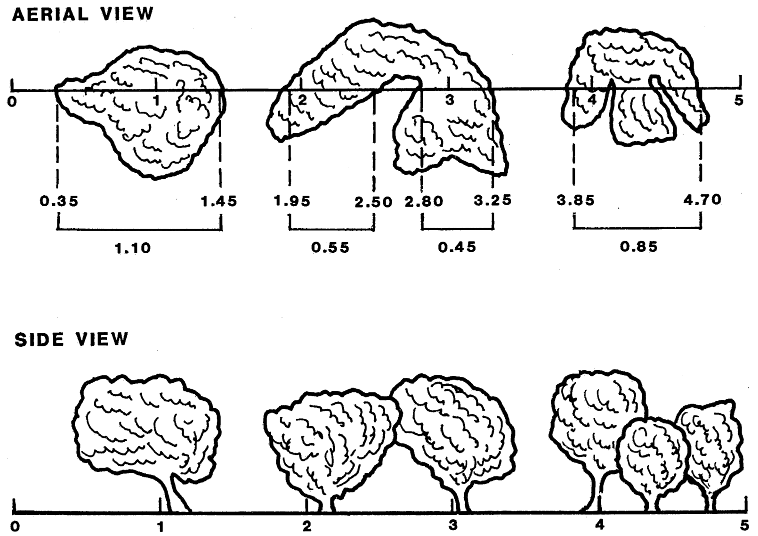


Figure 10—Line-intercept method for determining shrub cover.

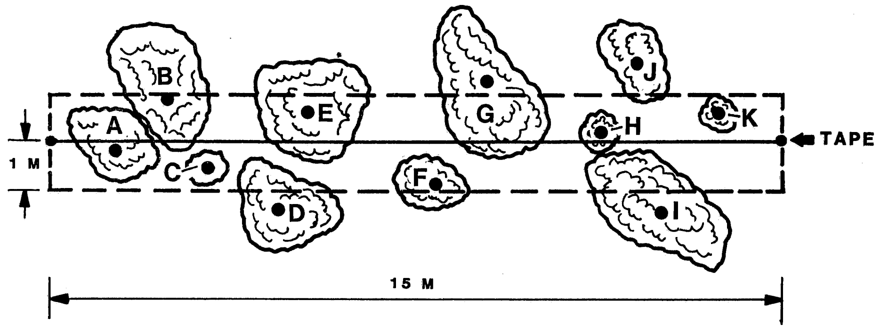


Figure 11—Belt transect layout for estimating shrub cover and density.

Plant Density—Although plants-per-unit-area is perhaps the easiest sampling method to grasp, it is difficult to apply (Mueller-Dombois and Ellenberg 1974). The number of plants does not accurately reflect the relationship between plants of different growth forms. The individual plant is difficult to determine when the species are rhizomatous or bunchgrasses whose crowns have begun to break up into smaller units. Also, sampling density may be very time-consuming for small and abundant species. Density measurements may be useful, however, for shrub species, particularly the nonrhizomatous species. The belt transect is an effective method of sampling shrub density (fig. 11). Only those plants rooted within the belt transect are recorded. Transects may be randomly established within a site. The length, width, and number will vary with the vegetation.

Plant Frequency—Frequency of occurrence is an effective method for detecting changes in composition in herbaceous vegetation (Smith and others 1986). Such surveys can be done rapidly and fairly consistently between observers because only species identification and whether or not the plant is rooted in the plot are required. Rooted frequency is directly related to basal crown cover and is therefore less sensitive to changes due to season, climate, and utilization by grazing animals than are many other descriptors such as foliar cover. Frequency has also been adopted by some land management agencies as the standard procedure to measure range trend.

In order for frequency to be sensitive to changes, the occurrence of an individual plant should be between 26 and 86 percent (Curtis and McIntosh 1950), preferably greater than 50 percent (Smith 1982). The size of quadrat required to give the desired frequency of occurrence varies with density, size of the average plant, and plant distribution. Preferred quadrat size varies among species. But we have found that the nested quadrat (fig. 12) gives adequate results for most species. Occurrence is recorded for all species in all plot sizes. Recording can be done rapidly by beginning with the smallest plot and adding individuals occurring in successively larger plots. Thus data for the correct plot size are recorded without extensive preliminary sampling.

The number of quadrats per site is an important factor if statistical analysis of the data is anticipated. Smith and others (1986) have shown that a minimum of 100 quadrats is necessary. Sensitivity will increase significantly up to about 200 quadrats per site, with only minor increases in sensitivity thereafter.

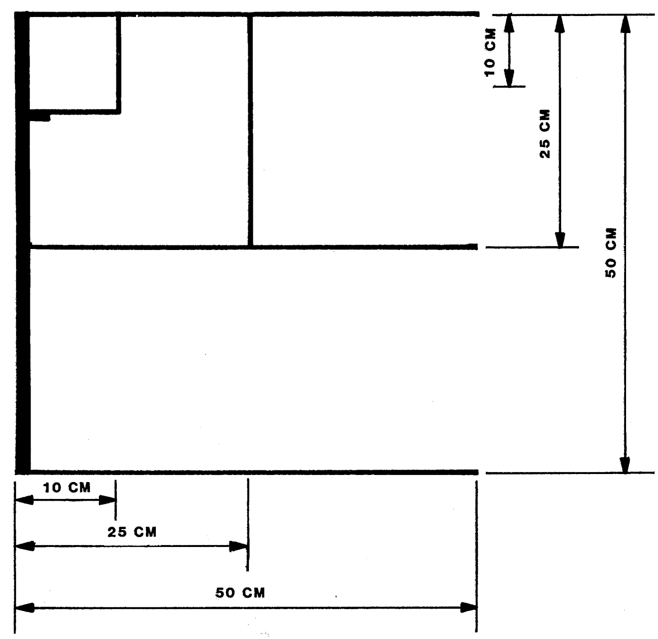


Figure 12—Nested frequency quadrat.

The quadrats are usually placed at a predetermined interval along a tape. Using a tape to determine plot position reduces bias in placement of the quadrat. The interval between quadrats should be greater than the maximum size of the plants sampled, thus eliminating the possibility of an individual falling into two quadrats. An interval of 3 feet is adequate for sagebrush-grass vegetation. Quadrats should never be placed adjacent to one another.

Because many will not survive, seedlings of perennial plants often increase the variability between sample periods. It is usually best to not record seedlings until they are well-established or record them separately from the established plants. Frequency may also be used to estimate density (Greig-Smith 1983) and basal area.

Plant Mortality—Frequently land managers are interested in assessing the mortality of key species. This is most efficiently accomplished by locating populations and permanently marking randomly selected individuals with stakes. Locations of individuals can then be mapped in reference to a witness marker (fig. 13). At least 20 individuals per species should be located. If the distance between individuals exceeds 15 feet for herbaceous plants or 30 feet for shrubs, relocation in future years may prove difficult. Mortality should be assessed for several years following the fire, particularly when sampling shrubs. Individuals may resprout but then die several years after the fire occurred (Bunting and others 1984; Clark and others 1982).

When permanent line transects are established for other sampling purposes, these may also be used to assess mortality of key species. Plant locations can be mapped in relation to distances along the tape (fig. 13). Plants should still be permanently marked with stakes. Stakes should be placed in the same location (for example, north side) and placed at the same distance from the plant base. Metal tags with stamped numbers have been found to work best. If a plant dies and disappears, it is difficult to determine whether mortality or a mismeasurement has occurred unless the location can be identified.

Plant Biomass—Determining productivity of herbs and shrubs is often desirable because it is directly related to carrying capacity. Unfortunately, sampling to determine productivity by species is most difficult. Great variability between plots requires a large number of samples. Mosley (1983) found that more than 50 samples were commonly required for major species. Total herbaceous productivity can be estimated more easily. Mueggler (1976) found that ten 4.8-ft^2 quadrats sampled total herbaceous production, with an 80 percent probability of coming within ± 20 percent of the mean in most Montana grassland and sagebrush-grass habitat types. Productivity estimates should be sampled at the same phenological stage each year, preferably after maximum standing production has occurred.

Herbaceous production should be sampled on a permanently located site. It must be remembered that the exact same area should not be clipped every year. The previous year's clipping will affect the next year's production.

Fuel Loading Measurements—The total fuel load may need to be estimated for prescribed burns. This may be particularly important at the onset of a burning program, to allow use of various fire behavior models (Albini 1976; Britton and Ralphs 1979; Brown 1982). Fine fuels may be

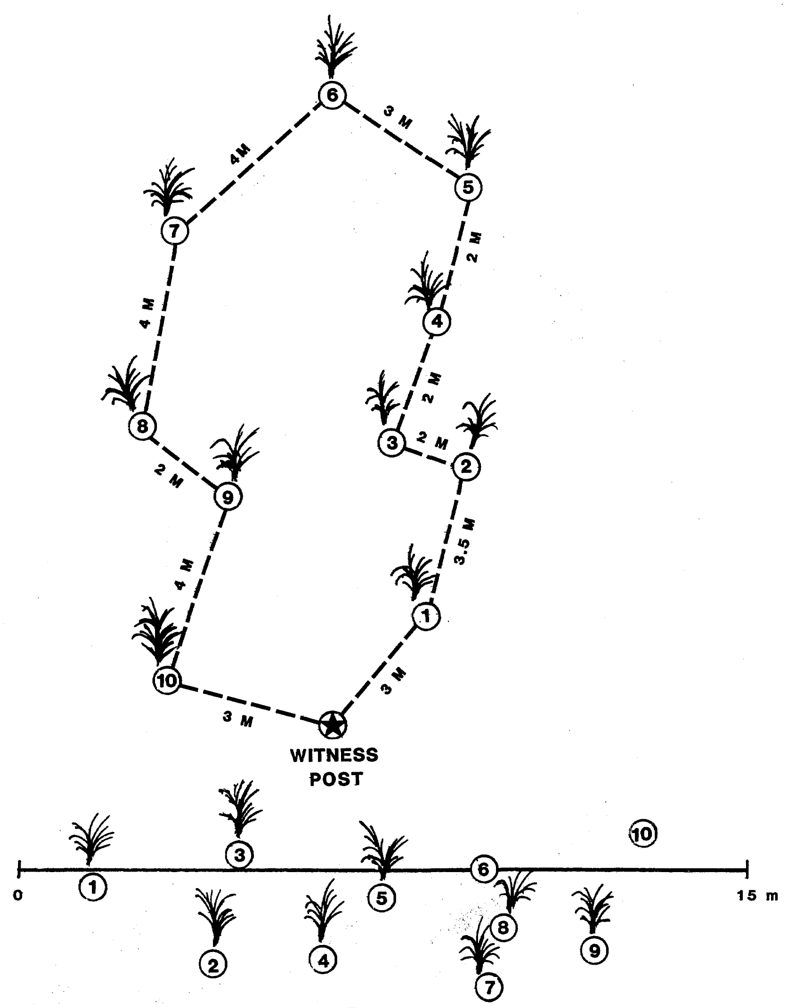


Figure 13—Two methods for locating permanently marked plants to determine mortality of key species.

sampled with the same procedures as used for herbaceous production. The only difference is that the litter must also be collected from the quadrats. Brown and others (1982) describe a less time consuming method, that utilizes a combination of clipping and weighing and weight estimation. Analysis is completed by an interactive computer program (FUELS), which provides mean loadings, standard deviations, and standard error as a percentage of the means.

The shrub component of the fuel load is also an important factor. The fine fuels and shrubs collectively determine whether or not the fire will spread. The lack of one may be partially compensated for by the presence of the other. The model by Britton and Ralphs (1979) used sagebrush cover as an indication of shrub fuel load. The combination of average sagebrush height and coverage is used in Brown's (1982) model. Frandsen (1983) utilized equivalent basal diameters to estimate shrub fuel loads. Shrub coverage can be estimated with the line-intercept, as previously described. Shrub heights can be recorded at predetermined intervals along the tape and then averaged to estimate mean height.

Burn Area—The total area burned can be estimated most effectively from the air. If precise estimates are required, aerial photographs can be taken after the fire, or the burn area can be mapped onto topographic maps, and the area estimated using standard dot grid or planimeter methods (Avery 1977; Colwell 1983). If aerial photographs are to be used, the scale of the photograph must be established.

Photography—Photographs can provide an effective means of documenting changes due to the prescribed burn. Permanent photopoints should be established at all vegetation sample locations. The photopoints should be carefully referenced and the major species listed. Closeup and oblique photos should be taken to illustrate ground details as well as overall community appearances.

Plot Layout

Many land managers may be unsure as to how to lay out and document a fire effects sample plot. Once data needs are determined, sampling should be done in a systematic manner that can be replicated in the future. We have

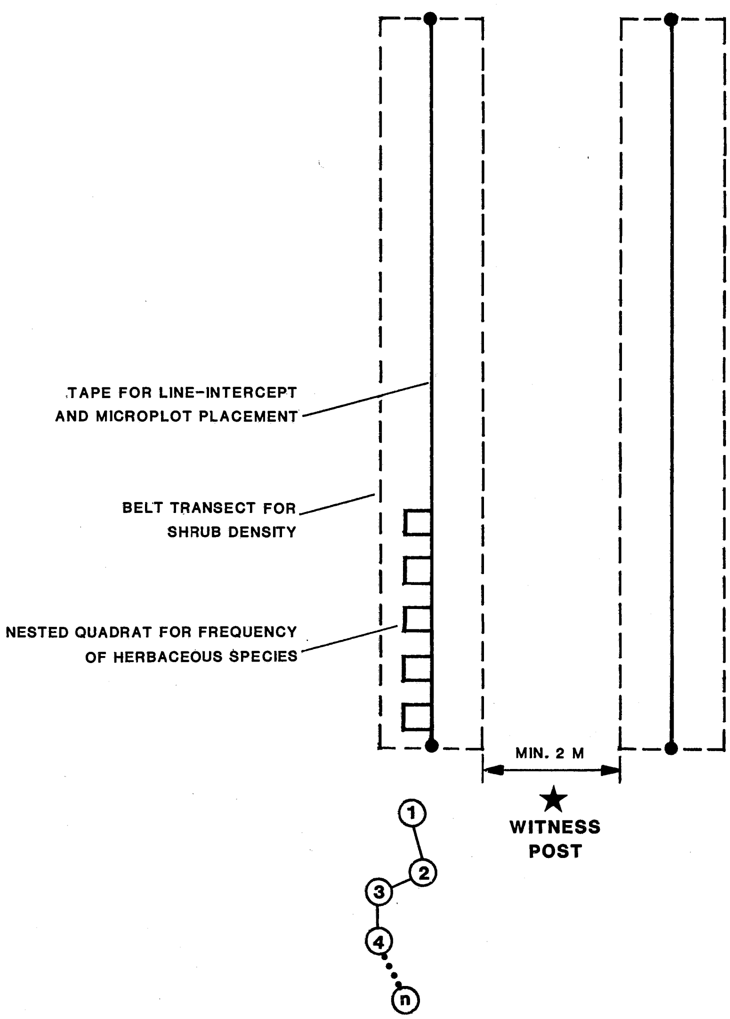


Figure 14—Suggested plot design for monitoring shrub cover, density, herbaceous species frequency, and mortality of key species.

established a system that has worked successfully in the past, although many modifications have also been used.

The system consists of a series of permanently established transect lines running parallel to one another (figure 14 shows sample plot layout as if all data previously discussed were being recorded). The length of the individual transects may vary between locations but should not cross vegetation or soil types. In most situations lines that are between 25 and 100 feet long seem to be appropriate in sagebrush-grass vegetation. The number of lines may also vary depending upon the length of each line. If a minimum of 100 frequency plots are sampled and they are at least 3 feet apart, this requires at least 300 feet of total transect length. This distance is also probably a minimum transect length from which to determine sagebrush cover. The parallel lines should be separated enough so that one line can be read without disturbing another.

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APPENDIX A: LIST OF SPECIES (SCIENTIFIC AND COMMON NAMES) USED IN THE TEXT.

Scientific name	Common name
Trees and Shrubs	
Artemisia arbuscula	low sagebrush
Artemisia cana	silver sagebrush
Artemisia nova	black sagebrush
Artemisia rigida	stiff sagebrush
Artemisia tridentata	
ssp. *tridentata*	basin big sagebrush
ssp. *vaseyana*	mountain big sagebrush
ssp. *wyomingensis*	Wyoming big sagebrush
Artemisia tridentata ssp. *vaseyana* form *xericensis*	"species X"
Artemisia tripartita	threetip sagebrush
Chrysothamnus spp.	rabbitbrush
Juniperus spp.	juniper
Pinus ponderosa	ponderosa pine
Pseudotsuga menziesii	Douglas-fir
Purshia tridentata	antelope bitterbrush
Tetradymia canescens	gray horsebrush
Grasses	
Agropyron smithii	western wheatgrass
Agropyron spicatum	bluebunch wheatgrass
Bouteloua gracilis	bluegrama
Bromus tectorum	cheatgrass
Elymus (Taeniatherum) caput-medusae	medusahead
Elymus cinereus	Great Basin wildrye
Festuca idahoensis	Idaho fescue
Poa sandbergii	Sandberg bluegrass
Poa spp.	bluegrass
Sitanion hystrix	bottlebrush squirreltail
Stipa comata	needle-and-thread
Stipa thurberiana	Thurber's needlegrass

Nomenclature used follows that of Hitchcock and Cronquist (1973) except for that of *Artemisia* which follows Beetle (1960) and Winward and Tisdale (1977).

APPENDIX B: ANNOTATED BIBLIOGRAPHY OF SAGEBRUSH-FIRE LITERATURE

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Fuels, *Purshia.*

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Succession, conifer invasion, fire frequency, fire management, fuels, *Pinus, Pseudotsuga, Populus, Amelanchier, Ceanothus, Cercocarpus ledifolius, Prunus, Purshia,* shrubs, *Achillea,* forbs, *Balsamorhiza, Agropyron spicatum, Festuca, Koeleria.*

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Resprouting, seedling establishment, fire management, *Purshia.*

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Succession, conifer invasion, fire frequency, *Sporobolus, Ceanothus, Pinus, Pseudotsuga, Juniperus, Populus.*

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Fire frequency, fire management, *Bromus.*

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Wildlife, *Lupinus, Epilobium, Agoseris.*

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Resprouting, morphology, physiology, mortality, succession, herbivory, fuel, seedling establishment, fire management, *Purshia, Pinus, Juniperus, Bromus.*

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Fuels, *Purshia, Ceanothus.*

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Fire prescriptions, fire management, fuels, *Cercocarpus, Pinus, Purshia, Bromus tectorum, Sitanion, Chrysothamnus, Festuca, Elymus, Poa.*

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Fire management, plant productivity, resprouting, seedling establishment, mortality, succession, *Purshia, Artemisia tridentata vaseyana, Chrysothamnus, Tetradymia.*

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Fire behavior, planning, fire prescriptions.

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Fire management, severity, succession, morphology, *Ceanothus.*

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Resprouting, fire management, fire severity, seed production, physiology, morphology, *Arctostaphylos, Symphoricarpos, Spirea, Amelanchier, Juniperus, Prunus, Purshia,* shrubs, forbs.

Olsen, C. M.; Johnson, A. H.; Martin, R. E. 1982. Effects of prescribed fires on vegetation in Lava Beds National Monument. In: Ecological research in national parks of the Pacific Northwest. Forest Research Laboratory Publication. Corvallis, OR: Oregon State University: 92-100.

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Summarizes recent literature on the effects of fire on sagebrush-grass vegetation. Also outlines procedures and considerations for planning and conducting prescribed fires and monitoring effects. Includes a comprehensive annotated bibliography of the fire-sagebrush-grass literature published since 1980.

KEYWORDS: vegetation monitoring, prescribed fire, management planning, fire effects

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