# Ponderosa Pine Ecosystems[1]

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## Abstract

Ponderosa pine is a wide-ranging conifer occurring throughout the United States, southern Canada, and northern Mexico. Since the 1800s, ponderosa pine forests have fueled the economies of the West. In western North America, ponderosa pine grows predominantly in the moist and dry forests. In the Black Hills of South Dakota and the southern portion of its range, the species primarily occupies ponderosa pine potential vegetation types (PVTs) but, in the northern portion of its range, it grows on Douglas-fir, grand fir and/or white fir and western redcedar PVTs. Within this wide range of biophysical settings it is often associated with complex vegetation mixes. Non-lethal, mixed, and lethal wildfires historically burned through most ponderosa pine forests leaving in their wake a wide variety of species compositions and vegetative structures arranged in a variety of mosaics. Since the 1800s, fire exclusion, animal grazing, timber harvest, and climate cycles have contributed to changing these forests. As a result, succession accelerated, plant compositions shifted, trees and other biomass accumulated, soil chemical and physical properties changed, non-native plants were introduced, and epidemics of insects and diseases are more common. Together these changes altered fire regimes, displaced native species, and disrupted other ecological processes. Although the extent of wildfires that now burn in these altered forests is not noteworthy, their severity is. Canopy treatments and surface fuel treatments in combination are most likely to reduce the risk of severe and intense wildfires in these forests that mean a great deal to individuals and society.

## Introduction

Ponderosa pine (*Pinus ponderosa* P. & C. Lawson), is a wide-ranging conifer occurring throughout the western United States, southern Canada, and northern Mexico (*fig. 1*) (Little 1971). Generally its greatest extent is in the Inland Northwestern United States and in northern California. However, it is a prevalent species in the Black Hills of South Dakota and Wyoming, along the Front Range of the Rocky Mountains in Colorado and along the Mogollon Rim in Arizona, the rugged escarpment that forms the southern limit of the Colorado Plateau. The species occupies sites with elevations ranging from sea level to 3,281 m (10,000 ft.) depending on latitude (Oliver and Ryker 1990). In terms of area occupied, it is only second to Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco var. *glauca* (Beissn.) Franco) (Van Hooser and Keegan 1988). Two geographic varieties are recognized, the Rocky Mountain (*Pinus ponderosa* var s*copulorum* Engelm.) which grows primarily in the Rocky Mountains and the Pacific (*Pinus ponderosa* var *ponderosa* which is widely distributed in the mountains of the Pacific Coast from British Columbia into California and western Nevada (Little 1979). Arizona pine (*Pinus arizonica* Engelm.), once considered to be a variety of ponderosa, grows in southwest

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New Mexico, southeast Arizona, and northern Mexico. Within this wide range, ponderosa pine grows across highly variable biophysical settings (e.g., soils, slopes, aspects, associated vegetation, and fauna). Our objective in this paper is to describe ponderosa pine ecosystems by drawing heavily from our familiarity with ponderosa pine forests within the Rocky Mountains. In addition, we describe briefly the changes that have occurred in ponderosa pine forests over the last 100 years as the result of disturbances or lack-there-of, vegetative succession, fire exclusion, and wildfires (Graham and others 2004). We also provide some insight into how treatments might be used to restore these forests. We suggest even though our paper may be Rocky Mountain centric, the concepts presented most likely have application to any location where ponderosa pine occurs within western North America.

Ponderosa pine is the principle species on over 11 million ha (27 million ac.) and for every 2.8 ha (7 ac.) it dominates, it is present on an additional 1.4 ha (3.5 ac.). Within the western United States, California alone contains the greatest concentrations of ponderosa pine (2.07 million ha (5 million ac.) closely followed by Oregon with 1.9 million ha (4.7 million ac.) and, when combined, Arizona and New Mexico contain an additional 2.5 million ha (6 million ac.) of ponderosa pine (Van Hooser and Keegan 1988). Ponderosa pine fueled the economies of the West beginning in the 1860s when pines were harvested to supply building material to farms, mines, and towns as they developed. With the coming of the railroads in the early 1900s, harvesting increased mostly by clearcutting. However, with the advent of improved roads allowing access by tractors and trucks, partial cutting became the dominant harvesting method. Ponderosa pine's high value, especially the value of mature and old trees, led to efforts in classifying tree vigor and the risk of mortality which was used in selection silvicultural systems (e.g., vigor selection) (Dunning 1928, Keen 1943, Meyer 1934). High risk trees were removed to decrease the incidence of bark beetles and capture the value of imminent mortality (Keen 1936, Barrett 1979). Ponderosa pine forests presented an opportunity for intensive management across large expanses of the West and considerable research and managerial effort was directed towards this end (Pearson 1950).

## Ponderosa Pine Characteristics

Ponderosa pine is three-needled, however, fascicles with both two and three needles can be found on the same tree (Harlow and Harrar 1968). Ponderosa pine trees can exceed 120 cm (48 in.) in diameter on good sites in northern Idaho and western Montana and exceed 183 cm (6 ft.) in diameter on sites in California (Van Hooser and Keegan 1988). The ability of the species to survive low severity wildfires is one of its most unique characteristics. At small diameters (e.g., 5 cm, 2 in.), ponderosa trees can withstand heat from most surface fires because of the insulating bark that protects the underlying cambial layers. Large ponderosa pines with yellow bark invoke a sense of a majestic forest and spiritual feeling in people who frequent these forests. These traits are exemplified by the many historical photos depicting people enjoying the presence of large yellow ponderosa pine trees (Grafe and Horsted 2002, Gruell and others 1982, Smith and Arno 1999). Moreover, these

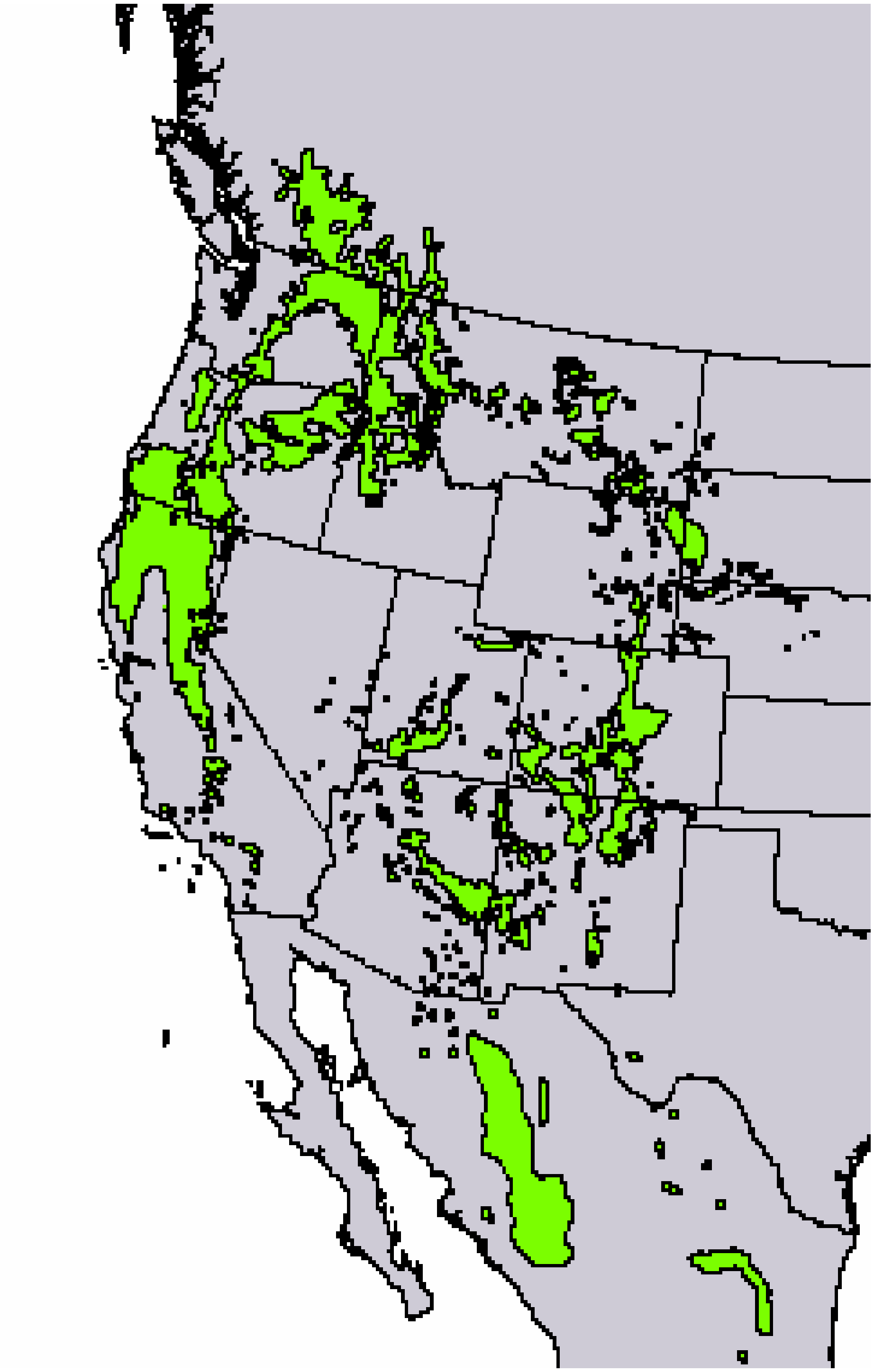


**Figure 1—**The range of ponderosa pine (Little 1971).

conditions provide valuable wildlife habitat (Long and Smith 2000, Reynolds and others 1992, Thomas 1979) and protect watersheds for the production of domestic water such as those occurring on the Front Range of the Rocky Mountains in Colorado (Robichaud and others 2003).

For trees to survive and develop they must be genetically adapted to the site. For example, the environmental interval in elevation in which ponderosa pine populations show habitat specificity is approximately 453 m (1380 ft.) or 38 frost-free days. In contrast, no habitat specificity in elevation has been found for western white pine (*Pinus monticola* Dougl. ex D. Don), and the habitat specificity interval in frost-free days is 90. The narrowest habitat specificity for any of the associates of ponderosa pine occurs with Douglas-fir which has an environmental interval of 113 m (650 ft.) in elevation or 18 frost-free days (Rehfeldt 1994). Genetically, ponderosa pine has intermediate adaptation to sites compared to Douglas-fir, considered a specialist, and western white pine, considered a generalist. The size of ponderosa pine seed crops in general is smaller than most of its associates and, if it wasn't for western larch (*Larix occidentalis* Nutt.) flowers being frequently damaged by frost, it would also have the most infrequent cone crop of any associated conifer (Minore 1979, Graham and others 1995). Ponderosa pine regenerates readily on both mineral and burned over seed beds, however, it does not establish well on unburned organic surfaces (Haig and others 1941).

## Ponderosa Pine Forests

In western North America, ponderosa pine grows within both moist and dry forests but seldom occurs in the cold forests (i.e. subalpine forests). Climate, as well as the associated tree species, distinguishes the two general forest classifications where ponderosa pine can grow (Hann and others 1997). In dry forests, associated species, beginning with the most intolerant to shade and competition, include quaking aspen (*Populus tremuloides* Michx.), western larch, lodgepole pine (*Pinus contorta* Dougl. ex Loud), Douglas-fir, and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) or white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.). In moist forests, the species most often grows on south facing aspects, but can occur in small amounts throughout the entire forest type. Early-seral associates include western larch and lodgepole pine while Douglas-fir, western white pine, and grand fir/white fir are more tolerant than ponderosa pine (Minore 1979). The most tolerant tree species associated with ponderosa pine in the moist forests is western redcedar (*Thuja plicata* Donn ex D. Don) (Cooper and others 1991, Daubenmire and Daubenmire 1968). The combination of species and their variable tolerances to competition and shade gives rise to a variety of forest compositions and structures in both forests types.

## Succession In Ponderosa Pine Forests

Succession is a term applied to the gradual supplanting of one community of plants by another on a given site through time (Smith and Arno 1999). Vegetative complexes evolve after a disturbance such as a lethal fire (i.e. fires that kill the majority of the dominant and codominant canopy layers) (Hann and others 1997). Early-seral stages often begin with a grass/forb/shrub stage, succeeded by tree seedlings and saplings which grow to young trees, and subsequently develop into the late-seral mature and old vegetative complexes. In some systems, such as those dominated by ponderosa pine, these or similar stages may develop in less than 250 years but in other systems, such as Pacific coastal Douglas-fir (*Psuedotsuga menziesii* (Mirbel) Franco var. *menziesii*), it may take in excess of 1,000 years for the full compliment of structural stages inherent to the system to develop (Franklin and others 2002, Reynolds and others 1992).

A very useful characteristic of vegetative succession is that for a given biophysical environment and species mix, the vegetative development over time from early-seral (pioneer) through late-seral (climax) is predictable. Because of this predictability it can be used to classify sites by the potential vegetation that will occur. These classifications are usually identified by indicator species occurring at the late-seral stage (Daubenmire and Daubenmire 1968, Hann and others 1997, Smith and Arno 1999).

Besides the conceptual endpoint vegetation, and depending on the intensity and severity of disturbances that may occur on a site, there can be many successional and developmental pathways along with many vegetative and structural mixes possible for a given site and species mix (Smith and Fisher 1997). For example, figure 2 shows the successional pathways for a Douglas-fir potential vegetation type (PVT) based on a fire's severity. Sites exhibiting this succession would be classified as a Douglas-fir potential vegetation type; however, it could be perpetually dominated by ponderosa pine (e.g., D2 – *fig. 2*). Of the PVTs on which ponderosa pine occurs this is one of the simpler in terms of potential species and disturbance interactions, yet a large number of vegetative compositions and structures are possible. This heterogeneity in composition and structure can be arranged in a variety of interspersed mosaics ranging in size from less than 0.1 ha (0.25 ac.) to 100s of hectares (Long and Smith 2000).

Albeit potential vegetation can be a superb classification with excellent interpretative relations, care must be exercised when using such systems. Two sites may have the same potential vegetation classification but their physical locations often reflect a different environment. Ponderosa pine growing on a Douglas-fir/nine bark (*Physocarpus malvaceus* (Greene) Kuntze) PVT in Montana, for example, usually occur on northerly aspects while sites similarly classified in Idaho regularly occur on south facing slopes (Cooper and others 1991, Pfister and others 1977). These differences are reflected in the classification systems used and the different environments expressed by similar species. Nevertheless, even with these differences, potential vegetation is very useful for classifying sites which provide interpretative value for ecological concepts such as successional pathways, fire relations, species mixes, wildlife relations, coarse woody debris relations, site productivity estimates, and vegetation simulations (Bradley and others 1992a, 1992b, Cooper and others 1991, Graham and others 1994, Graham and others 1999b, Pfister and others 1977, Smith and Fischer 1997, Wykoff and others 1982).

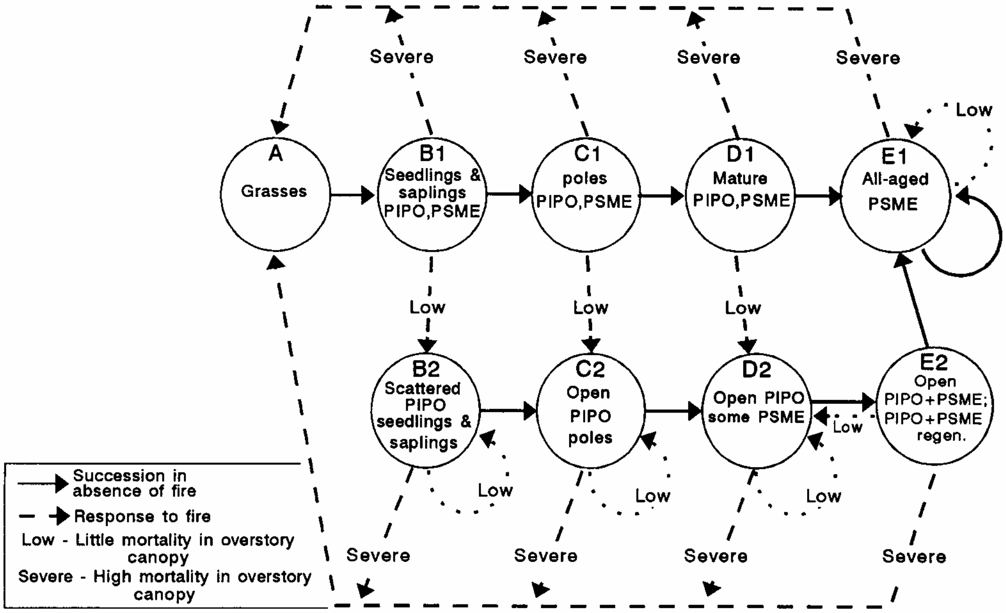


**Figure 2**—Possible successional pathways for a Douglas-fir potential vegetation type in response to fire as the only disturbance (Smith and Fisher 1997). Note the many different vegetative and structural combinations that can occur on one of the simpler potential vegetation types. PIPO=ponderosa pine, PSME=Douglas-fir.

## Vegetative Complexes

In the southern and extreme eastern portion of the range, ponderosa pine grows primarily on ponderosa pine PVTs. On these settings, quaking aspen is the most frequent early-seral tree species (Hoffman and Alexander 1987, Youngblood and Mauk 1985). Ground-level vegetation includes oaks (*Quercus* spp.), grasses (*Festuca* and *Agropyron* spp.), and low shrubs (e.g., snowberry (*Symphorcarpus* spp.) and spirea (*Spirea* spp.). Russet buffaloberry (*Shepherdia canadensis* (L.) Nutt.), a frequent shrub in these forests, stands out for its nitrogen fixing properties which is the process of making elemental nitrogen in the atmosphere available to plants (Jurgensen and others 1991).

With increasing moisture, ponderosa pine occurs as a mid-seral species and Douglas-fir becomes the late-seral species (*fig. 2*). Quaking aspen and lodgepole pine are early-seral associates of ponderosa pine on these Douglas-fir PVTs (Mauk and Henderson 1984). These ponderosa pine forests occur in the Rocky Mountains along the Front Range of Colorado, in Utah, and in southern Idaho. They also occur along the western slopes of the Sierra Nevadas in California and the eastern slopes of the Cascades in Oregon (Franklin and Fites-Kaufman 1996, Hann and others 1997, Steele and others 1983). Ground-level vegetation includes ninebark, elk sedge (*Carex geyeri* Boott), and pine grass (*Calamagrostis rubescens* Buckl.). These species, in particular, exemplify aggressive survivors after disturbance (e.g., fire, mechanical site preparation) and are strong competitors for light and nutrients which compete with ponderosa pine seedlings (Baumgartner and others 1986).

In several locales, dry grand fir and white fir PVTs represent the dry forests (Hann and others 1997). On such settings, ponderosa pine and Douglas-fir occur but are succeeded by late-seral grand fir and/or white fir in the absence of disturbance (Bradley and others 1992b). Additional trees that can occur in such forests include juniper (*Juniperus* spp.), pinyon pine (*Pinus edulis* Engelm.), sugar pine (*Pinus lambertiana* Dougl.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin), western larch, Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), and lodgepole pine. Pine grass and ninebark are frequent associates but tall shrubs such as Rocky Mountain maple (*Acer glabrum* Torr.) often occur.

The wettest forests where ponderosa pine occurs are the wet grand fir and/or white fir PVTs and the driest western redcedar PVTs. Such forests occur in the interior northwestern United States and in southern British Columbia (Cooper and others 1991, Daubenmire and Daubenmire 1968, Hann and others 1997). The western redcedar PVT is by far the most productive type on which ponderosa pine occurs, and lush and complex vegetation mixes may develop. Western white pine is a frequent associate of ponderosa pine with an occasional paper birch (*Betula papyrifera* Marsh.). A rich understory of shrubs, grasses, and forbs occur in these forests. Early seral-species such as redstem ceanothus (*Ceanothus sanguineus* Pursh), snowbrush ceanothus (*Ceanothus velutinus* Dougl. ex Hook.) and Sitka alder (*Alnus viridis* (Vill.) Lam. & DC. ssp. *sinuata* (Regel A. & D. Löve) rapidly colonize sites after disturbance and are also active nitrogen fixers (Jurgensen and others 1991, Smith and Fischer 1997). Mid-seral shrubs include Rocky Mountain maple which readily survives disturbances and is joined by late-seral species such as huckleberry (*Vaccinium* spp.) and false huckleberry (*Menziesia ferruginea* Smith). The latter readily survives disturbances but is an aggressive colonizer. Probably one of the greatest competitors and survivors after disturbance of any ground-level species occurring with ponderosa pine is pine grass. This ground-level vegetation can play critical roles in forests such as providing wildlife habitat, stabilizing soil, and capturing nutrients after disturbance. Fireweed, (*Chamerion angustifolium* (L.) Holub), for example, rapidly regenerates after fire and captures and recycles nitrogen (Baumgartner and others 1986, Cooper and others 1991, Daubenmire and Daubenmire 1968, Reynolds and others 1992, Smith and Fischer 1997). Because of the range of species that can occur with ponderosa pine and their wide range of tolerance (e.g., shade, competition, fire) along with how they interact with disturbances a plethora of vegetative compositions and structures can occur within ponderosa pine forests arranged and interspersed in a variety of mosaics.

## Wildfire and Ponderosa Pine Forests

Before successful fire exclusion, temperature and precipitation patterns combined with natural and human ignitions allowed fires to burn the dry forests at relatively frequent (e.g., < 40 years) intervals (Agee 1993, Hann and others 1997). Cultural burning by Native Americans augmented and even dominated burning in several locations (Barrett and Arno 1982, Stewart 1951). In the northern Rocky Mountains of Idaho and western Montana, dry settings (ponderosa pine and/or Douglas fir PVTs) historically burned by non-lethal (low severity surface fires that did not kill or kill few overstory trees) wildfires at 15 to 23 year mean return intervals

(Smith and Fischer 1997). Mesic forests containing ponderosa pine (grand fir and/or Douglas-fir PVTs) were burned frequently by lethal fires (i.e. fires that kill the majority of the dominant and codominant canopy layers) or mixed fires (a combination of lethal and non-lethal fires), at mean return intervals extending to over 60 years (Smith and Fischer 1997). In the central and southern Rockies (ponderosa pine and/or Douglas-fir PVT's), although non-lethal fires dominated, mixed fires also occurred, especially along the Front Range of the Rocky Mountains in Colorado (Bradley and others 1992a, 1992b, Fulè and others 1997, Kaufmann and others 2001). On the driest settings, (ponderosa pine and/or woodlands), because of discontinuous surface fuels, fires tended to be few (Bradley and others 1992b). In contrast to other locales dominated by late-seral ponderosa pine, the forests of the Black Hills possibly experienced greater extents of lethal fires (Shepperd and Battaglia 2002, Shinnen and Baker 1997). Nevertheless, historical wildfires most likely burned through most ponderosa pine forests leaving in their wake a wide variety of species compositions and vegetative structures.

## Other Disturbances

In the western United States domestic livestock grazing and harvesting of ponderosa pine forests was occurring by the mid 1800s (Cooper 1960, Rasmussen 1941). Ponderosa pine was extensively harvested, altering both forest composition and structure (Barrett 1979, Pearson 1950,Van Hooser and Keegan 1988). In mesic forests, grand fir and/or white fir and Douglas-fir rapidly colonized these sites when ponderosa pine was harvested. Especially on the ponderosa pine PVT, grass cover tended to decrease ponderosa pine seedling establishment and survival (Brawn and Balda 1988). However, when heavy livestock grazing ceased in the early 1900s in the southwestern United States, dense stands of ponderosa pine seedlings became established. Because of fire exclusion, climate changes, and other factors these trees readily developed into dense stands (Covington and Moore 1994, Pearson 1950, Stein 1988).

The dense stands that developed increased the abundance of insect and disease epidemics, and when combined with fire exclusion, significantly altered the composition and structure of these forests (Harvey and others 2000). Historically western pine beetle (*Dendroctonus brevicomis* LeConte), pine engraver (*Ips* spp.), fir engraver (*Scolytus ventralis* LeConte), Douglas-fir tussock moth (*Orgyia psudotsugata* McDunnough) were insects associated with regularly burned areas (Hessburg and others 1994). In most years bark beetles occurred at endemic levels in ponderosa pine, Douglas-fir, and grand fir killing large and weakened trees that were struck by lightning, infected by root disease (*Armellaria* spp.), or too old to resist attack (Williams and others 1986, Wu and others 1996). Pine engraver and fir engraver beetles attacked young, densely stocked ponderosa pine or removed trees scorched by low-intensity surface fires and/or trees severely infected with disease. Sometimes disease and insect infestations increased during droughts when trees were stressed.

Since fire exclusion in some settings, these same insects have occurred at epidemic levels (Hedden and others 1981, Gardner and others 1997, Schmid and Mata 1992). Today (2005) ponderosa pine continues to be susceptible to the western pine beetle and mountain pine beetle often kills ponderosa pine on Douglas-fir and grand fir/white fir PVTs. The pine engraver beetle is more abundant and destructive today with some of the severest outbreaks occurring on low-elevation ponderosa pine

PVTs (Hessburg and others 1994). Pandora moth (*Coloradia pondora* Blake) defoliates ponderosa pine and scattered outbreaks have occurred in Arizona, California, Colorado, and Oregon during the 20th century. The larvae prefer loose soils created by weathered granites or pumice where they burrow and pupate (Speer and others 2001). In addition to ponderosa pine being damaged by insects, dense stands of Douglas-fir and grand fir or white fir that developed on many settings are very susceptible to both defoliators and root diseases.

Weather, another formidable disturbance, in the form of snow, ice, or wind often creates variable sized canopy openings ranging to 16 ha (40 ac.) (Boldt and Van Deusen 1974, Shepperd and Battaglia 2002). The crowns of seral species (ponderosa pine, western larch, and western white pine) tend to shed snow thereby minimizing crown breakage. However, as the snow sloughed from tree crowns it could damage trees occurring in the lower layers. Often these mid- and late-seral species (e.g., grand fir, Douglas-fir) would break, creating canopy gaps, decreasing stand densities, and altering species composition (Jain and Graham 2005). In addition to being susceptible to weather damage when occurring in the lower canopy layers these same species when in the overstory are susceptible to the accumulation of snow and ice, which in turn often results in limb and bole damage, which in turn can increase the risk of bark beetle infestations (Jain and Graham 2005).

When combining forest succession, potential vegetation, disturbance, weather, and physical setting, it becomes obvious that ponderosa pine forests can be very complex. Depending on the combination of these components, multiple tree species can occur within stands and across landscapes, as can multiple shrub and forb species (*fig. 2*). This vegetation varies in arrangement, amounts, and juxtapositions that are continually changing, in response to the occurrence, extent, and severity of both natural and human caused disturbances.

## Ponderosa Pine Stand Structure

Historically, the development and maintenance of ponderosa pine forests was favored by non-lethal fires ignited by both humans and lightning. The continued fire presence in the drier potential vegetation types (PVTs), limited the regeneration and existence of fire intolerant species. These fires burned heterogeneously and isolated areas existed where ponderosa pine regenerated (i.e., old rotten logs) (Covington and Moore 1994, Everett and others 2000). As a result ponderosa pine (more than any other) trees were often clumped into small groups (*fig. 3*). For example, on the Boise Basin Experimental Forest located in southern Idaho, five to 15 tree clumps per hectare (2 to 6 per ac.) of mature ponderosa pine trees were observed with clumps ranging in size from 0.0004 to 0.02 ha (0.001 to 0.05 ac.) (*fig. 4*) (Graham and Jain 2005). The density of trees within these clumps ranged from 21.6 $m^2$ $ha^{-1}$ to 430 $m^2$ $ha^{-1}$ (94 to 1871 $ft^2$ per ac.) of basal area (*fig. 5*). However, on a stand basis, the basal area averaged 16 $m^2$ $ha^{-1}$ (70 $ft^2$ per acre) of basal area with 5.7 $m^2$ $ha^{-1}$ (25 $ft^2$ per ac.) occurring within clumps of trees and 10.3 $m^2$ $ha^{-1}$ (45 $ft^2$ per ac.) attributed to trees outside of the clumps (*fig. 6*). Pearson (1950) observed a similar clumpy nature on the Fort Valley Experimental Forest in Arizona and Youngblood and others (2004)

**Figure 3—**Mature ponderosa pine growing in clumps on the Pringle Falls Experimental Forest in central Oregon.

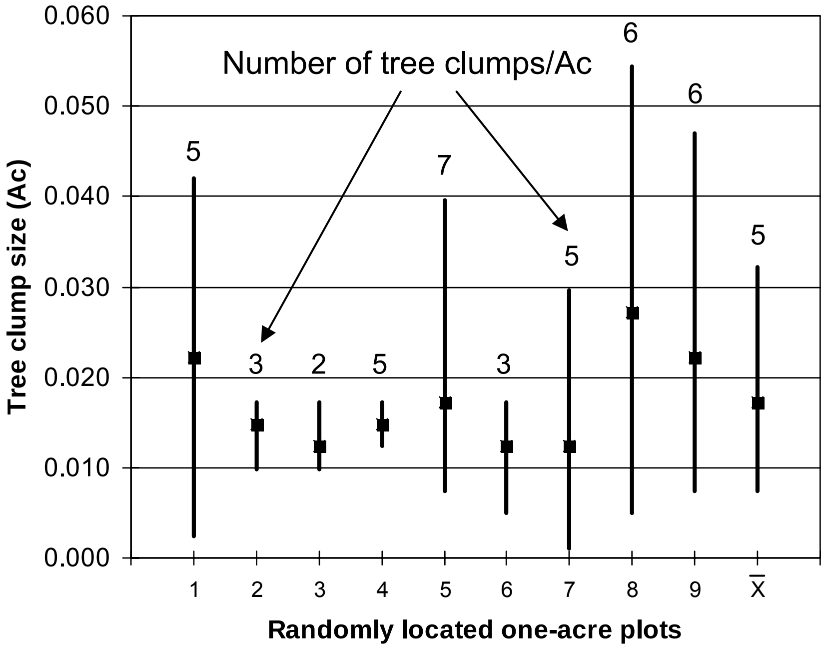


**Figure 4**—The maximum, mean, and minimum size of ponderosa pine tree clumps and their respective means occurring in a mature stand of ponderosa pine growing on the Boise Basin Experimental Forest in southern Idaho and the number of clumps occurring per acre. These values are displayed for nine randomly located plots as are the means ( $\bar{X}$ ) of the nine plots (Graham and Jain 2005).

observed similar distributions in California and Oregon (also see White 1985). Trees within clumps tend to have fewer limbs and be smaller in diameter while trees on the clump perimeters tend to be larger and lean away from the clump center (*fig. 3*). Even though it appears that space between clumps is not occupied, the root systems of trees within the clump most often occupy this space (Pearson 1950) (*fig. 7*).

Not only do ponderosa pine forests exhibit variation in the standing tree structure, but they also exhibit considerable variation in the amount of coarse woody debris (CWD) that is associated with soil productivity. For example, on ponderosa pine PVTs of Arizona, CWD associated with soil productivity range from 11 to 29 Mg ha$^{-1}$ (5 to 13 tons ac$^{-1}$). In contrast on Douglas-fir PVTs in Montana, CWD associated with soil productivity ranged from 10 to 55 Mg ha$^{-1}$ (5 to 25 tons ac$^{-1}$) (Graham and others 1994) (*fig. 8*). In general, ponderosa pine forests in which fires were frequent tended to maintain and use less CWD than those with less frequent fires. This open, clumpy forest structure along with the presence of some CWD benefits many wildlife species and are relatively resistant to stand replacing fire events (Graham and others 2004, Long and Smith 2000, Reynolds and others 1992) (*figs. 4, 5, 6, 7, 8*).

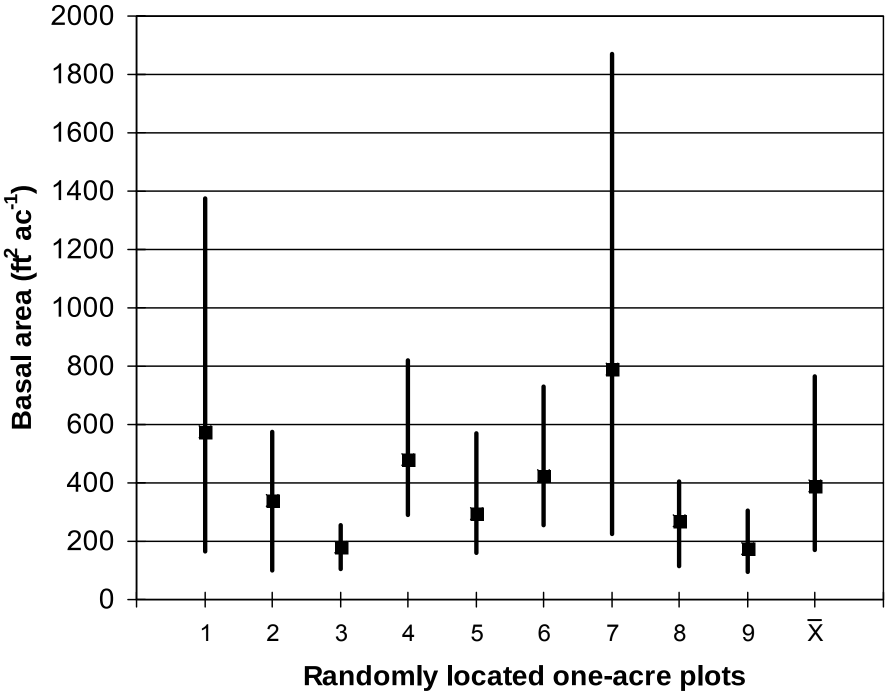


**Figure 5**—The maximum, mean, and minimum basal area of mature ponderosa pine trees occurring in clumps defined by trees with overlapping crowns growing on the Boise Basin Experimental Forest in Southern Idaho. These values are displayed for nine randomly located plots as are the means ( $\bar{X}$ ) of the nine plots (Graham and Jain 2005).

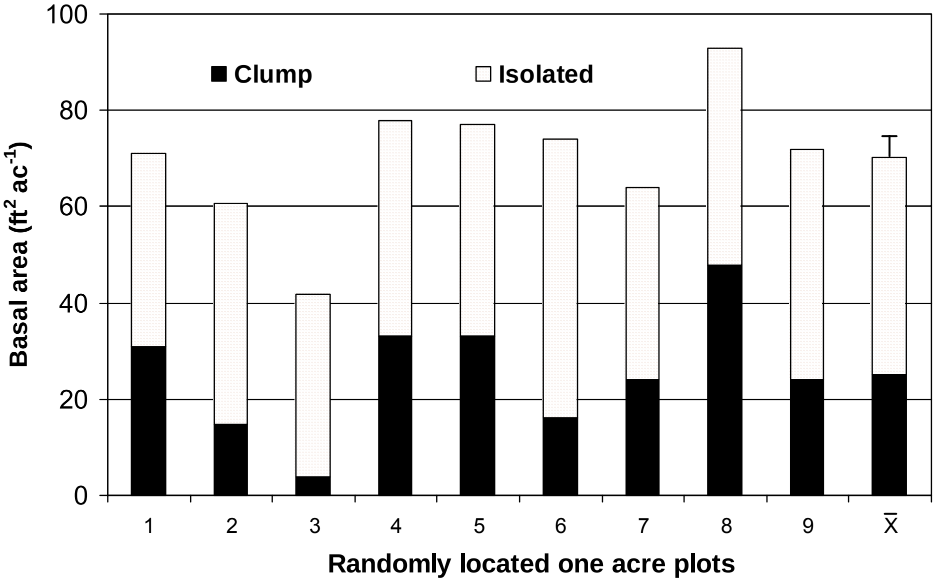
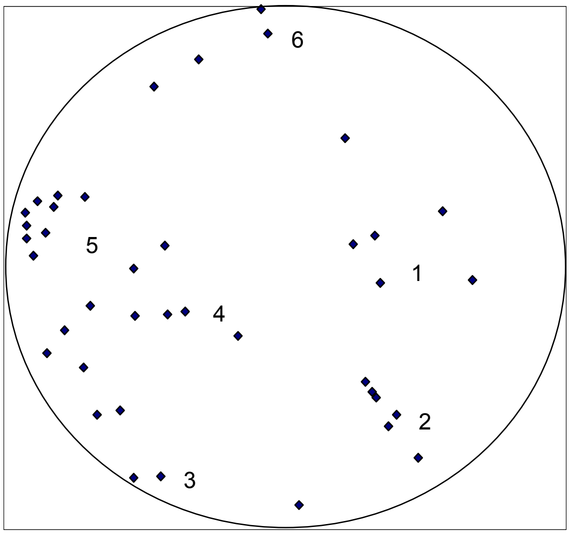


**Figure 6—**The basal area of mature ponderosa pine occurring within clumps (Clump) defined by trees with overlapping crowns and among trees not associated with clumps (Isolated) growing on the Boise Basin Experimental Forest in southern Idaho. These values are displayed for nine randomly located plots as are the means ( $\overline{X}$ ) of the nine plots. The bar represents the standard error of the mean for the total mean basal area (Graham and Jain 2005).

## Ponderosa Pine Forests as Fuel For Wildfires

Another way to characterize forest structure and composition is to describe how different forest components interact and influence fire intensity and severity. For example, forest structure can be divided into fuel bed strata where each level differentially influences combustion, fire propagation and spread, and fire effects (*fig. 9*). Canopy fuels (tree crowns), ladder fuels (midstory trees) and shrub layers contribute to crown fires. Low vegetation (low shrubs and grasses), down woody material (tree branches, boles), and ground fuel (needles, leaves, rotten wood, and litter on the forest floor) contribute to surface fires. Forests composed of mature ponderosa trees are susceptible to the accumulation of large amounts of organic material at the base of trees from both needle fall and bark slough (*fig. 3*). Also, woody material covering the forest floor, which is less than 7.6 cm (3.0 in.) in diameter, is the greatest contributor to the spread of surface fires while large wood (> 7.6 cm, 3.0 in.) and ground fuels tend to favor smoldering fires (Graham and others 2004, Peterson and others 2005). When burning, the intensity (flame length) of these fires determines the potential for the tree canopy to be ignited and most often determines if crown fires would likely be sustained (Graham and others 2004, Peterson and others 2005).



The size of the tree clumps and the basal area within the clumps

| Clump | Size (Ac) | Basal Area ($Ft^2\ Ac^{-1}$) |
|---|---|---|
| 1 | 0.030 | 406 |
| 2 | 0.032 | 315 |
| 3 | 0.010 | 261 |
| 4 | 0.004 | 366 |
| 5 | 0.034 | 116 |
| 6 | 0.054 | 152 |

**Figure 7—**A map showing an example of the spatial distribution of mature ponderosa pine growing on the Boise Basin Experimental Forest in southern Idaho (■ = trees in clumps defined by trees with overlapping crowns, ♦ = isolated trees). The circle represents a randomly located one-acre plot (Graham and Jain 2005).

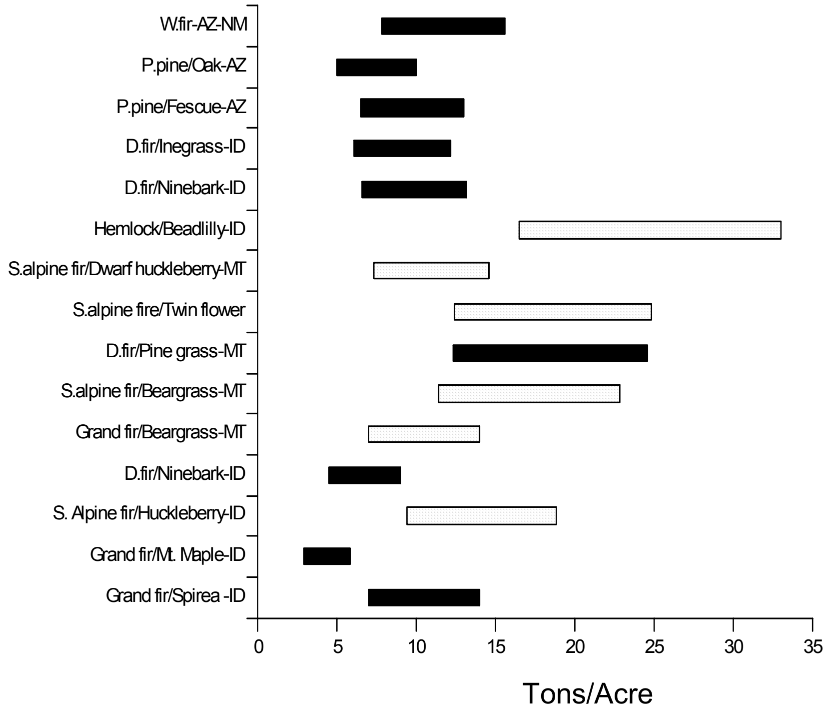


**Figure 8—**The amount of coarse woody debris recommended by Graham and others (1994) for maintaining soil productivity after disturbance for selected potential vegetation types of the Rocky Mountains. The solid bars represent types in which ponderosa pine is well represented. NM=New Mexico, AZ=Arizona, ID=Idaho, and MT=Montana).

## Changes in Ponderosa Pine Forests

With the advent of fire exclusion, animal grazing, timber harvest, and climate cycles on the moist potential vegetation types (e.g. grand/white fir), ponderosa pine is being succeeded by Douglas-fir, grand fir and/or white fir (*figs. 10, 11*) (Graham and others 2004, Gruell and others 1982, Smith and Arno 1999). The accumulation of fire intolerant vegetation, dense forest canopies, with homogenous and continuous horizontal and vertical structures are developing thus creating forests favoring crown fires rather than low intensity surface fires that historically occurred (*fig. 9*) (Arno and Brown 1991, Dodge 1972, Peterson and others 2005, Van Wagner 1977). Within the Inland Northwest, the extent of mid-seral (e.g., Douglas-fir) vegetation has increased by nearly 3.2 million ha (8 million acre) and the extent of single storied mature vegetation (e.g., ponderosa pine) has decreased by over 1.6 million ha (4 million ac.) (Hann and others 1997). Another way to view these changes is that the successional processes in some locations have been compressed by a factor of at least 10. For example, ponderosa pine may or may not be succeeded by Douglas-fir in 300 to 400 years within forests historically burned by frequent fires but in many locations Douglas-fir has succeeded ponderosa pine in less than 50 years (*fig. 2*) (Hann and others 1997, Harvey and others 1999, Smith and Arno 1999).

The structural and compositional changes occurring over the last 100 years in the dry forests are most noticeable within the tree and shrub component or the increase of canopy and ladder fuels (*figs. 9, 10, 11*). In addition; to noticeable changes in plant composition and structure, the soils (surface and mineral) in many settings have also changed considerably during the last century (*fig. 12*). The accumulation of organic materials on the soil surface and the frequent changes in their composition (e.g., ponderosa pine litter to true fir litter) can alter ectomycorrhizae habitat and water holding properties (Harvey and others 1999, Harvey and others 2000). For example, when the species within a forest shifts from being dominated by ponderosa pine to being dominated by Douglas-fir and/or true firs, the vertical distribution of ectomycorrhizal short roots is compressed dramatically (*figs. 10, 11*) (Harvey and others 1986). Ectomycorrhizal activities occur deeper in mineral soil of forests dominated by ponderosa pine compared to sites dominated by true firs; on these sites ectomycorrhizal activities occur in shallow organic horizons. In ponderosa pine dominated forests, ectomycorrhizal-mediated nutrient acquisition and turnover are relatively well protected from wildfire damage. However, when fires burn in forests with uncharacteristically deep organic layers on the surface they can have a detrimental impact on ectomycorrhizal activities and the post-fire acquisition and cycling of nutrients (Harvey and others 1999, Harvey and others 2000, Neary and others 1999) (*figs. 9, 10, 11, 12*). These changes in soil microbial activities may increase the likelihood of uncoupling any continuity between current and preceding vegetative communities (Amaranthus and Perry 1994).

Another soil-based change in pine compared to the fir forests is the type and distribution of substrates important for nutrient storage and cycling. There is a gradual shift in the proportion of soil nitrogen reserves and organic matter from mineral layers in pine forests to surface organic layers in fir forests (*figs.* 10, 11). Accumulation of both above-and below-ground biomass from roots, needles, and boles in fir forests accelerates activities of decomposers by increasing and changing the basic substrate they utilize. Because biological decomposition in ponderosa pine forests is more limited than biological production, accumulation of organic material is inevitable, especially in the absence of fire (*figs. 11B, 12*) (Harvey 1994). The result can be accumulations of materials that differ substantially from those occurring in historical pine forests (*fig. 11*). Associated with these changes in litter type and quantity is a likely change in soil surface chemistry, including the presence of allopathic substances with the potential to alter a variety of microbial activities (Rose and others 1983). Forests dominated by ponderosa pine develop brown cubical rotten wood products that are deposited on the forest floor and subsequently are incorporated into the mineral soil. These products can persist in soils for hundreds of years and during that time provide soil structural and nutritional benefits. In contrast, grand fir/white fir develop white rotten wood products that are dispersed in soil relatively rapidly (decades) shortening their contribution to soil productivity (Harvey and others 1987, Larsen and others 1979).

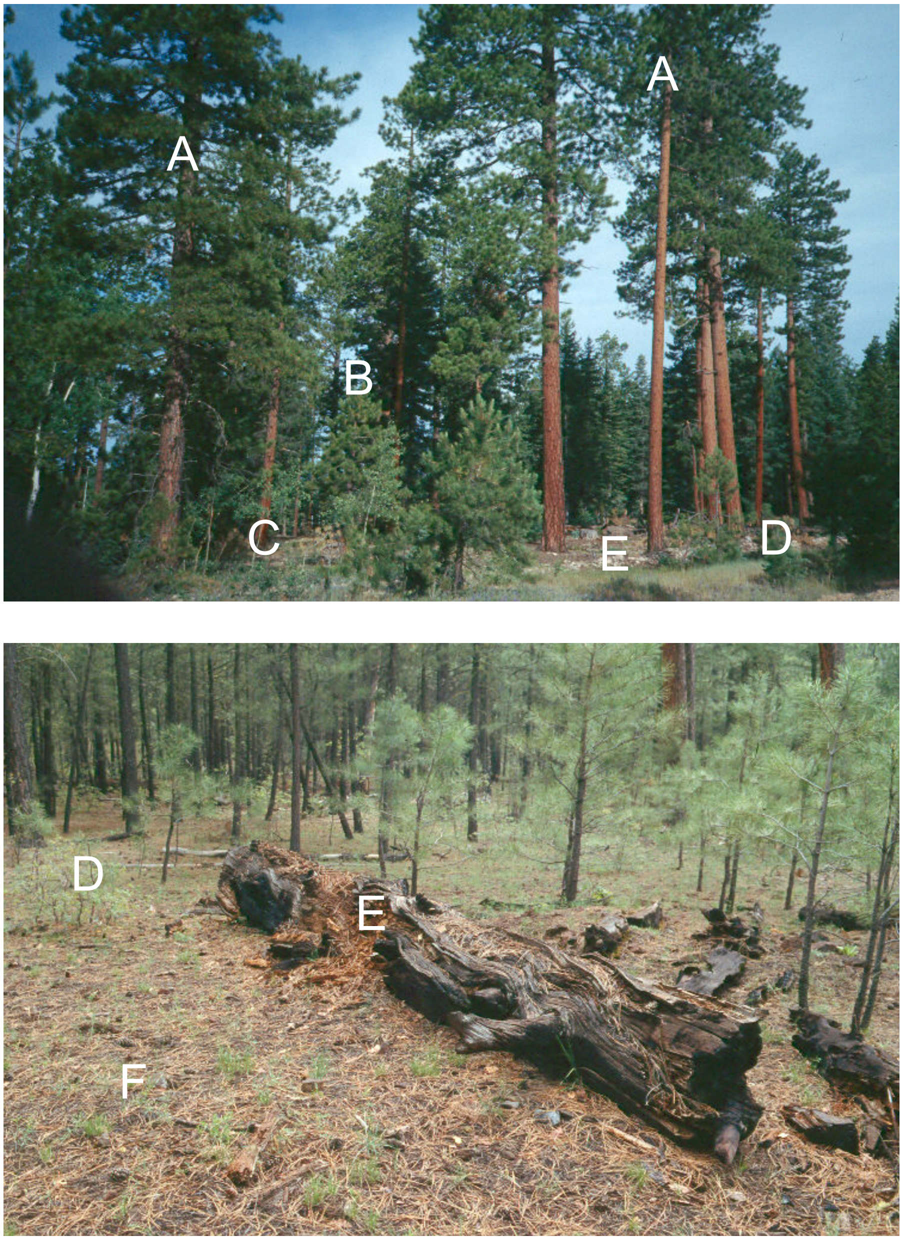


**Figure 9—**Fuelbed strata have different implications for combustion environment, fire propagation and spread, and fire effects. The canopy (A), ladder fuels (B) and shrub layers (C) contribute to crown fires. Low vegetation (D), woody fuel (E), and ground fuel (F) contribute to surface fires. Woody fuel (E) and ground fuels (F) are most often associated with smoldering fires and residual combustion that can transfer large amounts of heat deep into the soil (Sandburg and others 2001, Graham and others 2004).

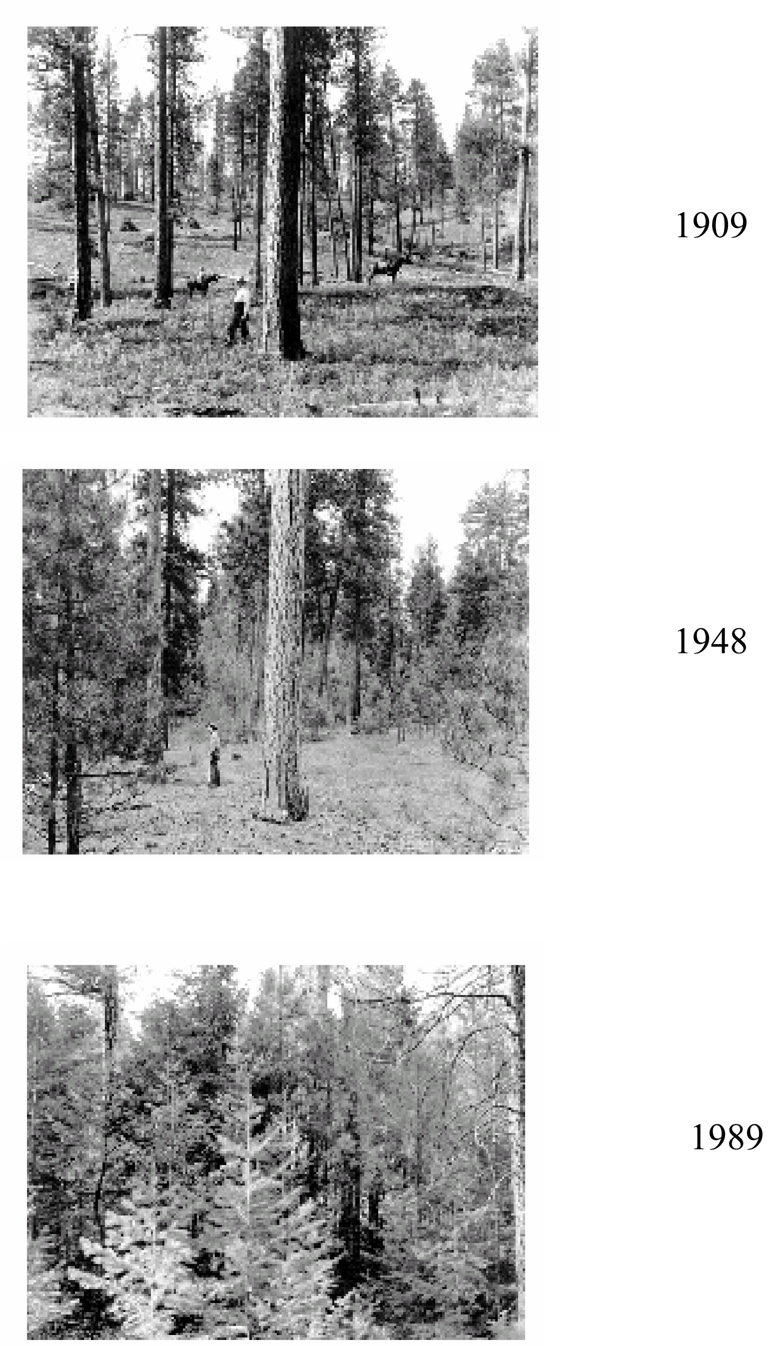


**Figure 10—**Forest development on the Bitterroot National Forest in Montana in a ponderosa pine stand after harvest (1909) in which fire was excluded since 1895. Note the changes in vertical arrangement and horizontal continuity in forest stand structure. In general many of today’s ponderosa pine forests contain higher densities of fire-intolerant species and suppressed trees than historical forests (Gruell and others 1982, Smith and Arno 1999, Graham and others 2004).

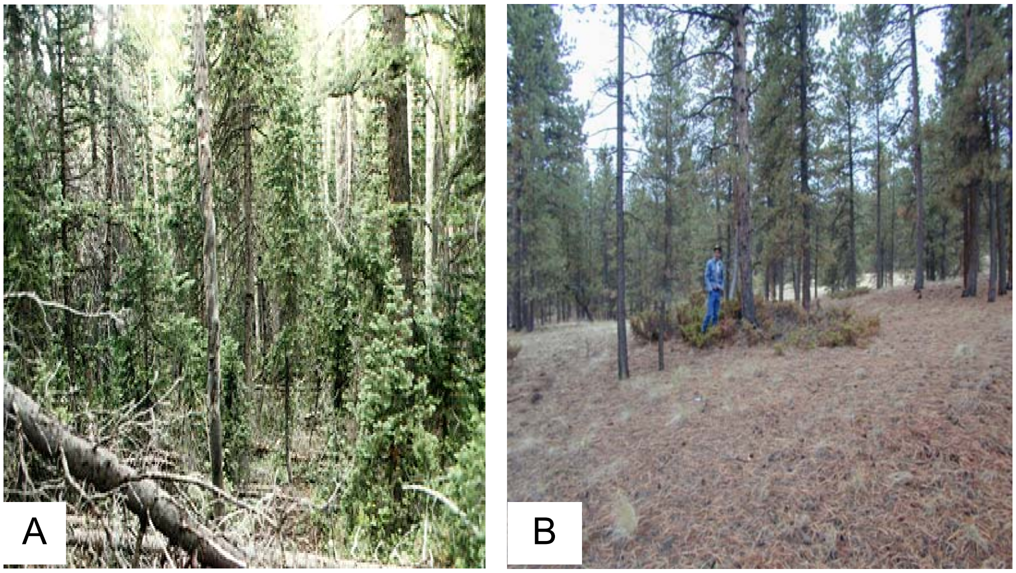


**Figure 11—**Photograph A shows the multiple canopy layers developed in a stand in Utah in which harvesting removed much of the ponderosa pine and fire has been excluded allowing abundant white fir trees to develop. Photograph B shows a ponderosa pine stand in which fire has been excluded, the development of multiple canopy layers, and a deep layer of needles and other organic material covering the forest floor (Graham 2003).

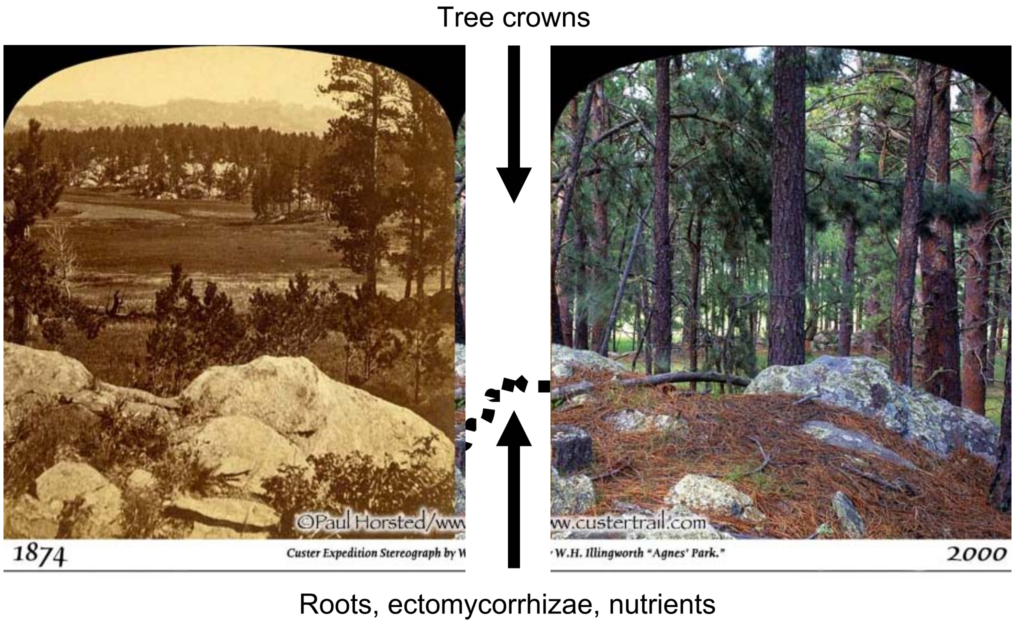


**Figure 12—**When fires are excluded from ponderosa pine forests organic layers tend to accumulate and tree roots, ectomycorrhizae, and nutrients also tend to concentrate in these layers. Note the contrast between the amount of organic material on the forest floor when General Custer came through the Back Hills in 1874 and the amount that has accumulated around the rocks in the photo in 2000. Photos courtesy of Paul Horsted/custertrail.com (Grafe and Horsted 2002).

Forests dominated by grand fir or white fir tend to concentrate both nitrogen and potassium in their foliage which often extends to the soil surface (*fig. 11*) (Mika and Moore 1990, Moore and others 1991). In general, the combination of a low canopy structure with nutrients and microbial activities concentrated in or near the soil surface make both of these critical ecological resources susceptible to both mechanical and fire destruction (*fig. 11*). Shifting from a few large stems of ponderosa pine to many Douglas-fir stems will maintain brown rotten wood in the system, but these conditions tend to sequester substantial nutrient resources in recalcitrant organic material which is slow to release, thus making these resources susceptible to loss from wildfire or timber harvest activities (Jurgensen and others 1997) (*fig. 10*).

In general, historical ponderosa pine forests were likely well matched to soil resources, relatively resistant to detrimental fire effects, well adapted to wide ranges of site and short-term climate variation, subject to modest (largely beneficial) insect and pathogen mortality, and could be considered long-lived and relatively stable (*fig. 10*). In contrast, forests that were dominated by ponderosa pine and are now dominated by Douglas-fir, grand fir or white fir are probably not well matched to soil resources and are also not likely resistant to the wide range of site and climate variation found within the dry forests (*figs. 10, 11*). In turn, they are often subject to high insect and pathogen mortality and can not be considered either long-lived or stable (Harvey and others 1999).

## Exotic Species

The introduction of non-native plant species can cause the decline of native species and pollinators, alter fire regimes, disturb nutrient cycling, and disrupt hydrologic processes (Chong and others 2003, Galley and Wilson 2001). Within the dry forests, some of the more notable invasive species include cheatgrass (*Bromus tectorum* L.), leafy spurge (*Euphorbia esula* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), and spotted knapweed (*Centaurea biebersteinii* DC.) (Hann and others 1997). Cheatgrass aggressively colonizes and invades exposed soil in the dry forests and tends to rapidly develop in the spring and then quickly dry. Annually, the continuous and dense covers of dead grass provide extremely flammable fuels that facilitate more frequent and severe wildfires than those that occurred historically. Because of its interaction with fire, cheatgrass has made some of the successional pathways in the dry forests of the western United States indeterminate (Bradley and others 1992b, Everett 1987, Graham and others 1999b). Cheatgrass is palatable during a portion of its annual development; subsequently it is not always considered a noxious weed. Therefore, even though mulch used in vegetation seeding programs (such as after wildfires) may be weed free, it may contain cheatgrass seed, thereby inadvertently spreading this exotic (Chong and others 2003, Robichaud and others 2003). Exotic plant species have readily spread throughout the Inland West. All 97 counties in the interior Columbia Basin contain cheatgrass and Canada thistle (even some of the most remote locations in central Idaho), 92 counties contain spotted knapweed, and 72 counties contain leafy spurge (Hann and others 1997).

## Wildfires in Current Ponderosa Pine Forests

Ponderosa pine forests appear to have evolved with fire and many authors have suggested that their composition and structure are dependent on the vegetation's relations with fire (Covington and Moore 1994, Everett and others 2000, Hann and others 1997, Harvey et al 1999). However, when wildfires burn altered ponderosa pine forests, the extent or area burned is similar to historical times but they tend to burn more severe (Graham 2003, Graham and others 2004, Hann and others 1997, Kaufmann and others 2001). They often kill large continuous expanses of vegetation, consume the forest floor, volatilize nutrients, provide for exotic species introductions, increase soil erosion, and, in general, create forest conditions that may not be favorable to society (*fig. 13*). The long-term consequences are not well understood for issues such as water quality and wildlife habitat. Nor will the sense of place that forests often provide which, in some cases, will not be replaced for many generations (Galliano and Loeffler 1999, Kent and others 2003, Schroeder 2002).

Some of the notable recent wildfires that burned the dry forests include at least 16 fires that burned in the Bitterroot Valley of western Montana in 2000, the Hayman Fire along the Front Range of the Rocky Mountains in Colorado in 2002, the Rodeo-Chediski Fire in Arizona in 2002, and the Biscuit Fire in Oregon in 2002 (USDA 2000, Graham 2003, Graham and others 2004). All of these wildfires exemplified large (≈40,000 to 200,000 ha) and severe events. The Rodeo-Chediski fire in Arizona severely burned over 6,000 ha (15,000 acre) in 15 minutes and moved on a broad front at over 6.4 kph (4 mph). The Hayman Fire severely burned over 19,000 ha (47,000 acre), much of it in one day (*fig. 14*) (Finney and others 2003, Robichaud 2003). Both of these fires burned in ponderosa pine forests that were accustomed to non-lethal or mixed fires. Also, what is striking about all of the fires occurring in the dry forests in recent years (2000-2004), is the large impact they had on real property by burning homes and businesses along with impacting municipal watersheds and the tourism industry (Graham and others 2004, Kent and others 2003, Robichaud and others 2003). The fires occurring in the dry forests and the hazard they pose to human values influenced the development of the Healthy Forests Initiative and the passing of the Healthy Forests Restoration Act (USDA 2004).

## Dry Forest Treatments

Dry forests, particularly those containing ponderosa pine, tend to occur at low elevations and along rivers and travel ways, resulting in some of the earliest silvicultural practices being developed and used in these forests (Meyer 1934, Pearson 1950). This long history of treatment application and the knowledge gained through these practices can be applied and adapted to meet present and evolving management objectives. Severe crown fires are often considered the primary threat to these forests (Graham and others 2004). Because of the many changes that have occurred in the dry forests, even low intensity surface fires can now damage soils, weaken or kill overstory trees, and provide an ignition source for homes and other property (Cohen and Stratton 2003, Hungerford and others 1991).

**Figure 13—**A photograph of the intense and severe Rodeo-Chediski Fire that burned in Arizona in 2002. This ponderosa pine forest was historically burned by low intensity surface fires but singly and in combination fire exclusion, timber harvest, climate change, and livestock stock grazing contributed to forest changes that facilitated this uncharacteristically severe fire.

The current understanding of fire behavior in dry forests indicates that a crown fire begins with a transition from a surface fire to the ignition of the canopy (*figs*. 9, 13, 14) (Finney and others 2003). Therefore, management activities can target specific fuel strata to disrupt the continuity of fuels from the soil surface to the crown and also target the horizontal arrangement of trees to disrupt the progression of fires especially from tree crown to tree crown (Graham and others 1999a, Scott and Reinhardt 2001) (*fig* 9). In the dry forest it appears the most effective strategy for reducing crown fire intensity and severity is (1) reduce surface fuels, (2) increase crown base heights, (3) reduce canopy bulk density, and (4) reduce continuity of the forest canopy (Graham and others 1999a, Cruz and others 2003, Scott and Reinhardt 2001, Van Wagner 1977). Generally, fuel treatments are beneficial for modifying both fire behavior and fire severity under normal weather conditions (Albini 1976). However, under extreme weather conditions (e.g., low humidity, high winds) fires can overwhelm most fuel treatments resulting in intense and severe fires (Finney and others 2003). Also, there is no guarantee that the combination of canopy and surface fuel treatments will reduce the risk of intense wildfires or immunize property losses when a fire does occur. Nevertheless there is the potential that treated areas will experience lower burn severity than untreated areas (Finney and others 2003, Graham and others 2004) (*fig. 14*).

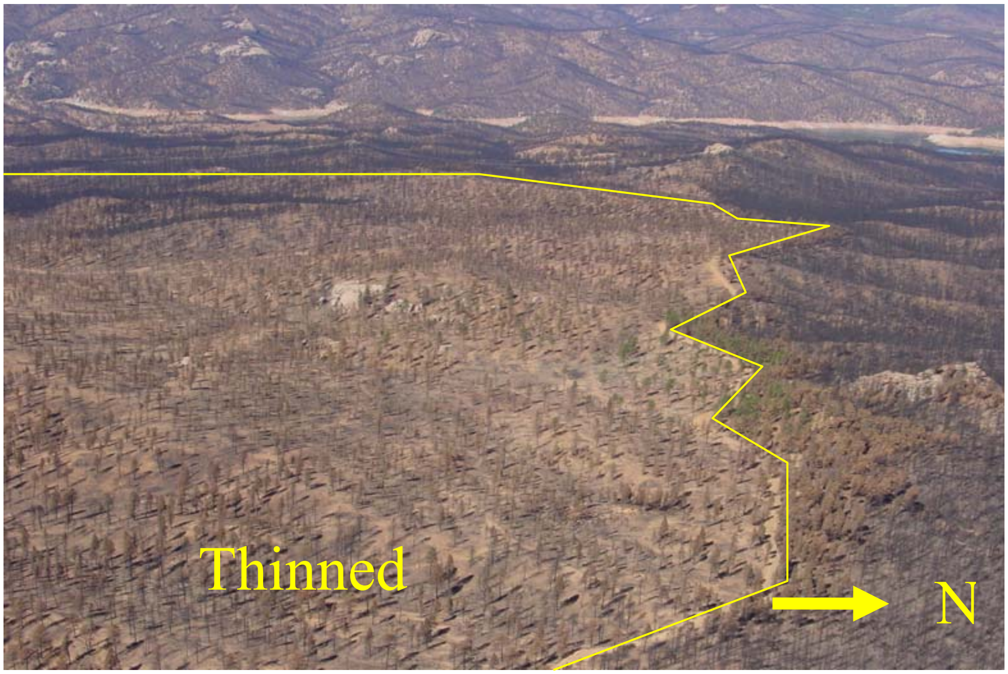


**Figure 14—**This photograph shows a ponderosa pine forest that was thinned in 2001 reducing the continuity and bulk density of the tree canopy. The surface fuels were in place when the Hayman Fire burned (moving from the left to the right in the photo) the area in on June 9, 2002. Even though the trees were killed the brown needles will mulch the forest floor when they fall reducing soil erosion compared to the areas in which all of the needles were consumed in the fire (Finney and others 2003, Pannkuk and Robichaud 2003).

Prescribed fire has long been used in the dry forests for cleaning the forest floor, increasing canopy base heights, and preparing seed beds for regeneration (Barrett 1979, Pearson 1950, Weaver 1943). Fire can alter multiple fuelbed characteristics by decreasing ground and surface fuels and decreasing ladder fuels (*fig. 9*) (Graham and others 2004, Peterson and others 2005). Mechanically thinning trees can also modify ladder fuels and decrease or alter the continuity of canopy fuels. Mechanical treatments offer more control in creating the desired forest structures than prescribed fire and they are less uncertain because of the inherent risk of prescribed fires escaping (Graham and others 1999a, Scott and Reinhardt 2001, Peterson and others 2005). However, if surface fuels created by mechanical treatments are not removed or treated they can exacerbate both the risk and hazard associated with fuel treatments (Brown and others 1977). This was exemplified on a portion of the Hayman Fire where the canopy bulk density and continuity had been greatly reduced within a treatment area, but because the surface fuels were not treated, the area burned intensely (*fig. 14*), yet the tree severity of the fire was less, as indicated by the presence of brown needles, compared to areas that were not thinned, where all needles were consumed leaving black branches. What is significant about this treatment is that when these brown ponderosa pine needles fall they will mulch the forest floor reducing soil erosion (interrill) by 60 percent compared to bare mineral soil. If they had been Douglas-fir needles, erosion would have been reduced by 80 percent (Pannkuk and Robichaud 2003).

Forests continue to regenerate, develop, and die, meaning that depending on how fast these processes occur, fuel treatments aimed at remediation of wildfire fire hazard need to be continued and/or maintained. For example, surface fuel treatments occurring within a year prior to the Hayman Fire in Colorado had a significant impact on the fire's progression. In contrast, areas with fuel treatments conducted seven years prior were intensely and severely burned (Finney and others 2003). As shown by the large fires that have occurred in the western United States during the last few years, most fuel treatments have local impacts on a fire's intensity and severity but for the most part made little impact on the overall outcome of the fire (Finney and others 2003). Strategically placed fuel treatments may have greater potential for altering the spread of large wildfires than randomly placed fuel treatments. Fuel treatments are most effective if they are encountered by a wildfire early in its development (Finney 2001, 2003, Finney and others 2003).

## Conclusions

Because of its wide distribution, ponderosa pine occurs in many diverse forests and it has been studied and managed for over a century (Barrett 1979, Meyer 1934, Pearson 1950, Shepperd and Battaglia 2002). Even though ponderosa pine forests are often considered simple in terms of species and structure they can be rather complex. The species grows on a variety of biophysical settings ranging from those where ponderosa pine is the late seral species and the only conifer species possible to those where western redcedar is the late seral species and over seven conifer species can occur (Cooper and others 1991). With the interaction of wind, snow, ice, diseases, insects, and fire, an abundance of successional pathways are possible (Bradley and others 1992a, Smith and Fischer 1997). The resulting species and structural mosaics can be rather intricate occurring within spatial scales as small as those defined by tree groups to large ones defined by landscapes. Similarly, temporal scales associated with the disturbance, regeneration, and development ponderosa pine forests can range from months to centuries (Hann and others 1997, Long and Smith 2000, Reynolds and others 1992).

Through the advent of fire exclusion, climate cycles, grazing, and harvesting ponderosa pine forests have changed (e.g., species composition, soil characteristics, horizontal and vertical structure) significantly during the last 100 years (Covington and Moore 1994, Hann and others 1997). Nevertheless, even with these changes there are tremendous opportunities for restoring these forests to their structure and composition reminiscent of historical conditions (Graham and Jain 2005, Jain and Graham 2005, Long and Smith 2000). Some key treatments such as reducing the quantity and continuity of surface fuels, increasing crown base heights, and decreasing crown continuity and density can lessen the risk of loss from extreme wildfire events (Graham 2003, Graham and others 2004, Peterson and others 2005 Scott and Reinhardt 2001). Both prescribed fire and mechanical techniques can be used to change the forest structure and encourage the regeneration and development of ponderosa pine, especially as an early seral species, within interspersed mosaics. If the structure were changed, such forests may be resistant and resilient to native insects and diseases, uncharacteristically severe wildfires, and be beneficial to many wildlife species (Graham and others 1999a, Graham and others 1999b, Graham and others 2004, Long and Smith 2000, Reynolds and others 1992).

Ponderosa pine forests extend throughout the western United States and Canada and they contain some of the most prized scenery and special paces in the West. The presence and existence of ponderosa pine reinforces these special qualities (Grafe and Horsted 2002, Gruell and others 1982, Smith and Arno 1999). Forests that contain large trees with yellow bark and emit that unique and pleasant odor on a warm summer day only attributable to ponderosa pine, provide the essence of being in or part of a forest. These attributes and the wildlife they support bring people solace and enjoyment when visiting or living in these settings. Because of these and other values to society, ponderosa pine forests often evoke strong feelings in people as to their management and conservation.

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