SEARCH FOR A SOLUTION

SUSTAINING THE LAND, PEOPLE, AND ECONOMY OF THE BLUE MOUNTAINS

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Chapter 7

FIRE IN THE BLUE MOUNTAINS: A HISTORY, ECOLOGY, AND RESEARCH AGENDA

by

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INTRODUCTION

Fire has been an important disturbance process for millennia in the wildlands of the Blue Mountains of northeastern Oregon and southeastern Washington. Records from early explorers and on many older trees suggest that fires burned at frequent intervals in many Blue Mountain forests and grasslands. One story is that the Blue Mountains were named for the persistent summer haze that accompanied frequent forest fires. However, Captain John Fremont in 1843 noted that "It is probable that they received their name of the *Blue mountains* from the dark blue appearance given to them by the pines" (from Evans 1991).

Fire has been described as both "benign" and "catastrophic" in the Blue Mountains and elsewhere. To make such judgments requires an understanding of how fire interacts with wildlands, and whether this interaction is desirable or not. Solutions to the forest health situation in the Blue Mountains will require both scientific and value decisions. This chapter focuses on the former: fire history and effects, with discussion of changes over the past century or more. Fire has been a variable in both space and time: low to high intensity, frequent to infrequent, and of small to large extent.

In prehistoric times, some forests may have burned every 5-10 years while others had fire return intervals more than an order of magnitude longer. The patterns of fire on the landscape have changed markedly over the past century. Suppressing all wildfires, selectively removing fire-tolerant tree species for wood, and grazing (both wild and domestic) have altered historical fire frequencies, intensities, and extent. These changes in fire regime have been more significant in some ecosystems of the Blue Mountains than in others and may be associated with changes in ecosystem health and forest sustainability.

The inclusion of fire in ecosystem management strategies will require incorporation of public perceptions about fire, and increased predictability of the effects of fire on the landscape and on other ecosystem components. A new research program is needed, and should be part of an integrated approach to ecosystem health and sustainability in the Blue Mountains; it cannot effectively function as an independent fire research program.

FIRE AS A NATURAL PROCESS

Although natural disturbances of many types have been present in wildland ecosystems for millennia, it is only recently that we have begun to quantify their importance in ecosystem structure and function. During most of the 20th century, our concept of ecosystem disturbance required that it must be a major, catastrophic event and that it must originate in the physical environment and is therefore an exogenous agent of ecosystem change. Over the past two decades we have recognized that disturbances span a wide gradient of intensity, and that many disturbances are at least partly a function of the state of the ecosystem (fuel buildup that affects fire intensity, or stressed trees that are more vulnerable to insect attack). Some disturbances, such as insect outbreaks, originate within the system, so disturbance can be an endogenous agent of ecosystem change.

Fire As A Disturbance Agent

Fire is a classic disturbance agent: relatively discrete in time, affecting ecosystem function and structure, and altering the physical environment (White and Pickett 1985). As mentioned earlier, it does so not as a uniform process but one that varies in space and time, over the same fire and between different fires. Gross generalizations about fire effects are risky, but predictions are possible if fire is described in a specific ecosystem and quantified by its characteristics: frequency, intensity, extent, seasonality, and synergism with other disturbances. Unfortunately, there are few ecosystems in which all of these parameters are well-characterized, including those of the Blue Mountains. We can apply data from similar ecosystems to the Blue Mountains if these data are carefully interpreted.

The characteristics of fire are important in understanding its direct and indirect effects. Fire frequency is the return interval of fire and is measured by counting years between fire scars on trees or analyzing age classes of forest stands on the landscape. Predictability is the variation in fire return interval. Together, frequency and predictability may determine which species may be able to exist on the landscape (figure 7.1).

The magnitude of a fire is most commonly described by its intensity. Fireline intensity is directly related to flame length. In this chapter, three general categories of fireline intensity (FLI) will be used. The surface fire is the lowest intensity category, with flame lengths to 1 m (FLI <400 kWm^{-1}). The understory fire is of intermediate intensity, with flame lengths between 1 and 3 m (FLI 400-1600 kWm^{-1}). It must be viewed from a distance, as heat and smoke can be excessive, and erratic fire behavior is possible. The crown fire is the highest intensity category, with flame lengths above 3 m (FLI > 1600 kWm^{-1}). Many

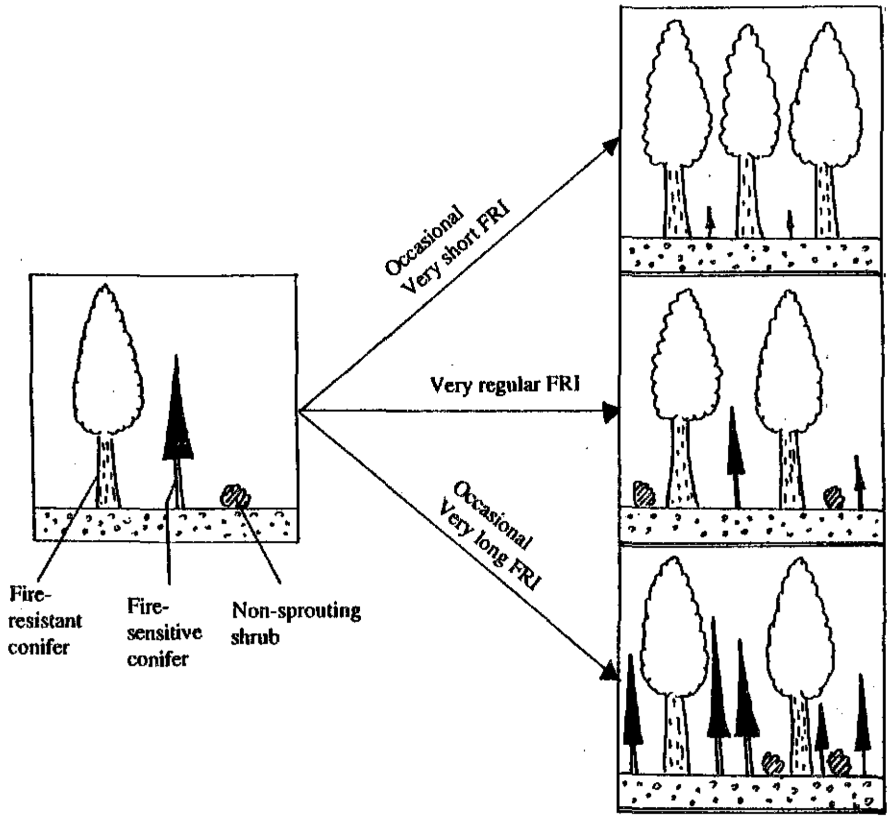

Figure 7.1 -- Variation in fire return intervals can result in different vegetation response, even when the mean fire return interval is the same. Short fire return intervals reduce non-sprouting species, while long intervals allow some species to pass through a fire-intolerant stage when young.

historical fires in the Blue Mountains were in the surface fire category, but historical fires spanned the entire range of intensities, including crown fires.

The extent of historical fires is poorly known. Cross-dated fire scars can be used to develop maps of fire extent in ecosystems with frequent, low-intensity fires. Even this technique is incomplete because such fires would not have scarred every tree within the fire perimeter. In ecosystems that historically burned with higher fire intensity, fire extent may be obvious for a century or more from the mosaic pattern of different-aged stands.

Most fires in the Blue Mountains must have burned during the summer months. Without fire suppression, fires may have burned sporadically from time of ignition until the autumn. Historical accounts can shed some light on the seasonality. In ecosystems with frequent fire-scarring, season can be deduced from the position of fire scars within the annual rings. If the scar occurred after the annual ring was completely formed, it was caused by a burn during mid-summer to autumn. However, fires in other seasons are possible. If the scar is in the lighter portion of the ring, called springwood because of the season it is produced, the fire likely occurred in middle to late spring. Surprisingly, even crown fires have been observed while spring snows totally covered the ground in the Cascades (Huff 1988).

Fire may interact with other disturbances in a synergistic manner to encourage them. Low-intensity, frequent burning may discourage massive insect outbreaks by controlling stand density, reducing breeding sites in the forest floor or coarse woody debris, and reducing competitive stress on residual trees. Conversely, it may encourage insect attack on trees damaged by fire. Intense fires, by creating open landscapes, may increase the effect of rain-on-snow events by allowing quicker snowmelt in the open. Stand replacement fires can increase shallow mass-movement erosion by reducing fine-root biomass that held marginally stable soil in place. Fires can inhibit some fungi through the effects of smoke (Parmeter and Uhrenholdt 1976), but can also encourage decay by opening wounds for entry of decay organisms. Synergistic effects introduce a fascinating but very complex aspect of fire as a disturbance factor.

The Fire Regime

A fire regime is a generalized way of integrating various fire characteristics. The organizing paradigm may be the characteristics of the disturbance (e.g., Heinselman 1973), the dominant or potential (climax) vegetation on the site (Davis et al. 1980), or fire severity, the magnitude of effects on dominant vegetation (Agee 1990). In this chapter, natural fire regimes will be defined at historical levels by the potential or climax vegetation (e.g., the *Abies grandis* series) and by fire severity within that classification (figures 7.2, 7.3). Changes to those fire regimes due to management activities will also be discussed.

The low-severity fire regime creates basal area reductions of 20% or less. Low-severity surface fires are most common, but moderate- and high-severity fires are possible. At the other end of the scale in the high-severity fire regime, basal area reductions of 70% or more are typical. A high proportion of fires are of understory to crown fire intensity. The middle of the scale is the moderate-severity fire regime, with a complex mixture of low-, moderate-, and high-severity fires. Historically, the Blue Mountains had all these natural fire regimes. Based on the distribution of forest types to be discussed later in this chapter, probably 80% of the Blue Mountain forest area burned in fires of low severity, with about 15% in the moderate-severity regime and 5% in the high-severity fire regime.

Fire Adaptations of Plants

Fire has interacted with individual plant species for millions of years, and plants have developed various adap-

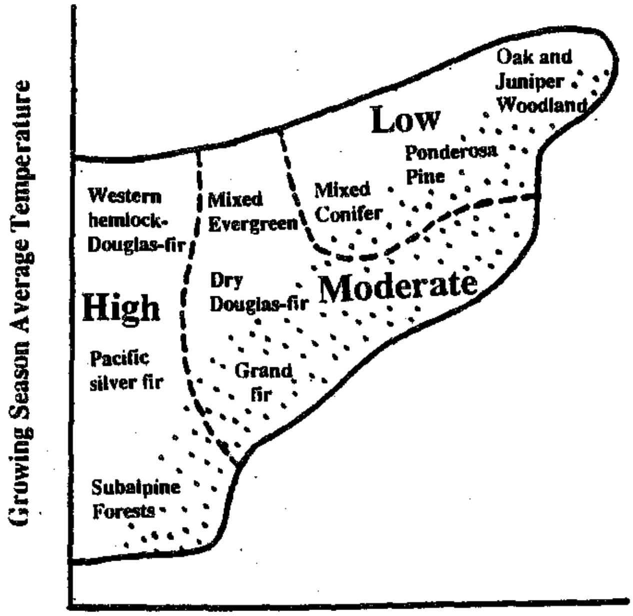

Figure 7.2 -- The fire-severity regimes of the Pacific Northwest (Low, Moderate, High) can be displayed within the matrix of Pacific Northwest forest types ordinated by growing season temperature and moisture stress. Ecosystems in the Blue Mountains are indicated by a stippled pattern.

tations to fire. Some allow the plant to persist as an individual in the presence of fire, while others allow the species to persist on the site even though individuals may be killed (Kauffman 1990). Many plants in the Blue Mountains possess such adaptations. Fire has predictable effects on individual plants. Various time-temperature sequences can be estimated from fireline intensity and have been used to predict crown scorch heights (Van Wagner 1973) and cambial damage (Peterson and Ryan 1986). Prediction of root damage is more difficult because of the variability in

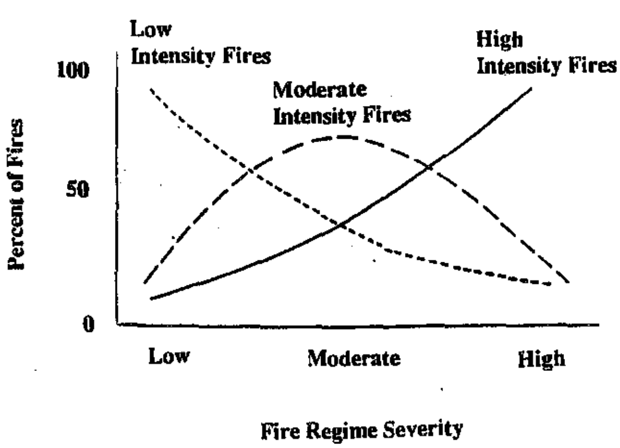

Figure 7.3 -- Each fire regime type has different proportions of dominant fire-severity levels. These can be interpreted from the mix of effects generated by a single fire, or from a series of fires in a forest type. The most complex mix of fire-severities is in the moderate-severity fire regime.

rooting patterns of plants and variation in soil properties.

Thick bark is a common adaptation found in trees, particularly in fire regimes where fires were frequent and of low intensity. In the Blue Mountains, Douglas-fir, ponderosa pine, and western larch are widely-distributed trees with thick bark. Mature trees are very well insulated against lethal temperatures for an hour or more because of the thick, corky bark, which is a better insulator than asbestos of equal thickness. This adaptation is most effective in low-intensity fires, which do not scorch the crown but may smolder around the base of the tree.

Epicormic sprouting (release of dormant buds from under the bark of fire-scorched stems and branches) occurs when fire is intense enough to kill the live foliage but does not persist long enough to create lethal temperatures under the bark. Mountain dogwood (*Cornus nuttallii*) and Oregon ash (*Fraxinus latifolia*) are local examples of such species. Basal sprouting occurs in many epicormic sprouting species, and also in other species, from root crowns or rhizomes [snowberry (*Symphoricarpos* spp.), ninebark (*Physocarpus malvaceus*), Scouler's willow (*Salix scouleriana*), huckleberries (*Vaccinium* spp.), and rabbitbrush (*Chrysothamnus* spp.), to name just a few]. Some species have buds that are well-protected by foliage from typical fires that occur in those habitats [Sandberg's bluegrass (*Poa sandbergii*) and bluebunch wheatgrass (*Agropyron spicatum*)].

Other species possess adaptations that facilitate survival of the species, even though individuals of that species are killed by fire (Kauffman 1990). Ceanothus (*Ceanothus* spp.) and lupines (*Lupinus* spp.) have dormant seeds which can lie in the soil for decades waiting to be scarified by fire. After fire, high densities of these plants may be found in locations where no live individuals existed at the time of the fire. A similar adaptation involving a seed-bank strategy is exhibited by the serotinous cone strategy of lodgepole pine (*Pinus contorta*). Seeds are protected beneath resin-sealed cone scales for decades and can remain viable while fire passes through and melts the resin seal. The tree may die, but the seeds are undamaged and fall to a newly fertilized ashbed. Some plants are stimulated to flower after burning, such as Great Basin wildrye (*Elymus cinereus*). Others have wind-blown seed that can rapidly invade burned sites, such as fireweed (*Epilobium angustifolium*). These adaptations ensure that some vegetative response is likely after fire passes through an ecosystem.

The Fire Environment

The Blue Mountains are a classic fire environment: a set of environmental conditions conducive to the recurring presence of fire. The behavior of fire can be predicted based on fuels, weather, and topography. Ignition from Native Americans and lightning over the past few millennia, together with factors influencing fire spread and behavior, have shaped the landscape by causing substantial areas to burn each summer. A brief summary of important fire behavior components is presented here by plant series to assist in more local interpretation of the information on fire effects.

Ignition is essential for a fire to occur. The importance of Native American burning will be discussed later in individual vegetation types. A source of fire with a much longer evolutionary influence is lightning. The Blue Mountains are one of the "hotspots" of the Pacific Northwest for lightning storms (figure 7.4). Locally, a gradient appears to exist from south to north, with more activity in the southern Blues. The patterns shown by early analyses (Morris 1934) are reinforced by more recent, sophisticated analyses of lightning activity (figure 7.5). Based on these data, we should expect variation in fire activity even within the same plant association, depending on where in the Blue Mountains that habitat type is located. Southerly locations should have shorter fire return intervals than more northerly locations. August is the month with the highest potential for lightning ignitions (USDA Forest Service 1981).

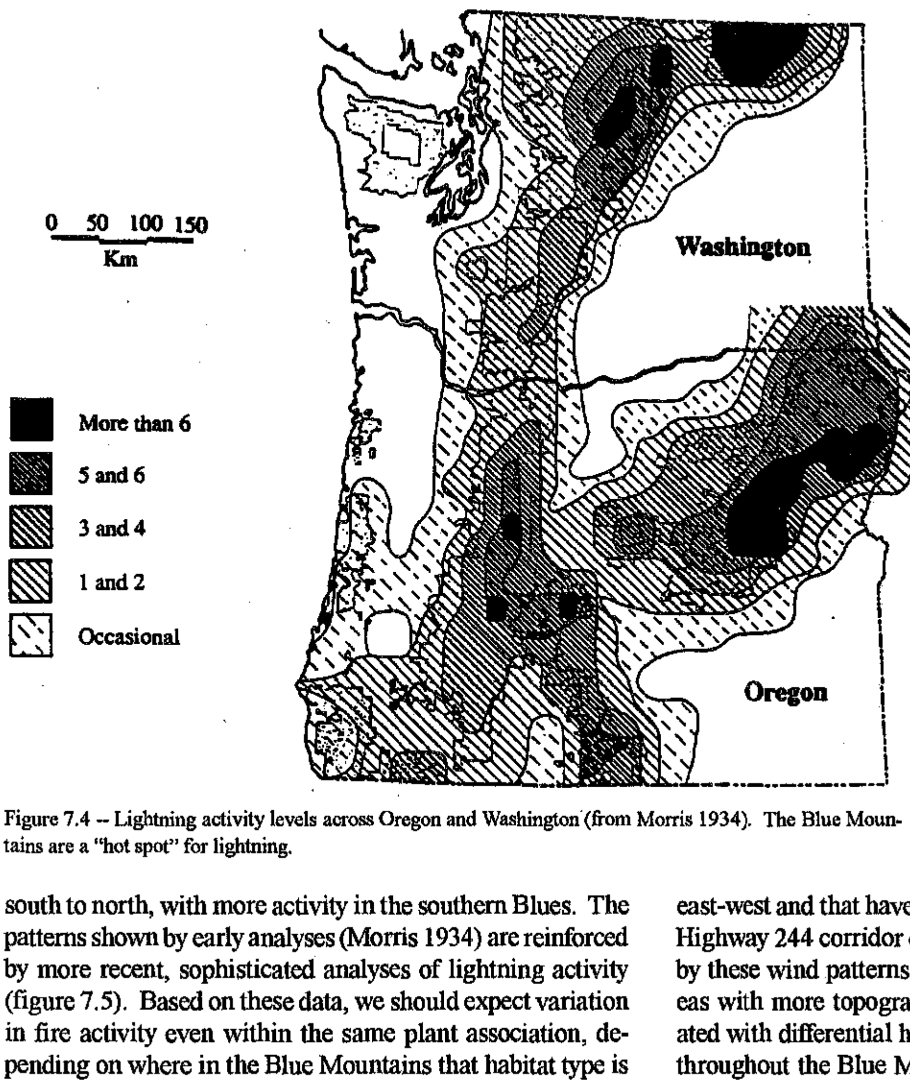

Figure 7.4 -- Lightning activity levels across Oregon and Washington (from Morris 1934). The Blue Mountains are a "hot spot" for lightning.

Once a fire occurs, its behavior is a function of fuels, weather, and topography. Throughout much of the lower elevation grassland, woodland, and forest, grasses and forbs are important fine fuels that allow fires to spread. Livestock grazing has had a significant effect on the availability of these fuels since European settlement began (>1850), although native ungulates probably had similar effects in localized areas or in unusual years. At middle to high elevation, dead conifer needles on the forest floor remain important vectors for fire spread. At high elevation, fire spread is augmented by live shrub and tree foliage, but this fuel becomes available only in late season or during drought. The plant series is a useful way to describe fuel profiles, but the location and extent of a plant series may require local interpretation of this information (in addition to lightning patterns described above). For example, the historical effects of fire in a small patch of *Abies grandis* forest surrounded by cooler, wetter *Abies lasiocarpa* forest will be quite different than if the small patch were surrounded by drier, warmer *Pinus ponderosa* forest.

Weather is important, not just for thunderstorm generation, but also for patterns of precipitation and wind that are important for fire behavior. Protected from Pacific storms by the Coast and Cascade mountain ranges, the Blue Mountains receive about half the precipitation of the mountain ranges to the West. The northern Blues have a slightly more maritime influence because of their proximity to the Columbia River. Most of the annual precipitation, which ranges from 25 to 150 cm, is received between late fall and early spring, and summer precipitation is usually light.

A gradient wind pattern known as a foehn wind produces hot, dry east winds in the Blue Mountains. Such winds occur several times a month during the summer and fall. The wind has low relative humidity and can quickly dry the fine fuels that carry fire. Such winds can also be strong. Valleys that trend east-west and that have low saddles at their crest (such as the Highway 244 corridor east of Ukiah) are likely to be affected by these wind patterns more than north-south valleys or areas with more topographic definition. Local winds associated with differential heating of the landscape are important throughout the Blue Mountains: upvalley winds during the day, downvalley at night. Topographic influences interact with weather, but have direct effects on fire as well. Steep slopes are more prone to burn than flat ones, southerly aspects more than northerly, and ridgelines more than valley bottoms.

The effects of the components of fire behavior on fire activity are important in understanding fire effects. They are helpful in interpreting what we see on the Blue Mountains landscape today, how we interpret or apply data from other areas to this landscape, and how we might apply fire in the future to achieve socially desirable ecological effects.

Environmental Effects of Fire

While the focus of this chapter is on vegetation ef-

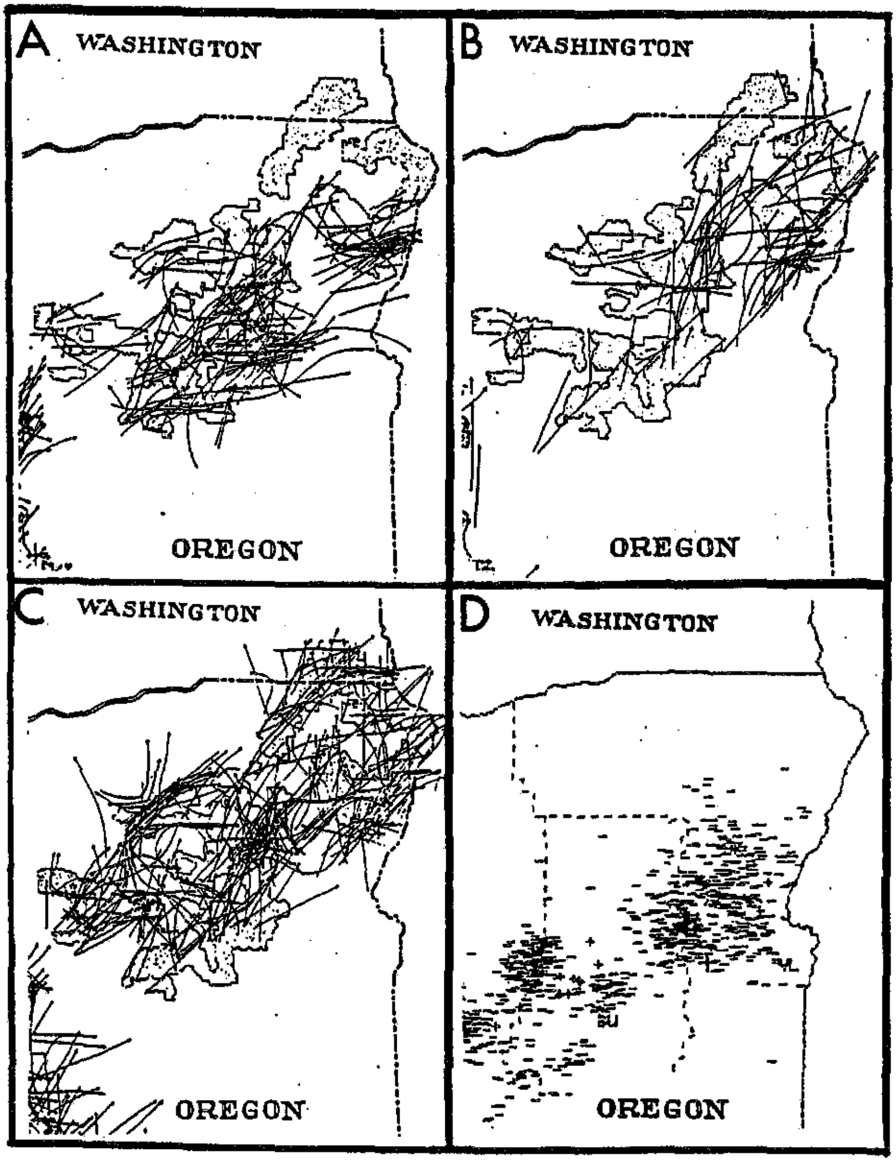

Figure 7.5 -- Lightning varies by year in the Blue Mountains, with more consistent patterns in the southern part of the range. Patterns of storms in (A) 1927, (B) 1929, (C) 1930, and (D) a May, 1992 storm showing individual strikes.

fects, fire has direct and indirect effects on most other components of the ecosystem. Wildlife effects are covered in other chapters, but fire effects on soil, water, and air resources are not covered elsewhere in much detail.

The Soil and Water Components -- Soil is a fundamental resource; most sustainable management objectives include maintenance of soil productivity as a key factor. Fire interactions with soil are significant because most fires spread by burning organic matter in contact with the soil. Fire creates physical, chemical, and biological changes that may either be desirable or detrimental in the context of long-term soil productivity.

Temperatures above the soil can exceed 700-800°C, but maximum soil temperatures are usually less than than 700°C, and usually do not exceed 200°C at 2.5 cm depth in the soil (Wells et al. 1979). Moist soil generally experiences less temperature rise than dry soil, given the same heat input. Fires burning over moist soil may not be able to increase soil temperature above the boiling point of water (100°C) until the water is vaporized (Agee 1973).

Although burning over moist soil in springtime is often recommended, it is not always desirable for plants to expose them to fire at a time of low root reserves, or to kill fine roots at the beginning of the dry season (Grier 1989, Swezy and Agee 1991). After burning, indirect effects of fire on soil temperature can be significant due to loss of some or all of the overstory, removal of forest floor, or blackened residual organic matter. Daytime soil temperatures may increase and nighttime temperatures decrease.

The physical properties of soils are usually less affected than soil chemical properties. Although soil texture can be affected by very hot pile burns, this effect is usually confined to the surface 2-3 cm of the soil. Soil wettability is a property that has received much attention in the last 25 years, primarily in chaparral ecosystems (DeBano et al. 1970). Coarse-textured soils and resinous vegetation, combined with intense fires, have been linked to water-repellent layers in the soil after burning. The cause is volatilization of waxes and resins from the burning vegetation and their diffusion into the soil where the hydrocarbons are deposited on cooler (<175°C) soil particles. The water-repellent effect is maximized when the soil is dry, so that intense fall rains may infiltrate the bared, burned soil slowly, resulting in runoff and erosion.

Water infiltration, or the process of water entry into the soil, is a function of many soil properties that may or may not be affected by burning. Light fires have often been associated with no effect, while intense burns have been associated with decreased infiltration (Burns 1952, Tackle 1962).

The chemical effects of fires depend on the amount of fuel consumed, the ability of "storage reservoirs" such as residual vegetation, the ability of the soil to adsorb nutrients, and the ability of the ecosystem to regenerate nutrients (such as nitrogen fixation). Fire volatilizes carbon, nitrogen, and sulfur from the organic matter it burns, and may volatilize phosphorus and potassium under some conditions (DeBell and Ralston 1970, Tiedemann 1987). Calcium, magnesium, and sodium are rarely volatilized and usually show increased availability after burning. The soil pH usually increases after burning.

Nitrogen-fixing plants may increase after a fire: lupines, ceanothus, and alders (*Alnus* spp.) are widely distributed nitrogen fixers. They form symbiotic relationships on their roots with bacteria capable of assimilating nitrogen from the atmosphere. Ceanothus has been documented to fix up to 1 t ha^{-1} over a decade (McNabb and Cromack 1983), as much nitrogen as is lost by a single intense forest fire.

We know little about soil biota effects after fire. Mycorrhizal fungi, which form symbiotic relationships with tree roots and increase their moisture- and nutrient-absorbing capability, may decline on some sites after intense burns, but the impact is not similar on all sites (Borchers and Perry 1990). Fire may reduce some plant diseases by burning out old root wads and stumps, sterilizing the soil in the vicinity. East of the Cascades, fire may have helped to control root diseases that now seem to be increasing in spread and intensity in overstocked stands protected from fire for many decades (Hessburg and Everett in press).

Much of the research on fire effects on soil and water has been done at a very small scale, but much of the geomorphic and hydrologic impact occurs at a much larger scale, that of the watershed or landscape. Changes in soil and water regimes are most significant where fire has a large impact on vegetation and soil. In historically low-severity fire regimes, fire impacts on soil and water were relatively benign, but where much of a basin is affected by fires of high severity, landscape effects on soil and water resources are possible.

Increased seasonal soil water due to less evapotranspiration can accelerate natural processes like soil creep. Snow avalanches can increase. Soil mass movements, streambank cutting, or channel aggradation, may all occur after large-scale intense fire events. These changes may be as much a function of storm events in the years following fire as a function of fire severity (Beschta 1990, McNabb and Swanson 1990).

Annual water yield can be significantly increased after fire due to less evapotranspiration. This effect is proportional to the amount of the watershed burned and to annual precipitation. After the 1933 Tillamook fire, water yield increased by about 10% for a decade (Anderson et al. 1976). Peak flows may increase, and summer flows generally show the highest percentage increase in flow.

Various erosion processes may be accelerated by high-severity fires. Generally, there is an immediate increase in sediment delivery, followed by an exponential decline to ambient levels over a decade or more in forested watersheds. The increase may be due to a variety of erosion processes set into motion by the removal of vegetation cover, increased water repellency, loss of forest floor, and reduced root strength. These include surface erosion from dry ravel, sheetwash and rill erosion, or wind; rapid mass movement processes; and a variety of sediment storage impacts in stream channels. In high-severity fire regimes, these significant impacts have always been a part of the natural landscape, infrequent though they may have been. In low-severity fire regimes where effective fire protection has caused the fire regime to shift to one of high severity, such significant soil and water impacts are rare in the presettlement record.

The Air Component -- Fire effects on air quality have become a critical limitation to the use of fire in wildland environments. By no means are these impacts new; fire and smoke were common in past centuries and over past millennia. Such natural sources of air pollution include volcanoes, emissions from live vegetation (the "smell" of the forest), and forest fires. But while totally "clean" air has not existed as long as physical and biological processes operate on the earth (Hall 1972), this does not mean that emissions are healthy, can be considered only background pollutants, or can be ignored in fire management planning.

The early travellers on the Oregon Trail provided many glimpses of local air quality in the Blue Mountains (Evans 1991). In 1834, Captain Benjamin Bonneville noted that "...smoke and fire were everywhere," and John Townsend, in the same year, complained, "These fires are kept smoldering, and the smoke from them effectually prevents our viewing the surrounding country, and completely obscures the beams of the sun." In 1844, James Clyman noted from southeast of present-day Baker City that the "...range of mountains to the west seem to be all enveloped in smoke," and to the north in the Grande Ronde valley he noted that "...the whole mountains which surround this valley completely enveloped in fire and smoke." In 1845, Joel Palmer described "...the fine view we had of the Cascade Mountains to the west. Mount Hood, the loftiest of these, was plain to the view." In 1852, Rev. Joseph Hanna had a "superb view of the Cascade Mountains," while in 1853 Rebecca Ketcham noted from the same area, "...we had a view of the Columbia Plains....The atmosphere was smoky and hazy; otherwise we would have had a magnificent view." These late summer vignettes suggest that smoke was common in the Blue Mountains but was not pervasive every year even in late summer.

Smoke is found in every fire environment. When a fire occurs, about 90% of fire emissions are carbon dioxide and water vapor. The portion of the carbon in smoke not converted to carbon dioxide is particulate matter, carbon monoxide, and volatile organic matter. Carbon dioxide is a major contributor to global warming scenarios, although it is not technically considered a pollutant (Sandberg and Dost 1990).

The other gaseous components of smoke are considered pollutants (Ferry et al. 1985). Carbon monoxide is the most abundant air pollutant, and its effect on human health depends on exposure, concentration, and level of physical activity during exposure. Firefighters at the edge of the combustion zone are most at risk, as dilution of carbon monoxide to acceptable levels usually occurs away from the edge of fires. Hydrocarbons, a vast family of chemicals containing hydrogen, carbon, and sometimes oxygen, may remain in the atmosphere as gases, condense into droplets, or be adsorbed onto particles (Sandberg and Dost 1990). Two of the most important classes of hydrocarbons are polynuclear aromatic hydrocarbons (PAHs) and aldehydes. PAHs are associated with cancer, but are emitted in such low quantities from wildland fires that human health risks are minimal. Aldehydes may be produced in sufficient quantity to result in eye irritation up to 3 km away from wildland fires for sensitive individuals (Sandberg and Dost 1990). In general, the production and effects of these compounds are fairly trivial compared to the production and effects of particulates.

Particulates are a major cause of reduced visibility, and serve as adsorption nuclei for harmful gases. In the 1970s, particulate regulation was based on total particulate mass per unit volume of air. Research indicated that the smaller size fractions were most harmful to human health, so standards evolved for particles less than 10 micrometers (called PM10), and more recently for particles less than 2.5 micrometers (called PM2.5). Forest fires produce a majority of particles in the 0.1-0.3 micrometer range, and proportion of PM2.5 in smoke may be 50-90% of the total particulate. Particulate production per unit of fuel consumed depends on the type of fuel and how it is burning; flaming combustion emits less particulate than smoldering combustion. Total tonnage consumed per unit area can be estimated from pre-fire fuel load and fuel moisture, so that particulate yield per ha burned can be predicted.

There are three primary control strategies to reduce smoke effects: avoidance, dilution, and emission-reduction (Ferry et al. 1985). Avoidance strategies depend on avoiding smoke intrusions into sensitive areas: burning when the wind is blowing away from the sensitive area, or burning at high mountainous locations above a layer of stable air below which the smoke will not penetrate. Dilution involves mixing the smoke into larger volumes of air to keep concentrations low: burning more slowly, burning into thicker stable layers or moderately unstable air, and burning in the morning so afternoon winds will blow away the smoke.

The most effective strategy employed recently is emission reduction. The strategy of emission reduction is simply to burn less fuel. Sometimes this is done by carefully weighing the costs and benefits of a burn and deciding the burn is not necessary. Usually, burns can be completed while achieving both site and off-site (air) objectives. Burning under wetter conditions is one way to reduce emissions. For naturally-ignited fires, control over moisture is not always possible, so that the decision criteria include either a "go" (allow the fire to burn) or "no-go" (suppress it) condition on a daily basis. For prescribed fires, air quality concerns can be and usually are a major prescription variable. Computer software is now available to help predict biomass consumption and emissions from individual burns as well as landscape-level emissions inventories or annual increments (Peterson and Ottmar 1991).

Natural Fire Regimes of the Blue Mountains

The natural or historical fire regime is described by those combinations of fire severities that occurred before significant European influence, generally before 1850 A.D. It can be argued that the influence of horses imported by Europeans onto the continent in the 1700s might require an earlier date, but little evidence exists in the Blue Mountains that significant European influence was exerted until after 1850. Native American influences on fire ignition and spread are incorporated into all the fire history information we have, and therefore those influences are considered for this discussion part of the natural fire regime.

Long-term climatic changes have caused individual plant species to migrate over the landscape, and natural fire regimes have also changed over time. Most paleoecological work has been conducted in areas north and east of the Blue Mountains (Barnosky et al. 1989). The Okanogan Highlands in eastern Washington have vegetation that today closely resembles that of the Blue Mountains, although the Highlands were nearer the terminus of the continental ice sheet at the end of the last glaciation. At that time, the pollen record suggests widespread sagebrush-grass vegetation with isolated pockets of forest species, including haploxylon pine ("soft" or white pines such as whitebark [*Pinus albicaulis*] or western white pine [*Pinus monticola*]) and spruce (*Picea* spp.) and fir. Present-day relict species, such as the small riparian population of Alaska yellow-cedar (*Chamaecyparis nootkatensis*) at the Cedar Grove Botanical Area on the Malheur National Forest, were probably more widely distributed in the Blue Mountains. Earlier hypotheses that the Columbia Basin was a lodgepole pine parkland (Hansen 1947) are now dismissed because of the low percentages of diploxylon pine ("hard" pines such as lodgepole or ponderosa pine) pollen at most late-glacial sites.

Almost all sites show evidence of increased summer drought beginning between 11 and 9 millennia before present (B.P.). The warmer, drier period commenced and ended at different times across the region. At Carp Lake, a lowland site 150 km west of the Blue Mountains, ponderosa pine was able to replace steppe vegetation 8,500 years ago, and it persists to the present (Barnosky 1985). Similar inferences may be extended to the *Pinus ponderosa* series in the Blue Mountains. In more southerly areas of the Columbia Plateau, western juniper range has expanded and contracted over the past 5,000 years (Mehringer and Wigand 1987), suggesting a rough balance in climatic shifts over that time. In subalpine areas, one of the closest analog sites is Lost Trail Bog Pass in the Bitterroot Mountains, Montana, which changed from sage-grass vegetation before 12,000 B.P. to lodgepole pine/Douglas-fir by 7000 B.P. (Mehringer et al. 1977). During this warming, many boreal species disappeared from the landscape, or were able to move upslope to form isolated patches, such as Alaska yellow-cedar in the Blue Mountains and the Siskiyou Mountains (Whittaker 1961).

Individual species have coevolved with fire longer than with any particular species mix on the landscape. Today's plant communities and their fire regimes represent the environment and species mix of the last few millennia at most. A corollary to this is that if global climate changes, today's fire regimes cannot be projected centuries into the future.

Vegetation and Fire Regimes

Today's Blue Mountains include a wide array of ecosystems, from xeric sage-steppe to alpine meadows (figure 7.6). Fire history and effects will be described for each of the major vegetation groupings shown, although several will be described together because of the general similarity in species responses. The plant association concept will be the model by which fire history and effects will be organized. A single plant association may encompass several plant communities (known as seral communities) that may replace each other over time on the same landscape but will be named after the successional endpoint, or climax, community. The climax community is defined by a single overstory species and understory species that will eventually dominate the site in the absence of disturbance. Disturbance such as fire will generally result in seral community dominance, while protection from disturbance will allow the community to proceed towards climax status.

A plant series consists of all the plant associations dominated by a single climax overstory species. Two communities, for example, may be dominated by ponderosa pine in the presence of repeated low-intensity fire. If protected from fire, one might remain dominated by ponderosa pine, although the structure of the community may change; this community would be part of the *Pinus ponderosa* series. The other community might become dominated by Douglas-fir, and would be part of the *Pseudotsuga menziesii* series. The implications of presence or absence of disturbance on species composition, structure, and function are well-described by such a classification system.

The primary tree species across the Blue Mountains often occur in more than one of the major plant series (figure 7.7). Their adaptations to fire (table 7.1), in combination with characteristics of natural fires of the past, have resulted in the natural fire regimes of the Blue Mountains.

The major natural fire regimes will be discussed in related groups. The grassland and shrubland communities, and the *Juniperus occidentalis* series, will be grouped together. The *Pinus ponderosa* series will be discussed separately. The *Pseudotsuga menziesii* and *Abies grandis* series, and the subalpine *Abies lasiocarpa* and *Tsuga mertensiana* series, will be discussed as groups. In refer-

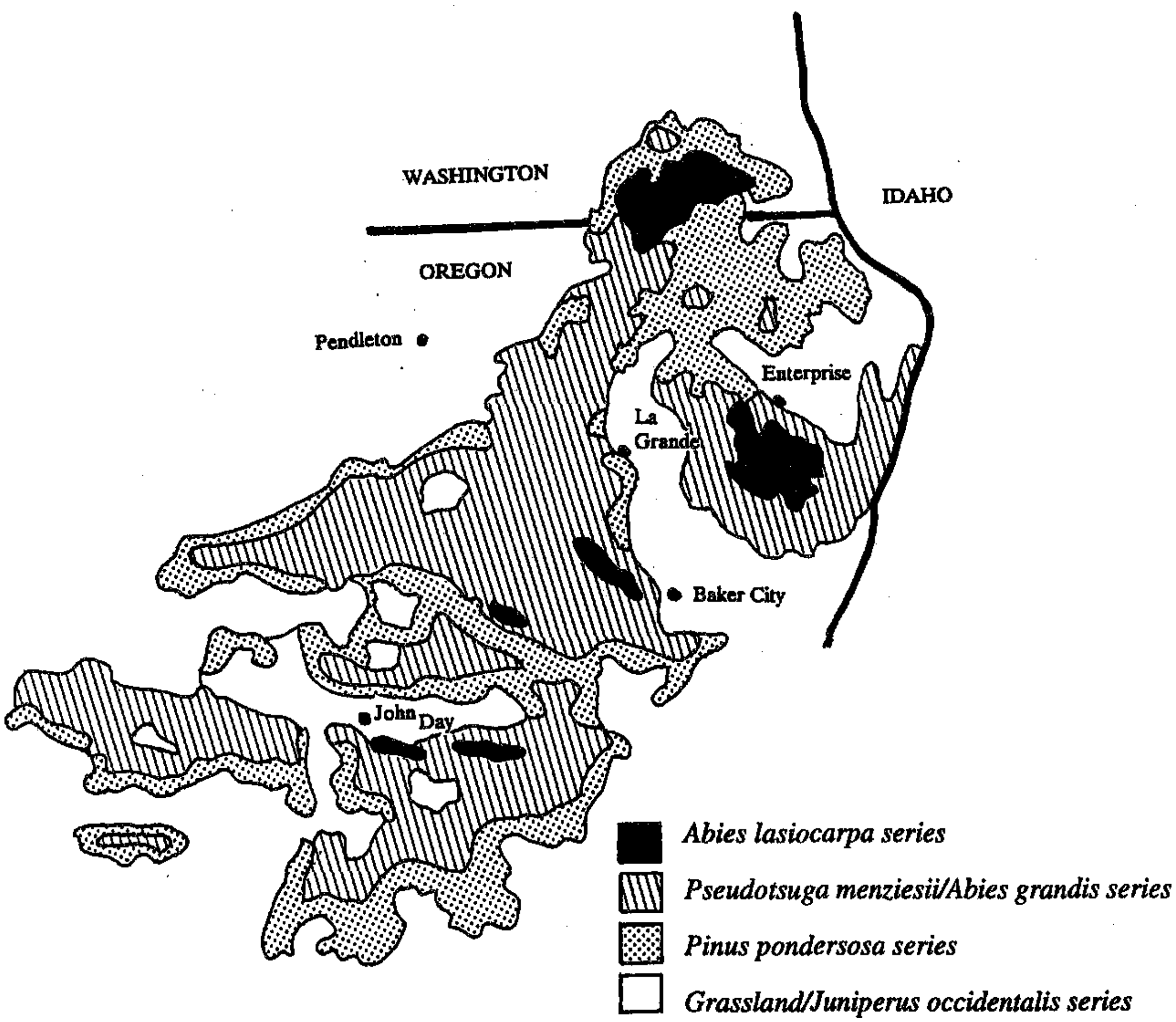

Figure 7.6 -- Major vegetation types of the Blue Mountains (adapted from Kuchler 1964).

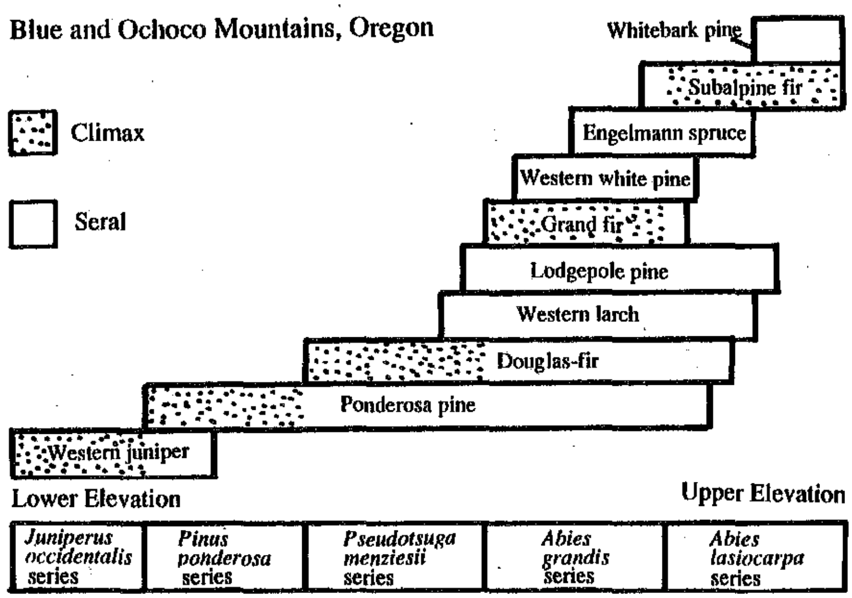

Figure 7.7 -- Environmental orientation of the major tree species of the Blue Mountains (from Johnson and Clausnitzer 1991). Individual species, such as ponderosa pine, are found over a broader range of plant series than the one in which it may be a climax dominant (climax portions of range shown as stipple pattern). Lower timberline is at left edge, upper timberline is at right edge of figure.

ence to a plant series, the latin name of the climax tree species will generally be used: e.g., the *Abies grandis* series. When discussing a particular species, the common name will be used, with the latin name used only in the first mention: e.g., grand fir (*Abies grandis*).

Fire History of the Blue Mountains

Almost all of the vegetated land of the Blue Mountains has burned repeatedly over the past millenium. Delineating that history is sometimes difficult, as most of the information must be gleaned from living vegetation. Grasses retain little evidence of fire, and shrubs may be useful in dating only the last fire by the age of germinated plants or sprouts from the root crown. More quantified estimates of fire return intervals are available for forested sites.

There are two types of fire interval estimation used in determination of forest fire history: point and area estimates. Point intervals are commonly used in fire regimes where fire-scarred trees are common. For example, the scar record of an individual tree is an estimate of a point frequency. However, not all fires will scar every tree, so the record of an individual tree is a conservative estimate of fire return interval. The fire scar records of several nearby trees may be combined (if crossdated to be synchronous) to produce a better estimate of point frequency called a composite fire interval, even though this combined record is over an area rather than a point. If too wide an area is selected, the composite fire interval loses its relevance as an estimate of point frequency. Where the fire regime is of moderate-to-high severity, various area frequency methods are used to determine fire history. These methods rely on reconstructing past fires by age classes of stands over the landscape (natural fire rotation, Heinselman 1973) or by using the present age-class distribution (negative exponential or Weibull distribution, Johnson and Van Wagner 1985).

Although few studies of forest fire history have been completed in the Blue Mountains, a substantial number have been completed in other areas of the Pacific Northwest (figure 7.8, table 7.2). These studies are arranged by plant series, and the general location of each study is noted. An important qualifier of

Tree Species	Response to Fire*	
Western juniper	Avoider	- easily killed at young or mature stages
Ponderosa pine	Resister	- has thick bark and develops at an early age
Douglas-fir	Resister	- has thick bark when mature but susceptible to fire when young
Western larch	Resister	- has thick bark and develop at an early age
Grand fir	Avoider	- thin bark when young, but moderately resistant when mature
Lodgepole pine	Evader	- thin bark even when mature, but has serotinous cones
Quaking aspen	Endurer	- thin bark, easily top-killed, but sprouts readily after burning
Subalpine fir	Avoider	- thin bark, shallow-rooted, almost always killed by fire
Engelmann spruce	Avoider	- same as subalpine fir
Mountain hemlock	Avoider	- same as subalpine fir
Whitebark pine	Moderate Resister	- thin bark but usually grows in fuel-limited environments with patchy fire

* Avoider - plant with little adaptation to fire, generally favored by lack of disturbance
Resister - plant will survive low-intensity fire relatively unscathed
Endurer - plant is top-killed but will resprout from the crown, base, or roots
Evader - plant is killed but reproduces from a protected seed bank

Table 7.1 -- Major tree species of the Blue Mountains and their response to fire (Rowe 1981).

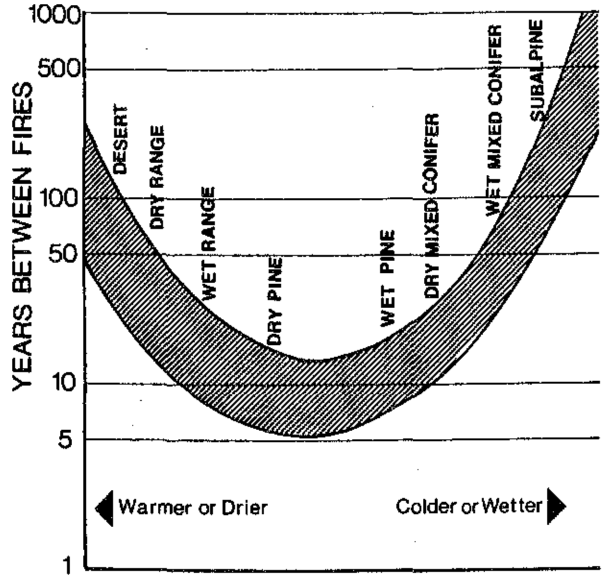

Figure 7.8 -- Studies of fire history in the Pacific Northwest, using a variety of methods, have resulted in a U-shaped curve of fire return intervals (Martin 1982). In dry desert environments, productivity apparently has limited fuel continuity, while in higher mountain areas, cool, wet conditions limit opportunities for fire spread.

the fire return interval is the analytical method chosen for fire frequency. Additional unpublished studies from the Blue Mountains will be discussed in the text.

Grasslands, Shrublands, and the *Juniperus occidentalis* series -- We have very little knowledge of historic fire frequency in the grasslands and shrublands of the Blue Mountains. The scabland plant series, such as the *Artemisia rigida/Poa sandbergii, Poa sandbergii/Danthonia unispicata, Eriogonum douglasii/Poa sandbergii*, and *Eriogonum strictum/Poa sandbergii* plant associations have such low biomass productivity (125-335 kg/ha, Johnson and Simon 1987) that they will not carry fire, and probably rarely burned. The *Festuca viridula* (1000-1100 kg/ha), *Festuca idahoensis* (400-1350 kg/ha), and *Agropyron spicatum* (425-950 kg/ha) plant series (Johnson and Simon 1987) have enough fuel to burn annually but probably did not because of low flammability early in the season, and lack of fire starts across grasslands late in the season. Native Americans must have been an important ignition source, as they were observed in the 1830s firing the prairies of the Blue Mountains (Shinn 1980). In 1834, Captain Bonneville noted, "it was the season of setting fire to the prairie." In 1843, Fremont noted near Grande Ronde that, "The old grass had been lately burned off from the surrounding hills, and, wherever the fire had passed, there was a recent growth of strong, green, and vigorous grass" (from Evans 1991). In the 1840s, James Clyman described an apparent Native American fire burning across 6-8 miles of grassland in the Grande Ronde country (Evans 1991). In 1852, Rev. Joseph Hanna noted the blackened and burnt appearance of the bunchgrass-covered hills surrounding the Burnt River and thought that was the origin of the river's name (Evans 1991). He described fires burning for miles and days and said "One of these burnings is in sight of us today. It is on the opposite side of the river from us, or I should feel alarmed." In 1852, several travellers noted burned grassland between the Burnt and Powder Rivers (Evans 1991). Fires must have also spread from adjacent forest, at least from those forest types where fires were frequent.

Little information is known about burning in shrub communities of the Blue Mountains. Occasional types such

Fire Return Interval (years)	Method 1	Location	Source
Juniperus occidentalis series			
15-20	CFI	Nevada	Young and Evans (1981)
7-17	P	N. California	Martin and Johnson (1979)
25	CFI (260)	SW Idaho	Burkhardt and Tisdale (1976)
Pinus ponderosa series			
16-38	CFI (16)	E. Oregon	Bork (1985)
7-20	CFI (16)	E. Oregon	Bork (1985)
11-16	P	E. Oregon	Weaver (1959)
3-36	P	E. Oregon	Soeriaatmadja (1966)
Pseudotsuga menziesii series			
7-11	CFI (20)	E. Washington	Wischnofske and Anderson (1983)
10	P	Blue Mtns.	Hall (1976)
10-24	P	E. Washington	Finch (1984)
14	CFI (40)	E. Washington	Finch (1984)
8-18	P	E. Washington	Agee (unpublished data)
Abies grandis series			
47	P	E. Oregon	Weaver (1959)
33-100	CFI (30)	E. Washington	Wischnofske and Anderson (1983)
17[2]	P	Montana	Arno (1976)
100-200[3]	-	Montana	Antos and Habeck (1981)
Abies lasiocarpa series			
25-75[2]	-	Montana	Barrett et al. (1991)
109-137	NFR	C. Washington	Agee et al. (1990)
140-340[3]	-	Montana	Barrett et al. (1991)
250	-	E. Washington	Fahnestock (1976)
50-300[4]	CFI	Montana	Arno (1980)
29[4]	CFI (100)	Montana	Morgan and Bunting (1990)

1 P = point or individual tree, CFI = composite fire interval, with size of area in parentheses, NFR = natural fire rotation
2 intermediate intensity fire return interval
3 stand replacement fire return interval
4 stands dominated by whitebark pine

Table 7.2 -- Fire return intervals for the major plant series found in the Blue Mountains. Most of the cited studies are from related vegetation types for other portions of the region.

as the *Eriogonum* spp./*Physaria oregana* are too fuel-limited to carry fire, but many of the rest burned periodically. Long fire return intervals are suggested by accounts cited in Vale (1975) in which early travellers in the Walla Walla area noted 15-cm thick sagebrush (Artemisia spp.) large enough to be used as fuelwood. As sagebrush is very fire sensitive, a long fire return interval is inferred from plants this large. Daubenmire (1970) claimed that no record of Native American burning existed for the sage-steppe region of eastern Washington, but Shinn's (1980) accounts suggest such ignitions were at least locally important. In 1844, James Clyman described what might be intrepreted as a sagebrush slope that had been recently burned, "entire country covered with sage which from some cause or other is nearly all dead" (from Evans 1991). Some shrubfields resulted from high-intensity fires on forested sites, and will be discussed as early seral communities on such sites.

Western juniper has expanded its range into grassland-shrubland communities over the past century. Most juniper older than 100 years are found on fuel-limited sites, such as rimrock, and much of the fire history data is from these rimrock sites. Historic fire return intervals in the *Juniperus occidentalis* series appear to range from a minimum of 7-25 years (table 7.2) to probably more than 100 years where older junipers with no fire evidence can be found. The intensity and extent of these fires depends in part on how much sage and juniper is present compared to grass. Grassy sites are more likely to burn completely over a wider range of conditions than sites with more shrub and tree cover (Clark et al. 1985). Most fires are severe enough to kill non-sprouting sagebrush and western juniper, as both species are sensitive to fire. The extent of historic fires is not well-known, but they had the potential to cover wide areas.

The *Pinus ponderosa* series -- This dry forest series is widely distributed in the Blue Mountains, although ponderosa pine is more common as a seral dominant in cooler, moister sites supporting the *Pseudotsuga menziesii* or *Abies grandis* plant series. The closest regional comparison for fire history in the *Pinus ponderosa* series is data west of the Blue Mountains (Bork 1985). Composite fire intervals (16-ha areas) ranged from 7 to 20 years at Pringle Butte and 16 to 38 years at Cabin Lake. Fire return intervals of <5 years on individual trees have been documented in the Southwest (Dieterich 1980), but such frequent burning has not yet been documented in the Blue Mountains. The intensity of these fires appears to have been low. Munger (1917) noted that fires in yellow-pine (ponderosa pine) woods of the eastern Cascades were relatively easy to check with a fireline a foot wide, because of the open nature of the woods. The extent of fires in ponderosa pine forests was probably wide because continuous fine fuel was available on the forest floor: fluffy pine needle litter and extensive grass. However, Bork (1985) was not able to show that fires were extensive. Most did not scar trees over areas larger than 16 ha, but this lack of scarring could be due to low fire intensities.

Early travelers to the Blue Mountains described these ecotonal forests as open and grassy. Medoram Crawford described the forest edge in 1842 near Elgin as he left the valley. "Came to trees, at first quite thin & withhout underbrush having fire scars" (from Evans 1991).

The *Pseudotsuga menziesii* and *Abies grandis* series -- The mixed conifer forests of the Douglas-fir and grand fir series show frequent fire activity (table 7.2), although cooler, wetter sites in the grand fir series have long fire return intervals. Frequency of fire in the drier plant associations of this series is likely due to their higher productivity compared to the *Pinus ponderosa* series, so that after a fire, fine fuels needed to carry a fire were more rapidly replaced. Hall (1976) used point samples to document a 10-year fire return interval in the *Pseudotsuga menziesii* series of the Blue Mountains. Fire intensities appear to have been low in the drier *Pseudotsuga menziesii* and *Abies grandis* plant associations where the associated dominant understory is *Carex geyeri, Calamagrostis rubescens*, or *Arctostaphylos uva-ursi*. The beauty of the mid-elevation forests of the Blue Mountains was described by early visitors (Evans 1991). One of the more beautiful descriptions was Rebecca Ketcham's. "...we looked back upon the country we had passed through. I can almost say I never saw anything more beautiful, the river [Grande Ronde] winding about through the ravines, the forests so different from anything I have seen before. The country all through is burnt over so often there is not the least underbrush, but the grass grows thick and beautiful."

Long fire return intervals and high fire intensities have been found in the eastern Cascades where the understory dominants are *Symphoricarpos albus, Physocarpus malvaceus*, and *Vaccinium* spp. (Williams et al. 1990); this pattern appears in the Blue Mountains in the cooler *Abies grandis* series. In the Elkhorn Mountains southwest of LaGrande, Joyce Bork (unpub. data on file at Wallowa-Whitman National Forest headquarters, Baker City, Oregon) found individual tree fire return intervals of 50-200 years (*Abies grandis/Vaccinium membranaceum*), and 66 and 100-200 years (*Abies grandis/Vaccinium scoparium*) on these cooler, wetter grand fir sites.

The *Abies lasiocarpa* and *Tsuga merten-siana* series -- The subalpine forests of the Blue Mountains are predominately of the *Abies lasiocarpa* series. The *Tsuga mertensiana* series occurs only in the northwest corner of the Eagle Cap Wilderness, and no fire history data were available for this series. Fire return intervals tend to lengthen to >100 years, and fire intensities tend to increase in subalpine forests compared to other forests of the Blue Mountains (table 7.2). Bork (unpub. rep., see paragraph above) noted a 40-50 year fire return interval in a location transitional from the *Abies grandis* to *Abies lasiocarpa* series. Fire intensities can be high in these forests and substantial mortality is the usual result. At the turn of the century, the U.S. Geological Survey completed a forest survey of the Blue Mountains and mapped stand replacement fires of the previous 4-5 decades. The only areas shown in the Blue Mountains with such intense fire activity were areas now designated as the Eagle Cap Wilderness, the

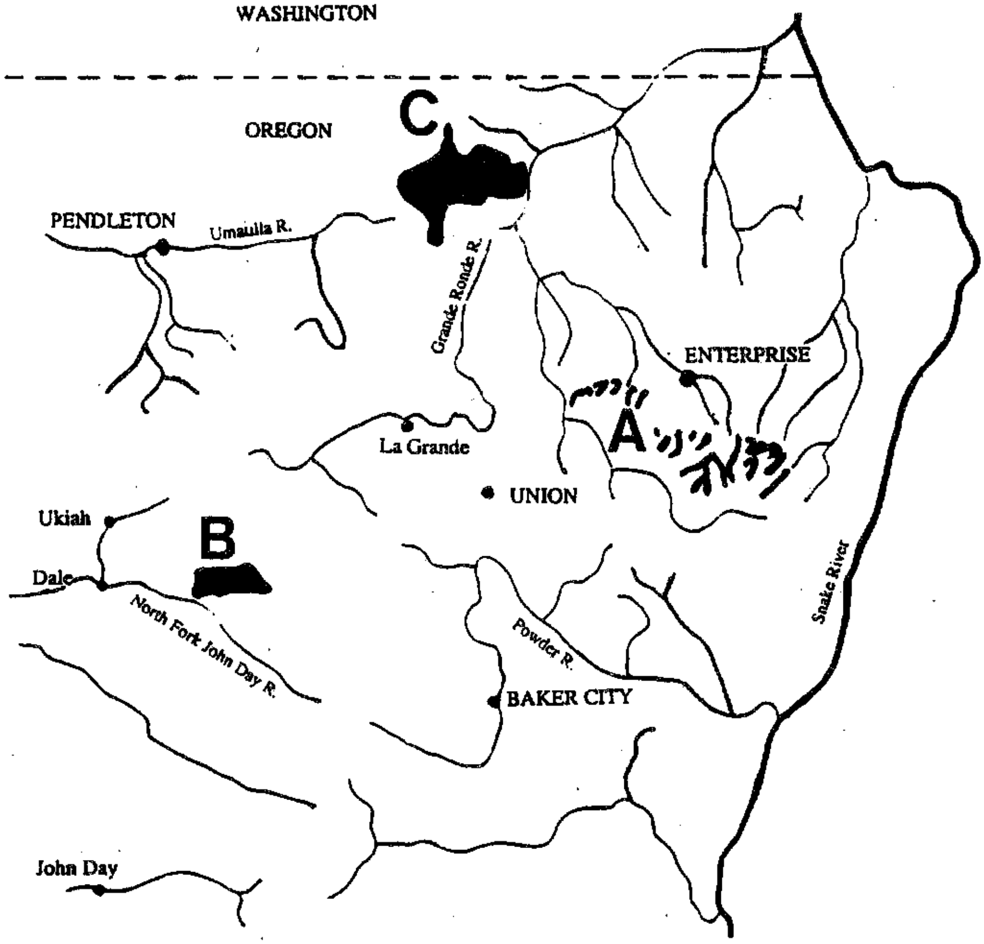

Figure 7.9 -- The only stand-replacement fires shown to have occurred in the Oregon Blue Mountains within the 4-5 decades prior to 1900 (Gannett 1902) are shown in black, and appear to be in the Abies lasiocarpa series in (A) the Powder Mountains (now the Eagle Cap Wilderness), (B) the upper North Fork John Day River, and (C) an area between the Grande Ronde River and Tollgate. Areas in Washington were not mapped.

North Fork John Day Wilderness, and an area from the Grande Ronde River west to Tollgate (figure 7.9) (Gannett 1902), all of which include some forest in the *Tsuga mertensiana* or *Abies lasiocarpa* series.

Historic Burned Area -- Considerable variability in burned area from year to year must have occurred in the Blue Mountains in past times, as it does now. From the fire return intervals known from the Blue Mountains and related forest types (table 7.2), together with area in the various types (calculated by dot grid from figure 7.6), a crude estimate of annual burned area can be made (table 7.3). The *Abies grandis/Pseudotsuga menziesii* plant associations were broken into four combinations of fire return interval and fire severity, because there appears to be considerable variation within the type. An annual average of about 175,000 ha yr^{-1} (425,000 acres) of forest is estimated to have burned, in addition to the grassland/shrub areas that burned. The percentage of area in each combined fire severity type is distributed as: low, 53%; moderate, 27%; high, 20%. However, due to more frequent burning in the low-severity fire regimes, the estimated annual area burned is skewed towards that fire severity level: low, 80%; moderate, 16%; high, 4%.

These figures are included for scale purposes, not for precise historical burn estimates. They provide an order-of-magnitude idea of fire presence and effect in the Blue Mountains and suggest that fire was an important ecological factor affecting species composition, structure, and function of Blue Mountain ecosystems, primarily through low-severity fires.

Fire Effects in the Blue Mountains

The fire regimes of the Blue Mountains had much to do with their biological diversity by maintaining a spectrum of seral vegetation types over the landscape.

Grassland, Shrubland, and the *Juniperus occidentalis* zone -- Three major plant series are present in the grassland zone: *Festuca viridula, Festuca idahoensis,* and *Agropyron spicatum*. Most of the fire effects described below are inferred from information in Johnson and Simon (1987). In general, grassland communities show increases in forb cover after fire, while most shrub communities show increased cover of grasses and forbs after fire.

Green fescue (*F. viridula*) is the dominant grass in the high elevation *Festuca viridula* series, and fire can damage green fescue if it occurs as a late-season, hot burn. Weedy forbs such as yarrow (*Achillea lanulosa*), aster (*Aster integrefolius*), penstemon (*Penstemon globusus*) and pokeweed (*Polygonum phytolaccaefolium*) are favored by fires, which historically probably occurred at infrequent intervals.

The *Festuca idahoensis* series is a widely distributed plant series with 11 plant associations in the Blue Mountains. As with the *Festuca viridula* series, hot late-season fires will favor forbs in these plant associations. Very late-season fires may be less damaging to Idaho fescue (*Festuca idahoensis*) than mid- to late-summer fires. Fires tend to burn within the accumulated fine needle-like culms at the base of the plant and produce temperatures sufficient to kill some of the basal meristematic tissue. In Idaho, return

Forest Type	Fire Severity	Fire Return Interval (Years)	Area (ha)	Area Burned (ha yr^{-1})
Pinus ponderosa	Low	15	1,377,000	91,800
*Abgr/Psme** (driest)	Low	10	472,000	47,200
Abgr/Psme (mod. dry)	Moderate	25	472,000	18,800
Abgr/Psme (mesic)	Moderate	50	472,000	9,400
Abgr/Psme (cool, moist)	High	100	472,000	4,700
Abies lasiocarpa	High	200	249,000	1,200
Totals			3,514,000	173,100

**Abies grandis* and *Pseudotsuga menziesii* plant associations

Table 7.3 -- Estimated forest area burned per year in the Blue Mountains.

to preburn cover took up to 30 years after summer fires (Harniss and Murray 1973). Natural fires of the past probably helped to favor plant diversity on these sites. Balsamroot (*Balsamorrhiza sagittata*), lupines (*Lupinus* spp.), Kentucky bluegrass (*Poa pratensis*), and yarrow are favored by burning, while harsh paintbrush (*Castilleja hispida*) and prickly lettuce (*Lactuca serriola*) are not adversely affected. Prairie junegrass (*Koeleria cristata*), a common codominant with Idaho fescue in four plant associations, appears to be favored by fire.

The *Agropyron spicatum* plant series is dominated by bluebunch wheatgrass. This grass is generally more tolerant of fire than Idaho fescue, and fire has been observed to stimulate flowering and seedset for bluebunch wheatgrass. Associates such as Sandberg's bluegrass, red threeawn (*Aristida longiseta*), and milkvetches (*Astragalus* spp.) are also favored by burning. Wyeth's buckwheat (*Eriogonum heracleoides*), a late-seral associate in the higher elevation *Agropyron spicatum* plant associations, is negatively affected by fire, and prickly pear (*Opuntia polycantha*) can be damaged after fire by grazing if its prickles are burned off.

In the shrublands, fire effects depend on the adaptive strategies of individual species to fire. Those that are capable of sprouting will be dominant over grasses and forbs more quickly than shrubs incapable of sprouting. Stiff sagebrush (*Artemisia rigida*), low sagebrush (*A. arbuscula*), and curlleaf mountain-mahogany (*Cercocarpus ledifolius*) are non-sprouters and recolonize burned areas slowly. Bitterbrush (*Purshia tridentata*) is a weak sprouter and is generally killed outright by summer or autumn fires (Clark et al. 1982). All of these species increase with protection from fire.

Other shrub species are moderate to strong sprouters, and unless fires are repeated and intense these species will regain dominance within 5-10 years. Ninebark, snowberry, spiraea (*Spiraea betulifolia*), and rabbitbrushes are common shrubland dominants that may increase after burning.

Juniperus occidentalis plant associations have many of the grassland or shrubland species mentioned above as codominants. In rimrock areas, western juniper has remained prevalent over past centuries because of the rocky substrate and lack of fuel to carry intense fire. These locations commonly contain juniper much older than that found elsewhere, and many are fire-scarred, suggesting that a moderate-severity fire regime occurred in these locations.

Historically, fires at 10-25 year intervals confined western juniper to protected microsites, although establishment might continually occur around these sites and into adjacent grasslands. Young junipers appear to establish best on "safe sites" (sensu Harper 1977): for example, under shrubs, such as bitterbrush, or the skeletons of dead and down junipers, where they are shaded for part of the day. Such shade can result in daytime temperatures up to 34°C cooler than on nearby bare ground (Burkhardt and Tisdale 1976). The process of juniper invasion into the sage-grasslands is slow. Established junipers grow slowly (6-9 cm yr-1 in height) and the sapling stage may last 30-40 years (Eddleman 1987). Fires moving across the sage-grasslands at 10-25 year intervals would have eliminated western juniper from unprotected sites.

The crown of an established juniper slowly expands over time, and as it does, herbaceous production declines from shading, litterfall, and soil moisture competition. Thus, the juniper may create its own fuelbreak. Individual, large trees at John Day Fossil Beds National Monument have survived multiple fires due to the lack of surface fuels surrounding the tree, while smaller trees in a matrix of sage-grassland were killed by a recent fire.

The effects on associated understory species have been previously summarized. Fires burning at 10-25 year intervals stimulate bluebunch wheatgrass, Sandberg's bluegrass, and numerous forbs, and have neutral-to-negative effects on Idaho fescue. Nonsprouting shrubs are temporarily eliminated from the community, and the cover of sprouting shrubs is temporarily reduced.

The *Pinus ponderosa* series -- There are between 10 and 15 plant associations within the *Pinus ponderosa* series with both grasses and shrubs as understory codominants. These understory species provide significant soil moisture competition for small ponderosa pine, with surface soils affected the most (Riegel et al. 1992). Some shading of seedlings may be important for protection from heat and frost (Cochran 1970), but height growth of established seedlings is reduced by competition with adjacent mature trees (Barrett 1973). Frequent historical burning killed most of these small understory trees, which colonized the sites during brief fire-free intervals, maintaining an open, park-like appearance in ponderosa pine forests. Mature trees were protected from these light fires by high crowns and thick bark.

Stand development of ponderosa pine forests is associated with the shade intolerance of the pine, good seed years, and frequent fire (Cooper 1960). Forest pattern is uneven-aged at the landscape level, but even-aged at the stand or group level (Cooper 1960). Gaps are thought to be created by the death of old, even-aged groups of trees (0.06-0.13 ha), which fall and scarify the soil after branches and boles are consumed by subsequent fires. Pines become established on these sites, and lack of pine-needle fuel in the gap may cause the gap to be missed by the next fire or two, allowing the small trees to develop a little more size and fire-resistance before a surface fire eventually moves through and thins the young landscape patch. The same fires would kill all the regeneration under mature tree canopies. Such regeneration was generally smaller than regeneration in gaps because of the competition of the larger trees and also was subjected to fires hotter than those in gaps because of the accumulated litter from those larger trees. The even-aged pattern was thus maintained within mature groups, and new groups formed only in openings. These new clusters of trees are thinned by fire over time and eventualy become a "yellow-belly" mature group of ponderosa pine.

Cooper's hypothesis, developed in Arizona, has been slightly altered by White (1985), who found a much wider age range of trees, and more variation in clump size in other Arizona pine stands. In the eastern Cascades, West (1969) found clump sizes of about 0.25 ha in *Pinus ponderosa* forests, with regular, uniform spacing of trees within clumps. He hypothesized the elliptical-shaped groups to be due to fires scarifying the soils along the axis of trees downed by generally west winds. Morrow (1985) found ponderosa pine cluster sizes from 0.02-0.35 ha near Bend. The establishment dates of surviving cohorts of trees in the 1980s were associated with occasionally long fire-free intervals of the past, suggesting saplings had an increased probability of survival if they were protected from fire for a cycle or two.

Understory production in these forests is inversely related to tree density and cover. Historically, these open and parklike stands had substantial grass and forb cover (Dutton 1887). Currently widespread nonsprouting shrubs such as bitterbrush were much more limited in cover because of frequent burning. Frequent, light burning allowed bunchgrasses to recover in 1-3 years, and most forbs also recovered quickly (Wright et al. 1979).

The *Pseudotsuga menziesii* and *Abies grandis* series -- Forests within these two plant series have higher tree species richness than the *Pinus ponderosa* series, although ponderosa pine may be the major seral dominant in many of these forests. In some locations of the Blue Mountains, either or both of the *Pinus ponderosa* or *Pseudotsuga menziesii* series is missing, so the transition from grassland or woodland to forest may be quite variable (Hall 1967), from grassland to any one of the three forest series. Fire-resistant western larch is also common in both of these plant series in the Blue Mountains (Daubenmire and Daubenmire 1968). As noted in table 7.2, fires were historically frequent in the *Pseudotsuga menziesii* series and the drier *Abies grandis* series, but fire return intervals lengthen significantly in the cooler, moister portions of the *Abies grandis* series.

Fire effects in the drier *Pseudotsuga menziesii* series with understory dominants such as snowberries, pinegrass (*Calamagrostis rubescens*), and elk sedge (*Carex geyeri*) are similar to the *Pinus ponderosa* series. Frequent, low-intensity fires kept these forests open and parklike. Although no information exists on stand pattern, occasional long fire-free intervals probably allowed some Douglas-fir to grow to fire-resistant size. The predictability of the fire regime was likely a major determinant of the proportion of Douglas-fir on these sites.

In the more mesic *Pseudotsuga menziesii* plant associations, a moderate-severity fire regime likely mixed these low-intensity fires with those of higher intensity. Understory fires may have opened larger patches in the forest for species such as western larch. Stand dynamics in a *Pseudotsuga menziesii/Physocarpus malvaceus* plant association in western Montana were simulated by Keane et al. (1990). At regular fire return intervals less than 20 years (figure 7.10) Douglas-fir is essentially absent from the landscape due to its low fire tolerance as a seedling/sapling. With increasing fire return intervals, Douglas-fir becomes a codominant with ponderosa pine and larch. Most real stands would show a mix of the fire return intervals in figure 7.10. Some *Pseudotsuga menziesii/Physocarpus malvaceus* stands in the Okanogan Highlands appear to have had occasional intense fires (Williams et al. 1990), suggesting these simulations may not incorporate the entire range of effects, or that this plant association may have a slightly different fire regime near the western end of its range. In the Blue Mountains, it tends to be a steep, canyon-slope forest type that had stand-replacing fires. The *Pseudotsuga menziesii/Vaccinium membranaceum* plant association likely had a similar fire regime.

The *Abies grandis* series in the Blue Mountains had a similar but wider range of natural fire regimes than the *Pseudotsuga menziesii* series. The drier *Abies grandis* plant associations, with understory dominants such as elk sedge or pinegrass appear to have burned frequently (Kathleen Maruoka, College of Forest Resources, University of Washington, data in prep.). Ponderosa pine and western larch, and to some extent Douglas-fir, were historically much more important than grand fir on these drier sites, and rhizomatous shrubs such as snowberry were common shrub associates. There is no information on stand-level pattern that specifically addresses these forest types, but in other mixed-conifer locations, clumping of single species (e.g., one group of ponderosa pine, another of true fir) tended to occur (Bonnicksen and Stone 1981, Thomas and Agee 1986).

In the cooler *Abies grandis* series, fire return inter-

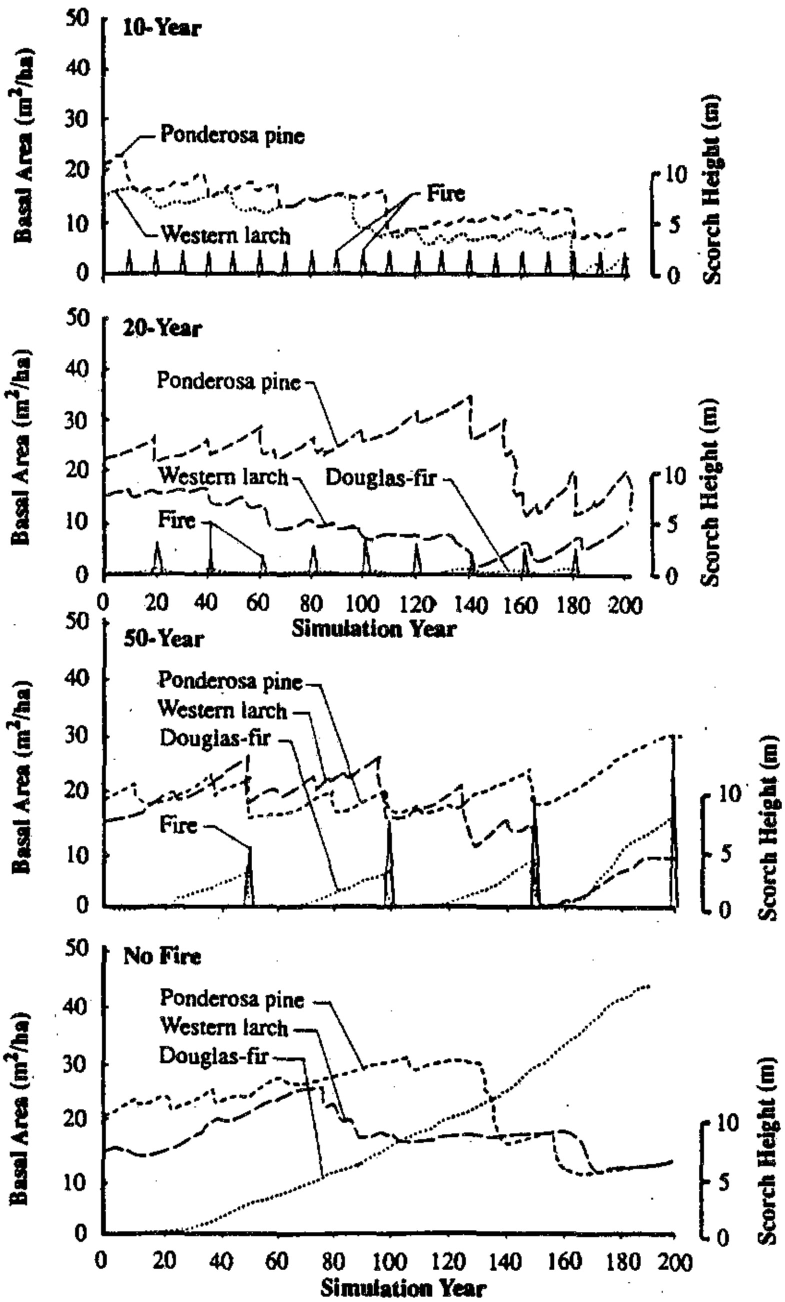

Figure 7.10 -- Simulations of relative basal area of species in a *Pseudotsuga menziesii*/ *Physocarpus malvaceus* plant association under varying disturbance regimes (Keane et al. 1990). As fire return intervals lengthen, ponderosa pine decreases in importance relative to Douglas-fir. Where grand fir is present, its response would be similar to that shown for Douglas-fir in these figures.

vals were longer, and the natural fire regimes shifted to moderate-severity. Stand replacement fires were more common. As canopy gaps became larger, occasionally comprising entire stands, a shift occurred in early seral regeneration to very shade-intolerant species with special adaptation to fire. Lodgepole pine, with its seed bank strategy of serotinous cones, and western larch, with its thick bark, light seeds, and long lifespan, became important associates of grand fir. The high early growth rates of these two species enabled them to become post-fire canopy dominants, while Douglas-fir and grand fir were relegated to subordinate canopy positions (Cobb 1988). A good example of this pattern is forest along the Highway 244 corridor along Camas Creek on the Wallowa-Whitman and Umatilla National Forests. This east-west corridor may have been the site of fires pushed by east winds, creating fires of higher intensity than those in valleys with different orientations. Where intense fires occurred at intervals less than 150 years, lodgepole pine generally shared dominance with other species at the site (Gabriel 1976, Antos and Habeck 1981). Repeated long-interval, intense burning will create almost pure lodgepole pine stands, which become difficult to assign to plant associations because of the complete absence of the climax species (Johnson and Clausnitzer 1991).

There is also a *Pinus contorta* series in the Blue Mountains, where lodgepole pine is the climax species, but it is of limited importance and is restricted to sites with cold air drainage and frost pockets. Whether it experiences the fire regimes of similarly looking stands on warmer sites (Johnson and Clausnitzer 1991) or the more varied interactive disturbance of fire, insects, and disease typical of the *Pinus contorta* series in south-central Oregon (Gara et al. 1985) is currently unknown.

Lodgepole pine is favored by intense fire: either low-intensity fire or absence of fire may favor other species. After a stand-replacement event, a stand of lodgepole pine, Douglas-fir, and western larch may lose its pine component if one or more subsequent fires of low intensity occur, eliminating the thin-barked lodgepole pine while not opening up sufficient growing space for a new generation of shade-intolerant pine. The absence of fire for a long period of time will favor longer-lived or more shade-tolerant species. Stands without lodgepole pine may be an historical artifact of occasionally long fire return intervals exceeding 200 years. The short-lived lodgepole pine may be killed by mountain pine beetles long before a fire moves through the stand, so that seed source for the pine may be absent (Haig et al. 1941). In the Blue Mountains, major mountain pine beetle outbreaks occurred in the 1907-1912 period (Burke 1990), probably in stands >80 years of age that regenerated following intense forest fires in the early 1800s.

Long fire return intervals may be typical of cool, moist *Abies grandis* plant associations with understory dominants oak fern (*Gymnocarpium dryopteris*), sword fern (*Polystichum munitum*), Rocky Mountain maple (*Acer glabrum*), and Pacific yew (*Taxus brevifolia*). Engelmann spruce (*Picea engelmannii*) may be present on some sites. Most of these locations are lower slope to riparian, and may exist as residual stringers that do not burn as often as the associated uplands. Although Pacific yew is very sensitive to fire, recent observations of seedlings on burned slash units (Roger Ottmar, USDA Forestry Science Lab, Seattle, unpublished data) suggest the species may be more resilient than earlier thought.

Two fires in quick succession may favor shrub dominance rather than trees. The shrubs will resprout but seed sources for trees may be lacking. Big huckleberry (*Vaccinium membranaceum*) and grouse huckleberry (*V. scoparium*) are two common understory dominants that may share dominance with lodgepole pine after intense fires. A second fire in a decade or two will kill the pine before many of the trees have developed a serotinous cone seedbank, leaving only sprouting shrubs and light-seeded herbs on site. Several of the herbs found in mature stands of the *Abies grandis* series typically root in the duff and are significantly reduced by fire (Flinn and Wein 1977) i.e., twinflower (*Linnaea borealis*), prince's pine (*Chimaphila umbellata*), rattlesnake plaintain (*Goodyera oblongifolia*), and strawberries (*Fragaria* spp.)].

The journals of early travellers support the idea that these cooler plant associations were not the clean, open, and parklike forests documented at lower elevations. In the forest northwest of present-day La Grande, Narcissa Whitman recorded in 1836 that they rode over many logs, which was unusual on their trip west (Evans 1991). In 1842, Medoram Crawford contrasted the ease of travel in the lower elevation forests without underbrush to the higher elevation, more densely timbered country: "Our traviling through the timber was quite difficult as the path wound back and forth and many logs lay across it." He also describes beautiful tall trees, suggestive of a past moderate-severity fire that may have killed lodgepole pine and fir but left western larch. William Newby complained in 1843 that, "the timber is so thick in many places that you coldant see a man 10 steps" (from Evans 1991). Captain Fremont noted a similar difficulty of travel in 1843. "We continued to travel through the forest, in which the road was rendered difficult by fallen trunks and obstructed by many smaller trees, which it was necessary to cut down" (from Evans 1991).

The *Abies lasiocarpa* and *Tsuga mertensiana* series -- These series occupy the coolest forested sites in the Blue Mountains, and the *Abies lasiocarpa* series by far is the most widespread of the two series. Fire tends to kill all tree species in these forests. The most typical replacement sequence is lodgepole pine, followed eventually by subalpine fir and Engelmann spruce dominance. Because of the cool conditions, growth is generally slow and the replacement may take over two centuries. Often, another fire occurs (table 7.2) before the replacement sequence is complete, and lodgepole pine is again favored.

In the Pasayten Wilderness of north-central Washington, Fahnestock (1976) showed lodgepole pine to be the exclusive dominant 50 years after stand-replacing wildfire. Spruce and fir then colonized in a relay floristics pattern (one set of species often absent after disturbance but eventually replacing another set [e.g., lodgepole pine] over time), becoming dominant 100-200 years postfire. Occasional lodgepole pines will persist for up to 400 years on these sites (Fahnestock 1976).

The *Abies lasiocarpa* plant associations with understory dominants Queen's cup beadlily (*Clintonia uniflora*), twinflower, and fool's huckleberry (*Menziesia ferruginea*) tend to be the most maritime plant associations and are found primarily in the northern Blue Mountains (Johnson and Clausnitzer 1991). They tend to have the longest fire return intervals, and are most likely to be sites on which seral lodgepole pine has disappeared. If lodgepole pine has largely been replaced by the time of the fire, shrubs such as the huckleberries may dominate the site for decades, or may share dominance with western larch. Trees slowly recolonize such sites, and huckleberries will eventually decline with increased shading. After 200 years, the only seral evidence of the previous fire will be the long-lived western larch, sharing dominance with generally younger subalpine fir and spruce. If lodgepole pine is present at the time of the fire, then it is likely to be a postfire dominant.

Little is known of fire effects in the *Tsuga mertensiana* series in the Blue Mountains, as it has such a limited distribution in and around the northwest portion of the Eagle Cap Wilderness. Stand-replacement fires will favor lodgepole pine. In some areas, old-growth mountain hemlock communities without much fire evidence suggest some stands have not burned for many centuries. In the Oregon Cascades, Dickman and Cook (1989) found that fire broke up laminated root rot (*Phellius weirii)* disease centers in mountain hemlock by favoring *Phellinus*-resistant lodgepole pines after large stand-replacement fires.

In timberline stands, whitebark pine may be a codominant with subalpine fir. Crown closure may not occur on these sites due to fire, snow avalanches, rockfalls, and other repetitive disturbances. Scattered vegetation is conducive to whitebark pine survival after fire, and individuals may be scarred rather than killed. Clark's nutcrackers (*Nucifraga columbiana*) are known to cache pine seeds in burned areas from pines in adjacent unburned areas (Tomback et al. 1990). This allows whitebark pine to colonize sites first after stand replacement burns, as subalpine fir has large seeds that are wind-dispersed but do not drift long distances. Establishment of subalpine fir subsequently occurs, but fire is likely to recur before whitebark pine is gone from the site (Morgan and Bunting 1990).

EFFECTS OF MANAGEMENT ON FIRE REGIMES

Three types of management activities have had the most significant impacts on fire regimes in the Blue Mountains: fire exclusion policies, grazing of livestock, and selective harvesting of trees. Other activities, such as pest suppression, wilderness fire management, etc., have had much less noticeable impact.

Fire Exclusion Policy

Near the beginning of the twentieth century, the European tradition of forestry began to be used as a model for American forestry. Fire was seen as one of the major threats, and legislation was enacted to protect forests (e.g., the Weeks Act of 1911). Indiscriminate fires from land clearing and other activities had threatened lives and property as well as timber reserves. Ironically, as fire was being institutionalized on the west side of the Cascades to reduce slash after logging, it was being eliminated in the eastern Cascades where its historic effect had been much greater.

The battle over "light burning" was staged in the pine forests of northern California between 1910 and 1925. The Southern Pacific and Red River timber companies were using low-intensity prescribed fire to manage their pine timberlands, but this practice was decried as "Piute forestry," a term meant to imply poor management. The issue was debated in Sunset Magazine in 1920 (White 1920), but the arguments by the Forest Service that fires killed regeneration under the larger trees led to the demise of "light burning" by the end of the 1920s. The implications of successful regeneration eventually leading to increased wildfire and forest health problems was not widely foreseen at the time.

Several courageous professionals, such as Harold Weaver of the Bureau of Indian Affairs in the eastern Cascades of Oregon and Washington, and Harold Biswell of the University of California in the pine forests of that state, attempted to show the long-term detrimental consequences of such a policy beginning in the 1940s. Both encountered tremendous resistance within their profession, but near the end of their careers in the 1970s both saw a change in attitude within the profession (Biswell 1989).

Changes in attitudes have not been translated to fire use on the ground, however. Most use of fire into the 1990s has been associated with activity fuels on harvest units over a small proportion of the landscape (e.g., Kilgore and Curtis 1987). In the Blue Mountains, current burning covers about 12,000 ha yr^{-1}, with about 85% of this accomplished by pile burning. Most of the fire activity is from wildfires, averaging 40,000 ha yr^{-1} over the 1986-92 period (T. Quigley, Blue Mountains Natural Resources Institute, presentation at fire seminar, Pendleton, Oregon, February 1993).

Timber Harvesting

Timber harvesting has historically focused on the more important commercial species, ponderosa pine and western larch. Early harvesting activities concentrated on only the largest trees, as milling techniques did not allow smaller stems to be efficiently processed. Lower elevation stands in the *Pinus ponderosa, Pseudotsuga menziesii,* and *Abies grandis* series were selectively logged for pine and larch. In general, early seral species were removed, leaving usually smaller climax species to capture the growing space.

In more recent decades, a wider suite of species has been utilized: grand fir, lodgepole pine, and subalpine fir. Smaller diameter material has increasingly been used for chips.

Livestock Grazing

Settlement of the Oregon Territory, and associated livestock, began in the late 1830s. By 1860, there were 200,000 cattle in Oregon, along with sheep and wild horses (Galbraith and Anderson 1991). In the winter of 1861-62, the practice of yearlong open range with no shelter or storage of hay had to be reconsidered. In the Walla Walla valley, dead animals were so numerous at the end of that winter that one could almost step from one dead cow to another throughout the whole valley (Galbraith and Anderson 1991). This episode did not repeat itself until 1880, so yearlong open range grazing continued until a third harsh winter in 1889-90 forced cattlemen to accept the need for supplying food and shelter for livestock in winter months.

Sheep numbers increased on eastern Oregon rangelands in the 1890s, because they were cheaper to raise than cattle. Bands of sheep wandering on already overgrazed ranges led to range wars in the early 1900s. The Sheep Shooter's Committee of Crook County claimed to have shot 8,000-10,000 sheep a year during this period (Galbraith and Anderson 1991). Grazing laws were developed for national forests by 1910, but much of the damage had been done by 1900 (Harris 1991). The rangelands had evolved without substantial grazing pressure (Mack and Thompson 1982), and intensive grazing significantly damaged the perennial bunchgrass ranges.

Effects of These Changes on the Landscape

The natural fire regimes of the Blue Mountains were interrupted by the combined effects of these management practices. In some ecosystems, the changes were minor, while in others the changes were catastrophic and probably irreversible.

Grasslands, Shrublands, and the *Juni-perus occidentalis* series -- The perennial grasslands surrounding the Blue Mountains have been subjected to severe overgrazing. Alien species, and in particular the annual cheatgrass (*Bromus tectorum*) have increased as a result. Cheatgrass germinates in the autumn in this region and maintains a rosette form as it develops a root system during the winter months (Young et al. 1987). It is capable of using much of the available soil moisture before the perennial grasses begin to grow. Cheatgrass completes its life cycle in late spring to early summer, and the fine-textured cured foliage is very flammable. This trait has expanded the historical burning season in some areas, which subsequently increased the dominance of these sites by annuals (Whisenant 1990). Intensive grazing has also removed perennial grass fuels and reduced potential fire behavior in other areas. In those areas, the absence of fire has allowed western juniper to spread across the landscape.

Western juniper has undergone a major expansion of its range over the last century, with the area covered now about twice that covered in 1860 (Burkhardt and Tisdale 1976). Several hypotheses have been generated to explain this expansion: climatic change favoring juniper; recovery from logging of juniper during European settlement; overgrazing by domestic livestock opening up competition-free microsites for juniper; and the absence of fire, which would otherwise kill the fire-sensitive western juniper. Expansion has been slower on low sagebrush sites than on big sagebrush (*Artemisia tridentata*) sites (Young and Evans 1981).

The climatic hypothesis has so far shown that juniper pollen (and presumably juniper abundance) in the eastern Oregon area has varied over the past 10 millennia perhaps as much as recently (Mehringer and Wigand 1987), but provides no climatic evidence for the recent expansion. The logging recovery hypothesis is locally valid in mining districts (Hattori and Thompson 1987) but not regionally important, and probably of little importance in the Blue Mountains. Areas invaded by junipers show no stumps or other evidence suggesting junipers existed there in the recent past. The overgrazing hypothesis is tenable, but juniper invasion has occurred even in ungrazed areas (Quinsey 1984). Overgrazing might interact with fire absence, as herbaceous fuel decline would restrict fire spread.

The most plausible single hypothesis is fire exclusion. Fires kill junipers by providing excessive heat to the base of trees or scorching the crown. Intense summer wildfires kill all the junipers, but individual fires under more moderate weather can leave some residuals (Martin 1978). Prolonged herb and shrub stages have been observed on burned *Juniperus occidentalis* sites (Everett 1987). A return to natural fire regimes would reduce but surely not eliminate juniper across the woodlands of the Blue Mountains.

The *Pinus ponderosa* series -- The forests of the *Pinus ponderosa* series changed in several significant ways over the last century. The developmental pattern of clumped groups of trees was interrupted by fire protection (Morrow 1985), allowing regeneration to survive not just in openings but under the mature clumps. A widespread, "fire-protection era" age class of trees has invaded across the landscape. This invasion has created dog-hair thickets of trees in many areas, with many trees no more than several cm in diameter after 60-80 years. This dense understory has created stress on the older trees, where they have not been selectively harvested. Where the older trees have been removed, the younger residual stands are too dense and have stagnated. They are susceptible to western pine beetle (*Dendroctonus brevicomis*) and mountain pine beetle (*Dendroctonus ponderosae*) attack (Gast et al. 1991), which can increase fuel hazards across the landscape. Where these younger stands have been mechanically or manually thinned, a mimic of what fire once did, there is less risk of beetle outbreaks (Sartwell and Stevens 1975), although pine engraver beetles (*Ips pini*) may breed in the slash and cause additional mortality.

While once-frequent surface fires were carried through these stands by needle litter and grass, they are carried now by needle and branch fuels. The vertical continuity of fuelbeds is much higher than historically, which allows surface fires to develop into understory or crown fires under less severe weather conditions. The lack of ability of trees to grow to fire-resistant sizes because of stagnation has resulted in stands being on average less fire tolerant, at the same time that average fire intensity, due to fuel buildup, is increasing.

The increase in tree density, together with intensive grazing, has caused a decline in shrub and herbaceous understory. Understory production in ponderosa pine forests is inversely related to tree crown cover (Pase 1958) or other measures of tree competition such as basal area, litter depth, or tree density. With dense tree canopies, forbs are favored over grasses (McConnell and Smith 1970). Once-common grasses such as Idaho fescue, bluebunch wheatgrass, and Sandberg's bluegrass have declined, also in part due to heavy grazing. In some areas of Montana, Idaho fescue was absent in grazed stands (Evanko and Peterson 1955). Average herbaceous production has probably declined from 1000-1500 kg/ha in open, mature stands, to 100 kg/ha or less (Biswell 1972) in stagnated, dense ponderosa pine stands.

Increased needle litter can replace grass as a fine fuel to carry fire, but a dense understory tree layer usually increases relative humidity and average fine fuel moisture content and will decrease average windspeed in these altered stands. On balance, there is an interaction in a statistical sense between fuels and the weather under which fire burns. Now, under moist conditions, fire will not carry through stands it once burned freely across; under dry conditions, it burns much more intensely than it did historically. The fire regime has been converted from a low-severity fire regime to one of moderate- to high-severity.

The *Pseudotsuga menziesii* and *Abies grandis* series -- Some of the most visible landscape changes have occurred in these two plant series, particularly on the drier sites. The structural changes noted for the *Pinus ponderosa* series have occurred in these series, too, but accompanied by a major shift to more shade-tolerant species composition. These mixed-conifer forests are also the types where forest health problems have been most severe.

The duration and intensity of insect outbreaks, such as by the western spruce budworm (*Christoneura occidentalis*), appear to have increased with this shift in species composition to budworm-sensitive species. In Montana, sites in the *Pseudotsuga menziesii* series once dominated by ponderosa pine are now dominated by Douglas-fir. As fire return intervals have lengthened beginning this century, duration of budworm outbreaks has increased from 8-13 years to 17-29 years, and outbreak severity (on a relative scale of 0-1) from 0.41-0.53 to 0.63-0.70 (Anderson et al. 1987). Similarly, tussock moth (*Orgyia pseudotsugae*) outbreaks have been most common at the low elevation border of the *Pseudotsuga menziesii* and *Abies grandis* series (Williams et al. 1980) or on ridgetops or south-facing slopes (Mason and Wickman 1988), where Douglas-fir was historically subordinate to ponderosa pine because of frequent fire. The first outbreaks known in the Blue Mountains were noted in 1928 (Gast et al. 1991), although this insect has likely been present at endemic levels for much longer periods of time. Establishment of non-host species such as ponderosa pine is the most effective control measure (Mason and Wickman 1988).

In most of these dry mixed-conifer forests, effective fire protection resulted in all of the growing space being filled by trees by about 1960 (McNeil and Zobel 1980) unless larger trees were harvested. Many trees less than 1 m tall are more than 30-40 years old (Agee 1982). These multi-layered forests are susceptible to budworm attack. This increase in tree density also affects stand pattern and understory production.

The architecture of mixed-conifer stands has changed both horizontally and vertically. The spatial pattern of pure species clumps has been erased by the density of a single (Douglas-fir or grand fir) shade-tolerant species (Thomas and Agee 1986). In some cases, where little harvesting activity has occurred, the historic pattern is still discernible if only older trees are considered, which suggests that the pattern is recoverable with intensive thinning operations. Where the early seral trees such as ponderosa pine have been removed, thinning will not help to recreate historic pattern. Larger openings will be required to encourage natural or artificial regeneration of ponderosa pine. Vertical continuity has increased in these stands similar to that seen in the *Pinus ponderosa* series, with most of the layers composed of shade-tolerant species.

A similar shift away from low-severity and towards moderate- to high-severity fire has occurred in the drier portions of the *Pseudotsuga menziesii* and *Abies grandis* series. For example, a recent fire in the Dooley Mountain area along Highway 245 south of Baker City killed most of the trees. The large size of ponderosa pine and Douglas-fir trees in this forest suggests that the site had sustained many fires in past centuries without similar effect. An increase in the normal intensity of fire has occurred on this site, apparently outside of the historical range, due to fuel buildup and "ladder" fuels enabling surface fires to move into the canopy. This is clearly a human-induced shift in the natural fire regime.

As in the *Pinus ponderosa* series, increases in tree density together with grazing have contributed to the decline in understory production. Frequent fires periodically consumed forage to ground level, but rhizomatous pinegrass and elk sedge were able to quickly recover. These two species were preferred by cattle and declined with overgrazing (Frederick Hall, 1975, Range management as a counterpart of forest management, unpublished report, Washington State University, Pullman, WA). In Idaho, pinegrass production in grazed stands was only 28% of that in ungrazed stands (Zimmerman and Neuenschwander 1984). The decline in competition from rhizomatous species and the ground disruption by hooves encouraged even more conifer regeneration.

In the more cool, moist *Abies grandis* series, with moderate-severity fire regimes, the proportion of low-severity fire has declined on areas burned over the last century. Small or low-intensity fires have been effectively controlled. The only fires capable of having a landscape impact are those burning under severe fire weather where initial attack has failed. Historically, fire created a complex mosaic composed of underburns where little regeneration was initiated, thinned stands with large residuals where both shade-tolerant and intolerant species could establish, and stand replacement patches where shade-intolerant species were best adapted. High-severity fires are now the dominant severity level in this portion of the *Abies grandis* series, a shift from the complex moderate-severity fire regime to one of high severity (figure 7.3).

Effects of management activities on montane meadows mixed with middle elevation forests are primarily related to overgrazing. In the Eagle Cap Wilderness, bluejoint reedgrass (*Calamagrostis canadensis*) and tufted hairgrass (*Deschampsia caespitosa*) have decreased with grazing, while Hood's sedge (*Carex hoodii*) and Kentucky bluegrass have increased (Cole 1981). A shift to forb-dominated meadows has occurred, with the forb/grass cover ratio shifting from 0.3 to 1.0-2.0. Total cover and dominance by perennials has shifted much less, so effects on fire spread have probably been insignificant.

The *Abies lasiocarpa* and *Tsuga merten-siana* series -- The changes of the last century have been least significant in the high elevation forest types of the Blue Mountains. Although a fire exclusion policy has been in effect for almost a century, the naturally long fire return intervals have resulted in little noticeable change in these ecosystems at the stand level. At the landscape level, the absence of fire has probably resulted in a slight shift towards later seral communities and away from earlier seral communities. In the Eagle Cap Wilderness, Cole (1981) suggested that valley bottom and lower slope plant associations (figure 7.11) had more subalpine fir in the understory than the overstory, and is where the floristic response to fire suppression has been most pronounced. However, fires have not been erased from the landscape in these plant series, as shown by the upper portion of the 1960 Anthony Lakes burn on the Wallowa-Whitman National Forest and other subalpine locations.

Limited application of modified fire suppression has occurred in several areas (Hunt Mountain on the Wallowa-Whitman National Forest. Joyce Bork, 1981 unpublished ms., Wallowa-Whitman N.F., Baker City, OR) but these fires have remained small, having spread only over a few hectares each.

Some ecological changes may be defined in terms of increased risk of wildfire rather than an observed change. For example, the relict population of Alaska yellow-cedar in the Cedar Grove Botanical Area on the Malheur National Forest is a very small grove surrounded by a much drier forest type. The grove has historically been a riparian stringer largely unaffected by the low-severity fires burning to its margins, although it has survived one fire this century. Many of the cedars are fire-scarred. With unprecedented fuel buildups in the bordering dry forests, the fire regime has been shifted to high severity. The grove is now at risk from the stand replacement fires that are likely to occur in these neighboring forests. A high-intensity fire event could extirpate the cedar from this site, and eliminate the only glacial relict population of Alaska yellow-

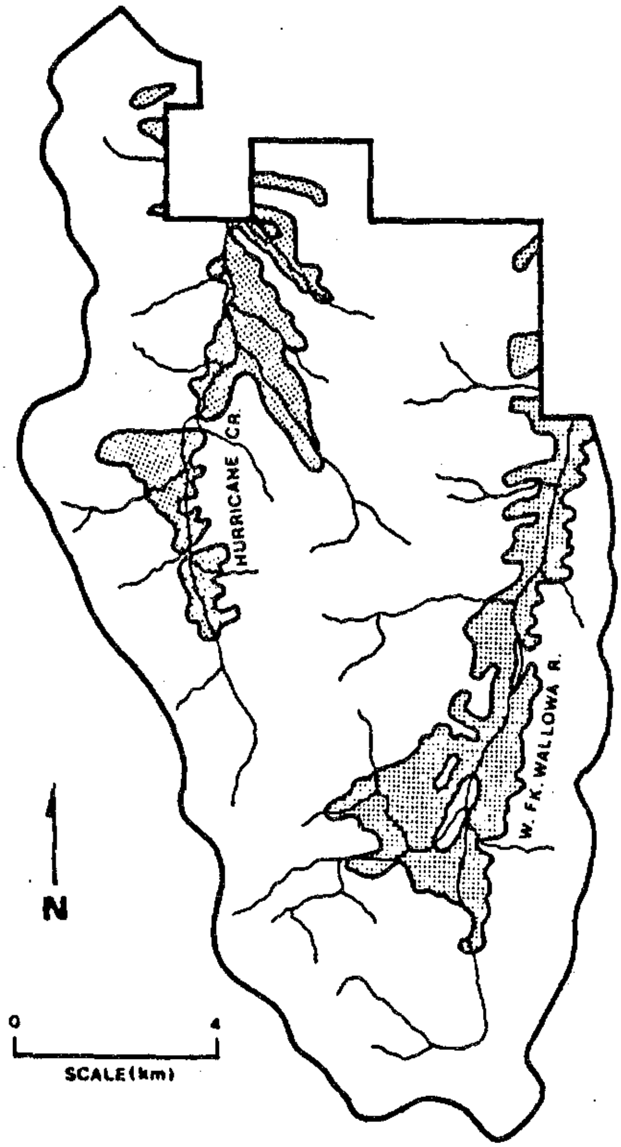

Figure 7.11 -- Areas of rapid successional change in the Eagle Cap Wilderness resulting from fire protection (Cole 1981). These are forested areas where the seedlings and saplings are predominately different species than those that dominate the overstory.

cedar in the Blue Mountains.

Tree invasion into high mountain meadows has sometimes been linked to fire protection (Ratliff 1985). However, under natural conditions such invasion may also occur, and separating the causes is difficult. In the Pacific Northwest, two distinct meadow invasion patterns have been documented. The first is tree invasion into snow-dominated meadows, where the shrub dominants are generally heathers (*Phyllodoce* spp.). These invasions have occurred due to natural droughts. During the 1920-40 regional drought, substantial invasion occurred in these meadows (Franklin et al. 1971). A second pattern is related to fire-created meadows being recolonized by trees (Henderson 1973, Agee and Smith 1984). Unless the fire was human-caused, this pattern is also natural. These sites are usually steep, south-facing slopes, and colonization occurs with a substantial lag time (30-50 years) during wetter-than-normal summers. Little (1992) has found that on burned sites, extended growing seasons created by early snowmelt in spring together with wetter-than-normal summers is associated with tree establishment. In the Blue Mountains, both of these patterns may exist, and may be accompanied by yet a third pattern.

A third pattern of tree invasion is associated with wet meadows that have been historically overgrazed. During the grazing, tree establishment may have been inhibited. While pristine subalpine meadows in the Eagle Cap Wilderness have an average cover of 40-75% composed of tufted hairgrass and Holm's Rocky Mountain sedge (*Carex scopulorum*), grazed meadows have 10-12% cover in these species (Cole 1981). Fringe leaf cinquefoil (*Potentilla flabellifolia*) is a common dominant forb in the grazed meadows. In Sierra Nevada wet meadows, slow recovery of herbaceous vegetation resulted in gully formation in some meadows, which created a drop of the water table. Better drainage encouraged trees, primarily lodgepole pine, to invade the drier edges of these meadows and the gully edges. Under drought conditions, such meadows have burned and killed the invading pines (DeBenedetti and Parsons 1979), but the invasion process is largely independent of fire. In the Blue Mountains, lodgepole pine and Engelmann spruce are the most likely invading tree species, but this has not been identified as a major problem in the Blue Mountains.

A RESEARCH PROGRAM IN FIRE ECOLOGY AND MANAGEMENT

The Management Challenge

The many ecological changes associated with fire exclusion and other management activities have created conditions of fire hazard and poor forest health that almost everyone views as undesirable. The solutions to forest health problems involve a better linkage of biological and sociopolitical systems than we have had in the past. Numerous popular articles describing these problems recognize that we must "get fire back into the system," but this is easier said than done. The natural role of fire in the ecosystems of the Blue Mountains is a template for management, but it is not a model for management: fire is a tool, not the rule. These systems are more complex in almost every respect than they were a century ago; the biological state of these ecosystems has experienced unprecedented changes in tree species composition and structure, fuel buildups, alien species, etc. Restoring a natural process, fire, to an altered ecosystem is fraught with uncertainty. Will old trees survive restoration fires with massive fuel buildups at their bases? Will alien species, so adept at colonizing disturbed ground, become even more dominant?

The land tenure system is crisscrossed with square and rectangular boundaries, although few fire boundaries can be so neatly scribed on the landscape. Liability problems for private landowners using broadcast fire are significant. Fires on public lands have the risk of spreading onto private land, and they will be producing smoke from decades of accumulating biomass in these forests, smoke that once drifted harmlessly across the valleys of the Blue Mountains but now drifts into local smoke-sensitive communities. Application of ecosystem management principles, including people as part of the system, are essential to achieving workable solutions (Agee and Johnson 1988). Adaptive management, including a strong monitoring and feedback approach, is also essential if successful treatments are to be expanded, and failed treatments abandoned (Walters 1986).

Several institutional issues clearly emerge as important management issues. The first is the scale: if fire is to be addressed at the proper landscape scale, drip torches won't do the job. Aerial ignition will be necessary; the technology is there, but the local skill at using it needs to be developed. Cooperation not only with other local institutions, but with international institutions such as Australian fire managers who regularly use aerial ignitions will be necessary. Expanded networks of fire weather stations critical to developing site-specific fire prescriptions are cheap insurance against expensive and avoidable fire escapes.

Local and regional land-zoning and fire-protection statutes will need review; all landowners are part of the solution. The urban-wildland interface exists in the Blue Mountains just as much as in Bend, Medford, Spokane, or Wenatchee.

Smokey can't say it all in one sentence anymore. The fire management job is much more complex than fire prevention, or as we have learned, prevention and fire suppression. In the Blue Mountains, posters on fire ecology should become as widely circulated as posters on preventing fire. Smokey could be positively involved in a program for changed public awareness of fire in the Blue Mountains. He should still be primarily involved as a symbol of fire prevention, but that role has to be more actively integrated with interpeting the use of fire. Fire management in the Blue Mountains may not otherwise succeed.

The Research Challenge

The research challenge outlined below assumes that our state of knowledge about fire and its effects is sufficient to conclude that fire is a part of the solution to the forest crisis of the Blue Mountains. Where other information can be applied to the Blue Mountains, there is no need to "reinvent the flame." Yet there is much we do not know about where fire should be employed, when it should be used, how often, and for what ends. The research challenge is to adaptively approach research, periodically redefining the questions as part of an adaptive management approach. A research agenda is neither more stable nor inflexible than the management agenda. The challenge for research is to create new information through basic and applied research and to transfer that information to practitioners. The agenda in this draft chapter is intended to be integrated with other disciplinary agendas for research.

The agenda is divided into two parts: education and training, and basic and applied research problems. The first part is important because much is known already about fire, and should be disseminated more widely than at present. The second part is important because we have to site-specifically apply fire with predictable outcomes.

Education and Training

Workshops should be organized to deal with three general groups of audiences: the general public, managers/resource specialists, and fire managers. Each has a unique need for fire information, and there is enough known to begin sessions immediately. The first group is the general public. It is likely to be most responsive to video formats shown on television, brief lecture series (such as at Eastern Oregon State College in La Grande or travelling evening "shows"), or one-day symposia. Themes including the forest health situation, the natural role of fire, or how fire can be integrated with community goals might be appropriate.

The second group includes people who are likely to be members of interdisciplinary planning teams. These professionals will be evaluating the combined impacts of actions on resources and need to know more specific factual information useful in planning: what fire history information is and how it is collected, techniques of managing fuel consumption, effects of fire on soils and wildlife, etc. A higher level of detail would be appropriate for this audience.

The third audience is the fire practitioner, people who will be applying fire. Some of the same material shared with the second group is useful for this group, but they will need more specific fire planning and operational background: ignition strategies, fire applications of geographic information systems, biomass consumption prescriptions, fire weather forecasting, fire danger rating, etc.

There is no need to wait until further research is done. A first round of training for all three groups could be accomplished and show substantial results in fire planning and community acceptance and trust before the first research project listed below has been completed. Continued technology transfer is certainly recommended but initial efforts could and should begin soon.

Fire Research

Natural Fire Regimes -- The earlier summaries in this chapter suggest we know a fair amount about the general fire regimes of most of the vegetation types of the Blue Mountains. Further information on fire regime definition and variation within the Blue Mountains is needed. In particular, fire return intervals are not well-documented, and the extent of historical fires is largely unknown. Landscape-level analyses of fire regimes from sage-steppe to alpine would be helpful in determining the degree to which vegetation type boundaries were also fire boundaries.

A current study is evaluating fire history in the *Pseudotsuga-Abies* series across the three national forests of the Blue Mountains. The fifteen sites are scattered across a 150 X 300 km area, which will provide wide geographic coverage but not landscape-level information about fire extent. Furthermore, this kind of fire-scar study can only be done in the low-severity fire regimes; area frequencies must be used in moderate- to high-severity fire regimes.

Research projects in juniper woodland, ponderosa pine, mixed-conifer, and subalpine fir forests, if geographically tied together, could provide more comprehensive fire history results while allowing each to be tied to the other studies in a spatial sense. This information would be useful in designing restorative fire treatments at a landscape level.

Global Change and Fire -- The global change scenarios for the Pacific Northwest suggest major shifts in vegetation types, with the shifts triggered by landscape disturbances such as timber harvesting or fire (Franklin et al. 1991). Past climate can be linked to forest fire history and may suggest likely future scenarios with climate change. Some reconstructions of climate based on tree-rings exist for the region (Keen 1937, Graumlich 1987) and can be integrated with new information to tie climate more closely with intense or widespread fire events of the past.

Ecosystem Components Affected by Restoration Fires -- All ecosystem components will be affected by fire. The focus of the research described below is on ecosystem components likely to be significant constraints or opportunities.

1. **Vegetation.**

a. Biomass estimates of major vegetation types are necessary to accurately predict consumption from fire. In particular, proportions of live to dead biomass will differ by forest type and by "forest health" category, and from first-time "restoration" burns to later "maintenance" burns.

b. Effects of fire on plants is a critical category in that fire prescriptions should be able to predict effects based on fireline intensity, season, and state of the ecosystem. Examples include effect of intensity and season on bunchgrasses, the relative effect on aliens such as cheatgrass and knapweeds (*Centaurea* spp.), effects on juniper (whether the juniper is felled or not before burning), effects on ponderosa pine where substantial fuel buildup has occurred at the base of trees, etc.

One of the primary weaknesses of current studies (e.g, Swezy and Agee 1991) is that the effect of only the first restoration fire has been measured. This is likely a maximum effect not likely to be repeated in subsequent burns. Yet few studies outside of the southeastern United States have studied the effects of repeated burns. This is a critical need for the Blue Mountains for all vegetation types, and should be a first priority in any demonstration area.

2. **Soil.** Research in physical, chemical, and biological soil effects will be necessary as restorative fire treatments are proposed. In the physical area, landscape-level erosion studies, which will tie slope processes to stream inputs, are needed most. An obvious tie to riparian studies is implied. The soil chemical area should focus on those nutrients volatilized by fire—sulfur and nitrogen—with some attention to other nutrients that are transformed to a soluble state where they may be leached from the system. The magnitude of these effects is a function of fire intensity (Klock and Grier 1979). Long-term productivity of these ecosystems may depend on the ability of N-fixing plants to replace nitrogen, while sulfur may continue to be a limiting nutrient, particularly in volcanic soils typical of the Blue Mountains. Effects of fire on biological properties of soils has historically been undervalued; mycorrhizal interactions with fire may be very important for tree regeneration in the moderate- and high-severity fire regimes.

3. **Wildlife.** Fire interacts with wildlife by indirectly affecting food, cover, and water; direct effects are very minor. Increased use of fire will generally increase water where it is a limiting factor, particularly in drier environments. This also has a tie to riparian issues. Both thermal and hiding cover are likely to be reduced for deer and elk with fire use or without (due to tree dieoffs from insect attacks). One important facet will be the value over time of dead understory, created by fire or insect mortality, as hiding or thermal cover. At the same time, volume of downed woody material and snags may decline in some ecosystems due to increased fire activity

Food is another aspect of wildlife habitat. Some of these effects are vegetative in nature, while others are predator-prey related. In general, summer range vegetative foods will increase, while winter range foods such as shrubs may show lower cover but increased palatability. Analyses for critical wildlife species will be important.

4. **Air.** Air quality is likely the major constraint to fire use in the Blue Mountains, as it is elsewhere. Particulate matter is the most important air quality parameter in terms of visibility reduction and potential health risks (Sandberg and Dost 1990). Biomass inventories need to be tied to emission factors by vegetation type and fuel moisture, and then projected into concentrations. Health effects on fire practitioners of proximity to smoke need to be better defined.

Comparisons of the integrated air quality effects of management regimes (total fire suppression, suppression + an active prescribed fire program, etc.) will help define the air quality tradeoffs in various forest health scenarios. Modelling the effect of various alternatives for fire use on downwind airsheds (regional scale, such as transport to the Grand Canyon) will be an important interregional need before large-scale burning is accepted.

5. **Visual Quality.** The effect of fire on scenery is an important element of public opinion concerning burning programs. The impact of fire use on visual quality of landscapes has been documented in ecosystems similar to the *Pseudotsuga menziesii* and *Pinus ponderosa* series. Site-specific effects over time of fire and other manipulations can be tested for effects on visual quality. This needs to be extended to the *Abies grandis* series in moderate-severity fire regimes, and to the *Juniperus occidentalis* series.

6. **Cultural resources.** The Blue Mountains contain literally thousands of cultural sites or artifacts, some of which may be at risk with increased fire use. Increased cultural resource inventories (what and where) will be needed to project potential impacts, and assessment of potential fire temperatures and effects on various artifacts or structures is needed.

CONCLUSIONS

Fire was a common visitor to Blue Mountain ecosystems in the past. It will be in the future. Although we lack the ability to predict or mimic many disturbances, we have the ability to choose, to some extent, what relationship we want with fire. Those choices have in the past not always been wise, either in fire exclusion or fire use. Future choices should be based on the notion that natural resources management is a grand experiment, but not one that has to be unpredictable.

Where the prediction tools are available, we need to make better use of them. Where they are absent, we need to develop them. The concepts of plant associations and landscape ecology are useful ways to organize and integrate information about fire and other ecosystem components and processes. Increasing and applying this information to the ecosystems of the Blue Mountains will ensure their sustained productivity in the broadest biological and social context.

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