The Story of Fire on Deschutes National Forest

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The Story of Fire on Deschutes National Forest

I. A Short Overview Provided for the General Public

A. Recent Fires vs. Natural, Historic Fires

Recent fires on the Deschutes National Forest have been larger and have burned at higher severity than those experienced historically. For example, the 2003 B&B Fire burned a total of 90,692 acres. The portion that burned on the Deschutes National Forest (67,112 acres) constitutes the largest fire on record for that Forest (Figure 1). B&B Fire impact on ecosystem components such as vegetation, organisms, forest floor, and soil was also greater than that experienced historically. For example, within the fire perimeter, almost a third of the ponderosa pine forest type experienced moderate to high mortality, and almost three quarters of all other forest types experienced moderate to high mortality.

Figure 1. This area of the Deschutes National Forest burned at high-severity during the August 2003 B&B Fire. The Fire burned a total of 90,692 acres.

Looking Ahead

How would you characterize historic, natural fire disturbance on the Deschutes National Forest? Would your answer be the same for ponderosa pine and subalpine fir forest types? What effects might you expect under different fire regimes? These questions will be answered in the next section.

B. Historic Ecosystems and Fire

There is awareness now that fire was a natural part of historic ecosystems in central Oregon. Fire occurred when lightning or humans ignited dry, usually dead, vegetation and down wood. Historically, fire characteristics varied with forest type along precipitation and temperature gradients associated with elevation and topographic changes. Major forest types in which fires occurred included ponderosa pine, mixed-conifer, lodgepole pine, and high elevation forests.

Ponderosa pine forests occur at lower elevations, where climate is warm and dry. These forests experienced frequent surface fire every 11-47 years. Frequent fire maintained low accumulations of understory and dead vegetation (Bork 1985, Soeriaatmadja 1965, and Weaver 1959).

High elevation forests were often dominated by subalpine fir, Pacific silver fir, mountain hemlock, or lodgepole pine. They experienced infrequent fire every 100-600 years. Moist conditions reduced forest flammability, resulting in long fire-free periods that allowed significant fuel accumulation (See Figure 2). Fires still occurred, however, especially during periods of exceptionally dry, hot, and windy weather. When fire did occur, it was usually so intense that a majority of

Figure 2. High elevation forest near Hoodoo Ski Area. Cool, moist climate of high elevation forest is associated with long, fire-free intervals that foster development of multistoried forest structure and high fuel accumulation.

vegetation was killed, including most of the large trees. Few trees survived, in part, because tree species common in high elevation forests have thin bark and shallow roots and are susceptible to fire induced damage and mortality.

Mixed conifer forests covered mid-elevations between ponderosa pine and high elevation forests. With greater precipitation than ponderosa pine forests and warmer temperatures than high elevation forests, mixed-conifer forests are productive. Rapid accumulation of vegetation and flammable dead material supported fire every 9-80 years, with more frequent fire on drier sites. Fire impact on ecosystems was more varied within the mixed-conifer forest type than in other forest types, with surface, understory, and crown fire all common. Generally, fire effects were less severe on drier mixed-conifer sites where fire occurred more frequently.

Finally, lodgepole pine formed pure, highly flammable stands within several forest types, and commonly experienced stand replacing fire (fire that killed most vegetation) every 60-80 years. Lodgepole pine is relatively common at higher elevations, but may also occur at lower elevations in frost pockets or on sites with poor soil, where harsh conditions limit establishment of other species. Extremely dense post-fire regeneration and mortality associated with mountain pine beetle often led to large accumulations of flammable material. In addition, lodgepole pine has thin bark and is susceptible to fire induced mortality, even from low intensity surface fires.

Although fire characteristics generally varied with forest type, the complexity of forest type distribution and variation in fire behavior are important. Not only did forest type vary across the landscape, but fire behavior also varied within each forest type and even within individual fires. Range and variability of fire characteristics on a given site may have been more important than average conditions in terms of ecosystem effects. For example, ponderosa pine seedlings may establish quickly following fire, but seedlings may be killed if another fire occurs within a few years before they develop fire resistant bark. Occasional longer fire-free periods are necessary to allow for seedling survival.

C. Drivers of Current Fire Behavior

Fire suppression, human fire starts, rural development, logging, and other management activities since about 1900 are largely responsible for the recent increase in stand replacing disturbances, including insect and disease outbreaks and high-severity fire (Agee 1993, Kilgore 1981, Simon 1991, USDA FS. 2005a, USDA FS 2004, USDA FS 1996, Walstad et al. 1990). Post-settlement human impact on forest composition and structure has been greatest in ponderosa pine and mixed-conifer forests, which historically experienced more frequent fire (Figure 3). Humans have not significantly altered frequency of wildfire in higher elevation forests, however, because natural fire free periods are longer than the time period since settlement.

Fire suppression has led to an increase in shrubs and small trees, which are more likely to carry fire into the canopy. Pine needles and branches have also accumulated at the base of large trees during prolonged fire-free periods; when fire occurs, these fuel accumulations may take a long time to burn, allowing heat to penetrate through tree bark and cause direct tree mortality or cause stress, which invites subsequent bark beetle attack.

Historic Conditions

Current Conditions

Figure 3. "Turn of the Century" and "Untreated" Metolius Demonstration Plots represent historic and current conditions in the ponderosa pine forest type. Post-settlement human activity, including fire suppression, has led to an increase in shrubs and small trees, which are more likely to carry fire into the canopy. Small trees are also less fire resistant. At a landscape scale, historic forests probably included some features seen in the photo of current conditions, however, such as snags, occasional patches of shrubs, or groups of closely spaced trees. Historic conditions were restored on the "Turn of the Century" plot by logging and underburning.

Fire suppression has also allowed the development of dense forest conditions. These dense forests not only contain large quantities of vegetation, but they are also susceptible to drought stress, insects, and diseases, which may result in additional accumulation of highly flammable dead vegetation.

Finally, where fire has been excluded for extended periods, non-fire resistant species including true firs, incense-cedar, and Douglas-fir have increased in dominance over fire resistant species such as ponderosa pine and western larch, increasing forest susceptibility to fire. In addition, the true firs are more susceptible to drought, insects, and disease (Filip 2002 in Fitzgerald 2002).

Timber harvest of large trees over the last century has exacerbated problems associated with fire suppression. In some areas, past timber harvest has converted landscapes of widely spaced trees of fire resistant species to mosaics of small patches that are densely stocked with young, small trees of fire sensitive species (USDA FS 1996).

Livestock grazing has contributed to reduced fire frequency in ponderosa pine and mixed-conifer forests by limiting growth of understory vegetation that would have periodically carried surface fire. Livestock grazed heavily within central Oregon forests by the mid to late 1800s (Agee 1993 p. 323, Weaver 1959).

Lightning ignites most fires on the Deschutes National Forest. From 1987 through 2001, lightning was responsible for 64% of the 2,815 fires (with identified ignition sources) and ***humans*** were responsible for the remainder. Shown in blue (See Figure 4), human fire starts appear to be concentrated near Sisters, between Bend and La Pine, and near recreation areas northwest of La Pine. When looking at this slide, the need for fuel treatments is obvious. Although the Forest Service might be able to reduce human ignitions some, there is nothing that can be done to limit lightning strikes. So, managers must suppress fires or proactively treat vegetation to alter fire behavior and reduce fire impacts.

Each of the following activities resulted in the specified number of human caused fires: campfires (482), smoking (223), arson (186), debris burning (51), equipment (41), children (31), and railroad (7). About 330 additional fires with unknown ignition sources were started during the same time. Human ignitions are increasing, especially in areas with high recreational use.

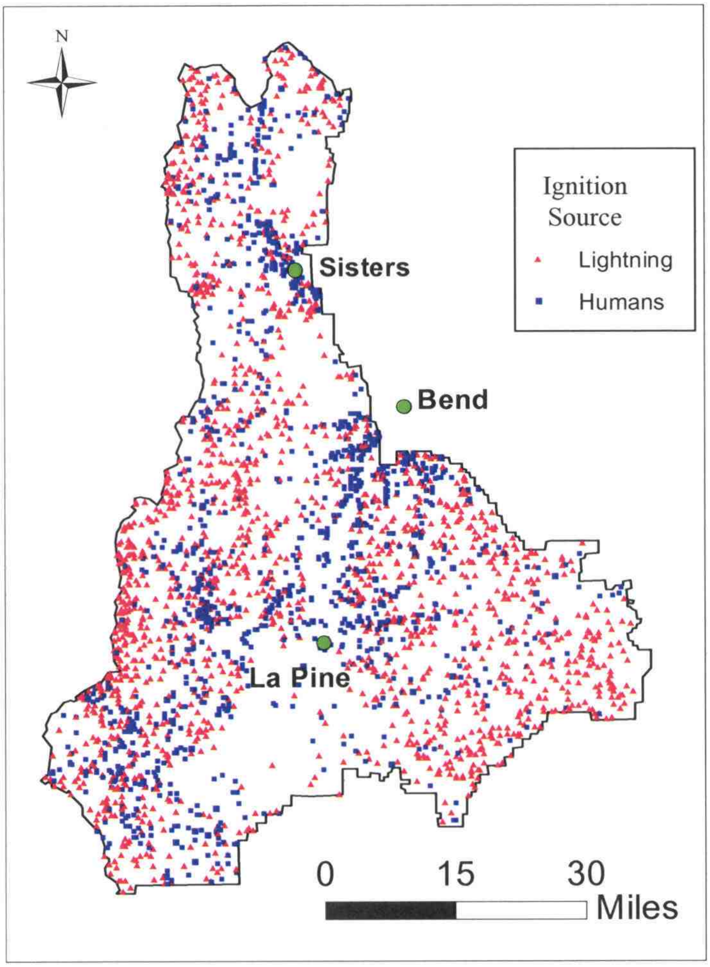

Figure 4. From 1987 through 2001, lightning and humans were responsible for 64% and 36% of 2,815 fires with identified ignition sources on the Deschutes National Forest. The Deschutes National Forest includes almost 1,600,000 acres of public lands.

D. Threat of High-Severity Fire to Multiple Resources

High-severity fire threatens multiple resources, because fire that burns at high temperature or continues to burn the same area for long periods of time generally has more severe impact on ecosystems. High-severity fire may cause high mortality of vegetation (including large overstory trees), delay establishment of new seedlings, accelerate soil erosion, cause the formation of hydrophobic soils, consume old growth habitat, compromise aquatic habitat, and impact scenic and recreational resources (Figure 5). Management activities that reduce the quantity of vegetation and fuels may restore forests so they can support low-severity fire more similar to that experienced historically.

Figure 5. Scenic and recreational values were compromised at Round Lake when the area burned at high-severity during the 2003 B&B Fire.

Looking Ahead

Given the threat of high-severity fire to valued resources and the negative consequences of fire suppression (i.e., change in forest composition and structure), what should be done to restore forests and associated fire regimes closer to those existing pre-settlement? Should all forests be treated in the same way?

E. Fuel Treatments

Vegetation can be treated in a variety of ways to reduce risk of high-severity fire. Although vegetation, climate, and topography all affect fire occurrence and behavior, managers can only influence vegetation (Figure 6). Vegetation may be treated with prescribed fire or mechanical treatments, including thinning, salvage logging, chipping, pruning, and mowing. Often a combination of mechanical treatments and prescribed fire is applied.

Figure 6. Small trees were cleared at this Camp Sherman site to slow the rate of fire spread through the urban interface and to aid in fire suppression. Piles will be burned during the next season.

Treatments are generally intended to create a fire resilient forest by reducing surface fuel loads, raising canopy height, disrupting crown density and contiguity, favoring large trees, and favoring fire resistant species (i.e., ponderosa pine and western larch) (Brown et al. 2003, USDA FS 2005b, Agee 1996, and Chappell and Agee 1996). With the exception of salvage logging, which involves harvest of dead or dying trees, treatments primarily impact litter on the forest floor and small trees and shrubs. Treatments that reduce litter, vegetation on the forest floor, and small trees reduce the likelihood of ground fire spreading upward to the canopy via ladder fuels. In contrast, thinning overstory trees disrupts horizontal contiguity of the canopy, reducing the likelihood of crown fire spreading from one tree canopy to the next. Regardless of treatment type, they are effective only until vegetation regrows, and therefore must be repeated every 10-20 years or so.

To create fuel breaks, forests are often treated in strips. Vegetation may be totally cleared in fuel breaks or widely spaced overstory trees retained in shaded fuel breaks.

Increased moisture and reduced growth of understory vegetation in shaded fuel breaks may offset any flammable material contributed by retained overstory trees. Fuel breaks are usually not intended to stop fires by themselves, but instead to reduce fire impacts, flame length, rate of fire spread, and to buy time until fires can be extinguished by fire suppression crews or by changing weather conditions, and to provide a place where crews may locate safe areas or take a stand when fighting forest fire.

On the Deschutes National Forest, 100-500 foot wide fuel breaks have been strategically located to protect high value resources such as homes in or adjacent to forest, recreation areas, major roads, and northern spotted owl habitat, and are intended to moderate fire behavior and aid in fire suppression efforts. Emphasis has also been placed on treatment of ponderosa pine and mixed-conifer forest to create and maintain stands of large, fire resistant trees that will support fire characteristics more similar to those experienced historically. Much of the Deschutes National Forest has not been treated, however. Investments in fuel treatments are inadequate and are dwarfed by typical fire suppression expenditures that can be thousands of dollars per acre (Calkin et al. 2005).

Prescribed fire is used to reduce forest litter and understory vegetation and to favor fire resistant tree species. Intentionally lit prescribed fires usually do not have severe ecological effects on overstory trees or soil, because they are conducted under relatively controlled conditions when cooler temperatures and higher relative humidity help to reduce fire intensity (Figure 7).

Figure 7. Ideal prescribed fire with short flame length is used at this Metolius Basin site to reduce forest litter and understory vegetation and to favor fire resistant species. (Photo by Jim Boyle)

Mechanical treatment is often necessary to reduce fuels before stands can be burned safely. For example, on the Deschutes National Forest, an understory of lodgepole pine has established on some sites within the ponderosa pine forest type since fire has been excluded (Figure 8). Now, fire would probably lead to high mortality of lodgepole and historically fire resilient, ponderosa pine.

Often mechanical treatment followed by periodic prescribed fire is recommended. In some cases, mechanical treatment may be the only option, because smoke, hot and dry weather, or risk of fire escape and damage to high-value resources precludes prescribed burning.

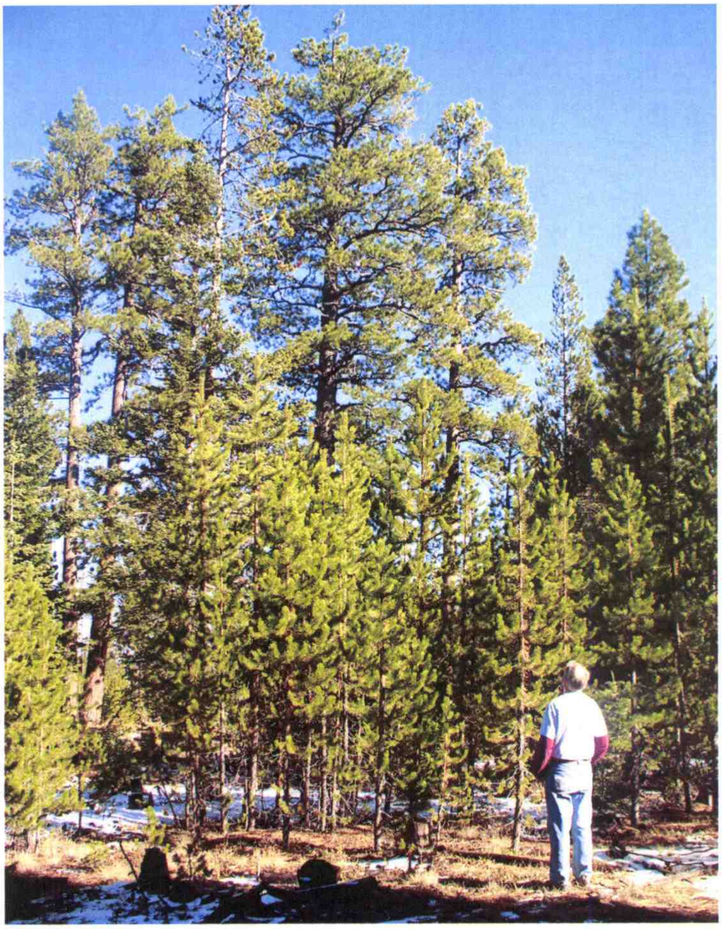

Figure 8. On the Deschutes National Forest, an understory of lodgepole pine has become established on some sites within the ponderosa pine forest type since fire has been excluded. Now, fire would probably lead to high mortality of lodgepole and historically fire resilient, ponderosa pine. Mechanical treatment will be necessary to reduce fuels before stands may be underburned safely.

Response of vegetation to different treatments is variable. For example, thinning at one site near Sisters resulted in only slight sprouting of *Ceanothus* shrubs, but at a nearby site, combined thinning and burning treatments led to vigorous growth of *Ceanothus* shrubs (Figure 9). At the thinned and burned site, heat from the prescribed fire probably stimulated germination of *Ceanothus* seed that had accumulated in the forest floor during the prior fire-free period. Thinning likely contributed to increased sprouting and shrub growth by allowing more sunlight through the canopy. At these sites, light thinning may be the best way to reduce flammable vegetation and associated risk of high-severity fire without stimulating excessive germination of *Ceanothus* seed or allowing too much sunlight to reach the forest floor. This is not universally true, however. In other habitat types, thinning plus burning to kill bitterbrush is better than thinning alone (Ayers et al. 1999, Clark et al. 1982; Clark and Britton 1979; and S. Fitzgerald, personal communication, October 4, 2005).

Figure 9. Thinning at one site near Sisters resulted in only slight sprouting of *Ceanothus* shrubs, but combined thinning and burning treatments stimulated vigorous growth of *Ceanothus*. At these sites, light thinning may be the best way to reduce ecosystem effects of subsequent fire. Aggressive thinning, especially when combined with prescribed burning may actually increase risk of high-severity fire by stimulating shrub growth. This is not universally true, however. In other habitat types, thinning plus burning to kill bitterbrush is better than thinning alone (S. Fitzgerald, personal communication, October 4, 2005 and D. Ayers et al. 1999).

Looking Ahead

Now that we've discussed the change in forest conditions over the past century and possible responses to the increased risk of high-severity fire, can you think of future challenges that may complicate implementation of fuel treatments?

F. Future Challenges and Management Options

Managers are challenged not only by uncertainty in forest response to treatment, but also by conflicting policy directives, management of northern spotted owl habitat, climate change, and other factors. Despite the challenges, fuel treatments are usually compatible with most forest objectives, including both short and long term objectives. Active fuels management is especially appealing once long term risks of inaction and fire suppression are considered.

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II. A Larger Paper Intended for Students, Professionals, and Others Who Want More Information and References

A. Introduction

Fire has been a significant disturbance agent in central Oregon forest ecosystems, but fire behavior and effects have changed over the past century. Post-settlement human activities have altered forest composition and structure, creating forests that are vulnerable to stand-replacing disturbance, including high-severity wildfire (Figure 10). Generally, fires have increased in severity and extent, and now pose a greater threat to valued resources.

Figure 10. This area of the Deschutes National Forest burned at high-severity during the August 2003 B&B Fire. The fire burned a total of 90,692 acres.

To better understand the story of fire on the Deschutes National Forest, I will introduce the concept of fire regime and discuss natural and current fire regimes on the Forest. Identification of pre-settlement, natural fire regimes is useful, because they may serve as baselines for managing fire in forests.

In certain forest types, fuel treatments may restore forest closer to historic conditions. Although fuels, climate, and topography all drive fire regimes, managers may most easily influence fuel characteristics (loading and arrangement). Treatments are designed at stand and landscape scales to maximize benefit, and may include mechanical treatments and/or prescribed fire. Although effectiveness of treatments is recognized by resource managers (Peterson et al. 2005), multiple and sometimes conflicting policy directives, climate change, and other variables complicate implementation of fire and fuel management.

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B. Fire Regime

1. Fire Regime Classification

Let's begin the story of fire on Deschutes National Forest by discussing the concept of fire regime, which incorporates characteristics of fire disturbance. Examination of fire regimes provides a better understanding of fire effects, including those experienced historically under natural fire regimes and those that might result where fire is reintroduced. In the Pacific Northwest, fire regimes are commonly classified according to fire effects on dominant vegetation, by vegetation type where fire regime is being described, or according to fire characteristics (Agee 1993). I will discuss these three systems next.

a. Classification by Fire Effects

Under the first classification system, fire regime is classified according to fire effects on dominant vegetation as low-, moderate-, or high-severity, indicating proportion of mortality. Comparison of fire effects is limited, however, to areas with the same dominant vegetation, because comparing fire effects on species with different fire tolerance indicates little about fire characteristics.

Low-, moderate-, and high-severity fire regimes occur along temperature, moisture, and productivity gradients (Figure 11) and have characteristic fire intensities and return intervals. The three fire regimes have arbitrarily defined mean fire return intervals of <25, 25-100, and >100 years respectively (Agee 1993).

Natural, low-severity fire regimes historically occurred in the Pacific Northwest ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) forest type, where the climate is hot and dry during the summer and productivity is relatively low (Burns and Honkala 1990). Low-severity fire regimes are characterized by frequent low-intensity surface fires with relatively short flame lengths.

High-severity fire regimes occurred in wetter and colder forest types often comprised of mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.), Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), Engelman spruce (*Picea engelmannii* Parry ex Engelm.), lodgepole pine (*Pinus contorta* Dougl. ex.

Loud.), and white bark pine (*Pinus albicaulis* Engelm.) (USDA FS 1996, Burns and Honkala 1990). Fires in high-elevation forests were largely high-intensity and stand replacing.

High-severity fire regimes were also common in forests dominated by lodgepole pine. Lodgepole pine commonly occupied sites where frost or poor soil quality limited establishment of other species (Burns and Honkala 1990). Lodgepole pine forest probably covered large contiguous blocks at higher elevations with more patchy distribution within ponderosa pine and mixed-conifer forests..

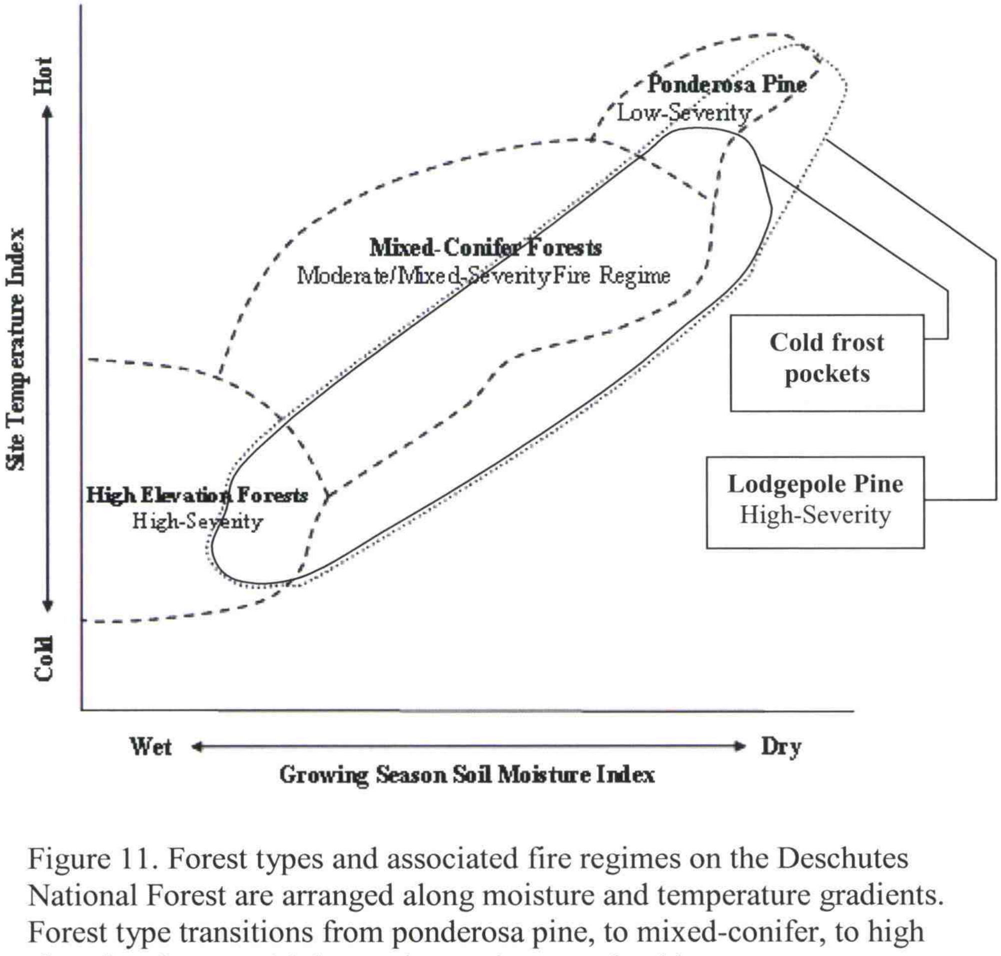

Figure 11. Forest types and associated fire regimes on the Deschutes National Forest are arranged along moisture and temperature gradients. Forest type transitions from ponderosa pine, to mixed-conifer, to high elevation forests with increasing moisture and colder temperatures. Lodgepole pine forms pure, highly flammable stands within several forest types and can be common in frost pockets and on sites with poor soil, where harsh conditions limit establishment of other species (Modified from Agee 1990).

Moderate-severity fire regimes fall in between low- and high-severity fire regimes along temperature and moisture gradients. They include a greater mix of surface, understory, and crown fire, and often result in significant tree thinning and mosaics of patchy vegetation (Agee 2002). Moderate- and mixed-severity fire was most common in this forest type.

Mixed-conifer forests are often highly productive because they receive ample moisture and warm temperatures during the growing season. Rapid vegetation growth provides fuel to support frequent fires.

b. Classification by Habitat Type

Under the second fire regime classification system, fire regime is classified according to the vegetation or habitat type that would potentially exist on a site with historic fire disturbance (Agee 1993, Daubenmire and Daubenmire 1968). Examples of central Oregon plant association groups include lodgepole pine, mixed-conifer wet, mixed-conifer dry, ponderosa pine dry, and ponderosa pine wet (USDA FS 2004). Examples of habitat types developed for the Lolo National Forest in Montana include warm, dry ponderosa pine and moist, Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) habitat types (Davis et al. 1980 and Burns and Honkala 1990). Classification by habitat type is most useful on scales of national forest size or smaller where the number of habitat types is limited, versus over the entire western U.S. that includes hundreds of habitat types.

c. Classification by Fire Characteristics

Pacific Northwest fire regimes are ranked numerically, with higher number indicating less frequent, but more intense fire (Heinselman et al. 1981, Agee 1993). Comparing fire regimes from different regions is possible under this system, because it is based on fire frequency and intensity, instead of on species composition or fire effects on vegetation. The Deschutes National Forest uses a system tailored to the Pacific Northwest that ranks fire regimes from I to V, with lower rank indicating more frequent, lower intensity fire (Table 1) (USDA FS 2005). Ponderosa pine fire regimes are included in Fire Regime Group I, mixed-conifer forests are included in Fire Regime Groups IIIa and

IIIb, lodgepole pine forests are included in Fire Regime Group IV, and high-elevation forests are included in Fire Regime Group V (USDA FS 2005). Fire regimes were mapped under this system during recent analysis of the Metolius Watershed (Figure 12) (USDA FS 2004). The District covers approximately 397,460 acres, with roughly 140,000 acres experiencing low-severity fire (FRG-I), 140,000 acres experiencing mixed-severity fire (FRG-IIIa), and 80,000 acres experiencing high-severity fire (FRG-IV) (USDA FS 2004 Map, USDA FS 2005b). Generally, fire regimes transition from low-severity at low elevations of about 3,000 feet along the eastern edge of the District to high-severity at higher elevations up to about 10,000 feet along the Cascade Crest at the western edge of the District. Drivers of fire regimes will be discussed further in section C.

Table 1. Deschutes National Forest ranks fire regimes from I to V, with lower rank indicating more frequent, lower severity fire. (Modified from USDA FS 2005)

Fire Regime Group	**Fire Frequency**	**Fire Severity**	**Forest Type (Plant Association Group)**
I	0 – 35 years	Low	Ponderosa Pine
II	0 – 35 years	Stand Replacment	Non-forest Grass
IIIa	< 50 years	Low/Mixed	Mixed-conifer Dry
IIIb	50 – 100 years	Mixed	Mixed-conifer Wet
IV	35 – 100 years	Stand Replacement	Lodegepole Dry
V	> 200 years	Stand Replacment	High Elevation (Mountain Hemlock & Whitebark Pine)

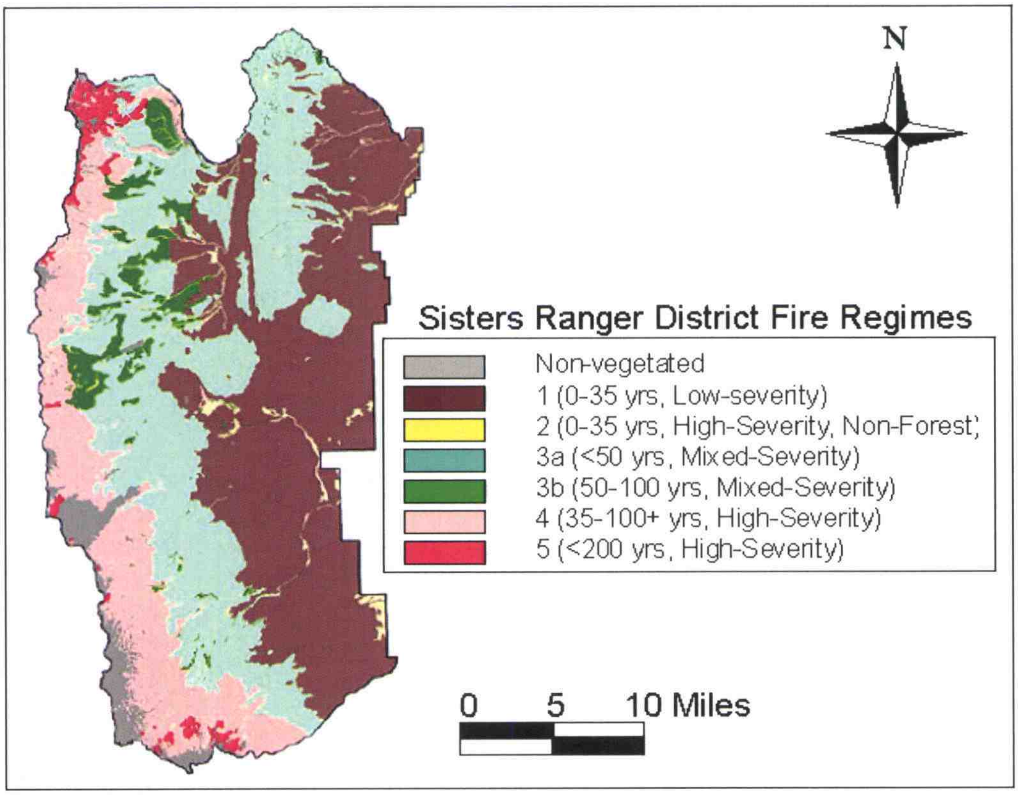

Figure 12. Fire regimes on Sisters Ranger District were mapped according to fire severity during recent analysis of the Metolius Watershed. The District covers approximately 397,460 acres, with roughly 140,000 acres experiencing low-severity fire, 140,000 acres experiencing mixed-severity fire, and 80,000 acres experiencing high-severity fire (USDA FS 2004, USDA FS 2005b)

2. Fire Regime Characteristics

Fire regime is a term that incorporates characteristics of fire disturbance, including frequency, severity, and variability (Pyne et al. 1996). On any large fire, most of us are concerned with ecosystem effects and with impacts of fire intensity and seasonality on fire severity. Through time, fire frequency and fire interaction with other disturbance also impact ecosystems. In many forest types, range and variability of fire effects are more important than average fire conditions. I will now discuss these disturbance characteristics that are incorporated into the concept of fire regime:

a. Fire Severity

Fire severity is of primary interest because it describes fire impact on ecosystem components such as vegetation, microorganisms, forest floor, and soil. Higher severity fire causes greater mortality and consumes more of the forest floor and soil organic matter. Death of plant tissue occurs when its temperature is maintained at or above 60°C for one minute (Agee 1993). For this reason, fires of longer duration or residence time and high intensity fires often have more severe effects.

High-severity fire threatens multiple resources. For example, re-establishment of forest cover may be delayed when high-severity fire causes high mortality of seed trees. Regeneration of ponderosa pine will be limited in areas beyond about 30 meters of seed-source trees (Barrett 1966). High-severity fire may also lead to mortality of the actual seed, even when cones are not consumed. Following the 2003 B&B Fire, seed germination was poor to non-existent on areas that experienced high-severity fire. In contrast, areas that experienced low- to moderate-severity fire had relatively uniform cone crop and seed distribution (USDA FS 2005).

High-severity fire may also impact watershed function by altering stream temperatures, timing of peak flows, and rates of erosion. Since the 2002 and 2003 fires in the Metolius Watershed, sedimentation of spawning areas, changes in stream morphology, and temperature increases have occurred in several subwatersheds (USDA FS 2005).

Finally, high-severity fire impacts recreational resources. According to the Sisters Ranger District, the public considers aesthetics negatively impacted after stand replacing fire. These individuals are likely to react negatively to what they see at severely burned sites for at least five years, until trees become reestablished (Figure 13) (USDA FS 2004).

Figure 13. Scenic and recreational values were compromised at Round Lake when the area burned at high-severity during the 2003 B&B Fire.

b. Fire Extent

Fire extent may refer to either the area burned by a single event or the area burned over a given time period, and varies with climate, vegetation, and other drivers of fire regimes (Agee 1993). Larger burn area may take longer to regenerate, depending on seed source. Survivors, species that regenerate vegetatively (e.g., by sprouting), and light seeded (i.e., wind disseminated) species may dominate in these areas. Fire extent, along with fire-severity, will influence the patchwork mosaic of vegetation found across the landscape. The extent of the B&B Fire seems to have been much larger than historical fires in the same area (Simon 1991)

c. Fire Intensity

Fire intensity is defined as the rate of energy release (kW) per unit length of flame front (m). Fire intensity is important, because of its correlation with fire severity; higher intensity fires are usually more severe. Fireline intensities fall into three categories based on flame length: surface fire, understory fire, and crown fire, with flame lengths of < 1 m, 1-3 m, and > 3 m respectively (Agee 1993). Flame length influences vegetation impacts such as scorch height.

Fire intensity is also relevant when planning fire suppression tactics. For example, frontal attack by handcrews is usually effective on surface fires and mechanized equipment is more appropriate on understory burns, but only remote monitoring is safe on crown fires (Agee 1993 and Pyne et al. 1996). If flame length is known, fire intensity may be calculated as follows:

$$I = 2258\ FL^{2.17}$$

with I = fire intensity ($kW\ m^{-1}$) and FL = flame length (m) (Agee 1993).

d. Fire Seasonality

The time of year during which fires occur also influences fire behavior and effects. In central Oregon, late summer burns tend to be of higher intensity than early spring burns, because fuel moisture decreases with dry weather. Significant mortality may result if burning of dry fuels leads to high intensity fire with long flame lengths. For this reason, prescribed burns are usually conducted in the spring or late fall.

Burning during the spring or late fall still has significant impacts, however. For example, sprouting shrubs are most susceptible during the spring when root carbohydrate reserves have been spent on new shoots, leaves, and flowers. Plant buds are also most susceptible to fire damage at this time of year when they are flushing and exposed (Agee 1993). Surprisingly, impact on seeds and underground roots may also be greatest during spring burns. Although soil temperature is limited to 100°C until all soil moisture is evaporated, soil conducts heat more effectively when wet. As a result, high temperatures may penetrate deeper into the soil profile during spring burns and kill seeds of herbaceous perennials and fine conifer roots (Agee 1993, Fisher and Binkley 2000). Loss of fine roots may exacerbate summer drought stress and increase tree susceptibility to insects and disease.

e. Fire Frequency

Fire frequency refers to the number of fires within a defined time period. It may also be expressed as mean fire return interval, which is the average length of fire free periods in a specified area and given time period. The term *fire return interval* is usually used in describing low-severity fire regimes. Mean fire return interval must be interpreted carefully; all fires are considered, even when they do not burn the entire area of concern, so it will decrease in length when applied over larger areas. Fire rotation is another way to express fire frequency. It is equal to the time theoretically required for an area of given size, say 10,000+ acres, to burn (Agee 1993). The term is usually used to characterize high-severity fire regimes. Finally, fire frequency may be expressed as the median fire return interval. The median return interval may better describe fire frequency than the mean because distributions are typically skewed (Stephens 2004).

f. Synergistic Effects

Fire and other disturbances act together to influence ecosystems and to cause synergistic effects (Agee 1993). For example, fire-induced root or crown mortality may stress trees and lead to insect and disease outbreaks. In some forest types, fire may also increase the risk of blowdown by creating forest gaps and increased canopy roughness, or lead to increased soil erosion by exposing bare mineral soil (Alexander 1964 and Fisher and Binkley 2000). In addition, fire may create more open conditions that encourage flammable herb and grass cover, leading to large, frequent, fast moving, low-severity fire (Harrod et al. 2000).

Not only does fire influence other disturbance, but these disturbances also impacts fire behavior and effects. For example, forest pathogens may alter fire severity as was the case near the Grand Canyon, where moderate-severity fire killed a greater proportion of mistle-toe infected trees than non-infected trees (Harrington and Hawksworth 1990).

g. Range and Variability

Although the differences in mean fire return interval among fire regimes are often emphasized, the variation in fire frequency within each fire regime is significant. Range and variability of fire characteristics on a given site may be more important than average conditions in terms of ecosystem effects. For example, in central Oregon, ponderosa pine and western larch (*Larix occidentalis* Nutt.) are favored by fire that burns with consistently short return intervals of less than a decade. Saplings of these species develop thick bark quickly, because the species evolved under frequent, low-intensity fire regimes (Agee 1993, Brown and Smith 2000, and Burns and Honkala 1990). Where the mean fire frequency is similar, but occasional longer fire free periods of up to 30 years occur, species that are less fire resistant in the sapling stage (i.e., Douglas-fir and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) are more likely to survive and mature (Brown and Smith 2000).

The range and variability of fire characteristics are also significant in the mixed-conifer forests of the southern Oregon Cascades. There, the mean fire return interval between 1700 and 1900 probably ranged from 7 to 13 years, but variation occurred spatially and temporally. Longer fire free periods of up to 30 years were not uncommon (Figure 14) (Sensenig 2002).

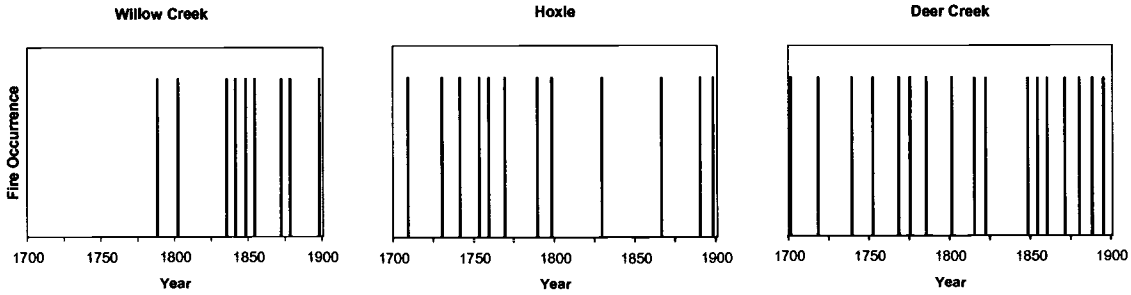

Figure 14. Fire events between 1700 and 1900 on three sites within the mixed-conifer forest of the southern Oregon Cascades. The mean fire return interval probably ranged from 7 to 13 years, but longer fire free periods of up to 30 years were not uncommon (Sensenig 2002).

3. Determining Fire History

Whether fire regimes are classified according to fire effects on dominant vegetation, habitat type, or fire characteristics, a record of fire history must be established prior to classification of natural fire regimes. Records of fire occurrence are created by analyzing fire scars, forest age class distributions, charcoal deposits, and historical accounts. Where possible, years of fires are determined by cross dating. Each method has strengths and weaknesses, and some are more suited for use in certain forest types than others. The different approaches are discussed next.

a. Fire Scars

Fire scar dating is most useful in areas with low-severity fire regimes where there are sufficient numbers of scarred trees. Fire scars are formed when high temperatures penetrate through the bark and kill part of the cambium and may appear as "catfaces" on the base of tree boles. Once a tree is scarred, it is likely to scar again (Figure 15), because the spot will have relatively thin bark, and may have increased buildup of flammable resins and have exposed dead, dry sapwood. Some trees may have up to 30 fire scars (Agee 1993, Sensenig 2002). During extended fire free periods, live cambium slowly grows over adjacent scars and hides record of past fire; stumps may provide a more easily seen fire record. Where stumps are not available and cutting trees down to obtain stem "cookies" is not practical, sections may be cut out of live trees or trees may be cored with an increment borer. Fire scars are an excellent resource when they are available, and can be cross-dated by confirming fire years with landscape-wide patterns of tree diameter growth associated with climatic fluctuations (Bork 1984).

Dating of fire scars is generally not possible in areas with high-severity fire regimes, because high tree mortality and fire consumption of snags and stumps leave limited or no fire scar record. Even in low-severity fire regimes, there are several difficulties in determining historic fire frequency without bias from fire scar records.

First, not every fire causes fire scars, so samples of individual trees probably provide an estimate of minimum fire frequency. Scars on several nearby trees may be tallied, however, to capture a greater number of fire events.

Second, the initial fire free period during which tree establishment occurs must be approximated or ignored when post-fire, pre-germination time period is unknown. If the period is ignored, the mean fire return interval may be underestimated (Baker and Ehle 2001).

Third, trees with multiple fire scars are often selected for sampling to efficiently obtain a relatively complete fire record. Although the point sample will probably underestimate fire frequency at that point because of unrecorded fires, selection of trees with multiple fire scars over a large area may overestimate fire frequency across the landscape (Baker and Ehle 2001). Where an adequate number of scarred trees are present, transect or random sampling may offer less biased alternatives (McBride 1983).

Finally, composite fire frequencies may overestimate fire occurrence when single fires are attributed to more than one year; composite fire frequencies are created by compiling fire scar data over large areas of 10,000s of hectares. Fires occurring within several years of one another are sometimes grouped into one fire event to account for margin of error when assigning fire year (Sensenig 2002).

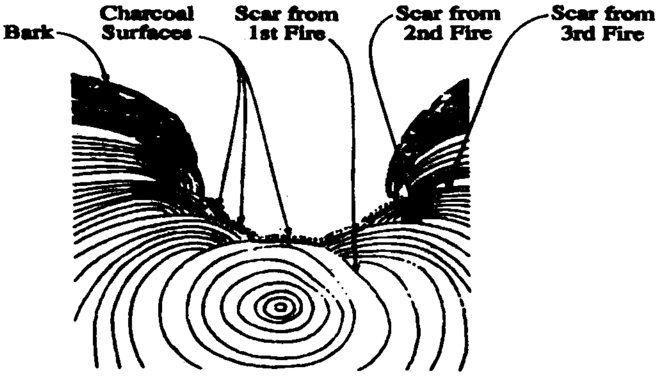

Figure 15. Multiple fire scars on a cross section of ponderosa pine. (Morrison and Swanson 1990)

b. Vegetation Age Class Distributions

Where forest regenerates after stand replacing fires, age class distributions of trees and shrubs (representing pulses of regeneration) may suggest the area frequency, or mean fire return interval across the landscape. In areas subjected to high-severity fire regimes, date of stand establishment and stand size may be the only surviving evidence of past fire. Date of stand establishment is determined by coring the oldest trees of early seral species (Douglas-fir, lodgepole pine, and western larch), but time between disturbance and stand establishment must still be estimated (Agee 1993). After stand replacing fires in the Jefferson Wilderness, regeneration occurred as soon as two years after disturbance on mesic sites near seed sources, but took almost 50 years on exposed south facing slopes (Simon 1991).

c. Historical Accounts

Written accounts and historical pictures also provide insight to historic fire regimes. For example, members of the Wilkes expedition of 1841 and settlers recorded observations of fire during the 1830-1860 period. Later in the nineteenth century, Mark Twain and John Muir wrote of their encounters with forest fire (Agee 1993).

d. Charcoal Deposits

Finally, charcoal deposits are analyzed to detect significant fire years within watersheds or local catchments by dating deposits in cores taken from lake bottoms or peat bogs (Agee 1993). In the North Cascades, fire history has been approximated for the past 12,000 years by analyzing charcoal deposits (Cwynar 1987). Charcoal on tree boles, on sloughed off bark, or in the surface soil also indicates past fire.

4. Looking Ahead

Now that you know what a fire regime is, how would you characterize historic, natural fire disturbance on the Deschutes National Forest? Would your answer be the same for ponderosa pine and subalpine fir forest types? What approach would you use to create a timeline of historic fires? What effects might you expect for different fire regimes?

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C. Natural and Current Fire Regimes

The following section describes natural, pre-settlement fire regimes and current fire regimes associated with ponderosa pine, mixed-conifer, lodgepole pine, and high elevation forests on Deschutes National Forest and discusses factors that shape these fire regimes. Natural fire regimes vary according to elevation and topographic position along precipitation and temperature gradients. Ponderosa pine forests generally occur below 3,500 ft and mixed-conifer forests are found between 3,000 and 5,000 ft. High elevation forests comprised of subalpine fir, mountain hemlock, or lodgepole pine usually occur above 4,000 ft (USDA FS 2005a). Relatively small patches of lodgepole pine will also occur at lower elevations in frost pockets or on sites with poor soil and where harsh conditions limit establishment of other species (Burns and Honkala 1990). Mixed-conifer forests covered mid-elevations between ponderosa pine and high elevation forests. Moisture increased within this forest type with increase in elevation. Of the almost 1,600,000 acres of public land now covered by the Deschutes National Forest, roughly 33% (650,000 acres) is ponderosa pine forest, 16% (311,000 acres) is mixed-conifer forest, 29% (567,000 acres) is lodgepole pine forest, and 10% (192,000 acres) is high elevation forest pre-settlement (D. Thomas, personal communication, September 7, 2005).

Identification of pre-settlement fire regimes (Figure 16) is useful, because pre-settlement fire regimes may serve as baselines for managing fire in forests. Risk to biological diversity and ecological function may increase when conditions do not fall within the natural historic range of variability under which species evolved, although this assumption has not been tested (USDA FS 1996). Delineation of forest types and fire regimes is not clear cut, however. There is a complex mosaic of forest types across the Deschutes National Forest and a lot of variability within each forest type. For example, sites within the ponderosa pine forest type may be occupied by ponderosa pine or by bitterbrush. From a practical standpoint, the complexity challenges managers today, but also presents an array of possible future forest conditions that may be managed for to achieve different objectives.

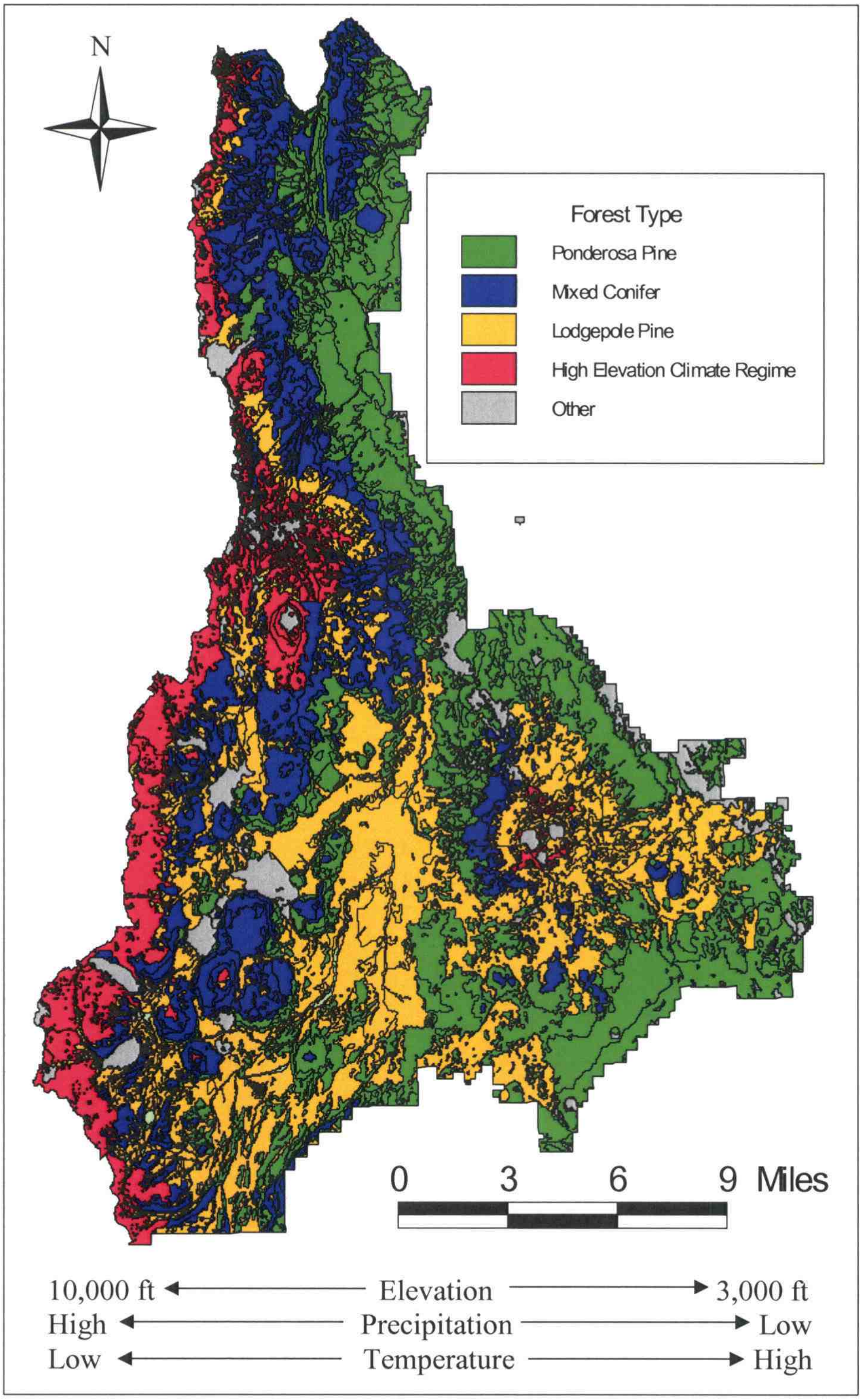

Figure 16. Historic, natural fire regimes, classified by forest type. The fire regimes varied along elevation, precipitation, and temperature gradients. Today, distribution of fire regimes is different, because human activities have altered forest composition and structure. (Data Source: USDA FS 2005b)

Distribution of fire regimes has changed over the last century, however. Current fire regimes on the Deschutes National Forest are different than those experienced historically, because fire suppression, logging, and grazing since about 1900 have altered forest and fuel structure. Large, high-severity fires are now more common. Recent fires support this trend. For example, within the Metolius Watershed average fire size increased from 984 acres during the 19th century to 3,330 acres over the 1900-2004 time period, with four times as many acres burned during 2002 and 2003 than from 1900 to 1999 (USDA FS 2005a). Across the entire Deschutes National Forest, 249 fires of at least 3 acres in size burned during the time period from 1908 through 2003, with more acres (approximately 200,000 acres) burned during the time period from 1990 through 2003 than in the previous 80 years (approximately 193,000 acres) (Figure 17). In addition, the portion of the 2003 B&B fire that burned on the Deschutes National Forest constitutes the largest fire on record for that Forest. The B&B Fire burned a total of 90,692 acres (USDA FS 2004, USDA FS 2005a). Severity of the B&B Fire was also outside the historic range of variability. Of areas burned by the fire on Sisters Ranger District, 32% of the ponderosa pine forest type experienced moderate (25-75%) to high (>75%) mortality. Mixed-conifer, lodgepole, and high-elevation forests experienced 68%, 82%, and 67% moderate to high mortality (USDA FS 2005a).

Change in fire regime has not been experienced equally across all forest types, however. Overall, impact of human activity has been greatest in forest types with shorter historic mean fire return intervals.

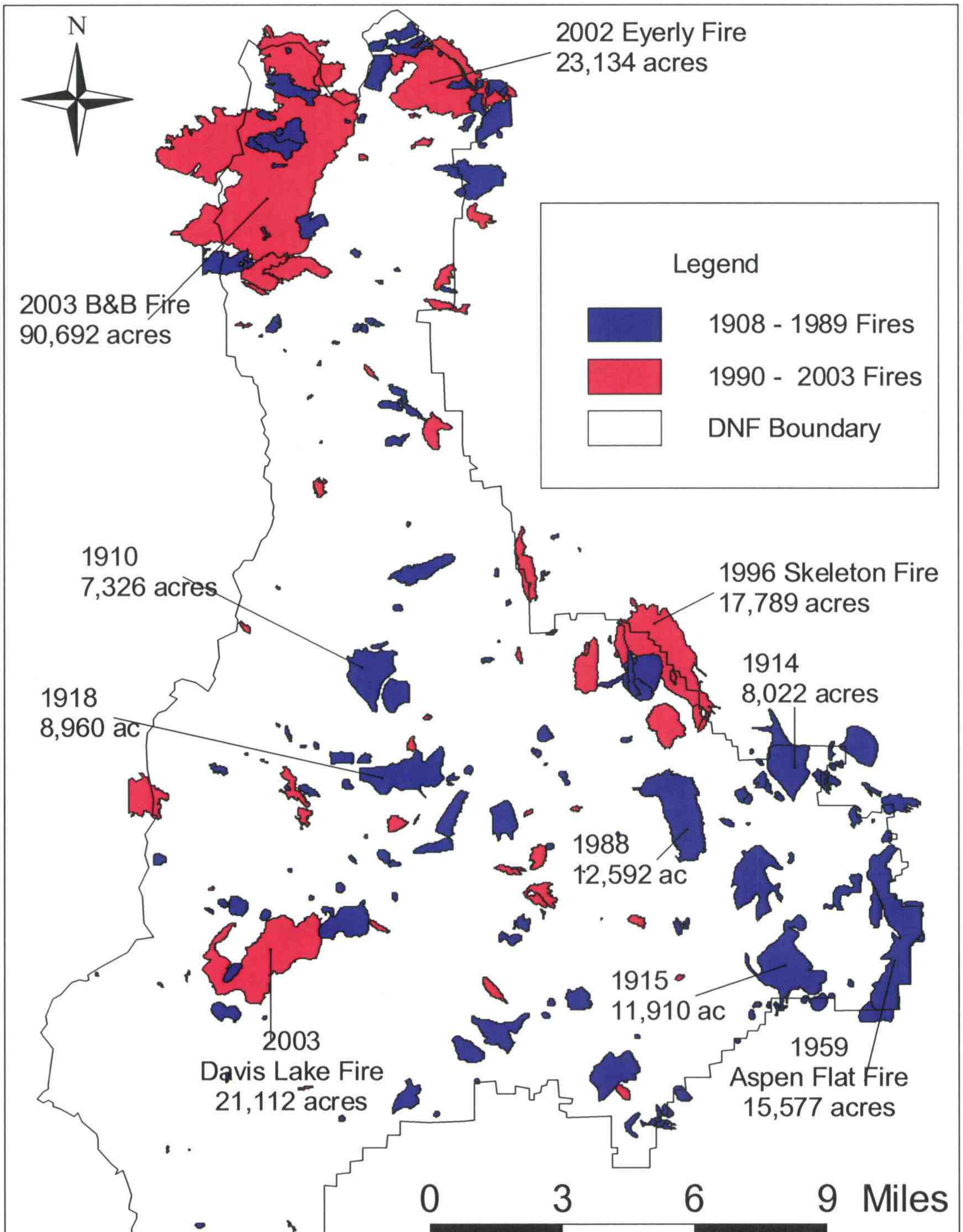

Figure 17. From 1908 through 2003, 249 fires of at least 3 acres were documented on or adjacent to Deschutes National Forest. A larger area (approximately 200,000 acres) burned during the time period from 1990 through 2003 than during the previous 80 years (approximately 193,000 acres). The 67,112 acres of Deschutes National Forest that burned during the 90,692 acre B&B Fire constitutes the largest fire on record within the Forest. (Data Source: USDA FS 2005b)

1. Ponderosa Pine Forest

Historic Conditions
Trees/Acre: 34
Mean Diameter: 23 in
Basal Area: 115 sq ft
Stand Density Index: 147
Relative Density Index: 0.293
Mean Height to Live Crown: 36 ft

Current Conditions
Trees/Acre: 141
Mean Diameter: 12 in
Basal Area: 144 sq ft
Stand Density Index: 233
Relative Density Index: 0.465
Mean Height to Live Crown: 21 ft

Figure 18. "Turn of the Century" and "Control" Metolius-Forest Service Demonstration Plots represent historic and current conditions in the ponderosa pine forest type. Development of high stand density and multistoried stand structure has led to increased risk of stand replacing disturbance. Not only has the fuel load increased, but the smaller trees are less fire resistant. Small trees can also carry fire up into the canopy. Historic conditions were restored on the "Turn of the Century" plot by logging and underburning.

Presettlement, ponderosa pine forest covered large areas. Forest canopy was open, giving a park-like appearance (Figure 18). Tree distribution was uneven, however, with clumps up to a few acres in size. Patches were created as clumped trees senesced, succumbed to insects or disease, or torched during otherwise low severity fires as a result of excessive fuel loading or mistletoe infestation (Agee 1992).

In moister ecotones, ponderosa pine forests were denser and included Douglas-fir and western larch. In drier ecotones, stands were more open and included juniper (*Juniperus* occidentalis Hook.), incense-cedar (Calocedrus decurrens Torr.), and some lodgepole stands. Grass, shrubs, and forbs were common in the understory (USDA FS 2005a and Burns and Honkala 1990).

a. Fire Severity

The Sisters ponderosa pine forests historically experienced frequent, low-severity fire. Low fire severity of past fires has been inferred from the survival of trees with fire scars and also from historical accounts. Short fire return intervals limited fuel accumulation in central Oregon ponderosa pine forests. With the exception of isolated spots with significant fuel accumulations, fire severity was commonly limited by the lack of fuel. Pine needles and other fine fuels produced by understory vegetation accumulated fast enough to support frequent surface fire, however.

Also, fire within the ponderosa pine forest type was often low-severity, in part, because the trees were adapted to this fire regime. For example, most mature ponderosa pine and western larch survived surface fire because they have thick cambium-insulating bark. Ponderosa pine, in particular, develops fire-resistant bark at a diameter of 5 cm (Hall 1976), allowing for some saplings to survive low-intensity fires.

Fire behavior and effects probably varied within perimeters of individual fires and among different fires. High-severity fire probably occurred even in low-severity fire regimes during especially hot, dry, and windy periods, or after fuels accumulated during prolonged fire free intervals. For example, a 1,000 acre even-aged stand of ponderosa pine in Pringle Falls Experimental Forest (within the Deschutes National Forest southwest of Bend) suggests the occurrence of stand replacing fire (Bork 1985).

b. Fire Extent

Most historic fires in central Oregon ponderosa pine forests were also probably small in extent. Frequent fires may have created a mosaic of vegetation and fuels that inhibited fire spread over large areas; fires may have stopped where fuel loads were reduced by past fire.

Small extent of past fires is evidenced on the Deschutes National Forest where the largest fire estimated for a dry Pringle Butte site was only 40 acres for the period from 1400 to 1900 (Bork 1985). In addition, at Pringle Butte and Cabin Lake sites, average within plot (40 acre) mean fire return intervals were 7 and 17 years less than mean fire return intervals across 6 plots (total of 240 acres), indicating the patchy burn pattern of either a single large fire or several small fires in these ponderosa pine forests. Furthermore, all six plots at each site never burned in the same year (Bork 1985). In addition, average patch size on Warm Springs and at Pringle Falls were only 0.62 and 0.06 to 0.86 acres (Morrow 1985 and West 1969). Interestingly, trees were relatively uniformly spaced within clusters at Warm Springs, perhaps because of selective natural thinning of denser clumps in response to competition for moisture (although eastside ponderosa pine tend not to self thin), and because of more intense fire in areas with greater fuel loads (Cooper 1960; Agee 1993; and S. Fitzgerald, personal communication, October 4, 2005).

c. Fire Seasonality

Most fires within the Deschutes National Forest occur mid-summer to fall. Seasonality is important because ecological effects differ with time of year fire occurs. For example, about 35% of bitterbrush will sprout after spring burns, but mortality is close to 100% after fall burns (Clark et al. 1982). Frequent fall burns favor grasses over bitterbrush (Agee 1993). In addition, Idaho fescue (*Festuca idahoensis* Elmer) and squirreltail (*Sitanion hystrix* (Nutt.) Smith) resist summer burns better than spring burns (Volland and Dell 1976). These grasses are abundant on the Deschutes National Forest (Bork 1985).

d. Fire Frequency

Historic fire return intervals have been estimated for several central Oregon locations, including two sites on the Deschutes National Forest, where the natural historic mean fire return interval was estimated to be 11 and 15 years at elevations of approximately 1900 and 1100 meters (Bork 1985). Estimates of fire return intervals on two Warm Springs Reservation sites ranged from 11 to 47 years and 14.2 to 30.2 years based on studies of 4 and 305 individual stumps respectively, with some stumps in mixed-conifer locations (Weaver 1959, Soeriaatmadja 1965). A longer return interval of 150 years has been suggested for stand replacing fire within the ponderosa pine forest type (USDA FS 1996). High-severity fire generally was limited in ponderosa pine forests, occurring only under extreme weather conditions or after fuels accumulated during relatively rare, long fire-free periods (USDA FS 1996).

Although fire was common in ponderosa pine forests, timing was variable and extended fire free periods did occur (Figure 19). Regeneration may be enhanced or inhibited, depending on fire return interval. For example, a new cohort may become established following fire that prepares a suitable seed bed by exposing bare mineral soil and removing competition. Scorched litter, including pine needles dropped from scorched tree canopies, may also benefit tree regeneration on some sites by moderating soil temperature fluctuation and slowing rate of soil moisture loss (Bonnet et al. 2005). At other sites, seedlings may establish where pine needles have been removed and roots can penetrate soil more easily. If a prolonged fire-free period follows, many seedlings may become established and grow into the sapling size (Agee 1993). If, however, the site burns again before trees mature and develop fire resistant properties, the disturbance is likely to remove younger cohorts and limit regeneration (Hall 1976). No relationship between fire-free periods and seedling establishment has been confirmed in central Oregon, however, possibly because climate trends (and associated fluctuation in available soil moisture) and timing of good cone crops complicate analysis (Bork 1985).

Fire frequency may also be related to understory composition. For example bitterbrush was historically reduced or absent in many places where, today, it is very abundant (S. Fitzgerald, personal communication, October 4, 2005; Clark et al. 1982; and Clark and Britton 1979).

e. Current Conditions

Central Oregon ponderosa pine forests have missed, perhaps, two or more fire cycles (S. Fitzgerald, personal communication, October 4, 2005) and as a result are increasingly subjected to high-severity fire. Whereas presettlement fire was typically carried by pine needles and other fine fuels produced by herbaceous vegetation, fires are now also carried by branches and other down wood that accumulate during extended fire-free periods and shrubs (USDA FS 1996). In addition, forests are denser and contain a greater proportion of young trees in the understory and mid-story canopy.

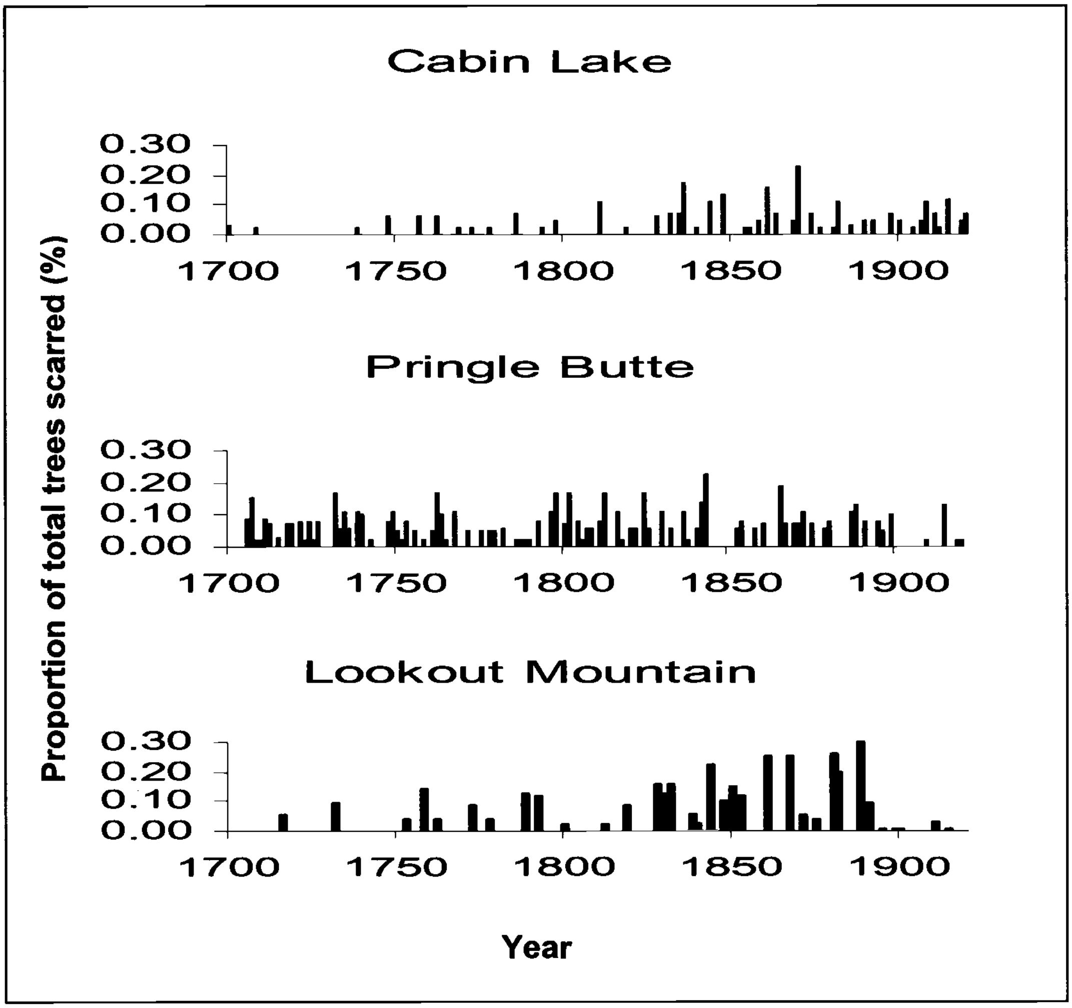

Figure 19. Proportion of total trees scarred at three Deschutes National Forest sites during from 1700 to 1920. Forest type is ponderosa pine at Cabin Lake and Pringle Butte and mixed-conifer at Lookout Mountain. Bar spacing indicates fire frequency. Although fire was common, timing was variable and extended fire free periods did occur. (Redrawn from Bork 1985)

In areas burned by the B&B Fire, pre-fire forest fuels were outside the historic range of variability. For example, the proportion of large trees (>20 inch dbh) declined from historical levels of 30-70% to only 15% by 2003. At the same time, the proportion of poles (5-9 inch dbh) and small trees (9-20 inch dbh) increased from historical reference conditions about 65% (USDA FS 2005a). Metolius demonstration plots illustrate the change in ponderosa pine forest structure experienced over the last century. The “Turn of the Century Forest,” which represents natural, historic conditions, has mean diameter of 18 inches and has 84 trees per acre. Munger (1917) found 12-35 trees per acre 12 inches diameter and larger in ponderosa pine forests of Oregon. In contrast, the "Untreated" control, which represents current conditions, has a mean diameter of 12 inches and 141 trees per acre (Figure 18).

2. *Mixed-Conifer Forest*

"Historic" Conditions	Current Conditions
Trees/Acre: 21	Trees/Acre: 656
Mean Diameter: 24 in	Mean Diameter: 6
Basal Area: 80 sq ft	Basal Area: 317
Stand Density Index: 100	Stand Density Index: 596
Relative Density Index: 0.189	Relative Density Index: 1.124
Mean Height to Live Crown: 43 ft	Mean Height to Live Crown: 22 ft

Figure 20. These Deschutes National Forest Stands represent historic and current conditions in the lower elevation mixed-conifer forest type. Development of higher stand density and multistoried stand structure has led to increased risk of stand replacing disturbance. At a landscape scale, historic forests probably included some features seen in the photo of current conditions, however, such as snags, occasional patches of shrubs, or groups of closely spaced trees.

Mixed-conifer forests are very productive and fuels accumulate in this forest type more rapidly than in either the lower and drier ponderosa pine forests or in the colder high-elevation forests. Historically, mixed-conifer forest often included ponderosa pine, Douglas-fir, and western larch as dominant overstory species with sparse understories of shade tolerant species such as white fir and incense cedar (Agee 1993, and USDA FS 1996). Frequent fire maintained open, parklike stand structure (Figure20) (USDA FS 2005a).

a. Fire Severity

Mixed-conifer forest historically experienced a more variable-severity fire regime than that of the ponderosa pine forest type, with low-, moderate-, and high-severity fires all common (USDA FS 1996). Fires were generally more frequent and less severe at lower elevations (drier sites) within this forest type. On average, sites within the Jefferson Wilderness grand fir zone burned about 2 ½ times during the period from 1720 to 1990, with 243% of the areas burned and reburned. About three-quarters of this area burned at high-severity (Simon 1991).

In addition to high forest productivity, insects and diseases affect rate of fuel accumulation in mixed-conifer forests. Western spruce budworm (*Choristoneura occidentalis* Freeman), fir engraver (*Scolytus ventralis* LeConte), western pine beetle (*Dendroctonus brevicomis* Leconte, Armillaria root disease (*Armillaria* sp.), and western dwarf mistletoe (*Arceuthobium campylopodum* Engelm.) have each played a role. For example, during the late 1980s and early 1990s, western spruce budworm caused defoliation of true fir and Douglas-fir leading to topkill and tree mortality. Subsequent drought, armillaria root disease (*Armillaria* sp.), and Douglas-fir bark beetle (*Dendroctonus pseudotsugae* Hopk.) also caused mortality of trees weakened by the western spruce budworm. Forest inventory in 1995 indicated cumulative reduction in basal area from about 323 to 200 square feet per acre (USDA FS 1996). However, fire exclusion may have exacerbated this situation with the increase in true fir species, which are more susceptible to insects, disease, and drought. This illustrates a negative feedback condition (S. Fitzgerald, personal communication, October 4, 2005).

Presettlement, mixed-conifer sites were typically dominated by ponderosa pine, western larch, and Douglas-fir (Agee 1993 and USDA FS 1996). These species develop thick bark that insulates the cambium from heat. These species are also relatively tall when mature, so they can often avoid crown scorch. Western larch has the additional advantage of being deciduous, so consequences of crown scorch are minimal, especially when fire occurs late in the growing season (Agee 1993). New spring foliage provides benefits early in the season too, because it generally has higher moisture content and is less flammable than older foliage of associated evergreen conifers (Agee 1993).

Understory species associated with the mixed-conifer forest also have evolved adaptations to fire. For example, *Ceanothus* seed in the soil (seedbank) may germinate profusely after stimulation by heat, as was the case in many areas inside the B&B Fire Complex perimeter (Figure 21). Post-fire germination of *Ceanothus* was also documented in Washington's Entiat River Drainage, where *Ceanothus* was the dominant understory species following a 1970 wildfire (Tiedmann and Klock 1976). Frequent fire will kill populations of non-sprouting shrubs, however, including certain populations of *Ceanothus*, as seed banks are depleted (Agee 1993).

Figure 21. Heat from the B&B Fire stimulated germination of *Ceanothus* seedbanks. Shrub cover is shown two years after the burn.

b. Fire Extent

Historically, patch size ranged from 100 to 1000 of acres in size (USDA FS 2005a). For example, a stand replacing fire was probably responsible for the establishment of a 1,000 acre mixed-conifer stand in Pringle Falls Experimental Forest.

Also, according to Deschutes National Forest records written in the early 1900s, the Edison Ice Cave lightning fire burned more than 7,000 acres of mixed-conifer forest southwest of Bend (Bork 1985). In addition, Simon (1991) identified 17 major fires within the Jefferson Wilderness that burned since 1518. Estimated area burned within the mixed-conifer forest type during each of these fires ranged from less than a hundred acres to more than 5,000 acres.

c. Fire Seasonality

Most fires within the Deschutes National Forest occur mid-summer to fall, when fuels are dry and lightning is common. Drivers of fire regime will be discussed further at the end of this section.

d. Fire Frequency

Mean fire return interval was estimated to range from 9 to 25 years for 40 acre plots at Lookout Mountain mixed-conifer sites in the Deschutes National Forest (Bork 1985). Fire frequency in Deschutes mixed-conifer forests of 30-50 years at lower elevations and 50-80 years at higher elevations have also been reported (USDA FS 1996). On Warm Springs Reservation, examination of one stump from the mixed-conifer forest indicated a fire return interval of 47 years (Weaver 1959). Other research in the eastern Cascades of Washington has found fire return intervals of 33-100 years over 30 ha sites (Wischnofske and Anderson 1983). In the central Oregon Cascade western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)/Pacific silver fir transition zone, mean fire return intervals were estimated to be 149 years and in the Jefferson Wilderness Pacific silver fir zone mean fire return intervals were estimated to be 138 years. During the time period from 1720 and 1990, only 5% of the Pacific silver fir zone did not burn (Simon 1991 and Morrison and Swanson 1990).

Drier sites, historically dominated by ponderosa pine, may have burned as frequently as every 8-20 years (Emmingham 2005). At grand fir dominated mixed-conifer forests in Montana, low- to moderate-severity fire was estimated to occur every 17 to 75 years and high-severity fire every 100 to 340 years (Agee 1993). Estimates of fire frequency are probably conservative, however, because stumps only record low- to moderate-severity fires and stand replacing fire also occurs in this forest type.

On drier mixed-conifer sites dominated by Douglas-fir, fire return intervals may be similar to those in the ponderosa pine forest type. Return intervals of light- and moderate-severity fire have been estimated for eastside Oregon and Washington Cascade sites to range from 8-24 years (Agee 1993). Some mixed-conifer sites may have shorter fire return intervals than typical ponderosa pine forests, because fuels accumulate faster in the more productive mixed-conifer forests (USDA FS 1996). On more mesic mixed-conifer sites, increased moisture leads to less frequent, but often more severe fire (USDA FS 2005a).

Short fire return intervals maintain classic "fire climax" communities dominated by fire resistant species such as ponderosa pine, western larch, and mature Douglas-fir. In scattered stands where fire is excluded for longer periods, non-fire resistant climatic climax species increase in importance (USDA FS 2005a).

e. Current Conditions

Where fire has been excluded for extended periods, shade tolerant Douglas-fir and true firs have increased in dominance over intolerant early seral species such as ponderosa pine and western larch, increasing forest susceptibility to high-severity fire. Fire suppression and logging have altered species composition of the Metolius Basin, where dominant tree species shifted from ponderosa pine in 1953 to Douglas-fir in 1993 (USDA FS 1996). Also, in dry mixed-conifer forest burned by the B&B Fire, pre-fire species composition was outside the historic range of variability; area dominated by early seral species had decreased from natural levels of 35-79% to 23% by 2003. At any one location, conditions had departed from historical reference conditions between 33 and 67%. In wet mixed-conifer forests, departure from historical reference conditions was less dramatic, where proportion of large trees (>20 inches dbh) decreased less than 33% (USDA FS 2005a).

A significant proportion of fires in Deschutes mixed-conifer forests now burn at high-severity. Mixed-conifer forest comprised almost ¾ of the area burned by the B&B Fire. Of this area, almost half burned at high-severity leading to tree mortality of greater than 75% (Figure 22) (USDA FS 2005a). Variability of fire severity within the fire perimeter was significant, however, with 20% of the area burning at mixed-severity (25% - 75% mortality) and 33% burning at low-severity (< 25% mortality) (USDA FS 2005a).

The proportion of fires in mixed-conifer forests burning at high-severity has increased because light intensity fires have been suppressed and because human activities during the past century have altered forest structure and composition. Areas in mixed-conifer fire regimes have probably missed at least one fire cycle over the last century (USDA FS 2005a).

Fire suppression has led to the development of more fuels and to more contiguous fuel distribution (Figure 20). Fuel loads have increased more in mixed-conifer forests than in any other forest type, because of high biomass production and high mortality associated with overstocking, moisture stress, insects, and disease (USDA FS 1996). Numerous insects and diseases impact mixed-conifer forests. With the exception of mistletoes, impact is usually greatest in dense stands (USDA FS 1996).

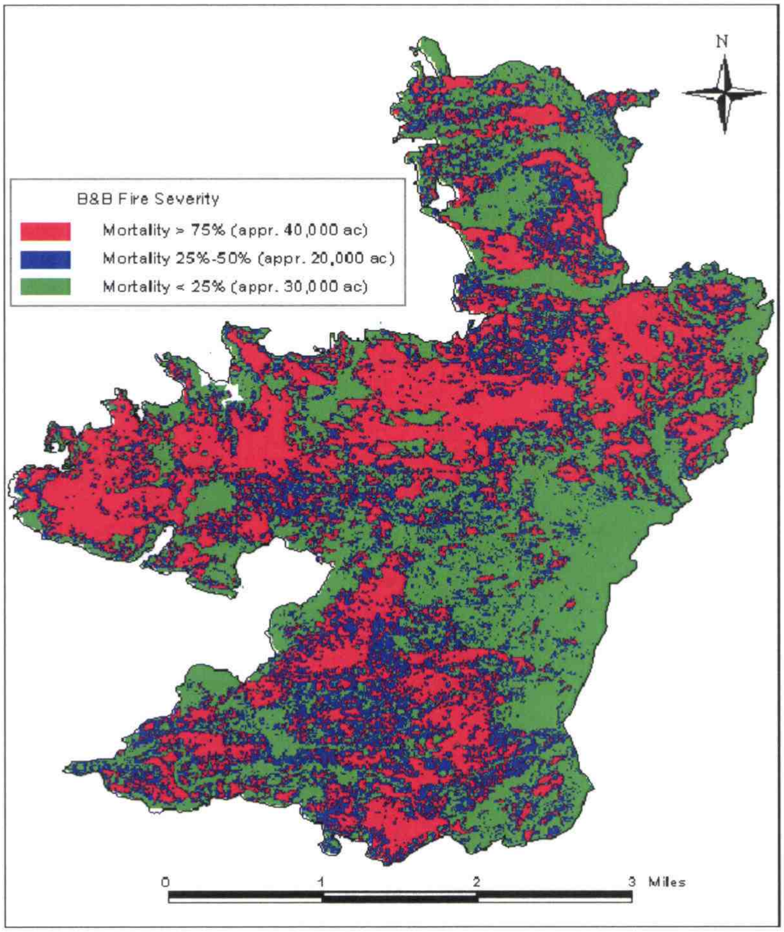

Figure 22. Fire severity within the B&B Fire Complex. Approximately 40,000 of the 90,692 acres affected burned at high-severity with resulting mortality greater than 75%. (Data: USDA FS 2005b)

3. Lodgepole Pine Forest

Figure 23. Pure stands of lodgepole pine occur at higher elevations near the Cascade Crest. Profuse regeneration often leads to dense stands, which are susceptible to high-severity crown fire.

Lodgepole pine dominates on pumice flats, frost pockets, and high-elevation plateaus (Figure 23) (Emmingham 2005). Lodgepole pine may also survive on sites where poor soil conditions exclude other species (USDA FS 1996 and Burns and Honkala 1990). Presettlement lodgepole pine stands were dominated by lodgepole pine, but contained smaller amounts of ponderosa pine, subalpine fir, mountain hemlock, spruce, and white pine depending on stand elevation and site conditions (USDA FS 1996). An understory of lodgepole pine has recently become established in parts of the ponderosa pine forest type since fire has been excluded on the Deschutes National Forest

(Figure 24). In many areas, forest composition has transitioned from ponderosa pine to lodgepole pine after logging.

Figure 24. An understory of lodgepole pine has become established in parts of the ponderosa pine forest type where fire has been excluded on the Deschutes National Forest. Fire would now probably lead to high mortality of lodgepole and historically fire resilient, ponderosa pine.

a. Fire Severity

Fire in lodgepole pine stands is typically high-severity. The species has thin bark and is susceptible to surface fire induced damage and mortality. Also, post-fire lodgepole pine regeneration can be very dense and capable of carrying crown fire (Figures 23 and 24). For example, on some unthinned sites in northeastern Oregon, lodgepole exists at 2,000 trees per acre with diameter of only about 4 inches at age 100. In contrast, stands that were previously thinned to 150 trees per acre average about 12 inches diameter (Emmingham 2005). In addition, in the central Oregon Cascade Mountains, densities of 1619 stems/ac have been reported in 60 year old lodgepole pine stands (Dickman and Cook 1989).

Lodgepole pine often regenerates profusely on mineral soil once the organic matter is removed by fire or other disturbance. As a result, the species increases in dominance over Douglas-fir and western larch under high-severity fire regimes (Kilgore 1981).

Insects and diseases also contribute to high-severity of fire in lodgepole pine forests. Risk of mountain pine beetle outbreak increases when fire free periods extend beyond 100-150 years. Mountain pine beetle may kill almost all of the larger trees, increasing fuel load dramatically.

In the Rocky Mountains, however, where a significant percentage of cones are serotinous, outbreaks of mountain pine beetle have resulted in species conversions to subalpine fir at lower elevations and to spruce at higher elevations. These species are most likely to dominate where lack of fire has limited lodgepole pine regeneration (Kilgore 1981).

In the central Oregon Cascade Mountains, laminated root disease (*Phellinus weirii* (Murrill) Gibertson) increases in significance in stands older than 200 years. The root rot may speed conversion to mountain hemlock on some sites (Dickman and Cook 1989).

Extremely dense post-fire regeneration and insect and disease related mortality typically lead to stand replacing fire, but low-severity fire does occur in this forest type (Agee 1993). For example, evidence of surface fire has been found in lodgepole pine stands of the Bitteroot National Forest and Northwest Wyoming (Kilgore 1981). Surface fire has also been documented in lodgepole pine forests of the Bob Marshall Wilderness with return intervals of 20 to 40 years, and scarred lodgepole pine and Douglas-fir within perimeters of high-severity fire indicated variability in fire severity (Kilgore 1981). In areas with large accumulations of down wood, even surface fire may cause significant mortality when fire consumes down logs and damages roots and tree boles (USDA FS 1996).

b. Fire Extent

Fires in lodgepole pine forests vary in extent. In central Oregon high elevation mountain hemlock forests where lodgepole pine is an early seral species, half of a 44,479 acre study area experienced stand replacing fire over the last 500 years. Fire size varied from less than 3 acres to about 7,900 acres (Dickman and Cook 1989). Fires of large extent are also evidenced by the 1988 Yellowstone fire (Agee 1993).

c. Fire Seasonality

Most fires in central Oregon lodgepole pine forests occur during late summer and early fall, as is evidenced by the distribution of lightning fire frequency in the Jefferson Wilderness (Figure 25). Further discussion of fire seasonality follows in the section on fire regimes of high elevation forests.

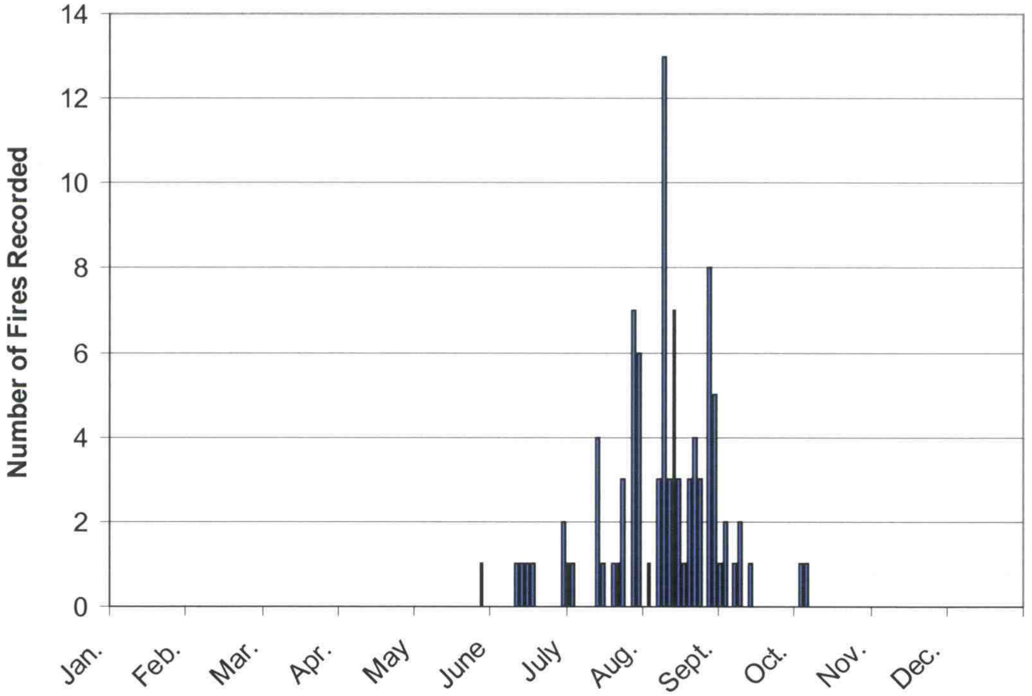

Figure 25. Most fires in the Jefferson Wilderness east of the Cascade Crest from 1918 to 1990 occurred mid- to late-summer, and none occurred before mid-May or after the first week in October. (Simon 1991)

d. Fire Frequency

Oregon's lodgepole pine forests probably had a mean fire return interval between 60 and 80 years, indicating a moderate- to high-severity fire regime (Agee 1993 and Emmingham 2005). Within the Metolius Watershed, lodgepole pine is common in areas that have burned in the last 100 years. Where fire has not occurred during this time period, mountain hemlock or silver fir is more likely to dominate as lodgepole pine senesce and die (USDA FS 1996).

In the northern Rockies mean fire return intervals for 100-200 acre areas ranged from 25 to 50 and 50 to 100 on sites with dry and wet summers respectively (Kilgore 1981). Lodgepole pine live only 100 to about 300 years, depending on site characteristics, so the species can be eliminated from sites with long fire return intervals that preclude conditions necessary for regeneration (Kilgore 1981). Lodgepole pine will also be lost on sites with fire return intervals less than about 25 years, the period required for new seed production. In such cases, persistent brushfields may result. Low-severity surface fire can lead to pure lodgepole stands, however, by thinning spruce and true firs from the understory (Kilgore 1981).

Interactions between fire and other disturbance are especially pronounced in lodgepole pine forests and can lead to relatively consistent fire return intervals. One common disturbance cycle identified by Agee (1993) involves fire, insects, and pathogens. During this cycle, an area is burned after down logs accumulate and log interiors rot sufficiently (over about 50 years) to carry fire. Ensuing bole and root damage then attract mountain pine beetle, which initially target large, fire-scarred lodgepole pine, but then expand to non fire-scarred trees and reach epidemic size causing significant mortality. Basal area loss can be more than 50%, with average tree age and size reduced. Fire scarred roots also provide entry points for fungal pathogens that may decay 40 cm of the bole in 50 years (Gara et al. 1985). Finally, fire fosters lodgepole regeneration by exposing bare mineral soil and reducing competition. The disturbance cycle then begins again once down logs accumulate from bark beetle killed trees and rot sufficiently to carry another fire.

Another possible pathway occurs when a series of moderate- to high-severity fires thins the lodgepole pine forest and removes ground and ladder fuels, leaving a vigorous, mature overstory. Surface fire will then be more likely than stand replacing fire until the forest structure changes again after the trees senesce (Kilgore 1981).

e. Current Conditions

Fire suppression has altered the natural, historic fire regime of lodgepole pine forest less than the ponderosa pine and mixed-conifer fire regimes. With a mean fire return interval of 60 to 80 years, probably only one fire cycle has been missed (Agee 1993. Fire patch size may now be larger, however, in lodgepole pine forests. Within lodgepole pine forest burned by the B&B Fire, pre-fire proportion of forest dominated by different seral/structural stages had departed less than 33% from historical reference conditions (USDA FS 2005a). Even so, lodgepole pine trees and stands have increased in size and density over the last century (USDA FS 1996).

4. High Elevation Forests

Figure 26. Moist climate associated with high elevation forests supports dense vegetation on this site near Hoodoo Ski Area.

Figure 27. Stand replacing fire may create mosaics of forest and meadow at high elevations, such as on this site near Hoodoo Ski Area.

High elevation forests may include mountain hemlock, subalpine fir, Pacific silver fir, white bark pine, Engelman spruce, and lodgepole pine (USDA FS 1996 and Burns and Honkala 1990). Within this forest type, higher soil moisture may support very dense vegetation where soil depth, temperature, and wind are not limiting (Figure 26), (USDA FS 1996). Fire has defined landscape mosaics of forest and meadow (Figure 27), and has impacted species distributions in this forest type. Non-fire disturbance may also be significant in the higher elevation forests, because fire-free periods are so long. (Agee 1993).

a. Fire Severity

Central Oregon high elevation forests historically experienced high-severity fire. For example, within the Jefferson Wilderness Pacific silver fir zone, 95% of the documented 1,804 acres experiencing wildfire between 1720 and 1990 burned at high-severity (Simon 1991).

High elevation forests are often dominated by species that are not fire-adapted, such as Pacific silver fir, subalpine fir, Engleman spruce, or mountain hemlock (Agee 1993). Subalpine fir, for example, has thin bark, a low crown with persistent branches, and shallow roots, making it one of the least fire-adapted conifers (Agee 1993). As a result, even surface fires in this forest type usually cause high mortality.

Lodgepole pine is the major early seral species within this zone, but environmental conditions are marginal for tree establishment, so fire can create meadows that persist for decades to centuries before significant seedling recruitment occurs (Agee 1993). Where fire is excluded, lodgepole pine will decrease as climax species increase in dominance (USDA FS 1996). In some areas in the Pacific Northwest, past fires converted subalpine forest to huckleberry (*Vaccinium ovatum*) fields (Agee 1993).

As under other fire regimes, however, fire behavior was variable, not only among fires, but also within individual fire perimeters. For example, the 1871 fire that burned most of the Jefferson Wilderness resulted in areas of stand replacement and others with only partial stand replacement (Simon 1991).

b. Fire Extent

Extent of fires within the Pacific silver fir forest type has also been variable. Within Mount Ranier National Park, one fire of about 25,000 ha and three of about 13,000 ha have been documented (Hemstrom and Franklin 1982). A more patchy mosaic has been identified in the Oregon Cascade Pacific silver fir forests where fire is thought to have burned areas at low-, moderate-, and high-severity with patches burned at each severity ranging from less than 10 ha to 150 ha (Morrison and Swanson 1990).

Fire may be limited in extent within high elevation forests where snow, rock, or other natural fire breaks obstruct fire spread. Isolated torching of subalpine fir clumps may also occur, especially once lichen develop on trees and dead fuels accumulate (Agee 1993).

c. Fire Seasonality

Most fires in central Oregon high elevation forests occur during late summer, as is evidenced by the distribution of lightning fire frequency in the Jefferson Wilderness (Figure 25). Of almost 100 recorded fires that occurred in the Jefferson Wilderness (eastside) during the period from 1914 to 1990, none occurred before mid-May or after the first week in October, and almost two-thirds occurred between mid-July and mid-August (Simon 1991).

Fires have been documented to occur, however, in all seasons within subalpine forest. Crown fires are most likely when foliar moisture content is low. This usually occurs during the summer drought, but also occurs during warm spells when tree roots are too cold to take up moisture and may be fueled by lichen within the canopy (Agee 1993 and USDA FS 1996). This was the case during 1986 and 1987 Cascade Spring crown fires in areas with 1 to 2 m of snow on the ground (Agee 1993). In addition, age classes of 100, 175 to 225, and 300 to 350 years were evident in cores taken from 800 trees in the Jefferson Wilderness, suggesting occurrence of stand replacing fires (Simon 1991).

d. Fire Frequency

High elevation forests have the coolest temperatures, shortest growing season, and longest fire return interval of all the forest types discussed. Fire return intervals for pacific silver fir forest have been estimated to range from 100 to 600 years, depending on topographic position, moisture, and proximity to other forest types (Morrison and Swanson 1990). The typical fire return interval of forests in the east Cascade subalpine fir zone is probably about 250 years. Fire return intervals of other subalpine forests in the Pacific Northwest have been estimated to be 109 to 137 years and 275 years (Agee 1993).

Estimates of fire return interval for high elevation forests are based primarily on forest age class distributions, because few fire scarred trees survive fire in this zone. Even underburned areas at the edge of fires often experience complete mortality (Agee 1993). In drier areas of this forest type, fire scarred Douglas-fir may provide evidence of past fire.

e. Current Conditions

Humans have not significantly altered mean fire return intervals in high elevation forests, because natural fire free periods are longer than the time period since settlement (USDA FS 1996). A century of fire suppression has had little impact on the natural fire regime of this forest type, especially where "minimum suppression techniques" have been employed, allowing more natural fire behavior and greater area burned than would have been the case if fires had been aggressively suppressed (Simon 1991).

Change has occurred for the most part within the historic range of variability (USDA FS 1996). For example, in the Metolius Watershed, stands have become denser, trees have grown older and larger, woody debris has accumulated on the forest floor, root rot has become more prevalent, spruce budworm has contributed to mortality of true firs, and mountain pine beetle and white pine blister rust have led to mortality of white bark pine (USDA FS 1996). At most, a slight deviation from natural, historic conditions may have occurred on a landscape scale as forest composition shifted from early to later seral species (USDA FS 1996). Recent estimates on high-elevation areas burned during the B&B Fire, put pre-fire departure at less than 33% (USDA FS 2005a).

5. Drivers of Fire Regimes

a. Climate

Probably the most significant driver of natural fire and current fire regimes is climate. Climate impacts fuel characteristics (moisture content) and fire behavior. In addition, lightning is a common ignition source.

Precipitation

Precipitation pattern is important because forests must be relatively dry to ignite and carry fire, and because vegetation type varies with elevation according to available soil moisture and snow cover (Simon 1991). Annual precipitation varies across the Sisters Ranger District from less than 15 inches to 120 inches (Figure 28) (USDA FS 2004).

Precipitation patterns through time also impact fire behavior. Fire in the Jefferson Wilderness during the 1980s provides an example of this relationship, where during a period of above average precipitation from 1980 to 1984, no lightning caused fires occurred despite lightning activity, because the forest/fuels were moist. In contrast, the greatest number of lightning fires occurred in 1998 after 3 years of drought (Simon 1991). In addition, historic occurrence of summer fires also clearly coincides with summer drought (Figures 25 and 30).

Precipitation also affects fire regimes indirectly by impacting other disturbance. For example, insect associated mortality of mature and old-growth ponderosa pine was observed after the drought of the 1920s and 1930s in the Pacific Northwest, increasing fuel loads (Agee 1993).

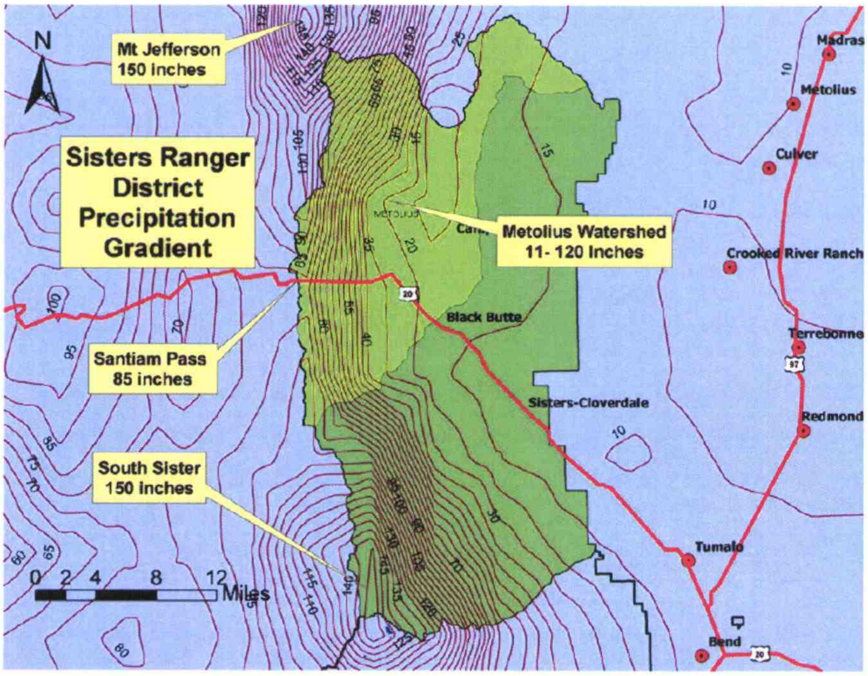

Figure 28. Precipitation varies across Sisters Ranger District from less than 15 inches near Sisters up to 120 inches at the Cascade Crest. (USDA FS 2004)

Temperature

Temperature influences fire behavior by affecting the amount of heat required to ignite and carry fire as well as affecting the drying of fuels. In addition, for given fireline intensity levels, scorch height is higher when air temperatures are warmer (Agee 1993).

Temperature and moisture also drive growth of fires when fire behavior is not dominated by surface winds. These environmental factors are ranked according to the Haines Index, which integrates a stability term based on the temperature at two atmosphere levels and a moisture term based on the difference between the temperature and dew point at a single atmosphere level. Haines Indexes range from 2 to 6, with 2 representing a moist, stable lower atmosphere with little potential for large fire growth, and 6 representing a dry, unstable lower atmosphere with high potential for large fire growth (Haines 1988, USDI NPS 2005, USDA FS 2002).

Climate also influences vegetative cover. Vegetation varies with elevation according to available soil moisture, temperature, and snow cover and can be inferred from plant association groups (PAGs). For example, Douglas-fir is susceptible to frost and is excluded from colder sites on the Deschutes National Forest. Also, Pacific silver fir is common on North facing slopes and lower elevation riparian areas where the environment is cool and moist (Simon 1991).

Lightning & Humans

Lightning ignites most forest fires on the Deschutes National Forest. From 1987 through 2001, lightning was responsible for 1,794 (or 64%) of the 2,815 fires with identified ignition sources and humans were responsible for 1,021 (or 36%) of fires (Figure 29). Human fire starts appear to be concentrated near Sisters, between Bend and La Pine, and near recreation areas northwest of La Pine. More detailed description of human ignitions is given below (Table 2). During the same time period, about 330 additional fires occurred with unknown ignition sources (USDA FS 2005b).

Figure 29 illustrates an important point: there is a large potential for fire on Deschutes National Forest. Given the inevitability of fire starts, managers may either suppress fires once started or proactively treat vegetation to alter fire behavior (and fire effects) and aid in fire suppression.

Ignition Source	Number of Ignitions
Lightning	1,794
Campfires	482
Smoking	223
Arson	186
Debris burning	51
Equipment	41
Children	31
Railroad	7

Table 2. Human ignitions on Deschutes National Forest with identified ignition sources from 1987 to 2001

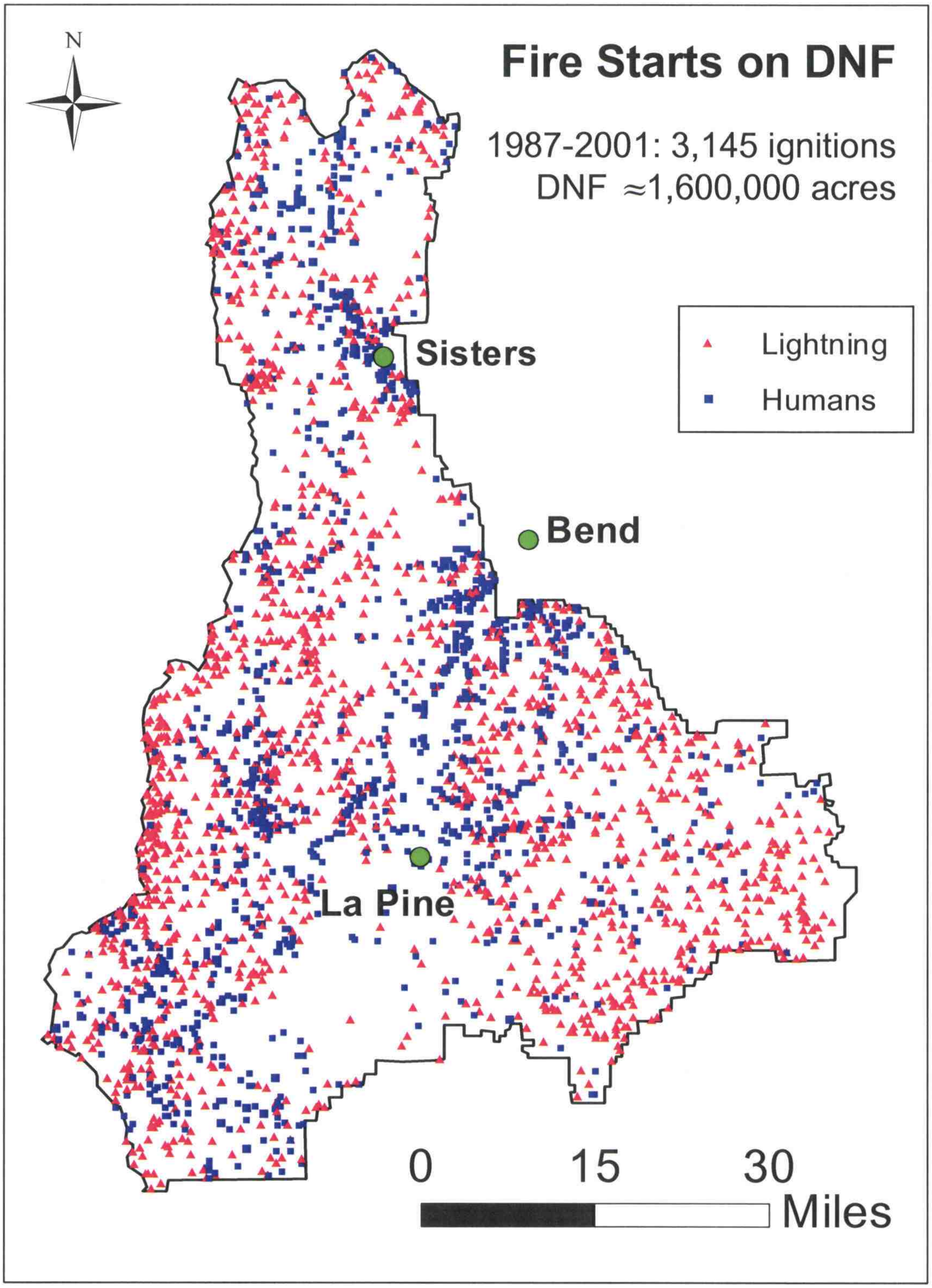

Figure 29. From 1987 through 2001, lightning and humans were responsible for 64% and 36% of 2,815 fires with identified ignition sources on the Deschutes National Forest. Human fire starts appear to be concentrated near Sisters, between Bend and La Pine, and near recreation areas northwest of La Pine.

Deschutes National Forest covers almost 1,600,000 acres of public lands. (USDA FS 2005b and USDA FS 2005c)

Incidence of fires on the Deschutes National Forest, including lightning and human caused ignitions, peaks during the dry summer months (Figure 30). Lightning not accompanied by precipitation (dry lightning) is especially likely to ignite forest fires.

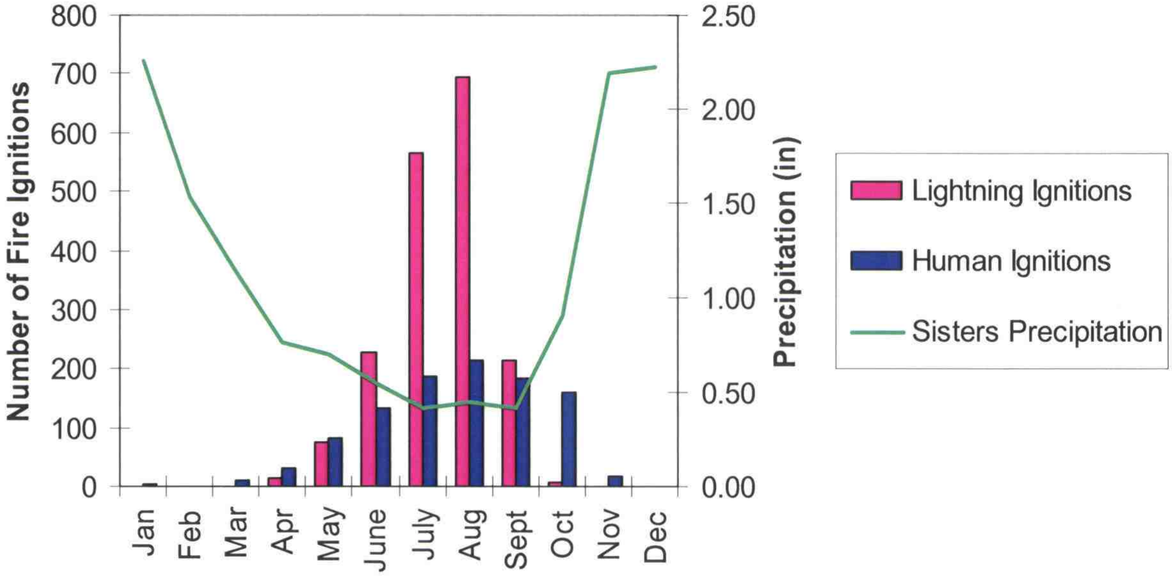

Figure 30. Incidence of fires on the Deschutes National Forest, including lightning and human ignitions, peaks during the dry summer months. (USDA FS 2005b, Oregon Climate Summaries 2005)

Once lit, fires may smolder for days, weeks, or longer until weather or fuel conditions allow fires to flare up. For example, holdover lightning fires are thought to be responsible for the Booth Fire that combined with the Bear Butte Fire to form the B&B Complex Fire of 2003. The Booth Fire officially started on August 19th, but two holdover fires had been reported near the fire origin on August 18 that probably resulted from reported lightning strikes near the fire origin August 4th (Central Oregon Arson Task Force 2003). Lightning struck snags were identified within the Bear Butte Fire Origin Area (Figure 31). Snags provide wildlife habitat, but may also serve as points of ignition and burning snags commonly throw embers and cause spot fires. Snags also present a safety risk to fire suppression crews.

Incidence of lightning strikes may be related to aspect and elevation. In the Jefferson Wilderness, more than two-thirds of documented fires between 1918 and 1990 were located at sites with aspects between 130 and 200 degrees (approximately SE to

SSW) or at sites with elevation above 5,000 feet (Simon 1991). In addition, young stands, which probably regenerated after fire, dominate on exposed south facing ridges providing additional evidence of lightning fire in these areas (Simon 1991).

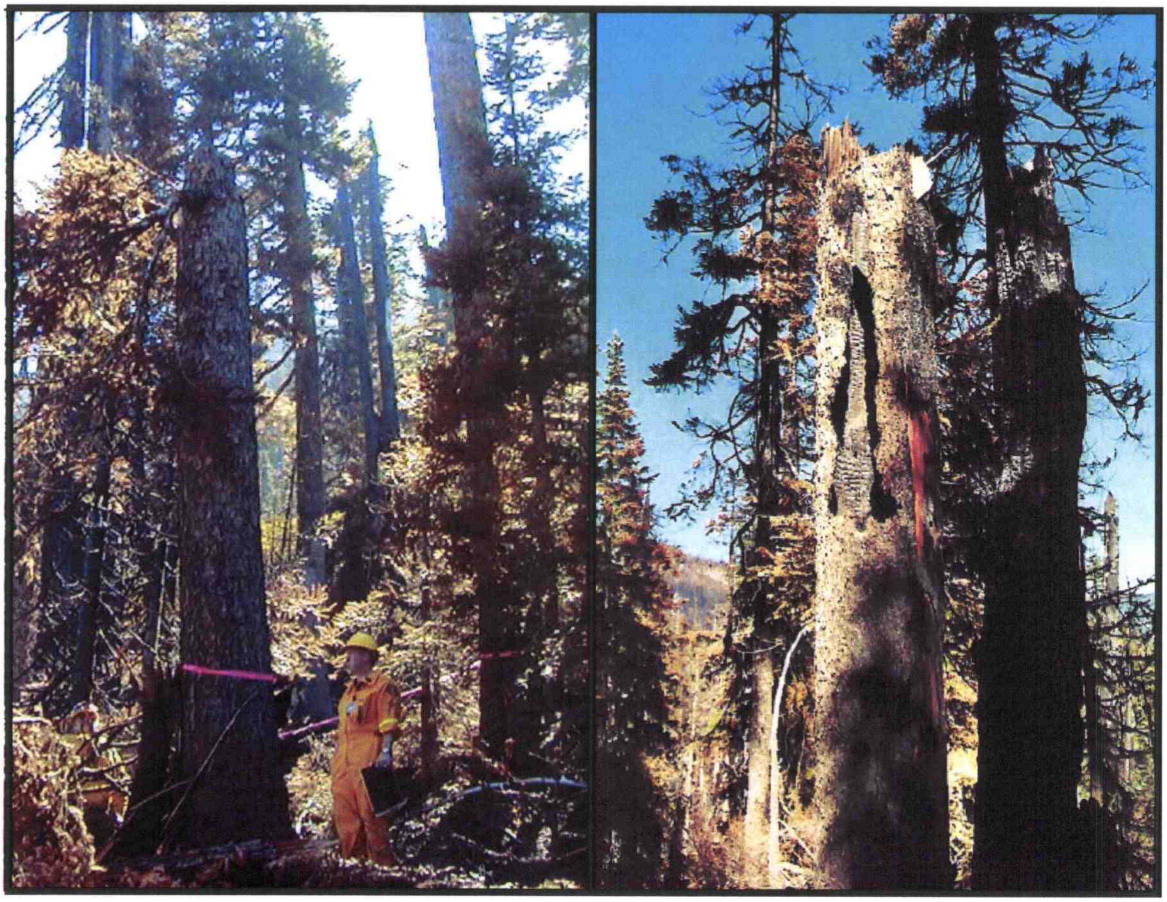

Figure 31. Front and back sides of a lightning struck tree within the Bear Butte Fire Origin Area (one of two fires that grew together to form the B&B Fire Complex). Snags provide wildlife habitat, but may also serve as points of ignition. Burning snags commonly throw embers and cause spot fires. In addition, they present a safety risk to fire suppression crews. (Central Oregon Arson Task Force 2003)

Wind

Wind affects fire spread and can be influenced by topographic factors. In the eastern Cascades, incidence of severe fires has been related to strong north winds (Agee 1993). Afternoon (diurnal) winds in the Metolius Basin have also driven large fires down-canyon from west to east (USDA FS 1996). Wind was also a big factor on the first day of the B&B Fire, when the fire made a strong push to the east (Robbins 2005).

Vegetation – Plant Association Groups

Climate affects fire regimes by influencing vegetative cover. I've already discussed the relationship between fire regime and vegetation in Chapter II, but as a summary, high forest productivity leads to dense stands that have greater fuel loads and greater susceptibility to insect and disease. Vegetation type and fire regimes are also related, because fire severity is generally lower in stands of fire adapted species such as ponderosa pine, western larch, and Douglas-fir, than species with thin bark and shallow rooting habit (i.e., lodgepole pine and subalpine fir).

b. Topography

Topography influences frequency and timing of burns, creating variation in stand ages, densities, species, and fuel loads across the landscape. For example, some areas are more prone to lightning ignitions than others (Figure 29). In addition, fuels on south facing slopes may dry out faster and support fire earlier in the dry season than those on north facing slopes. Topography can also influence fire behavior, such as when wind is funneled through canyons or saddles. The resulting vegetative mosaic tends to limit fire size in a positive feedback loop, because fire frequently slows and stops when it enters previously burned areas (Finney 2001). Spatially explicit forest simulation models for the Sierra Nevada support the hypothesis that connectivity is inversely related to fire frequency (Miller and Urban 2000).

Topography is also related to factors driving fire regimes such as climate and forest productivity. For example, fire simulation models for the Sierra Nevada indicate that fuel moisture content limits fire extent at elevations above 1500 meters, but fuel quantity is limiting at lower elevations (Miller and Urban 1999). On the Deschutes National Forest, elevation is a primary driver of vegetative cover, with pure ponderosa pine forests generally occurring below 3,500 ft, mixed-conifer forests between 3,000 and 5,000 ft, and high elevation lodgepole pine, subalpine fir, and mountain hemlock forests most above 4,000 ft (USDA FS 2005a). Soil type and depth and terrain aspect also influence severity of summer drought and associated disturbance (Emmingham 2005).

Finally, topography influences fire impacts on erosion. For example, streams located in steep terrain received greater amounts of overland flow following the 1988 Yellowstone wildfires than similarly sized streams with the same percentage of catchment burned in gentle terrain (Minshall 1997). In addition, contributions of fine sediment declined dramatically within two years after fire in central Idaho, but fine sediment contributions continued five years after the Yellowstone fires where terrestrial sediment storage was greater (Minshall 1997). In the Colorado Front Range, soil movement can be greatest on North facing hill slopes, because of differences in granite residuum (Moody 2001).

c. Fire Suppression

Since the large fires of 1910 in Idaho and Montana, the Forest Service has vigorously suppressed wildfire (Fitzgerald 2002). On the Deschutes National Forest annual suppression cost averaged $17,892,233 between FY1995 and FY2000 (Busby 2002).

Fire suppression has undoubtedly reduced the total acreage burned over the last century, saving lives and property, and it will continue to play an important role in the urban interface and other areas where the effects of wildfire are not acceptable. At the same time, however, fire suppression (along with logging and grazing) has changed forest composition and structure in many forests so that there is now an increased risk of stand replacing disturbance, including severe wildfire (Agee 1993). Fires that burn after extended fire free periods are usually more intense and usually cover large areas. In 1994, just 2% of the wildfires under jurisdiction of the USFS burned 94% of the total area burned that year (Husari and McKelvey 1996).

The effect of fire suppression is evident in terms of the area burned on the Deschutes National Forest; fire was effectively suppressed for much of the last century, but large areas have burned more recently (Figure 32).

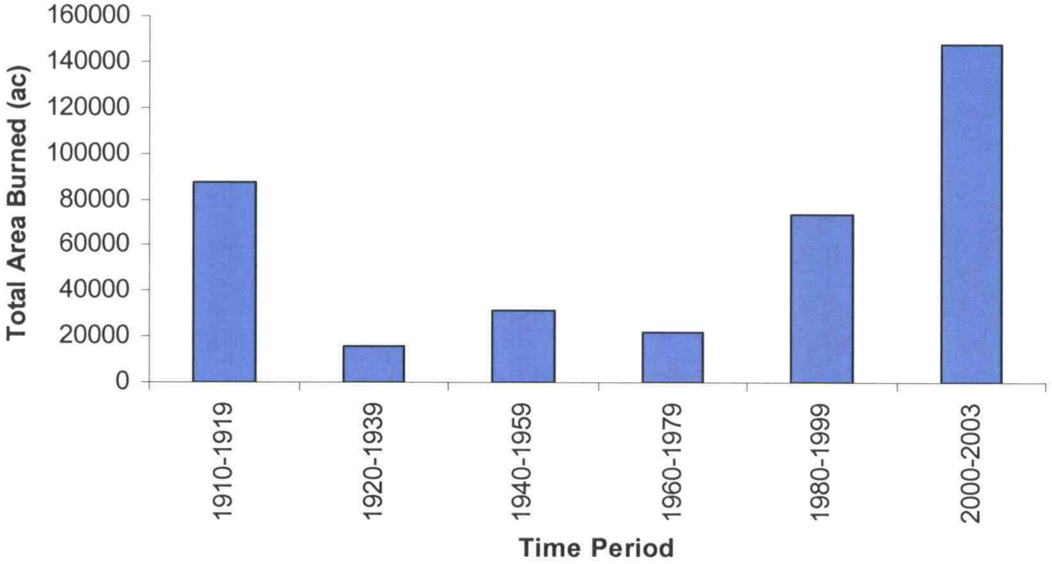

Figure 32. Fire suppression effectively reduced acres burned on the Deschutes National Forest for much of the last century, but associated increase in fuels has led to recent large fires. (Data: USDA FS 2005b)

Fire suppression has also allowed regeneration to survive not only in open patches, but also in the forest understory where accumulations of surface fuels historically would have carried frequent fire, thereby limiting regeneration development (Kilgore 1981). Multistoried stands contain contiguous vertical fuel structure ("fire ladders") and are more capable of supporting stand replacing fire. In the Bitteroot National Forest of Montana, fire has been suppressed since 1920; where an understory has developed, ladder fuels threaten even normally fire resilient old-growth forests of ponderosa pine, Douglas-fir, and western larch (Arno 1976). Not only is fire more likely to be carried into the canopy under less severe weather conditions, but higher fuel loads may also take longer to burn. Fire severity is increased where litter accumulations at the base of trees lead to longer fire residence time; mortality occurs once heat penetrates through the bark and girdles trees by killing the cambium.

Fire suppression has also led to increased stand densities (Kilgore 1981). Stands of high density not only provide more biomass (fuel), but they are more susceptible to insects and diseases. For example, mountain pine beetle and western pine beetle have caused significant mortality in dense ponderosa pine stands (USDA FS 1996).

Fire suppression can also lead to loss of spatial heterogeneity. Fire exclusion has been identified as the primary factor contributing to loss of landscape and habitat diversity in the Metolius Watershed (USDA FS 1996). Historically, fire frequency and intensity varied with fuel quantity and distribution, topography, and weather, resulting in landscape mosaics of exposed mineral soil, shrubs, conifer regeneration, and other seral stages. These mosaics were often self-perpetuating. Light-severity fire would reduce fuel loads, thereby limiting severity of subsequent fire. High-severity fire would lead to the development of dense pole sized stands eventually susceptible to stand replacing fire.

d. Timber Harvest

Timber harvest over the last century has exacerbated problems associated with fire suppression. In many areas, timber harvest has increased risk of high-severity fire by converting landscapes of widely spaced trees of fire resistant species to mosaics of small patches that are densely stocked with young saplings and poles of fire sensitive species. For example, large patches of ponderosa pine and high elevation forests were converted between 1953 and 1991 from 1-2 story stands of ponderosa pine with a mean patch size of 40 acres and predominant tree size of 21+ inches to multi-storied stands of white fir and Douglas-fir with trees of 9 to 21 inches (USDA FS 1996).

Loss of large trees is also evident in the Metolius Watershed where trees over 21 inches diameter decreased from 64% to 9% to 7% from 1953 to 1996 to 2004, respectively (USDA FS 2004). On some areas within the Metolius Watershed, timber harvest has led to increased fuel loads by providing large ponderosa pine stumps. These stumps serve as infection centers for annosus root disease, which can infect and kill adjacent ponderosa pines (USDA FS 1996).

e. Livestock Grazing

Livestock grazed heavily within central Oregon forests by the mid to late 1800s. Grazing has reduced fine fuels and probably contributed to reduced fire frequency in ponderosa pine and mixed-conifer forests (Agee 1993 p. 323, Weaver 1959).

f. Human Ignitions

Human ignitions are increasingly significant. Of 200 fires requiring suppression within the Metolius Watershed between 1982 and 1994, 44% (87 of 200) were human caused. Subwatersheds receiving greater recreational use experienced the highest proportion of human caused fires. For example, humans were responsible for at least 17 of 36 and 6 of 9 fires in the Suttle and Abbot subwatersheds (subwatersheds of the Metolius Watershed) respectively. Human ignitions were less important in areas with little recreational use, such as Candle and Metolius Horn Subwatersheds, where only 5 of 25 and 6 of 21 fires were human caused (USDA FS 1996). In addition, two of the eight fires over 100 acres in the Metolius Watershed that burned between 1995 and 2003 were human caused, including the 2003 Link Fire that burned 3,590 acres and the 1996 Jefferson Fire that burned 3,689 acres (USDA FS 2005a).

Across the Deschutes National Forest from 1987 to 2001, 36% of fires with identified causes were human caused. Each of the following activities resulted in the specified number of human caused fires: campfires (482), smoking (223), arson (186), debris burning (51), equipment (41), children (31), and railroad (7) (USDA FS 2005a). Human ignitions are increasingly significant, especially in areas with high recreational use.

A significant proportion of human ignitions are started by arsonists. The Central Oregon Agency Task Force (COATF) comprised of 18 local, state, and federal fire and law enforcement agencies and its predecessor COFIT have been responsible for the arrest of nine serial arsonists who were linked to 63 fires (Central Oregon Arson Task Force 2003).

6. Looking Ahead

Given the threat of high-severity fire to valued resources and the negative consequences of fire suppression (i.e., change in forest composition and structure), what should be done to restore forests and associated fire regimes closer to those existing pre-settlement? Should all forests be treated in the same way? These questions will be answered in the next section.

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D. Fuel Treatments

Fuels, climate, and topography are primary drivers of fire regimes. Of these three components, managers may most easily influence fuel characteristics, including fuel quantity, distribution, and composition. Fuels may be treated with prescribed fire or mechanical treatments, including thinning, salvage logging, chipping, pruning, and mowing. Often a combination of mechanical treatments and prescribed fire is applied. Regardless, re-treatment in 10-20 years may be needed as regeneration of shrubs and trees occurs.

With the exception of salvage logging, fuel treatments primarily impact fine fuels. Treatments that reduce surface and understory/ladder fuels reduce the likelihood of surface fire spreading to the canopy by reducing fire temperature and flame length. Thinning of overstory trees disrupts horizontal contiguity of the canopy, reducing the likelihood of crown fire spreading from one tree canopy to the next (Agee 1993).

Fuel treatments may manipulate species composition by favoring species that are resistant to fire, insects, and/or disease. For example, Sisters Ranger District has recommended limiting true fir component to 20% to maximize sustainability of stands (USDA FS 1996). In addition, fire resistant species will be favored during B&B Fire Recovery Project treatments designed to provide defensible space adjacent to nesting, roosting, and foraging (NRF) habitat for the northern spotted owl. In mixed-conifer forest, retention priority is Douglas-fir > ponderosa pine > western larch > incense cedar > white fir. In ponderosa pine forest, retention priority is ponderosa pine > incense cedar. Any existing spruce and western white pine will also be retained in these forest types to provide diversity (USDA FS 2005a).

B&B Fire Recovery Project treatments are generally intended to create a fire resilient forest by reducing surface fuel loads, raising canopy height, disrupting continuity and density of crown fuels, favoring large trees, and favoring fire resistant species (Table 3). Deschutes National Forest quantifies canopy density and contiguity objectives according to target crown bulk density. Crown bulk density is a measure of the weight of the canopy (kg) divided by the total canopy volume (m^3) (Keyes and O'Hara 2002). Crown bulk densities below 0.10 kg/m^2 may be insufficient to carry independent crown fire (USDA FS 2005a and Agee 1996).

Table 3. B&B Fire Recovery Project fuel treatment specifications. Treatments are intended to create a fire resilient forest by reducing surface fuel loads, raising canopy height, disrupting crown density and contiguity, and favoring large trees of fire resistant species. (USDA FS 2005a)

Forest Type	Surface Fuel Loading (t/ac)	Height to Base of Live Crown (ft)	Crown Density - Crown Bulk Density (kg/m2)	Diameter at Breast Height (in)	Fire Resistant Species
Ponderosa pine	< 5 (< 3") 7- 10 (total)	> 10	< 0.10	≥8	Ponderosa Pine
Mixed-conifer	< 5 (< 3") 7- 25 (total)	> 10	< 0.10	≥10	Ponderosa Pine, Douglas-fir, western larch

Design of fuel treatments must accommodate management objectives at stand and landscape scales to maximize benefit. Treatments are commonly designed to create fuel breaks. Vegetation may be totally cleared in fuel breaks or overstory trees retained in shaded fuel breaks. Shaded fuel breaks initially retain greater fuel loads, but increased moisture and reduced understory growth may yield net benefit on some sites. Fuel breaks are usually not intended to stop fires by themselves, but instead to reduce fire severity and rate of fire spread (Agee et al. 2000, Finney 2001). They are designed to impede headward movement of wildfire as predicted after considering historic burn patterns, topography, and prevailing wind direction. They are also created to buy time until fires can be extinguished by fire suppression crews or by changing weather conditions and to provide a place where crews can backburn, locate safe areas, etc. For example, shrubs and ladder fuels were cleared in Camp Sherman to slow the rate of fire spread through the urban interface to aid in fire suppression (USDA FS 1996). In addition, B&B Fire Recovery Project treatments are intended to create defensible space, which is defined as a "developed and/or maintained fuel break 100-500 ft wide that serves as an anchor point during fire suppression and as an escape route from wildfires for firefighters and the public" (USDA FS 2005a).

In other areas, fuel breaks have been constructed that serve multiple objectives. Fuel breaks were created along the Highway 20 corridor not only to reduce risk of high-intensity wildfire, but also to protect large ponderosa pines, to reduce risk of automobile collisions with wildlife by improving visibility through the forest, to improve scenic views, and to reduce the incidence of accidental ignitions (Figure 33) (USDA FS 1996).

Figure 33. Shrubs and ladder fuels were cleared in Camp Sherman to slow the rate of fire spread through the urban interface to aid in fire suppression. Piles will be burned during the next season.

A distinction should be made between fuel breaks and fire lines. Fire lines are constructed by clearing all vegetation and forest floor down to the mineral soil and are intended to actually stop fire spread. Fire lines are constructed prior to conducting prescribed burns and during wildfire suppression efforts (Agee 1993).

Fuel treatments provide the greatest benefit to fire suppression efforts during moderate weather conditions. During extremely hot, dry, and windy weather, fuel treatments may not make much difference, especially where cost and conflicting management objectives limit extent and maintenance of treatments. Fuel treatments also serve less use under very mild conditions, because fire suppression is already effective then (Finney 2001). Forest fire simulation models developed for the Sierra Nevada illustrate the relationship between weather and flammable fuel connectivity. Average length of contiguous flammable fuels was shown to increase from less than 50 meters to 135 meters as fuel moisture content decreased from 10% to 1% (Miller and Urban 1999).

1. Classification of Fuels

Dead fuels are often classified according to relative rate of moisture change or "time lag." Time lag is the period required for fuels to come within 63.2% of new atmospheric equilibrium moisture content. Common time lag categories include 1 hr, 10 hr, 100 hr, and 1,000 hr, corresponding to fuel size classes of 0-¼ in, ¼-1 in, 1-3 in, and 3-8 in respectively (Anderson 1982, Brown et al. 1982). Time lag classification is useful in predicting fire behavior. For example, moisture content of fine fuels may change significantly within a few hours, but large fuels may take a month or more to dry out. In addition to fuel size, other factors influence rate of change in fuel moisture content, including atmospheric temperature, relative humidity, wind, cloud cover, precipitation, shading, and fuel distribution/arrangement (Anderson 1989).

Fuels are also classified as surface, understory, or canopy fuels. Surface fuels are further classified as fine fuels, small woody fuels, and large fuels. Fine fuels include grass and forbs and contribute to rate of fire spread. Small woody fuels include branches and stems less than 3 inches in diameter and contribute to fire ignition, rate of fire spread, and fire intensity. Large fuels include branches and stems greater than 3 inches in diameter and contribute to fire residence time, fire severity, and fire extent (Rothermel 1983). Accumulation of large fuel may lead to fire of greater extent, because fire may smolder in these fuels and flare up when weather conditions permit (USDA FS 2005a).

Large surface fuel loads contribute to high fire severity. For example, fuel load has been positively correlated with soil heating; greater fuel loads have led to higher soil temperature impacting soil at greater depths and for longer periods (Figure 34) (Debano 1998). Excessive soil heating is experienced when down wood fuel loads are greater than about 40 tons/ac (Brown et al. 2003). Effects of soil heating can be significant, because temperatures of 140-212^{O}F kill most soil organisms, and soil organic matter combusts at temperatures between 428 and 860^{O} F (Debano et al. 1998). These temperatures are not that high, considering that flame temperatures may exceed 1,000^{O} F (Agee 1993). Loss of soil organisms and organic matter can lead to reduced nutrient processing and soil structure and infiltration capacity (i.e., hydrophobic soils) (Figure 35) (Fisher and Binkley 2000, USDA FS 2005a).

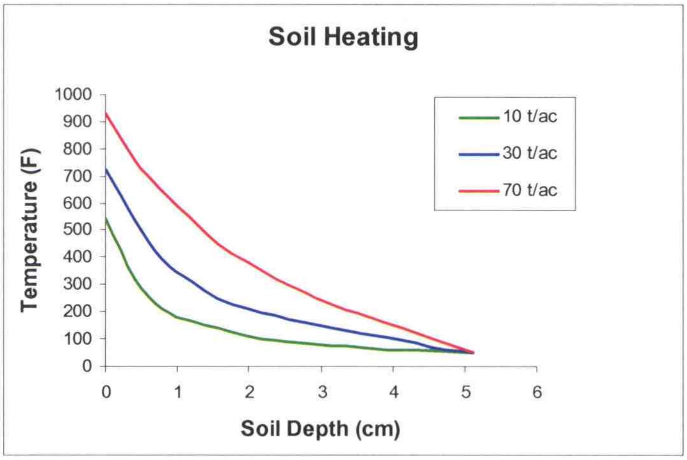

Figure 34. Greater fuel loads lead to higher soil temperatures at greater depths. (USDA FS 2005a)

Figure 35. Combustion of organic matter leads to loss of soil structure if it is not soon replenished. (Photo by Jim Boyle)

Pre-settlement and recommended fuel loads differ with those typically found in today's forests. In southern Oregon ponderosa pine forests, historic fuel loads are estimated to have ranged from 3-6 tons/ac (Hall 2003). In the Bitteroot National Forest, natural fuel loads probably varied among forest types as follows: ponderosa pine, 5-10 t/ac; mixed-conifer, 10-20 t/ac; and lodgepole pine and subalpine fir (high elevation), 8-24 t/ac (Brown et al. 2003). Sisters District Down Woody Material Guidelines call for surface fuel loads of 7-15 tons/ac in ponderosa pine forests, 15-25 tons/ac in mixed-conifer forests and lodgepole pine forests, and 10-30 t/ac in high elevation forests. Lower fuel loads of 7-10 t/ac and 7-25 t/ac are recommended when ponderosa pine and mixed conifer forests fall within the wildland urban interface (WUI) (Table 4). Fuel load recommendations in lodgepole pine forests reflect moderately long mean fire return intervals, but low productivity (USDA FS 1996, USDA FS 2005, and Brown et al. 2003). In general, recommended fuel loads are intended to limit fire intensity, yet still provide down wood for wildlife habitat (USDA FS 2005a).

Table 4. Recommended surface fuel loads are lower for areas that historically had little fuel accumulation due to frequent fire and within the Wildland Urban Interface (WUI). (Modified from USDA FS 2005a)

Forest Type	**Pre-settlement Conditions (Brown et al. 2003)**	**Recommended Fuel Loads (Brown et al. 2003)**	**Sisters Ranger District Down Woody Material Guidelines**	**WUI/Defensible Space Down Wood Objectives for B&B Fire Recovery Project**
Ponderosa pine	5 - 10 t/ac	5 - 20 t/ac	7 - 15 t/ac	7 - 10 t/ac
Mixed conifer	10 - 20 t/ac	10 - 30 t/ac	15 - 25 t/ac	7 - 25 t/ac
Lodgepole pine	8 - 24 t/ac	10 - 30 t/ac	15 - 25 t/ac	NA
High Elevation	8 - 24 t/ac	10 - 30 t/ac	10 - 30 t/ac	NA
In contrast to natural and recommended fuel loads, accumulations prior to the B&B Fire often exceeded 50 t/ac, and post-fire fuel loads may exceed 120 t/ac on some sites as snags fall and down wood accumulates.				

Current fuel loads are above historic and recommended levels in some forest types. For example, fuel loads in Metolius Basin mixed-conifer forests were estimated to range from 5 to 15 tons/ac and 15 to 45 tons/ac on ponderosa pine and mixed-conifer forests in 1996, and in some areas to be greater than 50 tons/ac prior to the B&B fire in 2003 as a result of spruce budworm infestation. Following the B&B Fire, fuel loads may exceed 120 t/ac in 20 years or so on some sites as snags fall and down wood accumulates. To put these quantities in perspective, fuel loads greater than 30 to 40 tons per acre are considered extremely resistant to fire suppression, based on difficulty of handline construction (USDA FS 2005, Brown et al. 2003). Fuels loads may be reduced to recommended levels that are closer to those experienced historically with prescribed fire or mechanical treatments.

2. *Prescribed Fire*

Figure 36. Ideal, low-intensity prescribed fire is used at this Metolius Basin site to reduce fine fuels, including surface and understory fuels, and to favor fire resistant species. (Photo by Jim Boyle)

Prescribed fire is used to reduce fine fuels, including surface and understory fuels, and to favor fire resistant species (Figure 36). Prescribed fires usually do not have severe ecological effects on overstory trees or soil, because they are conducted under relatively controlled conditions, including during spring or late fall, and even at night, when cooler temperatures and higher relative humidity help to control fire intensity. Lower intensity controlled burns that cover a smaller percentage of a catchment, or burn less of the vegetation and forest floor, also generally yield less sediment to streams than larger, higher intensity wildfires (Minshall et al. 1997 and Cannon and Reneau 2000). In addition, cooler prescribed burn temperatures limit consumption of organic matter. Limiting combustion of soil organic matter may help to maintain the ability of soil to absorb water, because volatile gasses are released during combustion of organic matter that may condense on, and impart water repellent properties to, soil particles. Organic matter protects soil from raindrop impact, slows overland flow, and is critical for soil structure (Benavides-Solorio 2001). Finally, most overstory trees survive a properly controlled prescribed burn, so root strength and evapotranspiration rates are maintained. In contrast to prescribed fire, wildfires may cause more significant reductions in infiltration rates, because they commonly burn at higher temperatures during the summer when fuels and soil are dry (McNabb et al. 1989).

An advantage of prescribed fire over mechanical treatments is that it may better provide forest conditions within the historical range of variability. For example, prescribed fire was recommended over mechanical treatments in the Central Basin of the Metolius Watershed to benefit the Peck's penstemon (*penstemon peckii* Pennell), tall agoseris (*Agoseris elata* (Nutt.) Greene), and mountain lady slipper (*Cypripedium montanum* Dougl. ex Lindl.) (USDA FS 1996). Prescribed fire may also be cheaper than mechanical treatments at approximately $150 per acre versus $500-$550/ac for small diameter thinning and slash treatment (Busby 2002 and Emmingham et al. 2005). Biomass sales, and in some cases faster tree growth and shorter time to precommercial thinning, may offset treatment costs.

In some areas, prescribed fire will stimulate growth of shrubs. For example, *Ceanothus* seed can survive for many decades in the soil and germinate in large numbers once heated by fire (scarified) (USDA 1988). Shrubs may then grow vigorously with reduced post-fire competition. Fire effect is variable, however, depending on fire intensity and fire frequency, and may also include sprouting or reduction in shrub populations (Halpern 1988 and Mozingo 1987). At one Pole Creek site near Sisters, prescribed burning stimulated only limited germination of *Ceanothus* seed where stand density remained high (Figure 37). At other Pole Creek sites, light thinning stimulated limited germination of *Ceanothus* seed, but combined thinning and burning treatment resulted in high seed germination with subsequent vigorous growth of *Ceanothus* shrubs (Figures 38 and 39).

After Prescribed Burn Treatment
Trees/Acre: 155
Mean Diameter: 13 in
Basal Area: 177 sq ft
Stand Density Index: 281
Relative Density Index: 0.561
Mean Height to Live Crown: 26 ft

Figure 37. Prescribed fire stimulated light sprouting of *Ceanothus* shrubs at this Pole Creek site on Deschutes National Forest. Compare stand conditions with those found after thinning and combined thinning and prescribed burn treatments at nearby sites (Figures 38 and 39).

3. Mechanical Treatments

Fuels may also be reduced with mechanical treatments, including thinning, salvage logging, chipping, pruning, and mowing. Mechanical treatment is often necessary to reduce fuels before stands can be burned safely. Often mechanical treatment followed by a prescribed fire rotation is recommended. In some cases, mechanical treatment may be the only option because of air quality concerns, short window of suitable weather conditions, or risk of fire escape preclude prescribed burning.

a. Thinning

Thinning may reduce intensity of understory fire, remove ladder fuels, disrupt canopy contiguity, and favor species resistant to disturbance. All thinning treatments are not equal, however. For example, removing small trees will impact behavior of subsequent fires differently than removing larger trees. Thinning smaller trees reduces intensity (temperature & flame length) of understory fire and reduces ladder fuels that carry fire up into the forest canopy. Treatment of fine woody fuels less than 3 inches in diameter is emphasized in the Final Environmental Impact Statement for the B&B Fire Recovery Project, because these fuels are "primary contributors to fire behavior" (USDA FS 2005a). Light thinning from below does not disrupt contiguity of the overstory canopy, however; heavy thinning from below or thinning of the overstory is often necessary to prevent spread of independent canopy fire. Harvest of some larger trees may help to reduce canopy density and also provide revenue to fund treatment of understory and surface fuels.

Another benefit of thinning may include reduced litter. On one California ponderosa pine site, thinning reduced needlefall from 3,650 to 2,000 kg ha^{-1} when basal area was reduced from 38 to 15 m^2 ha^{-}. Fine fuels remained essentially the same, however, because herbs increased after thinning from 250 to 1,600 kg ha^{-1} (Biswell 1973). Even so, the resulting open forest more closely resembled historic conditions by encouraging late season fire; live grasses delay the fire season by retaining moisture until later in the summer compared to accumulations of pine needles that dry out quickly (Agee 1993). At a different California site, the benefit of thinning was more obvious where no branch fuels fell in a thinned stand over a ten year period, but about 6,500 kg ha^{-1} of branch fuels fell to the forest floor in an adjacent unthinned stand (Agee and Biswell 1970). Finally, at one Pole Creek site on the Deschutes National Forest, thinning reduced ladder fuels and reduced stand density, but also stimulated light sprouting of *Ceanothus* shrubs (Figure 38).

Before Thinning Treatment	After Thinning Treatment
Trees/Acre: 228	Trees/Acre: 136
Mean Diameter: 12 in	Mean Diameter: 15 in
Basal Area: 221 sq ft	Basal Area: 194 sq ft
Stand Density Index (SDI): 362	Stand Density Index (SDI): 294
Relative Density Index: 0.723	Relative Density Index: 0.587
Mean Height to Live Crown: 25 ft	Mean Height to Live Crown: 30 ft

Figure 38. Thinning reduced ladder fuels, reduced stand density, and stimulated limited growth of *Ceanothus* shrubs at this Pole Creek site. Cruise data after thinning treatment is based on my cruise of standing trees only, and data before thinning treatment is based on my cruise of both standing trees and remaining stumps.

Response of vegetation to different treatments is variable. At another Pole Creek site on Deschutes National Forest, fuel treatment consisting of thinning and prescribed fire resulted in germination of large numbers of *Ceanothus* seed and subsequent vigorous shrub growth (Figure 39). On relatively high and moist sites such as these at Pole Creek near Sisters (Figures 37, 38, and 39), light thinning of ponderosa pine may be the best approach. Aggressive thinning, especially when combined with prescribed burning may actually increase risk of high-severity fire when treatment stimulates shrub growth, unless followed by another burn to kill shrubs and reduce seed bank. It should be noted that treatments are not a one-time effort to reduce risk and fire hazard; treatments will need to be repeated to maintain forests in a fire-resilient condition.

In addition to directly impacting fuels, thinning treatments that reduce stand density may also reduce future recruitment of dead and down wood by increasing tree resistance to insects and disease. For example, mountain pine beetle induced mortality of lodgepole pine has been found to be greatest in stands at densities above 160-170 SDI. Stand density index is a measure of stocking equal to the equivalent number trees per acre with a quadratic mean diameter of 10 inches (Reineke 1933). In ponderosa pine stands, mountain pine beetle mortality has been minimal in stands maintained at basal areas below 120-150 square feet (Cochran et al. 1994, Powell 1999).

Before Thinning Treatment	After Thinning Treatment
Trees/Acre: 128	Trees/Acre: 106
Mean Diameter: 14 in	Mean Diameter: 12 in
Basal Area: 171 sq ft	Basal Area: 90 sq ft
Stand Density Index: 263	Stand Density Index: 151
Relative Density Index: 0.524	Relative Density Index: 0.302
Mean Height to Live Crown: 23 ft	Mean Height to Live Crown: 20 ft

Figure 39. Combined thinning and prescribed burn treatment stimulated vigorous growth of *Ceanothus* shrubs at this Pole Creek site. Although stand density was reduced, shrubs now provide flammable understory fuels that are capable of supporting high-severity fire.

b. Salvage Logging

Fuels treatment is still appropriate after disturbance has occurred, and may reduce the probability of reburn. Salvage logging is expected to moderate fire behavior by reducing future recruitment of down wood. Reducing fuel loads toward historic levels not only reduces resistance of future fires to suppression, but also provides the opportunity to re-introduce fire in the future to maintain low fuel loads and historic forest conditions.

Following the B&B Fire, risk of subsequent high-severity fire is predicted to remain low for five years because of reduced fine fuels. Remaining large wood will not significantly affect fire ignition, fire intensity, and rate of spread, but may contribute to development of larger, higher-severity fires with longer residence time – fires that are often resistant to control. Fuel loads of 40 tons per acre or more are considered extremely resistant to control, in part, because large amounts of down wood make construction of fire lines very difficult, as do small trees and shrubs (USDA FS 1976). Combustion of large wood greater than 12 inches in diameter contributed to tree mortality and to severe soil heating during the B&B Fire and other recent fires on the Deschutes National Forest (USDA FS 2005a).

Surface fuels are expected to accumulate as understories recover and dead trees fall (Figures 40 and 41) (USDA FS 2005a). Fuel loads may reach a maximum 25 years post-fire and may exceed 120 tons/ac in some areas (USDA FS 2005a). Inventory of snags on one site above Suttle Lake indicates that fuel loads will reach approximately 46 tons/ac in that area (Figure 40). In contrast to current and predicted conditions, fuel loads probably ranged from only 5-35 tons/ac under ponderosa pine and mixed-conifer historic, natural disturbance regimes (USDA FS 2005a).

Figure 40. Fuel loads of 46 tons/ac are predicted at this Suttle Lake Site once the dead trees fall.

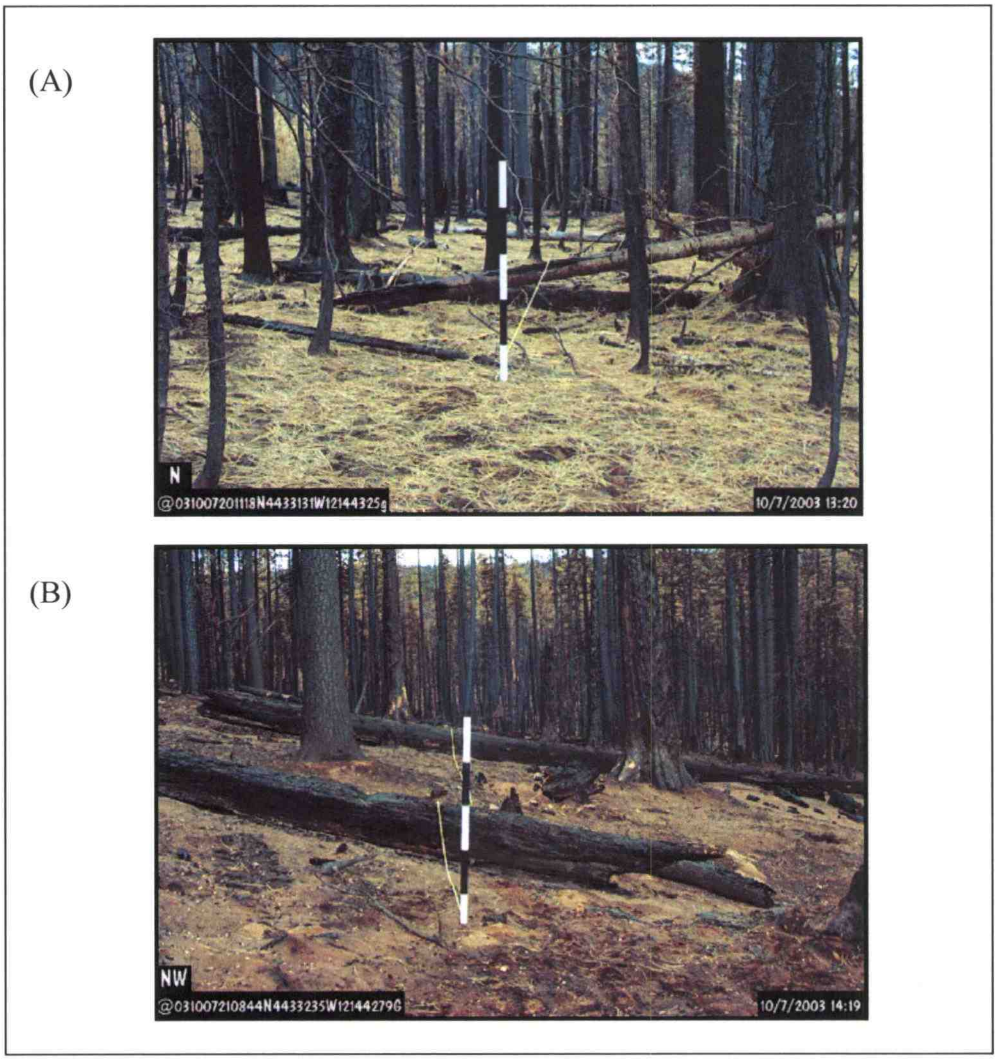

Figure 41. Surface fuel load and size class distribution were variable in October 2003 following the B&B Fire. Surface fuel load was 33 tons/ac at site A and 92 tons/ac at site B. Accumulations of fine and small woody fuels at site A increase the risk of high intensity, quickly spreading fire. Although the fuel load is greater at site B, large logs do not affect fire intensity or rate of fire spread significantly. Instead, large fuels contribute to increased fire severity associated with long fire duration. Partially decayed logs may also carry fire in some lodgepole pine forests and lead to fires of larger extent (Agee 1993). Although there is currently little risk of fire at site B, surface fuels of all size classes will increase, as snags fall and decay. (USDA FS 2005a)

Salvage logging is controversial, however. For example, salvage logging is proposed on only about 7% of the area burned by the Link and B&B Fires, or about 6,823 acres and has been legally challenged (USDA FS 2005a). One argument against salvage logging has been the associated loss of snags and down wood. In some western Cascade and eastern Olympic mountain forests, snags and logs shelter subalpine fir regeneration from full sunlight, browsing, and frost damage (Agee 1993). Microsites provided by snags may also be necessary for substantial regeneration to occur in the Pacific silver fir forest type (Agee 1993). In addition, snags have been associated with Northern Spotted Owl foraging intensity (North et al. 1999).

In areas that historically experienced frequent fire, however, dead trees would not have persisted in the landscape, because once created, the snags would have been consumed by the next few fires (Agee 1993). For example, during the B&B Fire, 25-75% of existing down wood was consumed in areas that experienced low to severe underburn (USDA FS 2005a). Historically, natural snag densities on ponderosa pine and mixed-conifer forest would have been low, with snags up to 20 inches diameter ranging from 2-12 snags/ac and those greater than 20 inches diameter ranging from 0.2-6 snags/ac (USDA FS 2005a).

When leaving snags, managers must consider long term risks associated with snags, including spotting and danger to firefighters. In some areas, snag retention may be less relevant since recent large, high-severity fires destroyed adjacent habitat. Management of owl habitat will be discussed further in the next section on future challenges.

Where long term benefits are determined to outweigh short term risk of management, salvage logging may provide economic benefit by producing wood products and providing jobs. Salvage logging following the B&B Fire is predicted to yield approximately 37 million board feet or about 9,000 truck loads of logs – enough structural timber to build almost three thousand, three bedroom homes (USDA FS 2005b).

Post-fire tours may improve public opinion of forest restoration treatments, including salvage logging. For example, not long after the B&B Fire was extinguished, the Sisters Ranger District conducted a tour of affected lands. Of 50 respondents to a follow-up telephone survey, 56% and 34% said the tour improved their opinion of forest thinning and prescribed fire, respectively. Even so, 28% of the respondents preferred that only danger trees be removed and 6% preferred no intervention (Shindler et al. 2004).

To maximize returns, salvage logging should be carried out within one year of mortality before significant decay of dead trees occurs. Opportunity to gain economic return and possibly fund post-fire forest restoration treatments diminishes rapidly and is typically lost within two to three years (Lowell et al. 1992 and USDA FS 2005a). Two years after the B&B Fire, generally only trees with 16+ inch dbh still have economic value. As a result, B&B Fire Recovery Project treatments will only be profitable on 6,823 acres of more than 94,000 acres burned. Delaying post- B&B Fire (2003) salvage logging an additional year from the 2005 to the 2006 field season may result in the loss of approximately 1.1 million dollars to the Federal Government (USDA 2005b).

c. Pruning

Pruning lower tree limbs removes ladder fuels and raises canopy height. Scorch of lower limbs during prescribed fire or removal of smaller trees will also raise canopy height. As with thinning, pruning will lead to increased surface fuels unless slash is treated (Brown et al. 2004). Although pruning does not yield timber, debris may be utilized in biomass plants. Pruning may also provide additional benefits of clear (knot free) wood, improved aesthetics, and reduced mistletoe infections (Emmingham 2005).

d. Chipping

Chipping involves grinding unwanted trees and understory vegetation into smaller pieces. Chipping traditionally redistributed fuels to the forest floor, where they are less likely to carry fire up into the canopy. Increased moisture content at the forest floor and limited oxygen within compacted fuels also moderate fire behavior. Fuels also decrease with time as chips decompose. Increasingly, wood chips are collected and transported to biomass plants for utilization. For example, the B&B Fire Recovery Project proposes biomass product sales as the primary treatment on 454 acres and as a post-harvest slash treatment on 4,775 acres (USDA FS 2005a).

e. Mowing

Shrubs are controlled with prescribed fire or mowing. Mowing involves using a 4-wheel drive tractor or a lightweight tracked vehicle with an attached heavy-duty mowing attachment. Under the B&B Fire Recovery Project, proposed treatment varies with site to minimize resource damage (USDA FS 2005a).

4. Slash Treatment

Mechanical treatment must be followed by slash treatment to reduce surface fuels. Removal of large diameter trees and logs can reduce long burn out periods and limit the initiation and spread of crown fires, but most fires are carried by surface fuels, so harvest without subsequent slash treatment will probably do more harm than good unless slash is treated. Simulations using the FARSITE fire model predict that group selection in Yosemite National Park without subsequent slash treatment will dramatically increase fuel loads and lead to increased spotting and crown fire (Stephens 1998).

Under extreme weather conditions models showed that group selection without slash or landscape fuel treatment led to fireline intensity that was double that predicted with no treatment, and almost 27 times that predicted after prescribed burn. Increased surface fuel loads led to not only increased fire intensity, but also to higher heat per unit area, rate of spread, area burned, and scorch height (Stephens 1998).

Slash may be broadcast burned, piled and then burned, lopped and scattered on site, removed, or left untreated. Broadcast burn, bioremoval, and pile burning are superior in fire model simulations to lopping and scattering or leaving slash untreated (Stephens 1998). Pile burning may be conducted under a wider range of environmental conditions than broadcast burning, offering a wider burn window (Busby 2002). If slash is not treated, fuel treatments including thinning and group selection may actually increase risk of extreme fire behavior, because harvest residue includes an abundance of small, flammable fuel. In addition, harvest opens up the canopy leading to increased windflow and increased solar radiation, both of which reduce fuel moisture content. Increased windflow may also cause blowdown, and in some forest types increased solar radiation may lead to increased surface fuels by stimulating growth of herbs, grasses, and shrubs. In certain climatic regions, however, a more open canopy will increase snow accumulation on the forest floor and lead to higher fuel moisture contents (Miller and Urban 1999). In any case, treatments need to be repeated as fuels accumulate and vegetation regrows if they are to provide sustained benefits, just like historic repeated low-intensity surface fire would do.

5. Landscape Considerations

a. Prioritization of Fuel Treatment Location

Fuel reduction across entire landscapes is rarely practical, so treatments must be prioritized according to forest type and management objectives. Areas treated first or more aggressively are often those with fuel accumulations outside the historic range of variability and/or with high-value resources.

Treatment of certain forest types may be more urgent or appropriate than treatment of other forest types. For example, prescribed burning ponderosa pine and dry mixed-conifer forests may create and maintain stands of large, fire resistant trees and move stand conditions back toward the natural, historic range of variability. In high elevation Pacific silver fir forest, however, prescribed fire is likely to cause high mortality and actually increase fuel loads (USDA FS 2004). For this reason, no B&B Fire Recovery Project treatments are located in areas that historically experienced natural, high-severity fire regimes, including high elevation forests (USDA FS 2005a).

Fuel treatments are also located to provide defensible space in areas with high ignition risk or near high value resources. B&B Fire Recovery Project treatments are proposed in and adjacent to Wildland Urban Interface (WUI); next to major roads; and near existing and potential northern spotted owl nesting, roosting, and foraging habitat; (USDA FS 2005a).

b. Landscape Pattern of Fuel Treatments

On a landscape scale, the mosaic of fuel treatments should meet management objectives, including reducing probability of large, high-severity wildfires. Treatments may be especially useful near ignition sources such as campgrounds. On the other hand, one isolated treatment surrounded by dense forest will probably not accomplish much. The most effective treatment is to reduce fuels across the entire landscape, but this is rarely practical. The traditional long, linear fuel break has been considered a more economic alternative, but many consider the treatment unsightly. In other cases landownership patterns make implementation unrealistic. In these cases, smaller gap treatments provide an alternative. Gap treatment typically involves clearing trees in small areas of width about twice the height of mature trees (Helms 1998). They appear relatively natural and are flexible enough to place in landscapes of mixed ownership.

Treated blocks do not have to form contiguous fuel treatments to provide benefits. Although some landscape scale benefit is provided directly within the treated area through reduced spotting and crown fire and reduced rate of fire spread, additional landscape scale benefit is provided indirectly, because fuel breaks slow headward movement of fire, forcing fire to spread relatively slowly in a flanking direction at lower intensity (Finney 2001).

Strategically located treatments may take advantage of existing landscape features such as lakes, rock outcrops, and roads, or may simultaneously address management concerns such as root rot, blow down, bark beetles, and revenue generation. They may also serve to recreate historic vegetative mosaics across the landscape. For example, small patches less than 2 acres are proposed as part of the B&B Fire Recovery Project to emulate natural, historic disturbance including spot fires and sporadic torching during otherwise low intensity wildfire, root rot pockets, and insect disturbance (USDA FS 2005a).

6. Looking Ahead

Now that we’ve discussed the change in forest conditions over the past century and possible responses to the increased risk of high-severity fire, can you think of future challenges that may complicate implementation of fuel treatments?

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E. Future Challenges

Managers are faced with many challenges when trying to restore fire resilient forests in central Oregon. Complex and often conflicting legal mandates, threatened and endangered species such as the northern spotted owl, and climate change are three examples.

1. Multiple and Conflicting Policy Directives

Restoring natural fire regimes and associated forest conditions is complicated by multiple, and often conflicting policy directives. For example, the Final Environmental Impact Statement for the B&B Fire Recovery Project identifies more than 20 laws and policies that were considered during project analysis, including the Endangered Species Act (1973), the National Environmental Policy Act (1969), the National Forest Management Act (1976), the Multiple Use Sustained Yield Act (1960), the Clean Air Act (as amended in 1990), and the Northwest Forest Plan (1994).

According to one formal survey conducted by Miller and Landres (2004) of 146 personnel employed in fire and fuels management with 5 federal agencies across 23 states, on average 40% of planned fuel treatments were not implemented. The survey included a questionnaire that asked several questions to determine why fire and fuel management objectives were not attained. Most common responses included poor weather, inadequate resources (funding and personnel), air quality regulations, public opinion, management of threatened and endangered species and other wildlife, requirements of the National Environmental Policy Act (NEPA), policy concerning private property in the wildland urban interface, and cultural or historical site protection (Miller and Landres 2004).

These same challenges are experienced to varying degrees on the Deschutes National Forest. Although some of the Deschutes National Forest is treated each year, there are always discrepancies between planned and implemented acres. Common reasons include weather, money, conflicting regulations, and litigation (D. Thomas, personal communication, September 7, 2005).

Insufficient funding precludes treatment in many areas. Based "solely on economic objectives to reduce suppression costs on treated acres," treatments are predicted to be cost effective at rates of only 20-115 $/ac, depending on initial site conditions, risk of ignition, and potential losses from stand replacing fire (Busby 2002). Treatments of young, dense stands may be particularly difficult, where costs cannot be supplemented by revenue from harvest of large trees.

Depending on method and location, cost of fuel treatments over the last decade has ranged from $25/ac to$800/ac on or near Deschutes National Forest (Table 5). Currently, treatment of hazardous fuels on Deschutes Forest cost on average about $149/ac. With current funding of almost 3 million dollars, managers are able to treat about 20,000 acres per year (M. Evans, personal communication, October 26, 2005). Just using information in this paper, however, Deschutes Forest would ideally treat a majority of ponderosa pine and mixed-conifer forests and some high elevation and lodgepole pine forests. At a rate of $149/ac, reducing fuels on just half of this area, or roughly 400,000 acres would cost almost 60 million dollars. At the higher rate of $800/ac experienced at Black Butte ranch in 2001, treatment of 400,000 acres would cost almost 320 million dollars.

Table 5. Fuel treatment costs on Deschutes National Forest and Black Butte Ranch. (Data compiled from: Aycock 2002; Hall 1988; and D. Thomas, personal communication, September 7, 2005

	Avg. DNF 1992-98 Cost per Acre ($/ac)	Predicted Cost to Treat 400,000 Acres at Avg. DNF Rate ($ Million)	Black Butte 2001 Cost per Acre ($/ac)	Predicted Cost to Treat 400,000 Acres at Black Butte Rate ($ Million)
Prescribed Fire	50 - 110	20 - 44	-	-
Mechanical Treatment	75 - 350	30 - 140	265-800	106 - 320
Mowing	25 - 52	10 - 21	-	-

Investments in proactive fuel treatments are surprisingly limited, however, contrasted with money spent on fire suppression. For example, only 9% of the annual fire budget between FY 1995 and FY 2000 was spent on treatments versus 91% on fire suppression (Busby 2002). In addition to losses associated with damaged or destroyed resources, fire suppression is expensive. For example, the 23,573 acre 2002 Eyerly Fire cost 12 million dollars ($509/ac) to extinguish, and the 4,200 acre 2002 Cache Mountain

Fire cost 6.2 million dollars ($1,476/ac) to put out. In addition, fire suppression costs associated with the approximately 500,000 acre Biscuit Fire totaled 133 million dollars ($266/ac) (Aycock 2002).

Litigation may also impede implementation of planned fuel treatments. Deschutes National Forest fire managers probably have greater public support, however, than managers on other forests. Based on a 2002 survey of 192 citizens of Jefferson and Deschutes Counties, the majority of central Oregon residents support fuel treatments with 56% and 64% of respondents agreeing that prescribed fire and mechanical treatments are legitimate tools (Shindler et al. 2002). Sisters residents may be even more supportive based on responses to a small 2003 survey, with 69, 60, and 79% of respondents agreeing that prescribed fire, mowing, and thinning are "totally acceptable" (Shindler and Toman 2003).

2. Northern Spotted Owl

Management of threatened and endangered species, including the northern spotted owl, also complicates fire and fuels management on the Deschutes National Forest, where northern spotted owls are most commonly found in closed canopy, mistletoed mixed-conifer slopes (E. Forsman, personal communication, September 23, 2005). Protection of northern spotted owl habitat is required under the 1973 Endangered Species Act, but the very forest conditions that provide suitable nesting, roosting, and foraging (NRF) habitat also are at increased risk of stand replacing fire, which threatens the (or calls into question) sustainability of owl habitat (North et al. 1999). Desired characteristics of owl habitat are identified in the B&B Fire Recovery Project Final Environmental Impact Statement (FEIS). Those that increase risk of high-severity fire include multi-storied stands with greater than 60% canopy cover, presence of snags and down wood, and understory species composition of white fir, Douglas-fir, mountain hemlock, and Engelmann spruce. Other habitat characteristics suggested in the FEIS are more compatible with maintaining fire resilient forests, such as overstories comprised of large (>21 inch dbh) Douglas-fir and ponderosa pine that developed in open grown conditions (USDA FS 2005).

a. Fire Suppression and Spotted Owl Habitat

Fire suppression may have initially contributed to an increase in spotted owl habitat on some eastside Oregon forest sites, because it allowed the development of multi-storied, high canopied habitat (North et al. 1999 and USDA FS 1996). As of 1996, there were 17 known spotted owl nests within the Metolius Watershed (USDA FS 1996). By 2002, there were 26 known spotted owl nests in the Metolius Late Successional Reserve (LSR) alone, an area designated for development of late successional habitat used by old-growth related species, including the northern spotted owl.

More recently, however, high-severity fire associated with almost a century of fire suppression has contributed to loss of owl habitat. For example, the Link and B&B Complex Fires caused high tree mortality on approximately 17,480 acres within the Metolius LSR. These fires, along with other 2002 and 2003 fires, led to mortality of 113,000 large trees over 21 inches in diameter and impacted 17 of 26 northern spotted owl nests within the LSR, resulting in 11 destroyed nests, 5 altered nests, and 2 dead nest groves (Figure 5.1) (USDA FS 2005). In addition, percentage of the watershed dominated by large trees declined to just 7%, contrasted with 64% in 1953 (USDA FS 2004).

Where fires are successfully suppressed, insect and disease outbreaks may impact owls (USDA FS 1996). According to a 1991 report to the Deschutes National Forest staff, tussock moth and spruce budworm outbreaks resulted in almost total mortality of true firs within the Brush Creek Spotted Owl Habitat Area. The report warned that continued fire suppression would accelerate tussock moth and budworm outbreaks (Simon 1991). In addition, 1985-1992 outbreak of western spruce budworm led to a loss of roughly 72% of nesting, roosting, and foraging habitat in the mixed-conifer portion of the B&B Fire Recovery Project area (USDA FS 2005).

b. Risk Management

Conflicting policies concerning management of northern spotted owl habitat are evident on the Deschutes National Forest. Long term planning is now required to maintain owl habitat on the Deschutes National Forest, because short term risk of active management must be balanced against risk of future loss to fire, insects, and disease. For example, habitat benefits provided by snags must be weighed against increased risk of spotting and danger to firefighters associated with snag retention (North et al. 1999 and USDA FS 2005).

Forsman (E. Forsman, personal communication, September 23, 2005) suggests protecting a majority of sites currently occupied by owls, but aggressively treating other areas to open up stands and increase forest resistance to fire and other disturbance. When currently occupied sites are lost to disturbance, the treated stands would be allowed to close in and replace lost owl habitat. Under this approach, managers would try to mimic fire and create a shifting mosaic of habitat where treated patches are allowed to come on line as needed.

Fuel treatments within northern spotted owl habitat are controversial, however. One reason is that treatments designed to reduce ladder fuels and canopy contiguity might negatively impact owl habitat (USDA FS 1996). Within the B&B Fire Recovery Project boundary, approximately 1,630 acres are designated as Nesting, Roosting, and Foraging (NRF) habitat. Ironically, these areas are excluded from treatment to minimize short term risk of management activity on critical remaining habitat (USDA FS 2005). The B&B Fire Recovery Project will, however, potentially create 2,376 acres of nesting, roosting, and forage habitat by increasing forest resilience to wildfire (USDA FS 2005).

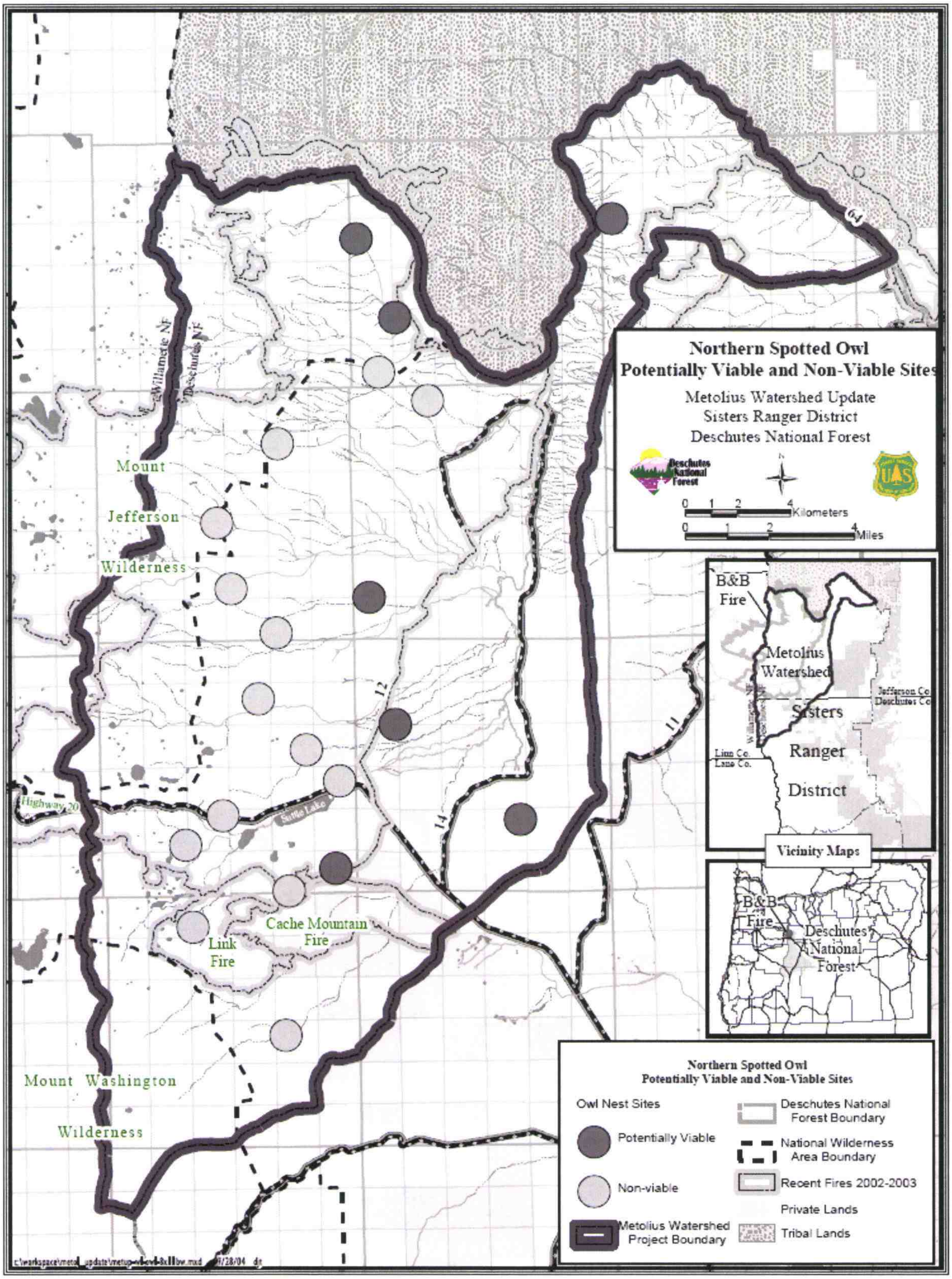

Figure 42. Fire has accelerated loss of spotted owl habitat within the Metolius Watershed, and along with drought, insects, and disease, has led to loss of over 11,000 acres of nesting, roosting, and foraging owl habitat and led to loss of at least 14 of 21 known owl sites.

3. Short Term Climate Change

Climate change further complicates fire and fuels management by influencing vegetation, fire behavior, and fire effects. For example, change in forest composition may impact forest (fuel) connectivity by altering fuel moisture, fuel load, and fuel bulk density (Miller and Urban 2000).

The effects of climate change on vegetation are varied. Regional warming during the twentieth century has been associated with subalpine forest invasion of cool, historically snow-dominated meadows, but in other areas, warming and drying trends have led to more frequent fire (i.e., steep south aspects) and forest loss (Agee 1993).

Within the Pacific silver fir forest type, the transitional boundary between areas that support regeneration of mixed-conifer and those that support regeneration of Pacific silver fir may have shifted upslope since existing older stands became established (Henderson et al. 1989). Areas suited for prescribed burning may increase if warmer and drier climate leads to expansion of drier mixed-conifer and ponderosa pine forest types.

Climate change may also influence fire effects. For example, climate change may increase the incidence of severe wildfire followed by intense rainstorms or the incidence of rain on snow events and lead to increased debris flow activity (Meyer et al. 2001). Effects are likely to be variable, however. In Ontario, declines in sediment yield in streams and lakes were more highly correlated with climate warming and drying trends than with forest regeneration of shrubs and trees after either clearcut or forest fire (Blais et al. 1998).

Fire effects may also vary with change in timing of weather events, because soil susceptibility to erosion diminishes with time as vegetation, forest floor, and root systems recover. For example, hill slope erosion was very low for the first two post-fire years following the 1988 Yellowstone fires due to reduced snow melt, but major runoff and associated erosion did occur in 1991 and 1992 during large rainstorms (Minshall 1997). High rainfall intensity is often critical. On the Colorado Front Range, a single 1999 summer storm with rainfall intensity of 35 mm/hr caused 90% of that year's 310 m^3 rill erosion sediment yield, compared with a total rill erosion yield of only 10 m^3 in 1997 immediately following the wildfire (Moody 2001).

Finally, the Pacific Decadal Oscillation adds another layer of complexity to analysis of wildfire trends in the Pacific Northwest. The Pacific Decadal Oscillation refers to fluctuations in sea surface temperature and wind patterns that occur on about a 20-40 year frequency that are related to warm and cold climatic phases in the inland Northwest. Drought (and associated wildfire) is generally more common during warm phases (Hessl et al. 2004).

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F. Conclusion

Natural fire regimes differed pre-settlement with forest type on the Deschutes National Forest along temperature and moisture gradients often associated with elevation change and topography. Lower and drier ponderosa pine forests experienced frequent, low-severity fire. Mixed-conifer forests grew at mid-elevations above the ponderosa pine forests and below the lodgepole and high elevation forest. They are very productive and experienced moderate- or mixed- severity fires, with more frequent fire in drier areas. Lodgepole pine and high-elevation forests were less productive and received the greatest moisture. They experienced less frequent, but more severe fire. Spatial and temporal variation was important, however. Forest type varied across the landscape, and fire behavior varied within forest type and even within individual fires.

Forest conditions and fire regimes have changed in Oregon's east Cascade ecosystems over the last century. Fire suppression and logging have altered forest composition and structure and increased forest susceptibility to stand replacing fire. Impact has been greatest in today's ponderosa pine and mixed-conifer forest types, which historically experienced relatively frequent, low-severity fire. Fuel treatments are now needed to return forest conditions closer to those experienced historically.

On the Deschutes National Forest, mechanical treatments and prescribed fire have recently been implemented to reduce fuel loads, alter fuel distribution, and favor fire resistant species. Fuel breaks have been created to moderate fire behavior and aid in fire suppression efforts. They have been strategically located to protect high value resources such as the wildland urban interface, recreation areas, major roads, and northern spotted owl habitat. Emphasis has also been placed on treatment of ponderosa pine and mixed-conifer forest to create and maintain stands of large, fire resistant trees and move stands back toward the natural, historic range of variability. Much of the Deschutes National Forest has not been treated, however, and investment in proactive fuel treatments is inadequate, particularly after considering expenditures required for fire suppression.

Although challenges remain, such as conflicting policy directives, management of northern spotted owl habitat, and climate change, actively reducing fuels is usually compatible with many forest objectives. Active fuels management is especially appealing once long term risks of inaction and fire suppression are considered.

APPENDICES

APPENDIX A

Plot locations.

Demonstration plots were established on the Deschutes National Forest. Pictures taken at the plots and plot inventory data were used within this paper. The plots are located between Suttle Lake and Sisters. More detailed descriptions of plot locations follow. General plot locations are also identified on the map following the directions listed below.

Note: all plots are rectangular or square (with 90° corners). Reference markers are identified below and are tagged. Plot corners are also tagged.

Road 12 & HWY 20 Junction

The 1 acre plot is located northwest of the Road 12 and Highway 20 junction. From the "caution stop sign ahead" signpost, the NE corner of the plot is 209 feet N26°W. Plot sides from the NE corner are 208 feet S60°W and 208 feet N30°W.

Lower Suttle Lake

The ¼ acre plot is above the Road 2070, which is just south of Suttle Lake. The plot is approximately 2 miles up Road 2070 off of Highway 20. From the "caution right turn ahead sign, the NW corner of the plot is 327 feet S75°E. Plot sides off of the NW corner are 104 feet S22°E and 104 feet N68°E.

Upper Suttle Lake

The 1 acre plot is located just above Road 2066, which is the second road south of Suttle Lake. The plot is approximately 0.3 miles up 2066 from Road 2070.From a dead 10" dbh grand fir just south of Road 2066 and west of a dirt side road, the SW corner of the plot is 53 feet S40°E. Plot sides from the SW corner are 208 feet N25°E and 208 feet S65°E.

"Untreated" Metolius Demonstration Plot near Camp Sherman

From the interpretation sign post marked "Untreated," the NW corner of the plot is 147 feet N70°E. Plot sides from the NW corner of the plot are 153 feet S10°E and 285 feet N80°E. The plot is 1 acre.

“Turn of the Century” Metolius Demonstration Plot near Camp Sherman

The 1 acre plot is across the street from the “Untreated” Metolius Demonstration Plot. From the interpretation sign post marked “Turn of the Century,” the SW corner of the plot is 225 feet N58^{O}E. Plot sides from the SW corner are 208 feet N68^{O}E and 208 feet N22^{O}W.

Pole Creek 1

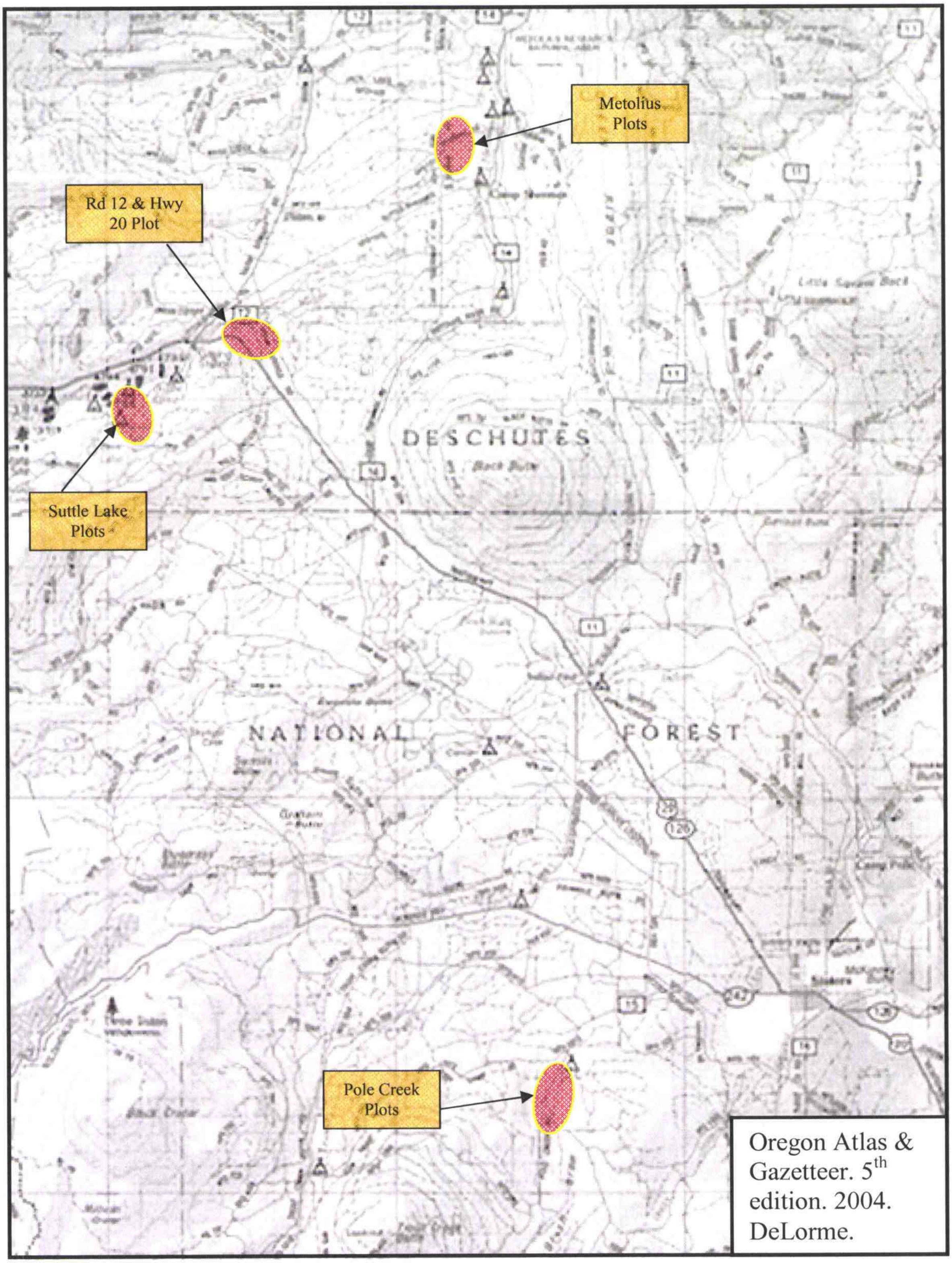
The 0.44 acre plot is located approximately 3.3 miles up Pole Creek Road near Sisters. From a tree in the “Y” formed by the fork between Pole Creek Road and Rd 260 the SE corner of the plot is 25 feet N50^{O}W. Plot sides from the SE corner are 208 feet N80^{O}W and 92 feet N10^{O}E.

Pole Creek 2

The ½ acre plot is located approximately 3.9 miles up Pole Creek Road near Sisters. The plot is approximately 20 feet to the west of Pole Creek Rd. From an ≈20” ponderosa pine about 5 feet south of a ditch relief culvert the SE corner is 100 feet N12^{O}W. Plot sides from the SE corner are 148 feet N76^{O}W and 148 feet N14^{O}E.

Pole Creek 3

The ½ acre plot is located approximately 3.8 miles up Pole Creek Road near Sisters. The plot is east of Pole Creek Road. From a 20” ponderosa pine the SW corner is 81 feet N79^{O}E. . Plot sides off of the SW corner are 148 feet N10^{O}E and 148 feet S80^{O}E.



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General plot locations.

APPENDIX B

Plot Characteristics and History.

Road 12 & HWY 20
- 1 acre plot
- Mixed conifer forest type
- Backburned during the B&B Fire
- Experienced extensive understory mortality

Lower Suttle Lake
- ¼ acre plot
- Mixed conifer forest type
- Experienced 100% mortality during the B&B Fire

Upper Suttle Lake
- 1 acre plot
- Mixed conifer forest type
- Thinned
- Experienced natural burn with little damage

"Untreated" Metolius Demonstration Plot near Camp Sherman
- 1 acre plot
- Ponderosa pine forest type
- No treatment

"Turn of the Century" Metolius Demonstration Plot near Camp Sherman
- 1 acre plot
- Ponderosa pine forest type
- Thinned and burned

Pole Creek 1
- 0.44 acre plot
- Ponderosa pine forest type
- Prescribe burned
- Light germination/sprouting of *Ceanothus*

Pole Creek 2

- ½ acre plot
- Ponderosa pine forest type
- Thinned
- Light germination/sprouting of *Ceanothus*

Pole Creek 3

- ½ acre plot
- Ponderosa pine
- Thinned and prescribe burned
- Extensive germination/sprouting of *Ceanothus*

APPENDIX C

Road 12 & Hwy 20 Junction Plot Tree List

Cruised Plot Size: 1 acre
Total Trees Cruised: 655
Total Trees Entered in ORGANON: 328
Effective Plot Size: 1/2 acre

Pre- backburn/B&B Fire stand conditions are approximated by including standing fire killed trees in the inventory. Dead trees include trees numbered 108 to 328 and are italicized.

Tree #	Species	DBH	Tree Height	Height to Crown	Crown Ratio
1	Incense Cedar	1	6	3	0.50
2	Incense Cedar	1	5	3	0.40
3	Douglas-fir	1	7	5	0.29
4	Incense Cedar	4	13	5	0.62
5	Incense Cedar	1	12	6	0.50
6	Incense Cedar	2	10	6	0.40
7	Incense Cedar	5	25	8	0.68
8	Incense Cedar	5	25	10	0.60
9	Incense Cedar	2	17	10	0.41
10	Incense Cedar	4	22	11	0.50
11	Douglas-fir	9	50	12	0.76
12	Incense Cedar	3	23	12	0.48
13	Incense Cedar	4	23	13	0.43
14	Incense Cedar	3	18	13	0.28
15	Douglas-fir	11	44	15	0.66
16	Douglas-fir	6	35	15	0.57
17	Douglas-fir	5	32	15	0.53
18	Douglas-fir	11	65	15	0.77
19	Douglas-fir	6	35	15	0.57
20	Incense Cedar	2	21	15	0.29
21	Incense Cedar	2	20	16	0.20
22	Incense Cedar	9	40	17	0.58
23	Douglas-fir	13	44	20	0.55
24	Incense Cedar	7	40	20	0.50
25	Douglas-fir	8	20	10	0.50
26	Douglas-fir	12	70	20	0.71
27	Douglas-fir	23	110	21	0.81
28	Douglas-fir	12	60	23	0.62
29	Douglas-fir	8	50	25	0.50
30	Douglas-fir	10	50	25	0.50
31	Douglas-fir	9	52	25	0.52
32	Grand Fir	16	87	28	0.68
33	Douglas-fir	7	50	28	0.44
34	Incense Cedar	1	35	30	0.14
35	Douglas-fir	8	45	30	0.33
36	Douglas-fir	9	74	30	0.59
37	Douglas-fir	14	60	30	0.50
38	Douglas-fir	7	64	30	0.53
39	Grand Fir	7	50	30	0.40
40	Douglas-fir	8	65	30	0.54
41	Douglas-fir	8	50	30	0.40
42	Douglas-fir	9	82	30	0.63
43	Douglas-fir	12	77	30	0.61
44	Douglas-fir	11	48	35	0.27
45	Douglas-fir	6	50	35	0.30
46	Douglas-fir	13	85	35	0.59
47	Douglas-fir	8	48	38	0.21

Road 12 & Hwy 20 Junction Plot Tree List (continued)					
48	Douglas-fir	12	71	40	0.44
49	Douglas-fir	8	59	40	0.32
50	Douglas-fir	8	80	40	0.50
51	Douglas-fir	14	76	40	0.47
52	Douglas-fir	5	65	43	0.34
53	Douglas-fir	10	81	44	0.46
54	Douglas-fir	7	64	45	0.30
55	Douglas-fir	18	102	45	0.56
56	Douglas-fir	17	103	45	0.56
57	Douglas-fir	12	85	45	0.47
58	Douglas-fir	8	60	45	0.25
59	Douglas-fir	9	70	45	0.36
60	Grand Fir	9	75	47	0.37
61	Douglas-fir	16	95	50	0.47
62	Douglas-fir	11	76	50	0.34
63	Douglas-fir	12	81	50	0.38
64	Douglas-fir	15	90	50	0.44
65	Grand Fir	11	84	50	0.40
66	Douglas-fir	9	73	50	0.32
67	Douglas-fir	7	60	50	0.17
68	Douglas-fir	17	98	50	0.49
69	Ponderosa pine	30	147	51	0.65
70	Ponderosa pine	24	113	51	0.55
71	Douglas-fir	10	81	51	0.37
72	Grand Fir	15	88	51	0.42
73	Douglas-fir	12	82	52	0.37
74	Grand Fir	18	101	52	0.49
75	Douglas-fir	12	94	55	0.41
76	Douglas-fir	14	94	55	0.41
77	Ponderosa pine	16	72	55	0.24
78	Douglas-fir	12	88	55	0.38
79	Douglas-fir	12	83	55	0.34
80	Douglas-fir	17	101	56	0.45
81	Ponderosa pine	25	110	56	0.49
82	Douglas-fir	7	65	57	0.12
83	Douglas-fir	11	68	58	0.15
84	Douglas-fir	7	65	58	0.11
85	Grand Fir	13	83	58	0.30
86	Ponderosa pine	53	150	60	0.60
87	Douglas-fir	15	98	60	0.39
88	Douglas-fir	21	105	60	0.43
89	Douglas-fir	15	102	60	0.41
90	Douglas-fir	8	70	62	0.11
91	Douglas-fir	14	89	62	0.30
92	Ponderosa pine	24	115	63	0.45
93	Douglas-fir	8	81	63	0.22
94	Douglas-fir	11	87	65	0.25
95	Douglas-fir	15	100	65	0.35
96	Douglas-fir	16	105	67	0.36
97	Douglas-fir	10	93	67	0.28
98	Douglas-fir	13	95	68	0.28
99	Douglas-fir	22	108	70	0.35

Road 12 & Hwy 20 Junction Plot Tree List (continued)					
100	Douglas-fir	12	90	70	0.22
101	Ponderosa pine	28	126	70	0.44
102	Douglas-fir	12	88	71	0.19
103	Douglas-fir	16	90	72	0.20
104	Douglas-fir	18	110	73	0.34
105	Douglas-fir	10	84	74	0.12
106	Ponderosa pine	38	158	80	0.49
107	Ponderosa pine	42	155	85	0.45
Dead Trees					
108	*Grand Fir*	*2*	*14*	*8*	*0.43*
109	*Grand Fir*	*1*	*20*	*11*	*0.43*
110	*Douglas-fir*	*1*	*17*	*10*	*0.43*
111	*Douglas-fir*	*1*	*3*	*2*	*0.43*
112	*Douglas-fir*	*4*	*20*	*11*	*0.43*
113	*Douglas-fir*	*1*	*13*	*7*	*0.43*
114	*Douglas-fir*	*11*	*44*	*25*	*0.43*
115	*Douglas-fir*	*3*	*20*	*11*	*0.43*
116	*Douglas-fir*	*9*	*50*	*28*	*0.43*
117	*Douglas-fir*	*7*	*35*	*20*	*0.43*
118	*Incense Cedar*	*1*	*6*	*3*	*0.43*
119	*Incense Cedar*	*1*	*10*	*6*	*0.43*
120	*Douglas-fir*	*1*	*12*	*7*	*0.43*
121	*Douglas-fir*	*2*	*14*	*8*	*0.43*
122	*Douglas-fir*	*2*	*13*	*7*	*0.43*
123	*Douglas-fir*	*4*	*25*	*14*	*0.43*
124	*Grand Fir*	*1*	*15*	*8*	*0.43*
125	*Grand Fir*	*1*	*12*	*7*	*0.43*
126	*Grand Fir*	*1*	*18*	*10*	*0.43*
127	*Douglas-fir*	*4*	*24*	*14*	*0.43*
128	*Incense Cedar*	*1*	*6*	*3*	*0.43*
129	*Douglas-fir*	*4*	*22*	*12*	*0.43*
130	*Douglas-fir*	*1*	*7*	*4*	*0.43*
131	*Grand Fir*	*2*	*12*	*7*	*0.43*
132	*Grand Fir*	*2*	*12*	*7*	*0.43*
133	*Incense Cedar*	*2*	*10*	*6*	*0.43*
134	*Douglas-fir*	*2*	*15*	*8*	*0.43*
135	*Douglas-fir*	*3*	*30*	*17*	*0.43*
136	*Incense Cedar*	*1*	*10*	*6*	*0.43*
137	*Incense Cedar*	*1*	*12*	*7*	*0.43*
138	*Incense Cedar*	*3*	*18*	*10*	*0.43*
139	*Grand Fir*	*4*	*30*	*17*	*0.43*
140	*Grand Fir*	*2*	*12*	*7*	*0.43*
141	*Grand Fir*	*2*	*15*	*8*	*0.43*
142	*Incense Cedar*	*1*	*10*	*6*	*0.43*
143	*Grand Fir*	*2*	*11*	*6*	*0.43*
144	*Incense Cedar*	*1*	*7*	*4*	*0.43*
145	*Grand Fir*	*1*	*8*	*5*	*0.43*
146	*Incense Cedar*	*2*	*15*	*8*	*0.43*
147	*Douglas-fir*	*4*	*35*	*20*	*0.43*
148	*Douglas-fir*	*2*	*15*	*8*	*0.43*
149	*Incense Cedar*	*3*	*18*	*10*	*0.43*
150	*Incense Cedar*	*1*	*9*	*5*	*0.43*

Road 12 & Hwy 20 Junction Plot Tree List (continued)

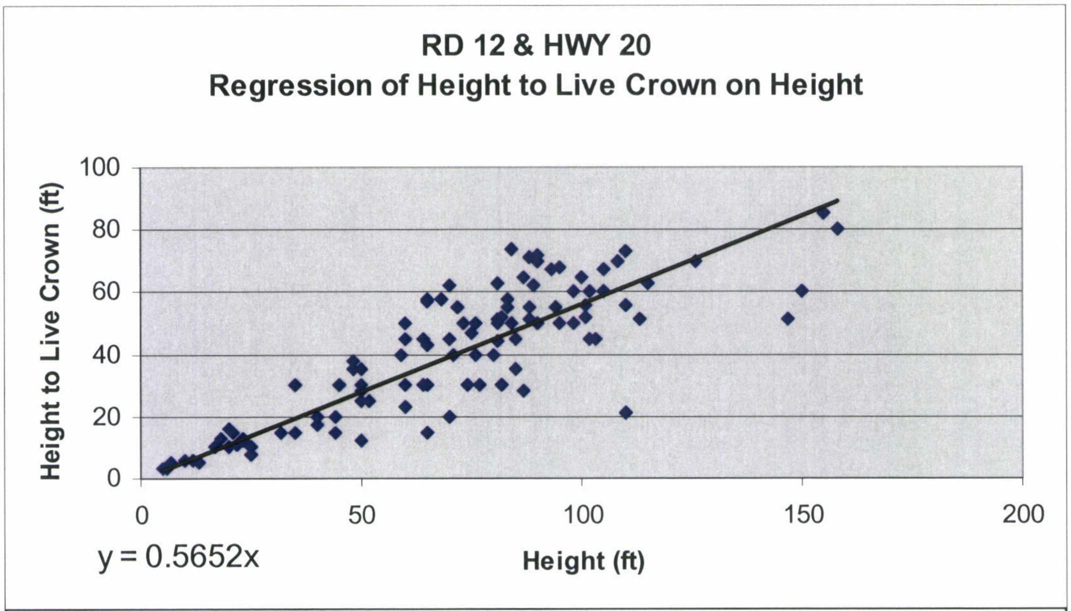
151	Incense Cedar	3	25	14	0.43
152	Douglas-fir	6	45	25	0.43
153	Douglas-fir	4	40	23	0.43
154	Incense Cedar	1	8	5	0.43
155	Incense Cedar	1	11	6	0.43
156	Incense Cedar	2	12	7	0.43
157	Incense Cedar	1	8	5	0.43
158	Incense Cedar	1	10	6	0.43
159	Incense Cedar	2	17	10	0.43
160	Douglas-fir	2	18	10	0.43
161	Incense Cedar	5	25	14	0.43
162	Douglas-fir	8	49	28	0.43
163	Incense Cedar	1	8	5	0.43
164	Incense Cedar	2	12	7	0.43
165	Grand Fir	7	38	21	0.43
166	Incense Cedar	3	10	6	0.43
167	Incense Cedar	3	15	8	0.43
168	Incense Cedar	2	15	8	0.43
169	Incense Cedar	3	15	8	0.43
170	Incense Cedar	1	7	4	0.43
171	Douglas-fir	6	27	15	0.43
172	Incense Cedar	1	7	4	0.43
173	Incense Cedar	1	13	7	0.43
174	Incense Cedar	1	6	3	0.43
175	Incense Cedar	1	7	4	0.43
176	Grand Fir	2	20	11	0.43
177	Incense Cedar	1	7	4	0.43
178	Incense Cedar	4	22	12	0.43
179	Incense Cedar	1	18	10	0.43
180	Douglas-fir	8	73	41	0.43
181	Douglas-fir	15	93	53	0.43
182	Incense Cedar	1	12	7	0.43
183	Douglas-fir	5	20	11	0.43
184	Incense Cedar	2	14	8	0.43
185	Douglas-fir	7	20	11	0.43
186	Incense Cedar	3	10	6	0.43
187	Douglas-fir	1	7	4	0.43
188	Douglas-fir	8	48	27	0.43
189	Douglas-fir	10	52	29	0.43
190	Douglas-fir	1	15	8	0.43
191	Douglas-fir	5	35	20	0.43
192	Douglas-fir	3	20	11	0.43
193	Incense Cedar	1	7	4	0.43
194	Douglas-fir	4	28	16	0.43
195	Douglas-fir	5	40	23	0.43
196	Incense Cedar	1	11	6	0.43
197	Douglas-fir	2	19	11	0.43
198	Douglas-fir	7	44	25	0.43
199	Incense Cedar	2	15	8	0.43
200	Incense Cedar	1	12	7	0.43
201	Incense Cedar	1	12	7	0.43

Road 12 & Hwy 20 Junction Plot Tree List (continued)					
202	Douglas-fir	1	7	4	0.43
203	Douglas-fir	4	22	12	0.43
204	Incense Cedar	3	15	8	0.43
205	Douglas-fir	4	28	16	0.43
206	Douglas-fir	1	6	3	0.43
207	Incense Cedar	4	22	12	0.43
208	Douglas-fir	5	27	15	0.43
209	Douglas-fir	1	11	6	0.43
210	Grand Fir	5	27	15	0.43
211	Incense Cedar	1	7	4	0.43
212	Incense Cedar	1	9	5	0.43
213	Incense Cedar	5	28	16	0.43
214	Douglas-fir	21	84	48	0.43
215	Incense Cedar	1	6	3	0.43
216	Douglas-fir	7	54	31	0.43
217	Incense Cedar	2	13	7	0.43
218	Incense Cedar	1	8	5	0.43
219	Douglas-fir	10	65	37	0.43
220	Grand Fir	19	126	71	0.43
221	Douglas-fir	16	80	45	0.43
222	Douglas-fir	8	31	18	0.43
223	Incense Cedar	1	10	6	0.43
224	Incense Cedar	1	11	6	0.43
225	Incense Cedar	1	12	7	0.43
226	Douglas-fir	13	83	47	0.43
227	Douglas-fir	6	32	18	0.43
228	Grand Fir	6	40	23	0.43
229	Grand Fir	17	104	59	0.43
230	Douglas-fir	5	47	27	0.43
231	Grand Fir	2	14	8	0.43
232	Douglas-fir	2	18	10	0.43
233	Douglas-fir	3	32	18	0.43
234	Douglas-fir	5	35	20	0.43
235	Ponderosa pine	41	143	81	0.43
236	Incense Cedar	1	10	6	0.43
237	Douglas-fir	8	36	20	0.43
238	Douglas-fir	1	11	6	0.43
239	Grand Fir	5	25	14	0.43
240	Douglas-fir	4	32	18	0.43
241	Incense Cedar	3	15	8	0.43
242	Douglas-fir	2	5	3	0.43
243	Douglas-fir	1	5	3	0.43
244	Incense Cedar	1	8	5	0.43
245	Incense Cedar	3	23	13	0.43
246	Incense Cedar	2	21	12	0.43
247	Grand Fir	8	61	34	0.43
248	Grand Fir	4	20	11	0.43
249	Incense Cedar	1	5	3	0.43
250	Incense Cedar	1	5	3	0.43
251	Douglas-fir	1	15	8	0.43
252	Douglas-fir	4	40	23	0.43
253	Grand Fir	1	3	2	0.43
254	Douglas-fir	9	60	34	0.43
255	Incense Cedar	3	16	9	0.43

Road 12 & Hwy 20 Junction Plot Tree List continued					
256	*Incense Cedar*	*1*	*10*	*6*	*0.43*
257	*Douglas-fir*	*1*	*13*	*7*	*0.43*
258	*Incense Cedar*	*2*	*15*	*8*	*0.43*
259	*Incense Cedar*	*4*	*26*	*15*	*0.43*
260	*Douglas-fir*	*1*	*10*	*6*	*0.43*
261	*Douglas-fir*	*3*	*10*	*6*	*0.43*
262	*Douglas-fir*	*6*	*20*	*11*	*0.43*
263	*Douglas-fir*	*10*	*64*	*36*	*0.43*
264	*Douglas-fir*	*12*	*75*	*42*	*0.43*
265	*Incense Cedar*	*1*	*9*	*5*	*0.43*
266	*Incense Cedar*	*1*	*13*	*7*	*0.43*
267	*Douglas-fir*	*7*	*54*	*31*	*0.43*
268	*Douglas-fir*	*6*	*50*	*28*	*0.43*
269	*Incense Cedar*	*1*	*11*	*6*	*0.43*
270	*Douglas-fir*	*15*	*82*	*46*	*0.43*
271	*Douglas-fir*	*11*	*45*	*26*	*0.43*
272	*Douglas-fir*	*2*	*20*	*11*	*0.43*
273	*Incense Cedar*	*1*	*10*	*6*	*0.43*
274	*Incense Cedar*	*1*	*10*	*6*	*0.43*
275	*Incense Cedar*	*1*	*7*	*4*	*0.43*
276	*Douglas-fir*	*1*	*5*	*3*	*0.43*
277	*Incense Cedar*	*1*	*13*	*7*	*0.43*
278	*Douglas-fir*	*10*	*89*	*50*	*0.43*
279	*Douglas-fir*	*3*	*15*	*8*	*0.43*
280	*Ponderosa pine*	*3*	*15*	*8*	*0.43*
281	*Ponderosa pine*	*2*	*10*	*6*	*0.43*
282	*Douglas-fir*	*3*	*20*	*11*	*0.43*
283	*Grand Fir*	*7*	*44*	*25*	*0.43*
284	*Douglas-fir*	*2*	*14*	*8*	*0.43*
285	*Incense Cedar*	*3*	*15*	*8*	*0.43*
286	*Douglas-fir*	*8*	*49*	*28*	*0.43*
287	*Incense Cedar*	*2*	*12*	*7*	*0.43*
288	*Incense Cedar*	*1*	*6*	*3*	*0.43*
289	*Incense Cedar*	*1*	*7*	*4*	*0.43*
290	*Douglas-fir*	*4*	*30*	*17*	*0.43*
291	*Incense Cedar*	*1*	*6*	*3*	*0.43*
292	*Douglas-fir*	*5*	*54*	*31*	*0.43*
293	*Douglas-fir*	*3*	*20*	*11*	*0.43*
294	*Douglas-fir*	*4*	*60*	*34*	*0.43*
295	*Douglas-fir*	*2*	*20*	*11*	*0.43*
296	*Grand Fir*	*2*	*15*	*8*	*0.43*
297	*Douglas-fir*	*7*	*65*	*37*	*0.43*
298	*Douglas-fir*	*8*	*25*	*14*	*0.43*
299	*Incense Cedar*	*1*	*6*	*3*	*0.43*
300	*Incense Cedar*	*1*	*6*	*3*	*0.43*
301	*Douglas-fir*	*1*	*11*	*6*	*0.43*
302	*Incense Cedar*	*1*	*13*	*7*	*0.43*
303	*Douglas-fir*	*7*	*45*	*25*	*0.43*
304	*Douglas-fir*	*7*	*70*	*40*	*0.43*
305	*Douglas-fir*	*7*	*40*	*23*	*0.43*
306	*Incense Cedar*	*1*	*5*	*3*	*0.43*
307	*Incense Cedar*	*2*	*17*	*10*	*0.43*
308	*Incense Cedar*	*1*	*5*	*3*	*0.43*

Road 12 & Hwy 20 Junction Plot Tree List (continued)

309	*Incense Cedar*	*1*	*14*	*8*	*0.43*
310	*Incense Cedar*	*3*	*20*	*11*	*0.43*
311	*Incense Cedar*	*1*	*8*	*5*	*0.43*
312	*Douglas-fir*	*10*	*25*	*14*	*0.43*
313	*Incense Cedar*	*2*	*13*	*7*	*0.43*
314	*Incense Cedar*	*1*	*7*	*4*	*0.43*
315	*Grand Fir*	*1*	*9*	*5*	*0.43*
316	*Incense Cedar*	*1*	*6*	*3*	*0.43*
317	*Incense Cedar*	*2*	*15*	*8*	*0.43*
318	*Incense Cedar*	*2*	*12*	*7*	*0.43*
319	*Incense Cedar*	*1*	*5*	*3*	*0.43*
320	*Incense Cedar*	*2*	*15*	*8*	*0.43*
321	*Incense Cedar*	*1*	*10*	*6*	*0.43*
322	*Incense Cedar*	*1*	*7*	*4*	*0.43*
323	*Ponderosa pine*	*7*	*27*	*15*	*0.43*
324	*Incense Cedar*	*4*	*12*	*7*	*0.43*
325	*Incense Cedar*	*1*	*5*	*3*	*0.43*
326	*Douglas-fir*	*3*	*32*	*18*	*0.43*
327	*Douglas-fir*	*1*	*14*	*8*	*0.43*
328	*Incense Cedar*	*1*	*13*	*7*	*0.43*



Regression was used to estimate pre-fire height to live crown on dead trees.

Rd 12 & Hwy 20

Down Wood Tallied for Entire 1 Acre Stand

Length (ft)	Width (in)	Width (ft)	Volume (cu ft)
28	4	0.3	9.33
16	2	0.2	2.67
32	7	0.6	18.67
15	3	0.3	3.75
30	6	0.5	15.00
30	6	0.5	15.00
30	4	0.3	10.00
25	4	0.3	8.33
20	3	0.3	5.00
10	5	0.4	4.17
15	5	0.4	6.25
30	9	0.8	22.50
30	7	0.6	17.50
70	8	0.7	46.67
25	6	0.5	12.50
20	4	0.3	6.67
20	4	0.3	6.67
35	6	0.5	17.50
30	3	0.3	7.50
30	2	0.2	5.00
30	2	0.2	5.00
15	2	0.2	2.50
15	2	0.2	2.50
10	3	0.3	2.50
10	3	0.3	2.50
10	3	0.3	2.50
40	3	0.3	10.00
20	3	0.3	5.00
50	5	0.4	20.83
60	6	0.5	30.00
30	2	0.2	5.00
15	1	0.1	1.25
3	55	4.6	13.75
3	30	2.5	7.50
20	2	0.2	3.33
20	2	0.2	3.33
20	2	0.2	3.33
5	10	0.8	4.17
5	10	0.8	4.17
5	10	0.8	4.17
50	6	0.5	25.00
35	5	0.4	14.58
30	4	0.3	10.00
15	1	0.1	1.25
12	3	0.3	3.00
10	5	0.4	4.17
8	35	2.9	23.33
3	35	2.9	8.75
3	2	0.2	0.50

Volume Down Wood = 465 cubic feet per acre

Mass of Down Wood = 7 tons/acre (assuming 1 cu ft wood = 30 lbs)

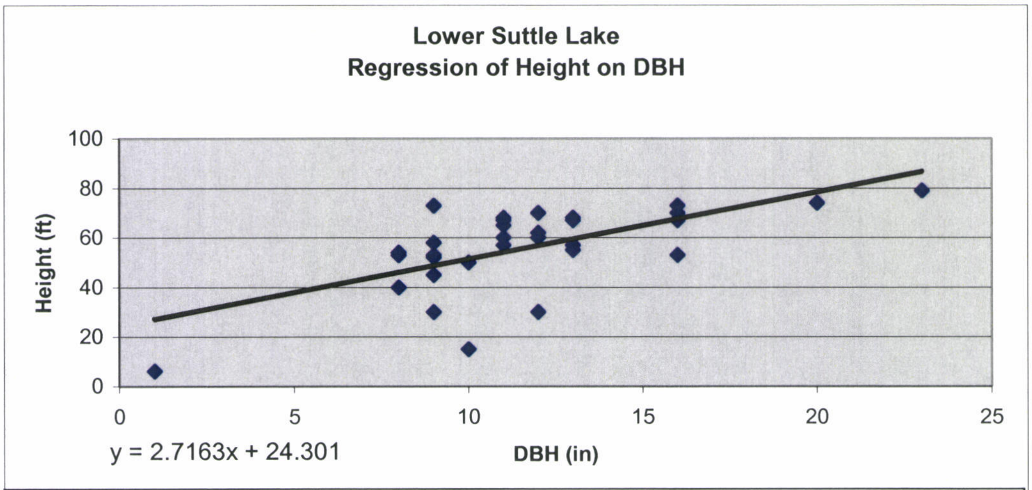
Lower Suttle Lake Plot Tree List				
Plot Size: 1/4 acre	Pre-burn Height to Live Crown Ratio assumed to be 0.55			
Stand was thinned, but experienced 100% mortality during the B&B Fire.				
Trees 38-110 were "grown" from cruised stumps and are italicized.				
Tree #	**Species**	**DBH**	**Tree Height**	**Crown Ratio**
Standing dead trees				
1	Douglas-fir	1	6	0.55
2	Douglas-fir	10	15	0.55
3	Douglas-fir	12	30	0.55
4	Douglas-fir	9	30	0.55
5	Douglas-fir	9	30	0.55
6	Douglas-fir	8	40	0.55
7	Grand fir	9	45	0.55
8	Grand fir	10	50	0.55
9	Douglas-fir	9	52	0.55
10	Douglas-fir	9	52	0.55
11	Grand fir	8	53	0.55
12	Douglas-fir	9	53	0.55
13	Douglas-fir	16	53	0.55
14	Grand fir	8	54	0.55
15	Grand fir	8	54	0.55
16	Douglas-fir	13	55	0.55
17	Douglas-fir	13	55	0.55
18	Grand fir	13	57	0.55
19	Douglas-fir	11	57	0.55
20	Douglas-fir	9	58	0.55
21	Douglas-fir	9	58	0.55
22	Douglas-fir	11	60	0.55
23	Douglas-fir	11	60	0.55
24	Grand fir	12	60	0.55
25	Douglas-fir	12	62	0.55
26	Ponderosa pine	11	65	0.55
27	Ponderosa pine	11	67	0.55
28	Douglas-fir	13	67	0.55
29	Douglas-fir	16	67	0.55
30	Grand fir	13	68	0.55
31	Douglas-fir	11	68	0.55
32	Ponderosa pine	12	70	0.55
33	Douglas-fir	16	70	0.55
34	Douglas-fir	9	73	0.55
35	Grand fir	16	73	0.55
36	Douglas-fir	20	74	0.55
37	Douglas-fir	23	79	0.55
Stumps				
38	*Douglas-fir*	*6*	*41*	*0.55*
39	*Douglas-fir*	*4*	*35*	*0.55*
40	*Douglas-fir*	*9*	*49*	*0.55*
41	*Douglas-fir*	*9*	*49*	*0.55*

Lower Suttle Lake Plot Tree List (continued)

42	Douglas-fir	5	38	0.55
43	Douglas-fir	2	30	0.55
44	Douglas-fir	5	38	0.55
45	Douglas-fir	5	38	0.55
46	Douglas-fir	3	32	0.55
47	Douglas-fir	6	41	0.55
48	Douglas-fir	8	46	0.55
49	Douglas-fir	12	57	0.55
50	Douglas-fir	13	60	0.55
51	Grand fir	4	35	0.55
52	Grand fir	6	41	0.55
53	Douglas-fir	12	57	0.55
54	Douglas-fir	2	30	0.55
55	Douglas-fir	2	30	0.55
56	Douglas-fir	8	46	0.55
57	Douglas-fir	6	41	0.55
58	Douglas-fir	2	30	0.55
59	Douglas-fir	6	41	0.55
60	Douglas-fir	12	57	0.55
61	Douglas-fir	5	38	0.55
62	Douglas-fir	5	38	0.55
63	Douglas-fir	10	51	0.55
64	Douglas-fir	2	30	0.55
65	Douglas-fir	1	27	0.55
66	Douglas-fir	5	38	0.55
67	Douglas-fir	5	38	0.55
68	Douglas-fir	10	51	0.55
69	Douglas-fir	12	57	0.55
70	Douglas-fir	4	35	0.55
71	Douglas-fir	3	32	0.55
72	Douglas-fir	4	35	0.55
73	Douglas-fir	7	43	0.55
74	Douglas-fir	1	27	0.55
75	Douglas-fir	3	32	0.55
76	Douglas-fir	2	30	0.55
77	Douglas-fir	1	27	0.55
78	Douglas-fir	5	38	0.55
79	Douglas-fir	5	38	0.55
80	Douglas-fir	3	32	0.55
81	Douglas-fir	2	30	0.55
82	Douglas-fir	1	27	0.55
83	Douglas-fir	8	46	0.55
84	Douglas-fir	7	43	0.55
85	Douglas-fir	2	30	0.55
86	Grand fir	5	38	0.55
87	Grand fir	3	32	0.55
88	Douglas-fir	3	32	0.55
89	Grand fir	5	38	0.55
90	Douglas-fir	5	38	0.55
91	Douglas-fir	7	43	0.55
92	Douglas-fir	4	35	0.55
93	Douglas-fir	5	38	0.55
94	Grand fir	9	49	0.55

Lower Suttle Lake Plot Tree List (continued)

95	*Douglas-fir*	*8*	*46*	*0.55*
96	*Grand fir*	*2*	*30*	*0.55*
97	*Douglas-fir*	*7*	*43*	*0.55*
98	*Douglas-fir*	*8*	*46*	*0.55*
99	*Douglas-fir*	*6*	*41*	*0.55*
100	*Douglas-fir*	*8*	*46*	*0.55*
101	*Douglas-fir*	*5*	*38*	*0.55*
102	*Douglas-fir*	*3*	*32*	*0.55*
103	*Douglas-fir*	*5*	*38*	*0.55*
104	*Douglas-fir*	*6*	*41*	*0.55*
105	*Douglas-fir*	*4*	*35*	*0.55*
106	*Douglas-fir*	*5*	*38*	*0.55*
107	*Douglas-fir*	*10*	*51*	*0.55*
108	*Douglas-fir*	*4*	*35*	*0.55*
109	*Douglas-fir*	*7*	*43*	*0.55*
110	*Douglas-fir*	*11*	*54*	*0.55*



Regression was used to estimate heights of trees “grown” from stumps.

Upper Suttle Lake Plot Tree List

Plot size: 1 acre

Stand was thinned and experienced light mortality during the B&B Fire. Trees 22 to 180 were "grown" from stumps and are italicized.

Tree #	Species	DBH	Tree Height	Height to Crown	Crown Ratio
1	Grand fir	15	88	43	0.51
2	Douglas-fir	20	96	47	0.51
3	Grand fir	24	98	42	0.57
4	Ponderosa pine	26	106	50	0.53
5	Grand fir	22	95	51	0.46
6	Ponderosa pine	24	94	70	0.26
7	Ponderosa pine	18	85	64	0.25
8	Ponderosa pine	24	115	65	0.43
9	Douglas-fir	41	130	50	0.62
10	Douglas-fir	47	146	57	0.61
11	Douglas-fir	38	153	50	0.67
12	Ponderosa pine	27	119	59	0.50
13	Grand fir	13	67	37	0.45
14	Grand fir	10	41	10	0.76
15	Douglas-fir	24	121	15	0.88
16	Douglas-fir	27	114	37	0.68
17	Douglas-fir	23	125	73	0.42
18	Ponderosa pine	2	5	1	0.78
19	Douglas-fir	33	132	42	0.68
20	Douglas-fir	28	112	42	0.63
21	Grand fir	8	45	8	0.82
Stumps					
22	*Douglas-fir*	*14*	*70*	*33*	*0.53*
23	*Douglas-fir*	*9*	*55*	*27*	*0.50*
24	*Douglas-fir*	*10*	*58*	*28*	*0.51*
25	*Douglas-fir*	*18*	*82*	*37*	*0.55*
26	*Douglas-fir*	*7*	*49*	*25*	*0.49*
27	*Douglas-fir*	*7*	*49*	*25*	*0.49*
28	*Douglas-fir*	*3*	*36*	*21*	*0.44*
29	*Douglas-fir*	*19*	*85*	*38*	*0.55*
30	*Douglas-fir*	*25*	*104*	*45*	*0.57*
31	*Douglas-fir*	*13*	*67*	*32*	*0.53*
32	*Douglas-fir*	*8*	*52*	*26*	*0.50*
33	*Douglas-fir*	*13*	*67*	*32*	*0.53*
34	*Douglas-fir*	*6*	*46*	*24*	*0.48*
35	*Douglas-fir*	*15*	*73*	*34*	*0.54*
36	*Grand fir*	*4*	*40*	*22*	*0.45*
37	*Douglas-fir*	*17*	*79*	*36*	*0.54*
38	*Douglas-fir*	*17*	*79*	*36*	*0.54*
39	*Douglas-fir*	*14*	*70*	*33*	*0.53*
40	*Douglas-fir*	*13*	*67*	*32*	*0.53*
41	*Douglas-fir*	*15*	*73*	*34*	*0.54*
42	*Douglas-fir*	*22*	*95*	*42*	*0.56*
43	*Douglas-fir*	*24*	*101*	*44*	*0.56*
44	*Douglas-fir*	*9*	*55*	*27*	*0.50*
45	*Douglas-fir*	*16*	*76*	*35*	*0.54*

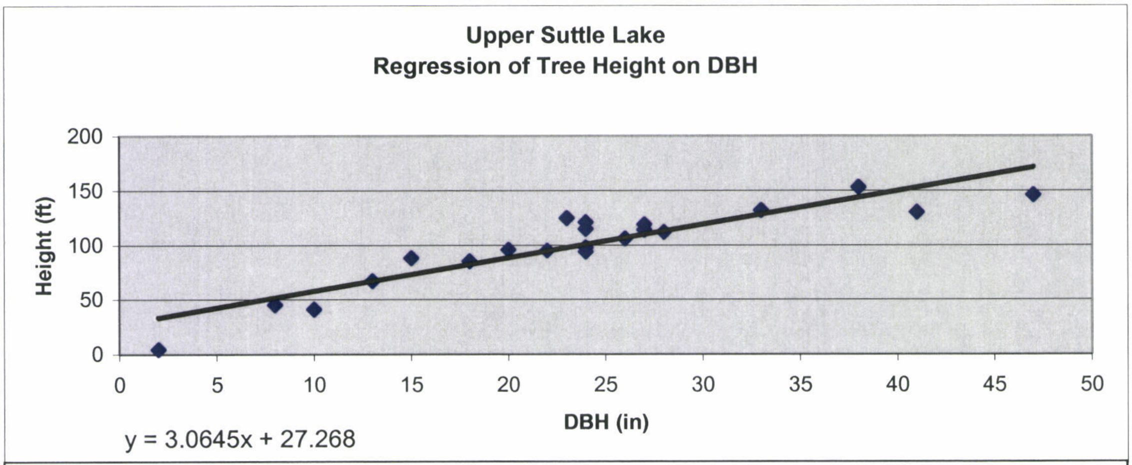
Upper Suttle Lake Plot Tree List (continued)

46	Douglas-fir	9	55	27	0.50
47	Douglas-fir	3	36	21	0.44
48	Douglas-fir	10	58	28	0.51
49	Douglas-fir	17	79	36	0.54
50	Douglas-fir	4	40	22	0.45
51	Douglas-fir	20	89	40	0.55
52	Douglas-fir	17	79	36	0.54
53	Douglas-fir	11	61	29	0.52
54	Douglas-fir	12	64	31	0.52
55	Douglas-fir	11	61	29	0.52
56	Douglas-fir	10	58	28	0.51
57	Douglas-fir	9	55	27	0.50
58	Douglas-fir	10	58	28	0.51
59	Douglas-fir	9	55	27	0.50
60	Douglas-fir	17	79	36	0.54
61	Douglas-fir	4	40	22	0.45
62	Douglas-fir	21	92	41	0.56
63	Douglas-fir	11	61	29	0.52
64	Douglas-fir	9	55	27	0.50
65	Douglas-fir	21	92	41	0.56
66	Douglas-fir	25	104	45	0.57
67	Douglas-fir	6	46	24	0.48
68	Douglas-fir	7	49	25	0.49
69	Douglas-fir	2	33	19	0.42
70	Douglas-fir	14	70	33	0.53
71	Douglas-fir	10	58	28	0.51
72	Douglas-fir	12	64	31	0.52
73	Douglas-fir	10	58	28	0.51
74	Douglas-fir	16	76	35	0.54
75	Douglas-fir	9	55	27	0.50
76	Douglas-fir	11	61	29	0.52
77	Douglas-fir	8	52	26	0.50
78	Douglas-fir	10	58	28	0.51
79	Douglas-fir	5	43	23	0.47
80	Douglas-fir	10	58	28	0.51
81	Douglas-fir	14	70	33	0.53
82	Douglas-fir	26	107	46	0.57
83	Douglas-fir	7	49	25	0.49
84	Douglas-fir	6	46	24	0.48
85	Douglas-fir	2	33	19	0.42
86	Douglas-fir	2	33	19	0.42
87	Grand fir	2	33	19	0.42
88	Douglas-fir	22	95	42	0.56
89	Douglas-fir	20	89	40	0.55
90	Douglas-fir	3	36	21	0.44
91	Douglas-fir	27	110	47	0.57
92	Douglas-fir	9	55	27	0.50
93	Douglas-fir	39	147	61	0.59
94	Douglas-fir	23	98	43	0.56
95	Douglas-fir	32	125	53	0.58
96	Douglas-fir	25	104	45	0.57
97	Douglas-fir	32	125	53	0.58
98	Douglas-fir	14	70	33	0.53

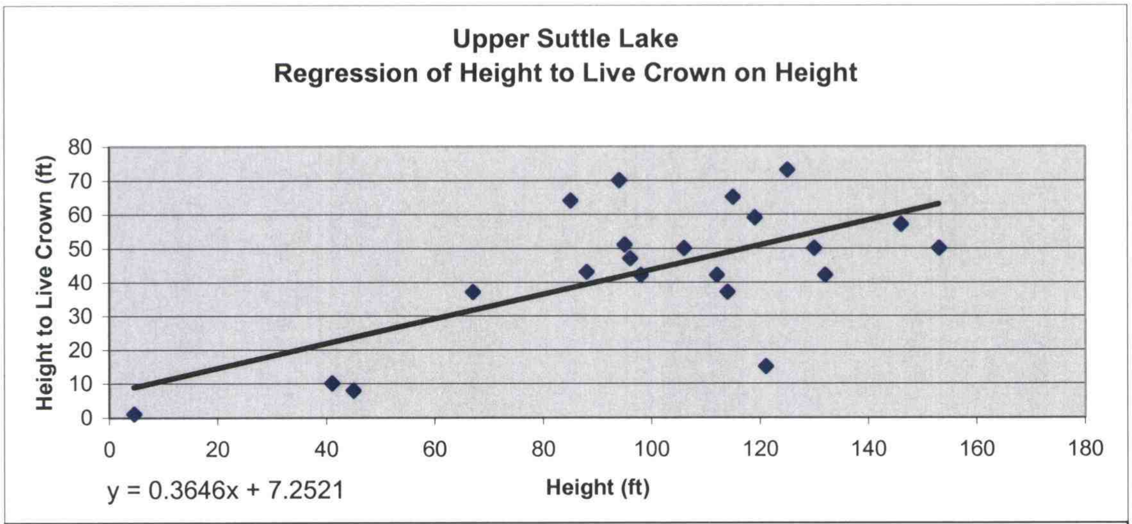
Upper Suttle Lake Plot Tree List (continued)

99	Douglas-fir	9	55	27	0.50
100	Douglas-fir	21	92	41	0.56
101	Douglas-fir	21	92	41	0.56
102	Douglas-fir	26	107	46	0.57
103	Douglas-fir	3	36	21	0.44
104	Douglas-fir	6	46	24	0.48
105	Douglas-fir	40	150	62	0.59
106	Douglas-fir	9	55	27	0.50
107	Douglas-fir	7	49	25	0.49
108	Douglas-fir	36	138	57	0.58
109	Douglas-fir	35	135	56	0.58
110	Ponderosa pine	20	89	40	0.55
111	Douglas-fir	9	55	27	0.50
112	Douglas-fir	21	92	41	0.56
113	Douglas-fir	11	61	29	0.52
114	Douglas-fir	11	61	29	0.52
115	Douglas-fir	10	58	28	0.51
116	Douglas-fir	13	67	32	0.53
117	Douglas-fir	14	70	33	0.53
118	Douglas-fir	19	85	38	0.55
119	Douglas-fir	22	95	42	0.56
120	Douglas-fir	17	79	36	0.54
121	Douglas-fir	14	70	33	0.53
122	Douglas-fir	16	76	35	0.54
123	Douglas-fir	17	79	36	0.54
124	Douglas-fir	14	70	33	0.53
125	Douglas-fir	19	85	38	0.55
126	Douglas-fir	19	85	38	0.55
127	Douglas-fir	48	174	71	0.59
128	Douglas-fir	17	79	36	0.54
129	Ponderosa pine	15	73	34	0.54
130	Douglas-fir	8	52	26	0.50
131	Douglas-fir	10	58	28	0.51
132	Douglas-fir	7	49	25	0.49
133	Douglas-fir	13	67	32	0.53
134	Douglas-fir	33	128	54	0.58
135	Douglas-fir	32	125	53	0.58
136	Douglas-fir	11	61	29	0.52
137	Douglas-fir	8	52	26	0.50
138	Douglas-fir	8	52	26	0.50
139	Douglas-fir	8	52	26	0.50
140	Douglas-fir	16	76	35	0.54
141	Douglas-fir	4	40	22	0.45
142	Douglas-fir	11	61	29	0.52
143	Douglas-fir	10	58	28	0.51
144	Douglas-fir	18	82	37	0.55
145	Douglas-fir	8	52	26	0.50
146	Douglas-fir	12	64	31	0.52
147	Douglas-fir	17	79	36	0.54
148	Douglas-fir	28	113	48	0.57
149	Douglas-fir	29	116	50	0.57
150	Douglas-fir	8	52	26	0.50
151	Douglas-fir	12	64	31	0.52

Upper Suttle Lake Plot Tree List (continued)					
152	*Douglas-fir*	*7*	*49*	*25*	*0.49*
153	*Douglas-fir*	*12*	*64*	*31*	*0.52*
154	*Douglas-fir*	*8*	*52*	*26*	*0.50*
155	*Douglas-fir*	*8*	*52*	*26*	*0.50*
156	*Douglas-fir*	*8*	*52*	*26*	*0.50*
157	*Douglas-fir*	*15*	*73*	*34*	*0.54*
158	*Douglas-fir*	*27*	*110*	*47*	*0.57*
159	*Douglas-fir*	*18*	*82*	*37*	*0.55*
160	*Douglas-fir*	*35*	*135*	*56*	*0.58*
161	*Douglas-fir*	*32*	*125*	*53*	*0.58*
162	*Douglas-fir*	*32*	*125*	*53*	*0.58*
163	*Douglas-fir*	*20*	*89*	*40*	*0.55*
164	*Douglas-fir*	*22*	*95*	*42*	*0.56*
165	*Douglas-fir*	*12*	*64*	*31*	*0.52*
166	*Douglas-fir*	*6*	*46*	*24*	*0.48*
167	*Douglas-fir*	*5*	*43*	*23*	*0.47*
168	*Douglas-fir*	*14*	*70*	*33*	*0.53*
169	*Douglas-fir*	*30*	*119*	*51*	*0.57*
170	*Douglas-fir*	*5*	*43*	*23*	*0.47*
171	*Douglas-fir*	*5*	*43*	*23*	*0.47*
172	*Douglas-fir*	*11*	*61*	*29*	*0.52*
173	*Douglas-fir*	*11*	*61*	*29*	*0.52*
174	*Douglas-fir*	*24*	*101*	*44*	*0.56*
175	*Douglas-fir*	*16*	*76*	*35*	*0.54*
176	*Douglas-fir*	*12*	*64*	*31*	*0.52*
177	*Douglas-fir*	*5*	*43*	*23*	*0.47*
178	*Douglas-fir*	*10*	*58*	*28*	*0.51*
179	*Douglas-fir*	*10*	*58*	*28*	*0.51*
180	*Douglas-fir*	*27*	*110*	*47*	*0.57*



Regression was used to estimate heights of trees "grown" from stumps.



Regression was used to estimate height to live crown on trees “grown” from stumps.

Upper Suttle Lake			
Down Wood			
Length (ft)	**Width (in)**	**Width (ft)**	**Volume (cu ft)**
14	5	0.4	5.83
7	14	1.2	8.17
34	10	0.8	28.33
10	7	0.6	5.83
20	3	0.3	5.00
25	3	0.3	6.25
6	12	1.0	6.00
5	5	0.4	2.08
40	22	1.8	73.33
21	9	0.8	15.75
60	14	1.2	70.00
25	3	0.3	6.25
105	25	2.1	218.75
20	7	0.6	11.67
30	3	0.3	7.50
Volume of Down Wood = 471 cubic feet per acre Mass of Down Wood = 7 tons/acre (assuming 1 cu ft = 30lbs)			

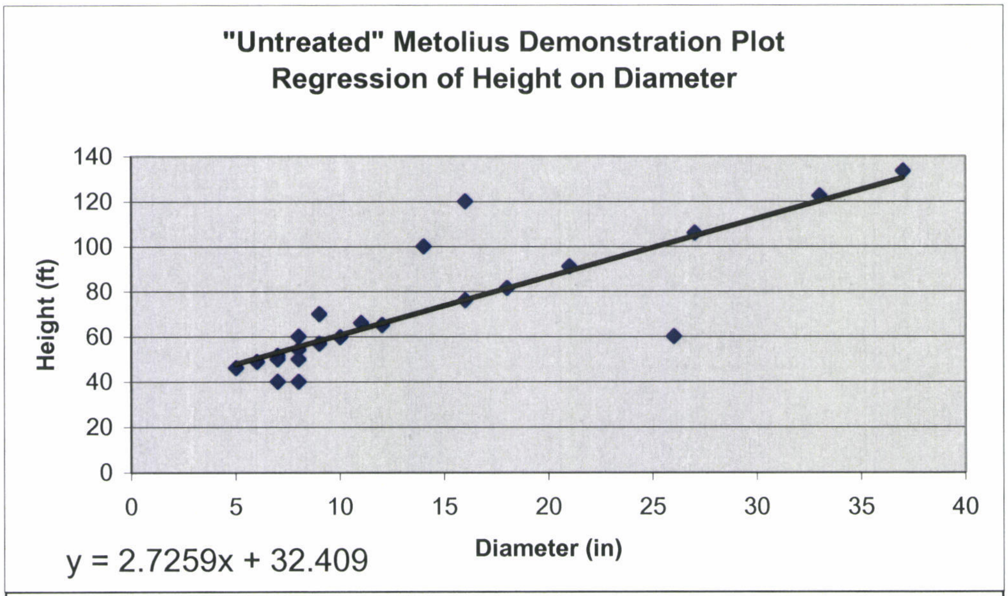
"Untreated" Metolius Demonstration Plot Tree List						
Plot size: 1 acre						
Lodgepole pine and western larch were entered as Ponderosa pine in ORGANON				***Heights and heights to live crown that were predicted with regression analysis are italicized bold.***		
Tree Tag #	**Actual Species**	**ORGANON Species**	**DBH**	**Tree Height**	**Height to Crown**	**Crown Ratio**
1	Ponderosa pine	Ponderosa pine	37	***133***	50	0.62
2	Ponderosa pine	Ponderosa pine	33	***122***	60	0.51
3	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
4	Western larch	Ponderosa pine	11	66	10	0.85
5	Western larch	Ponderosa pine	7	40	***15***	0.62
6	Western larch	Ponderosa pine	8	50	***16***	0.67
7	Ponderosa pine	Ponderosa pine	26	60	40	0.33
8	Ponderosa pine	Ponderosa pine	16	***76***	40	0.47
9	Ponderosa pine	Ponderosa pine	18	***81***	40	0.51
10	Western larch	Ponderosa pine	10	***60***	***19***	0.68
11	Ponderosa pine	Ponderosa pine	27	***106***	40	0.62
12	Ponderosa pine	Ponderosa pine	8	60	40	0.33
13	Ponderosa pine	Ponderosa pine	7	***51***	***15***	0.70
14	Western larch	Ponderosa pine	10	***60***	***19***	0.68
15	Western larch	Ponderosa pine	6	***49***	***14***	0.71
16	Ponderosa pine	Ponderosa pine	7	***51***	***15***	0.70
17	Ponderosa pine	Ponderosa pine	21	91	30	0.67
18	Western larch	Ponderosa pine	8	***54***	***16***	0.70
19	Western larch	Ponderosa pine	12	***65***	***21***	0.67
20	Ponderosa pine	Ponderosa pine	7	50	20	0.60
21	Western larch	Ponderosa pine	16	120	6	0.95
22	Western larch	Ponderosa pine	8	40	3	0.93
23	Western larch	Ponderosa pine	8	***54***	***16***	0.70
24	Western larch	Ponderosa pine	10	***60***	***19***	0.68
25	Western larch	Ponderosa pine	10	***60***	***19***	0.68
26	Western larch	Ponderosa pine	7	***51***	***15***	0.70
27	Western larch	Ponderosa pine	6	***49***	***14***	0.71
28	Western larch	Ponderosa pine	9	***57***	***18***	0.69
29	Western larch	Ponderosa pine	9	70	15	0.79
30	Western larch	Ponderosa pine	14	100	4	0.96
31	Western larch	Ponderosa pine	5	***46***	***13***	0.72
32	Western larch	Ponderosa pine	10	***60***	***19***	0.68
33	Western larch	Ponderosa pine	8	***54***	***16***	0.70
34	Western larch	Ponderosa pine	9	***57***	***18***	0.69
35	Western larch	Ponderosa pine	9	***57***	***18***	0.69
36	Western larch	Ponderosa pine	6	***49***	***14***	0.71
37	Ponderosa pine	Ponderosa pine	10	45	22	0.51
38	Western larch	Ponderosa pine	12	80	8	0.90
39	Ponderosa pine	Ponderosa pine	16	***76***	***26***	0.66
40	Western larch	Ponderosa pine	6	***49***	***14***	0.71
41	Western larch	Ponderosa pine	10	***60***	***19***	0.68
42	Western larch	Ponderosa pine	11	***62***	***20***	0.68
43	Ponderosa pine	Ponderosa pine	7	***51***	***15***	0.70
44	Western larch	Ponderosa pine	14	***71***	***24***	0.67
45	Western larch	Ponderosa pine	15	***73***	***25***	0.66
46	Western larch	Ponderosa pine	11	***62***	***20***	0.68
47	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72

"Untreated" Metolius Demonstration Plot Tree List (continued)

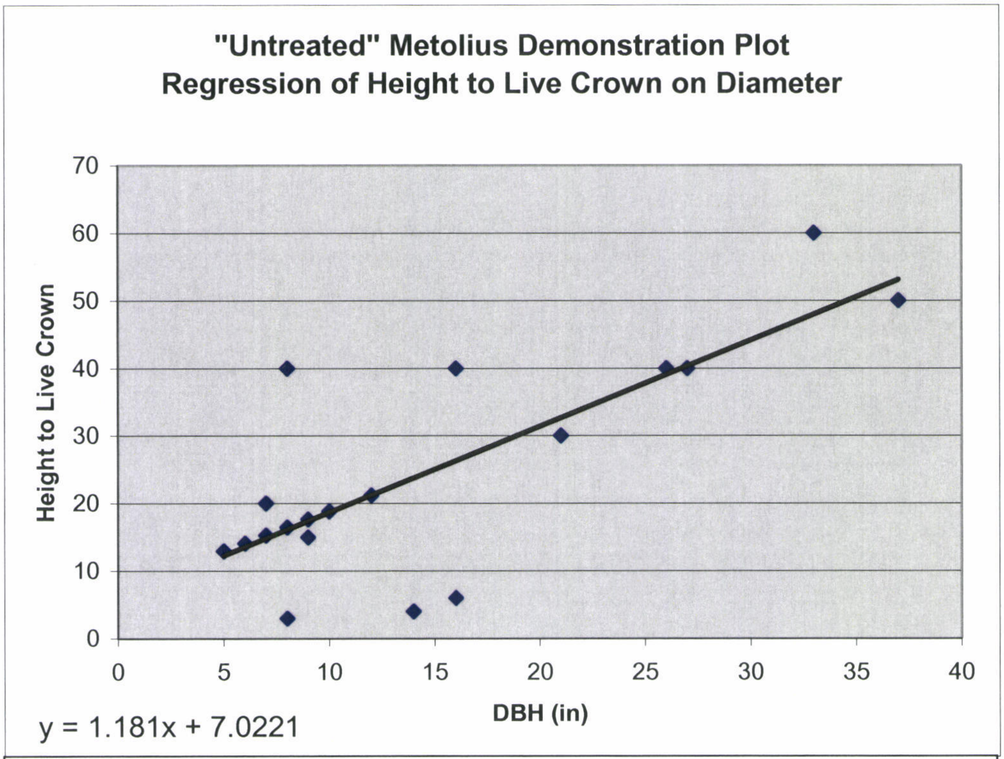
48	Western larch	Ponderosa pine	12	84	10	0.88
49	Lodgepole pine	Ponderosa pine	11	69	13	0.81
50	Ponderosa pine	Ponderosa pine	6	***49***	***14***	0.71
51	Ponderosa pine	Ponderosa pine	8	***54***	***16***	0.70
52	Ponderosa pine	Ponderosa pine	14	***71***	***24***	0.67
53	Western larch	Ponderosa pine	8	***54***	***16***	0.70
54	Ponderosa pine	Ponderosa pine	7	***51***	***15***	0.70
55	Western larch	Ponderosa pine	8	***54***	***16***	0.70
56	Western larch	Ponderosa pine	10	***60***	***19***	0.68
57	Western larch	Ponderosa pine	11	***62***	***20***	0.68
58	Western larch	Ponderosa pine	6	***49***	***14***	0.71
59	Ponderosa pine	Ponderosa pine	15	***73***	***25***	0.66
60	Ponderosa pine	Ponderosa pine	15	***73***	***25***	0.66
61	Western larch	Ponderosa pine	9	***57***	***18***	0.69
62	Western larch	Ponderosa pine	7	***51***	***15***	0.70
63	Western larch	Ponderosa pine	6	***49***	***14***	0.71
64	Ponderosa pine	Ponderosa pine	20	***87***	***31***	0.65
65	Western larch	Ponderosa pine	5	***46***	***13***	0.72
66	Western larch	Ponderosa pine	7	***51***	***15***	0.70
67	Western larch	Ponderosa pine	6	***49***	***14***	0.71
68	Western larch	Ponderosa pine	11	***62***	***20***	0.68
69	Ponderosa pine	Ponderosa pine	24	98	35	0.64
70	Western larch	Ponderosa pine	7	***51***	***15***	0.70
71	Ponderosa pine	Ponderosa pine	7	***51***	***15***	0.70
72	Ponderosa pine	Ponderosa pine	14	***71***	***24***	0.67
73	Western larch	Ponderosa pine	9	***57***	***18***	0.69
74	Ponderosa pine	Ponderosa pine	9	45	20	0.56
75	Ponderosa pine	Ponderosa pine	9	53	26	0.51
76	Western larch	Ponderosa pine	9	63	15	0.76
77	Ponderosa pine	Ponderosa pine	12	57	16	0.72
78	Ponderosa pine	Ponderosa pine	11	57	20	0.65
79	Ponderosa pine	Ponderosa pine	8	***54***	***16***	0.70
80	Western larch	Ponderosa pine	8	***54***	***16***	0.70
81	Western larch	Ponderosa pine	8	59	10	0.83
82	Western larch	Ponderosa pine	12	***65***	***21***	0.67
83	Ponderosa pine	Ponderosa pine	9	***57***	***18***	0.69
84	Ponderosa pine	Ponderosa pine	17	79	35	0.56
85	Ponderosa pine	Ponderosa pine	11	69	20	0.71
86	Western larch	Ponderosa pine	8	***54***	***16***	0.70
87	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
88	Ponderosa pine	Ponderosa pine	8	60	35	0.42
89	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
90	Ponderosa pine	Ponderosa pine	16	***76***	***26***	0.66
91	Western larch	Ponderosa pine	5	***46***	***13***	0.72
92	Ponderosa pine	Ponderosa pine	18	***83***	44	0.47
93	Western larch	Ponderosa pine	9	***57***	***18***	0.69
94	Ponderosa pine	Ponderosa pine	8	***54***	***16***	0.70
95	Western larch	Ponderosa pine	6	***49***	***14***	0.71
96	Western larch	Ponderosa pine	8	63	12	0.81
97	Western larch	Ponderosa pine	7	***51***	***15***	0.70
98	Western larch	Ponderosa pine	9	***57***	***18***	0.69
99	Ponderosa pine	Ponderosa pine	4	***43***	***12***	0.73
100	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
101	Ponderosa pine	Ponderosa pine	4	22	11	0.50

“Untreated” Metolius Demonstration Plot Tree List (continued)

102	Ponderosa pine	Ponderosa pine	6	20	11	0.45
103	Ponderosa pine	Ponderosa pine	8	42	20	0.52
104	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
105	Ponderosa pine	Ponderosa pine	38	***136***	***52***	0.62
106	Ponderosa pine	Ponderosa pine	4	***43***	***12***	0.73
107	Ponderosa pine	Ponderosa pine	23	***95***	***34***	0.64
108	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
109	Ponderosa pine	Ponderosa pine	5	***46***	***13***	0.72
110	Ponderosa pine	Ponderosa pine	4	***43***	***12***	0.73
111	Ponderosa pine	Ponderosa pine	6	***49***	***14***	0.71
112	Western larch	Ponderosa pine	13	***68***	***22***	0.67
113	Western larch	Ponderosa pine	5	***46***	***13***	0.72
114	Western larch	Ponderosa pine	10	***60***	***19***	0.68
115	Western larch	Ponderosa pine	5	***46***	***13***	0.72
116	Ponderosa pine	Ponderosa pine	30	***114***	***42***	0.63
117	Western larch	Ponderosa pine	7	***51***	***15***	0.70
118	Ponderosa pine	Ponderosa pine	19	***84***	***29***	0.65
119	Western larch	Ponderosa pine	8	***54***	***16***	0.70
120	Ponderosa pine	Ponderosa pine	15	***73***	***25***	0.66
121	Ponderosa pine	Ponderosa pine	18	***81***	***28***	0.65
122	Ponderosa pine	Ponderosa pine	29	***111***	***41***	0.63
123	Lodgepole pine	Ponderosa pine	13	***68***	***22***	0.67
124	Douglas-fir	Douglas-fir	9	***57***	***18***	0.69
125	Western larch	Ponderosa pine	7	***51***	***15***	0.70
126	Ponderosa pine	Ponderosa pine	12	79	50	0.37
127	Ponderosa pine	Ponderosa pine	33	118	49	0.58
128	Ponderosa pine	Ponderosa pine	29	***111***	***41***	0.63
129	Western larch	Ponderosa pine	6	***49***	***14***	0.71
130	Western larch	Ponderosa pine	7	***51***	***15***	0.70
131	Ponderosa pine	Ponderosa pine	27	***106***	***39***	0.63
132	Western larch	Ponderosa pine	6	***49***	***14***	0.71
133	Western larch	Ponderosa pine	6	***49***	***14***	0.71
134	Ponderosa pine	Ponderosa pine	28	***109***	***40***	0.63
135	Western larch	Ponderosa pine	7	***51***	***15***	0.70
136	Ponderosa pine	Ponderosa pine	22	***92***	***33***	0.64
137	Western larch	Ponderosa pine	11	***62***	***20***	0.68
138	Ponderosa pine	Ponderosa pine	22	***92***	***33***	0.64
139	Ponderosa pine	Ponderosa pine	17	***79***	***27***	0.66
140	Western larch	Ponderosa pine	12	***65***	***21***	0.67
141	Douglas-fir	Douglas-fir	4	***43***	***12***	0.73



Regression was used to estimate heights of trees when only diameter was measured.



Regression was used to estimate heights of trees when only diameter was measured.

No Treatment Metolius Demonstration Plot

Down Wood

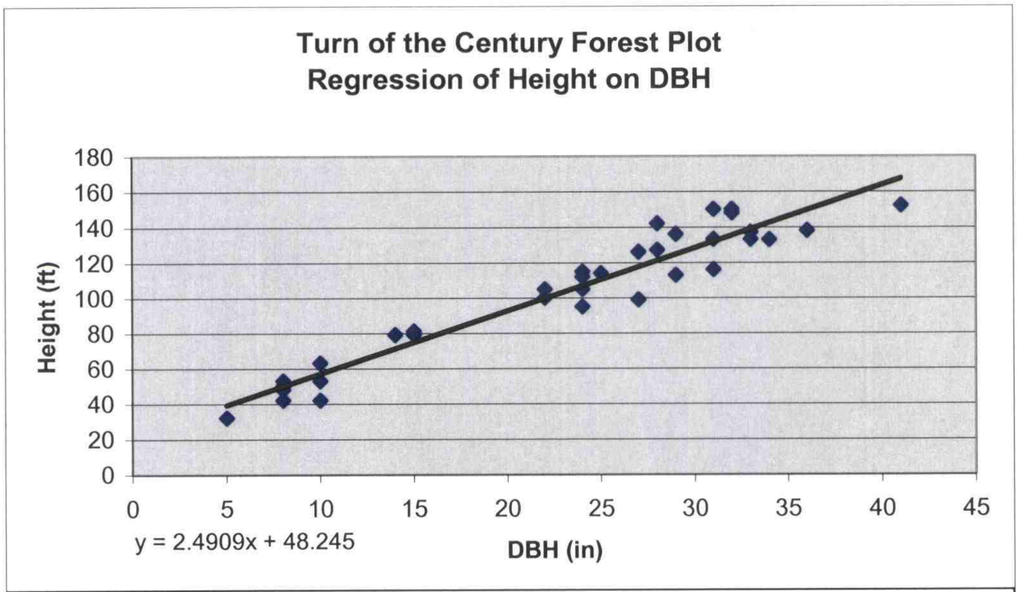
Length (ft)	**Width (in)**	**Width (ft)**	**Volume (cu ft)**
5	6	0.5	2.50
11	12	1.0	11.00
5	12	1.0	5.00
5	10	0.8	4.17
5	10	0.8	4.17
40	10	0.8	33.33
10	10	0.8	8.33
10	8	0.7	6.67
14	5	0.4	5.83
20	3	0.3	5.00
20	5	0.4	8.33
20	6	0.5	10.00
20	8	0.7	13.33
20	1	0.1	1.67
12	19	1.6	19.00
40	5	0.4	16.67
30	5	0.4	12.50
35	10	0.8	29.17
20	10	0.8	16.67
30	10	0.8	25.00
14	11	0.9	12.83
25	10	0.8	20.83
25	5	0.4	10.42
15	28	2.3	35.00
30	4	0.3	10.00
35	4	0.3	11.67
25	4	0.3	8.33
20	5	0.4	8.33
40	6	0.5	20.00
30	4	0.3	10.00
15	24	2.0	30.00
40	10	0.8	33.33
25	5	0.4	10.42
5	3	0.3	1.25
55	4	0.3	18.33
20	12	1.0	20.00
45	20	1.7	75.00
15	22	1.8	27.50
45	16	1.3	60.00
10	5	0.4	4.17
15	18	1.5	22.50
10	24	2.0	20.00
40	12	1.0	40.00
30	6	0.5	15.00
35	15	1.3	43.75
20	20	1.7	33.33
30	5	0.4	12.50

Volume of Down Wood = 853 cubic feet per acre
Mass of Down Wood = 13 tons/acre (assuming 1 cu ft = 30 lbs)

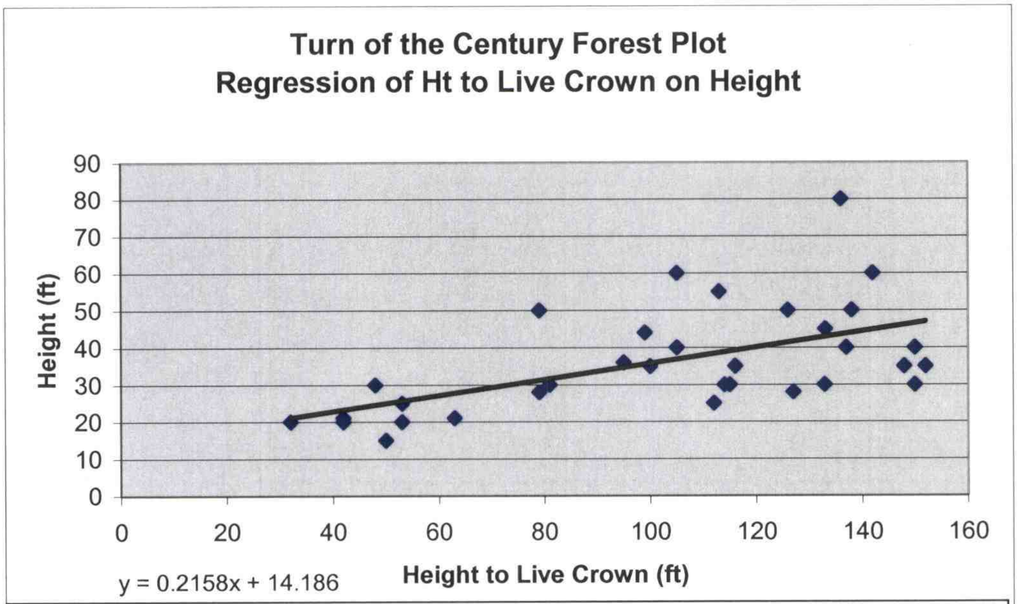
"Turn of the Century Forest" Plot Tree List					
Plot = 1 acre		Stand was thinned.			
	Trees 35 through 84 were "grown" from stumps and are italicized.				
Tree #	**Species**	**DBH**	**Tree Height**	**Ht to Live Crown**	**Crown Ratio**
1	Ponderosa pine	8	50	15	0.70
2	Ponderosa pine	8	53	20	0.62
3	Ponderosa pine	10	42	20	0.52
4	Ponderosa pine	5	32	20	0.38
5	Ponderosa pine	8	42	21	0.50
6	Ponderosa pine	10	63	21	0.67
7	Ponderosa pine	24	112	25	0.78
8	Ponderosa pine	10	53	25	0.53
9	Ponderosa pine	28	127	28	0.78
10	Ponderosa pine	14	79	28	0.65
11	Ponderosa pine	24	115	30	0.74
12	Ponderosa pine	25	114	30	0.74
13	Ponderosa pine	31	150	30	0.80
14	Ponderosa pine	34	133	30	0.77
15	Ponderosa pine	8	48	30	0.38
16	Ponderosa pine	15	81	30	0.63
17	Ponderosa pine	41	152	35	0.77
18	Ponderosa pine	22	100	35	0.65
19	Ponderosa pine	32	148	35	0.76
20	Ponderosa pine	31	116	35	0.70
21	Ponderosa pine	24	95	36	0.62
22	Ponderosa pine	32	150	40	0.73
23	Ponderosa pine	22	105	40	0.62
24	Ponderosa pine	33	137	40	0.71
25	Ponderosa pine	27	99	44	0.56
26	Ponderosa pine	33	133	45	0.66
27	Ponderosa pine	31	133	45	0.66
28	Ponderosa pine	36	138	50	0.64
29	Ponderosa pine	27	126	50	0.60
30	Ponderosa pine	15	79	50	0.37
31	Ponderosa pine	29	113	55	0.51
32	Ponderosa pine	28	142	60	0.58
33	Ponderosa pine	24	105	60	0.43
34	Ponderosa pine	29	136	80	0.41
Stumps					
35	*Ponderosa pine*	*18*	*93*	*34*	*0.63*
36	*Ponderosa pine*	*27*	*115*	*39*	*0.66*
37	*Ponderosa pine*	*21*	*101*	*36*	*0.64*
38	*Ponderosa pine*	*21*	*101*	*36*	*0.64*
39	*Ponderosa pine*	*25*	*111*	*38*	*0.66*
40	*Ponderosa pine*	*18*	*93*	*34*	*0.63*
41	*Ponderosa pine*	*10*	*73*	*30*	*0.59*
42	*Ponderosa pine*	*6*	*63*	*28*	*0.56*
43	*Ponderosa pine*	*6*	*63*	*28*	*0.56*
44	*Ponderosa pine*	*13*	*81*	*32*	*0.61*
45	*Ponderosa pine*	*5*	*61*	*27*	*0.55*
46	*Ponderosa pine*	*20*	*98*	*35*	*0.64*
47	*Ponderosa pine*	*24*	*108*	*37*	*0.65*
48	*Ponderosa pine*	*12*	*78*	*31*	*0.60*

"Turn of the Century Forest" Plot Tree List (continued)

49	*Ponderosa pine*	*27*	*115*	*39*	*0.66*
50	*Ponderosa pine*	*15*	*86*	*33*	*0.62*
51	*Ponderosa pine*	*24*	*108*	*37*	*0.65*
52	*Ponderosa pine*	*25*	*111*	*38*	*0.66*
53	*Ponderosa pine*	*12*	*78*	*31*	*0.60*
54	*Ponderosa pine*	*22*	*103*	*36*	*0.65*
55	*Ponderosa pine*	*22*	*103*	*36*	*0.65*
56	*Ponderosa pine*	*20*	*98*	*35*	*0.64*
57	*Ponderosa pine*	*20*	*98*	*35*	*0.64*
58	*Ponderosa pine*	*19*	*96*	*35*	*0.64*
59	*Ponderosa pine*	*10*	*73*	*30*	*0.59*
60	*Ponderosa pine*	*16*	*88*	*33*	*0.62*
61	*Ponderosa pine*	*6*	*63*	*28*	*0.56*
62	*Ponderosa pine*	*8*	*68*	*29*	*0.58*
63	*Ponderosa pine*	*13*	*81*	*32*	*0.61*
64	*Ponderosa pine*	*36*	*138*	*44*	*0.68*
65	*Ponderosa pine*	*19*	*96*	*35*	*0.64*
66	*Ponderosa pine*	*12*	*78*	*31*	*0.60*
67	*Ponderosa pine*	*5*	*61*	*27*	*0.55*
68	*Ponderosa pine*	*5*	*61*	*27*	*0.55*
69	*Ponderosa pine*	*4*	*58*	*27*	*0.54*
70	*Ponderosa pine*	*20*	*98*	*35*	*0.64*
71	*Ponderosa pine*	*20*	*98*	*35*	*0.64*
72	*Ponderosa pine*	*10*	*73*	*30*	*0.59*
73	*Ponderosa pine*	*4*	*58*	*27*	*0.54*
74	*Ponderosa pine*	*10*	*73*	*30*	*0.59*
75	*Ponderosa pine*	*5*	*61*	*27*	*0.55*
76	*Ponderosa pine*	*12*	*78*	*31*	*0.60*
77	*Ponderosa pine*	*17*	*91*	*34*	*0.63*
78	*Ponderosa pine*	*11*	*76*	*31*	*0.60*
79	*Ponderosa pine*	*6*	*63*	*28*	*0.56*
80	*Ponderosa pine*	*16*	*88*	*33*	*0.62*
81	*Ponderosa pine*	*7*	*66*	*28*	*0.57*
82	*Ponderosa pine*	*14*	*83*	*32*	*0.61*
83	*Ponderosa pine*	*8*	*68*	*29*	*0.58*
84	*Ponderosa pine*	*12*	*78*	*31*	*0.60*



Regression was used to estimate heights of trees “grown” from stumps.



Regression was used to estimate height to live crown of trees “grown” from stumps.

Turn of the Century Forest

Down Wood

Length (ft)	**Width (in)**	**Width (ft)**	**Volume (cu ft)**
10	3	0.3	3
15	2	0.2	3
20	2	0.2	3
20	3	0.3	5
20	8	0.7	13
30	2	0.2	5
5	7	0.6	3
15	6	0.5	8
25	3	0.3	6
10	8	0.7	7
30	7	0.6	18
30	6	0.5	15
10	8	0.7	7
1510	3	0.3	378
20	18	1.5	30
45	3	0.3	11
100	3	0.3	25
50	3	0.3	13

Volume of Down Wood = 550 cubic feet per acre

Mass of Down Wood = 8 tons/acre (assuming 1 cu ft wood = 30 lbs)

Pole Creek Plot 1 Tree List

Plot Dimensions = 92' X 208' = 0.439302 acres

Tree #	Species	DBH	Tree Height	Ht to Live Crown	Crwn Ratio
1	Ponderosa pine	9	40	18	0.55
2	Ponderosa pine	15	61	21	0.66
3	Ponderosa pine	51	14	16	-0.14
4	Ponderosa pine	13	55	15	0.73
5	Ponderosa pine	11	56	16	0.71
6	Ponderosa pine	9	37	18	0.51
7	Ponderosa pine	14	82	40	0.51
8	Ponderosa pine	11	80	40	0.50
9	Ponderosa pine	16	95	38	0.60
10	Ponderosa pine	14	73	23	0.68
11	Ponderosa pine	12	73	23	0.68
12	Ponderosa pine	13	58	20	0.66
13	Ponderosa pine	16	84	35	0.58
14	Ponderosa pine	12	60	25	0.58
15	Ponderosa pine	13	55	20	0.64
16	Ponderosa pine	14	62	30	0.52
17	Ponderosa pine	11	64	32	0.50
18	Ponderosa pine	13	60	20	0.67
19	Ponderosa pine	13	56	20	0.64
20	Ponderosa pine	15	65	25	0.62
21	Ponderosa pine	12	64	24	0.63
22	Ponderosa pine	11	54	25	0.54
23	Ponderosa pine	18	84	35	0.58
24	Ponderosa pine	15	83	24	0.71
25	Ponderosa pine	10	64	26	0.59
26	Ponderosa pine	15	73	35	0.52
27	Ponderosa pine	12	68	28	0.59
28	Ponderosa pine	11	59	33	0.44
29	Ponderosa pine	12	62	33	0.47
30	Ponderosa pine	11	59	33	0.44
31	Ponderosa pine	11	54	29	0.46
32	Ponderosa pine	13	65	22	0.66
33	Ponderosa pine	12	71	24	0.66
34	Ponderosa pine	10	62	27	0.56
35	Ponderosa pine	29	93	39	0.58
36	Ponderosa pine	13	73	32	0.56
37	Ponderosa pine	13	55	30	0.45
38	Ponderosa pine	9	50	25	0.50
39	Ponderosa pine	11	65	28	0.57
40	Ponderosa pine	13	71	34	0.52
41	Ponderosa pine	12	65	20	0.69
42	Ponderosa pine	15	68	22	0.68
43	Ponderosa pine	10	58	20	0.66
44	Ponderosa pine	13	71	29	0.59
45	Ponderosa pine	13	71	29	0.59
46	Ponderosa pine	12	60	32	0.47
47	Ponderosa pine	19	75	23	0.69
48	Ponderosa pine	14	65	30	0.54

Pole Creek Plot 1 Tree List (continued)					
49	Ponderosa pine	11	60	20	0.67
50	Ponderosa pine	11	65	35	0.46
51	Ponderosa pine	16	72	35	0.51
52	Ponderosa pine	15	74	35	0.53
53	Ponderosa pine	16	70	33	0.53
54	Ponderosa pine	12	57	20	0.65
55	Ponderosa pine	15	66	26	0.61
56	Ponderosa pine	13	70	20	0.71
57	Ponderosa pine	11	65	20	0.69
58	Ponderosa pine	12	65	20	0.69
59	Ponderosa pine	13	70	24	0.66
60	Ponderosa pine	14	77	27	0.65
61	Ponderosa pine	11	62	25	0.60
62	Ponderosa pine	7	46	30	0.35
63	Ponderosa pine	5	26	14	0.46
64	Ponderosa pine	20	77	28	0.64
65	Ponderosa pine	19	89	29	0.67
66	Ponderosa pine	10	54	24	0.56
67	Ponderosa pine	7	37	18	0.51
68	Ponderosa pine	8	42	17	0.60

Pole Creek 1			
Down Wood			
Length (ft)	**Width (in)**	**Width (ft)**	**Volume (cu ft)**
12	6	1	6
16	5	0	7
6	6	1	3
10	6	1	5
33	5	0	14
10	6	1	5
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	7	1	18
30	6	1	15
30	5	0	13
Volume of Down Wood = 710 cubic feet per acre Mass of Down Wood = 11 tons/acre (assuming 1 cu ft = 30 lbs)			

Pole Creek Plot 2 Tree List

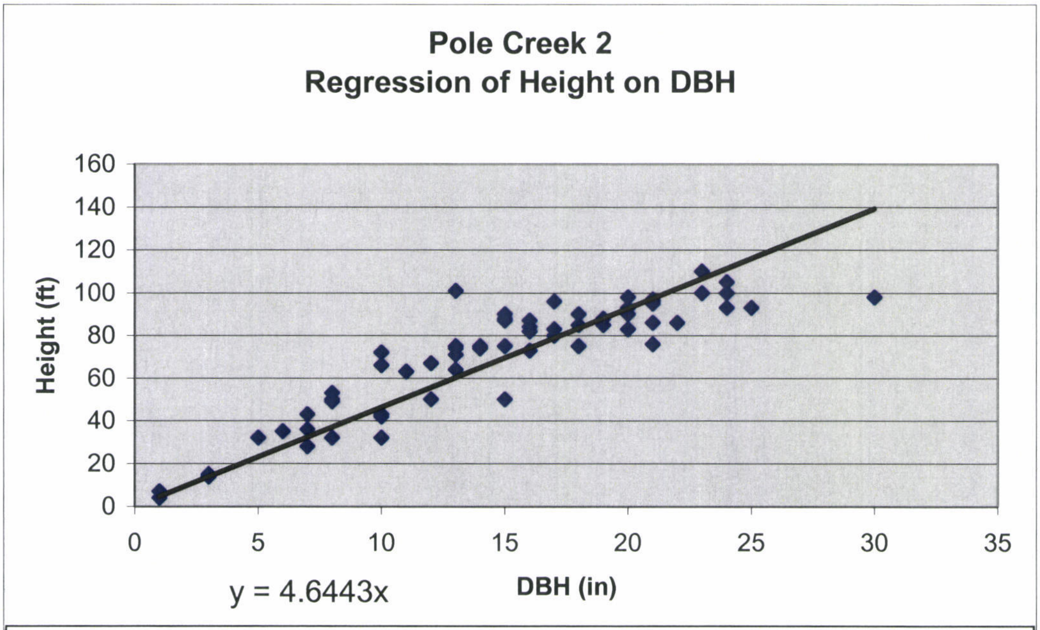
Plot Size: 1/2 acre

Trees 69 through 109 were "grown" from stumps and are italicized.

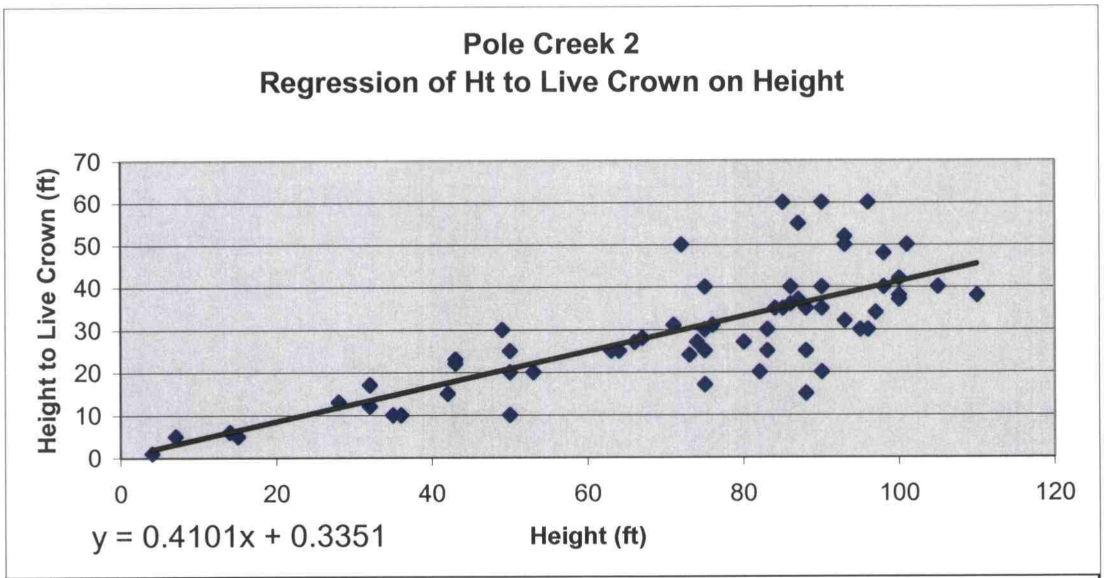
Tree #	Species	DBH	Tree Height	Ht to Live Crown	Crown Ratio
1	Ponderosa pine	17	83	30	0.64
2	Ponderosa pine	20	83	25	0.70
3	Ponderosa pine	13	101	50	0.50
4	Ponderosa pine	21	76	31	0.59
5	Ponderosa pine	21	97	34	0.65
6	Ponderosa pine	10	42	15	0.64
7	Ponderosa pine	16	84	35	0.58
8	Ponderosa pine	20	93	32	0.66
9	Ponderosa pine	21	97	34	0.65
10	Ponderosa pine	7	28	13	0.54
11	Ponderosa pine	13	74	27	0.64
12	Ponderosa pine	14	74	27	0.64
13	Ponderosa pine	10	66	27	0.59
14	Ponderosa pine	23	110	38	0.65
15	Ponderosa pine	15	90	35	0.61
16	Ponderosa pine	16	82	20	0.76
17	Ponderosa pine	17	96	60	0.38
18	Ponderosa pine	5	32	12	0.63
19	Ponderosa pine	23	100	37	0.63
20	Ponderosa pine	12	67	28	0.58
21	Ponderosa pine	13	64	25	0.61
22	Ponderosa pine	7	43	23	0.47
23	Ponderosa pine	13	71	31	0.56
24	Ponderosa pine	16	73	24	0.67
25	Ponderosa pine	10	32	17	0.47
26	Ponderosa pine	15	87	37	0.57
27	Ponderosa pine	15	87	37	0.57
28	Ponderosa pine	8	32	17	0.47
29	Ponderosa pine	6	35	10	0.71
30	Ponderosa pine	21	96	30	0.69
31	Ponderosa pine	30	98	40	0.59
32	Ponderosa pine	15	88	15	0.83
33	Ponderosa pine	10	43	22	0.49
34	Ponderosa pine	8	53	20	0.62
35	Ponderosa pine	24	100	38	0.62
36	Ponderosa pine	23	100	42	0.58
37	Ponderosa pine	14	75	40	0.47
38	Ponderosa pine	13	75	25	0.67
39	Ponderosa pine	18	90	60	0.33
40	Ponderosa pine	18	85	35	0.59
41	Ponderosa pine	8	50	10	0.80
42	Ponderosa pine	7	36	10	0.72
43	Ponderosa pine	1	7	5	0.29
44	Ponderosa pine	3	15	5	0.67
45	Ponderosa pine	1	4	1	0.75
46	Ponderosa pine	16	87	55	0.37
47	Ponderosa pine	18	75	17	0.77
48	Ponderosa pine	21	95	30	0.68

Pole Creek Plot 2 Tree List (continued)					
49	Ponderosa pine	22	86	36	0.58
50	Ponderosa pine	21	86	40	0.53
51	Ponderosa pine	15	90	20	0.78
52	Ponderosa pine	24	105	40	0.62
53	Ponderosa pine	10	72	50	0.31
54	Ponderosa pine	19	88	35	0.60
55	Ponderosa pine	19	88	25	0.72
56	Ponderosa pine	3	14	6	0.57
57	Ponderosa pine	20	98	48	0.51
58	Ponderosa pine	8	49	30	0.39
59	Ponderosa pine	17	80	27	0.66
60	Ponderosa pine	15	50	20	0.60
61	Ponderosa pine	20	90	40	0.56
62	Ponderosa pine	20	93	52	0.44
63	Ponderosa pine	25	93	50	0.46
64	Ponderosa pine	12	50	25	0.50
65	Ponderosa pine	24	93	50	0.46
66	Ponderosa pine	11	63	25	0.60
67	Ponderosa pine	19	85	60	0.29
68	Ponderosa pine	15	75	30	0.60
Stumps					
69	*Ponderosa pine*	*6*	*39*	*16*	*0.58*
70	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
71	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
72	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
73	*Ponderosa pine*	*4*	*26*	*11*	*0.58*
74	*Ponderosa pine*	*6*	*39*	*16*	*0.58*
75	*Ponderosa pine*	*10*	*64*	*27*	*0.58*
76	*Ponderosa pine*	*9*	*58*	*24*	*0.58*
77	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
78	*Ponderosa pine*	*7*	*45*	*19*	*0.58*
79	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
80	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
81	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
82	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
83	*Ponderosa pine*	*4*	*26*	*11*	*0.58*
84	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
85	*Ponderosa pine*	*7*	*45*	*19*	*0.58*
86	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
87	*Ponderosa pine*	*9*	*58*	*24*	*0.58*
88	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
89	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
90	*Ponderosa pine*	*2*	*13*	*6*	*0.56*
91	*Ponderosa pine*	*6*	*39*	*16*	*0.58*
92	*Ponderosa pine*	*15*	*97*	*40*	*0.59*
93	*Ponderosa pine*	*11*	*71*	*29*	*0.59*
94	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
95	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
96	*Ponderosa pine*	*8*	*52*	*21*	*0.58*
97	*Ponderosa pine*	*6*	*39*	*16*	*0.58*
98	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
99	*Ponderosa pine*	*5*	*32*	*14*	*0.58*
100	*Ponderosa pine*	*6*	*39*	*16*	*0.58*
101	*Ponderosa pine*	*16*	*103*	*43*	*0.59*

Pole Creek Plot 2 Tree List (continued)					
102	Ponderosa pine	9	58	24	0.58
103	Ponderosa pine	8	52	21	0.58
104	Ponderosa pine	8	52	21	0.58
105	Ponderosa pine	3	19	8	0.57
106	Ponderosa pine	4	26	11	0.58
107	Ponderosa pine	8	52	21	0.58
108	Ponderosa pine	6	39	16	0.58
109	Ponderosa pine	14	90	37	0.59
110	Ponderosa pine	5	32	14	0.58
111	Ponderosa pine	3	19	8	0.57
112	Ponderosa pine	6	39	16	0.58
113	Ponderosa pine	5	32	14	0.58
114	Ponderosa pine	3	19	8	0.57



Regression was used to estimate height of trees "grown" from stumps.



Regression was used to estimate height to live crown of trees "grown" from stumps.

Pole Creek 2			
Down Wood			
Length (ft)	**Width (in)**	**Width (ft)**	**Volume Cubic Feet**
12	5	0.42	5
25	5	0.42	10
10	4	0.33	3
4	4	0.33	1
10	3	0.25	3
50	3	0.25	13
10	2	0.17	2
5	3	0.25	1
20	4	0.33	7
10	8	0.67	7
25	14	1.17	29
6	6	0.50	3
5	2	0.17	1
12	7	0.58	7
15	6	0.50	8
25	7	0.58	15
12	6	0.50	6
10	7	0.58	6
14	5	0.42	6
10	3	0.25	3
10	3	0.25	3
5	6	0.50	3
15	3	0.25	4
10	5	0.42	4
8	8	0.67	5
10	1	0.08	1
22	4	0.33	7
10	6	0.50	5
10	11	0.92	9
33	15	1.25	41
20	2	0.17	3
28	15	1.25	35
35	3	0.25	9
Volume of Down Wood = 525 cubic feet per acre Mass of Down Wood = 8 tons/acre (assuming 1 cu ft wood = 30 lbs)			

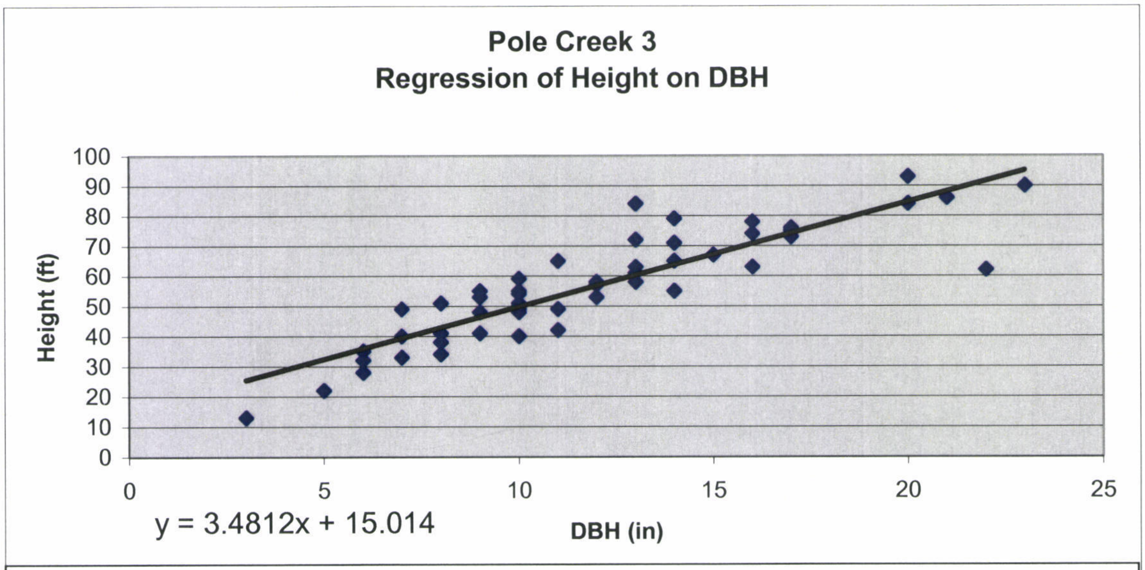
Pole Creek 3 Plot Tree List

Plot Size: 1/2 acre

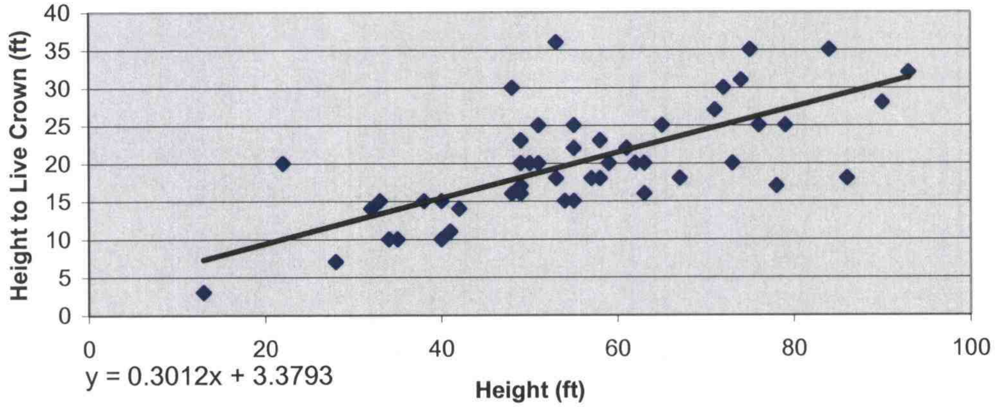
Trees 54 through 64 were "grown" from stumps and are italicized.

Tree #	Species	DBH	Tree Height	Ht to Crown	Crown Ratio
1	Ponderosa pine	17	75	35	0.53
2	Ponderosa pine	16	78	17	0.78
3	Ponderosa pine	8	51	25	0.51
4	Ponderosa pine	9	55	15	0.73
5	Ponderosa pine	23	90	28	0.69
6	Ponderosa pine	7	33	15	0.55
7	Ponderosa pine	11	49	17	0.65
8	Ponderosa pine	6	32	14	0.56
9	Ponderosa pine	13	58	18	0.69
10	Ponderosa pine	6	35	10	0.71
11	Ponderosa pine	14	55	22	0.60
12	Ponderosa pine	9	41	11	0.73
13	Ponderosa pine	14	71	27	0.62
14	Ponderosa pine	10	49	20	0.59
15	Ponderosa pine	12	57	18	0.68
16	Ponderosa pine	8	38	15	0.61
17	Ponderosa pine	10	51	20	0.61
18	Ponderosa pine	5	22	20	0.09
19	Ponderosa pine	16	63	20	0.68
20	Ponderosa pine	13	63	16	0.75
21	Ponderosa pine	10	54	15	0.72
22	Ponderosa pine	20	93	32	0.66
23	Ponderosa pine	16	74	31	0.58
24	Ponderosa pine	12	58	23	0.60
25	Ponderosa pine	14	79	25	0.68
26	Ponderosa pine	10	59	20	0.66
27	Ponderosa pine	12	53	18	0.66
28	Ponderosa pine	17	76	25	0.67
29	Ponderosa pine	10	49	16	0.67
30	Ponderosa pine	10	55	25	0.55
31	Ponderosa pine	13	72	30	0.58
32	Ponderosa pine	9	53	36	0.32
33	Ponderosa pine	10	50	20	0.60
34	Ponderosa pine	14	65	25	0.62
35	Ponderosa pine	11	65	25	0.62
36	Ponderosa pine	10	48	30	0.38
37	Ponderosa pine	20	84	35	0.58
38	Ponderosa pine	9	48	16	0.67
39	Ponderosa pine	11	42	14	0.67
40	Ponderosa pine	22	62	20	0.68
41	Ponderosa pine	13	84	35	0.58
42	Ponderosa pine	7	49	23	0.53
43	Ponderosa pine	17	73	20	0.73
44	Ponderosa pine	13	61	22	0.64
45	Ponderosa pine	3	13	3	0.77
46	Ponderosa pine	6	28	7	0.75
47	Ponderosa pine	7	40	15	0.63

Pole Creek 3 Plot Tree List (continued)					
48	Ponderosa pine	7	40	15	0.63
49	Ponderosa pine	10	40	10	0.75
50	Ponderosa pine	8	34	10	0.71
51	Ponderosa pine	15	67	18	0.73
52	Ponderosa pine	21	86	18	0.79
53	Ponderosa pine	8	41	11	0.73
Stumps					
54	*Ponderosa pine*	*18*	*78*	*27*	*0.66*
55	*Ponderosa pine*	*18*	*78*	*27*	*0.66*
56	*Ponderosa pine*	*28*	*112*	*37*	*0.67*
57	*Ponderosa pine*	*26*	*106*	*35*	*0.67*
58	*Ponderosa pine*	*29*	*116*	*38*	*0.67*
59	*Ponderosa pine*	*37*	*144*	*47*	*0.68*
60	*Ponderosa pine*	*32*	*126*	*41*	*0.67*
61	*Ponderosa pine*	*15*	*67*	*24*	*0.65*
62	*Ponderosa pine*	*15*	*67*	*24*	*0.65*
63	*Ponderosa pine*	*35*	*137*	*45*	*0.67*
64	*Ponderosa pine*	*20*	*85*	*29*	*0.66*



Regression was used to estimate height of trees "grown" from stumps.



Pole Creek 3
Regression of Height to Live Crown on Height

Regression was used to estimate height to live crown of trees "grown" from stumps.

Pole Creek 3			
Down Wood			
Length (ft)	**Width (in)**	**Width (ft)**	**Volume (cu ft)**
25	6	0.5	12.5
15	4	0.3	5.0
60	8	0.7	40.0
5	7	0.6	2.9
25	3	0.3	6.3
5	5	0.4	2.1
10	2	0.2	1.7
10	8	0.7	6.7
40	5	0.4	16.7
20	5	0.4	8.3
30	5	0.4	12.5
20	5	0.4	8.3
20	10	0.8	16.7
25	3	0.3	6.3
70	5	0.4	29.2
60	5	0.4	25.0
Volume of Down Wood = 400 cubic feet per acre Mass of Down Wood = 6 tons/acre (assuming 1 cu ft wood = 30 lbs)			

APPENDIX D

Plot Summary Data.

Plot data was entered into the individual tree growth model ORGANON, which was developed by David W. Hann, Ph.D., professor of forest biometry in the College of Forestry at Oregon State University.

Road 12 and Hwy 20

Dead trees included to represent conditions before backburn/B&B Fire

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	334	161.3	4699	16447
Grand/white fir	68	24	897	3540
Ponderosa pine	26	125.2	5443	32162
Other conifer	228	6.8	65	26
TOTALS:	656	317.4	11104	52174

Stand Density Index: 596
Quadratic Mean Diameter: 9.4
Mean Diameter: 6.3
Sum % Largest Crown Areas: 193.7

Relative Density Index: 1.124
Height of 40 Largest: 114.3
Mean Crown Ratio: 0.425
Down Wood: 7 tons/ac

Road 12 and Hwy 20

Dead trees not included so summary describes conditions after backburn/B&B Fire

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	148	118.5	3816	14142
Grand/white fir	14	13.4	489	1893
Ponderosa pine	18	106.2	4635	27208
Other conifer	34	3.7	45	51
TOTALS:	214	241.8	8985	43294

Stand Density Index: 384
Quadratic Mean Diameter: 14.4
Mean Diameter: 11.9
Sum % Largest Crown Areas: 125.4

Relative Density Index: 0.728
Height of 40 Largest: 114.5
Mean Crown Ratio: 0.428
Standing Dead and Down Wood: 39 tons/ac
Down Wood: 7 tons/ac

Pole Creek 1

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	154.8	177.5	3559	10609
TOTALS:	154.8	177.5	3559	10609

Stand Density Index: 281
Quadratic Mean Diameter: 14.5
Mean Diameter: 13.3
Sum % Largest Crown Areas: 82.9

Relative Density Index: 0.561
Height of 40 Largest: 71.9
Mean Crown Ratio: 0.592
Down Wood: 11 tons/ac

Pole Creek 2

Stumps "grown" so summary represents conditions before thinning treatment.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	228	221.4	6172	22329
TOTALS:	228	221.4	6172	22329

Stand Density Index: 362
Quadratic Mean Diameter: 13.3
Mean Diameter: 11.6
Sum % Largest Crown Areas: 101.2

Relative Density Index: 0.723
Height of 40 Largest: 94.4
Mean Crown Ratio: 0.578
Down Wood: 8 tons/ac

Pole Creek 2

Stumps not "grown" so summary describes conditions after thinning treatment.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	136	194	5526	20416
TOTALS:	136	194	5526	20416

Stand Density Index: 294	Relative Density Index: 0.587
Quadratic Mean Diameter: 16.2	Height of 40 Largest: 93.8
Mean Diameter: 14.9	Mean Crown Ratio: 0.585
Sum % Largest Crown Areas: 84.4	Down Wood: 8 tons/ac

Pole Creek 3

Stumps "grown" so summary represents conditions before thinning and burning.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	128	171	5023	20665
TOTALS:	128	171	5023	20665

Stand Density Index: 263	Relative Density Index: 0.524
Quadratic Mean Diameter: 15.6	Height of 40 Largest: 91.8
Mean Diameter: 13.8	Mean Crown Ratio: 0.637
Sum % Largest Crown Areas: 78.4	Down Wood: 6 tons/ac

Pole Creek 3

Stumps not "grown" so summary describes conditions after thinning and burning.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	106	90.2	2028	6048
TOTALS:	106	90.2	2028	6048

Stand Density Index: 151	Relative Density Index: 0.302
Quadratic Mean Diameter: 12.5	Height of 40 Largest: 72.9
Mean Diameter: 11.7	Mean Crown Ratio: 0.636
Sum % Largest Crown Areas: 48.3	Down Wood: 6 tons/ac

Lower Suttle Lake

Stumps "grown" to approximate conditions before thinning treatment. All trees are now dead.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	364	144.6	2972	7113
Grand/white fir	64	28.5	695	1821
Ponderosa pine	12	8.4	199	632
TOTALS:	440	181.5	3866	9566

Stand Density Index: 352	Relative Density Index: 0.663
Quadratic Mean Diameter: 8.7	Height of 40 Largest: 66.2
Mean Diameter: 7.5	Mean Crown Ratio: 0.55
Sum % Largest Crown Areas: 162.9	Down Wood: 8 tons/ac

Lower Suttle Lake

Stumps not "grown" so summary describes condtions after thinning. All trees are dead.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	104	89	1839	5034
Grand/white fir	32	20.6	510	1455
Ponderosa pine	12	8.4	199	632
TOTALS:	148	117.9	2548	7121

Stand Density Index: 201	Relative Density Index: 0.378
Quadratic Mean Diameter: 12.1	Height of 40 Largest: 61.4
Mean Diameter: 11.5	Mean Crown Ratio: 0.55
Sum % Largest Crown Areas: 83.4	ost B&B Standing & Down Wood: 46 tons/ac
	Down Wood: 8 tons/ac

Upper Suttle Lake

Stumps "grown" to approximate conditions before thinning treatment.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	165	303.8	11140	48585
Grand/white fir	8	8.9	300	1087
Ponderosa pine	7	17.9	602	2808
TOTALS:	180	330.7	12042	52480

Stand Density Index:	477	Relative Density Index:	0.900
Quadratic Mean Diameter:	18.4	Height of 40 Largest:	119.9
Mean Diameter:	15.7	Mean Crown Ratio:	0.528
Sum % Largest Crown Areas:	172	Down Wood:	7 tons/ac

Upper Suttle Lake

Stumps not "grown" so summary describes condtions after thinning.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	9	55.7	2378	11468
Grand/white fir	6	8.8	298	1087
Ponderosa pine	6	15.7	539	2565
TOTALS:	21	80.2	3215	15120

Stand Density Index:	100	Relative Density Index:	0.189
Quadratic Mean Diameter:	26.50	Height of 40 Largest:	99.0
Mean Diameter:	24.00	Mean Crown Ratio:	0.570
Sum % Largest Crown Areas:	30.90	Down Wood:	7 tons/ac

Turn of the Century Forest

Stumps "grown" to approximate conditions before thinning treatment.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	84	188.4	7055	32915
TOTALS:	84	188.4	7055	32915

Stand Density Index:	261	Relative Density Index:	0.521
Quadratic Mean Diameter:	20.30	Height of 40 Largest:	117.0
Mean Diameter:	17.90	Mean Crown Ratio:	0.615
Sum % Largest Crown Areas:	75.40	Down Wood:	8 tons/ac

Turn of the Century Forest

Stumps not "grown" so summary describes condtions after thinning.

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Ponderosa pine	34	114.9	4603	22931
TOTALS:	34	114.9	4603	22931

Stand Density Index:	147	Relative Density Index:	0.293
Quadratic Mean Diameter:	24.90	Height of 40 Largest:	103.0
Mean Diameter:	22.90	Mean Crown Ratio:	0.623
Sum % Largest Crown Areas:	42.70	Down Wood:	8 tons/ac

Control Plot

SPECIES	Trees per Acre	Basal Area	CF Vol	Scrib BF Vol
Douglas-fir	2	0.5	11	27
Ponderosa pine	139	143.3	4253	17381
TOTALS:	141	143.8	4264	17409

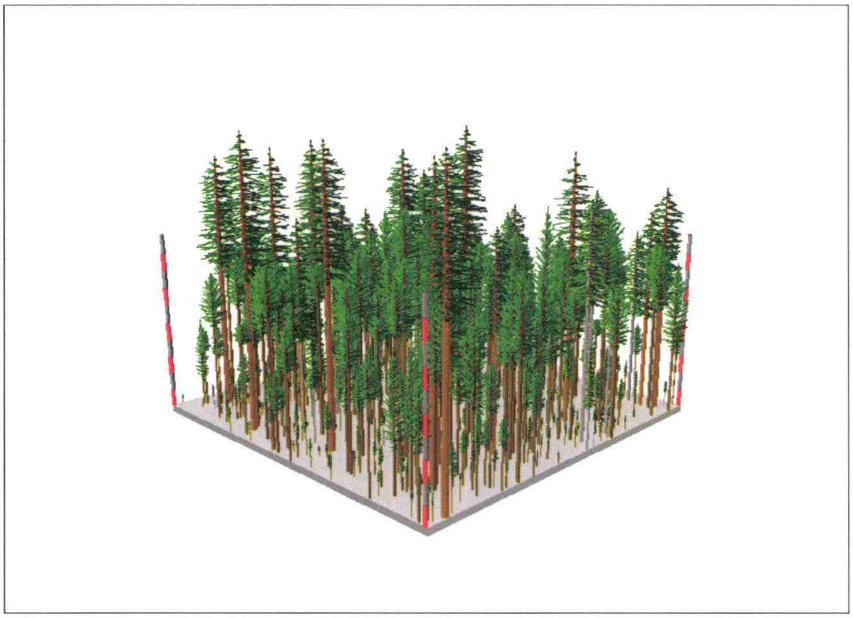
Stand Density Index:	233	Relative Density Index:	0.465
Quadratic Mean Diameter:	13.70	Height of 40 Largest:	89.8
Mean Diameter:	11.60	Mean Crown Ratio:	0.673
Sum % Largest Crown Areas:	67.70	Down Wood:	13 tons/ac

APPENDIX E

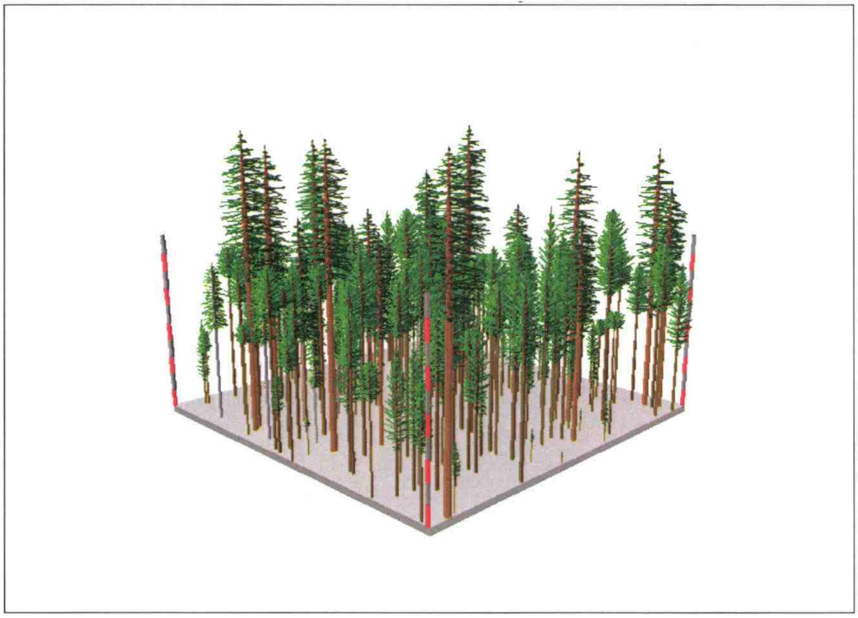
Stand Visualization Images.

ORGANON output is displayed using the Stand Visualization System developed by Robert J. McGaughey with the USDA Forest Service Pacific Northwest Research Station.

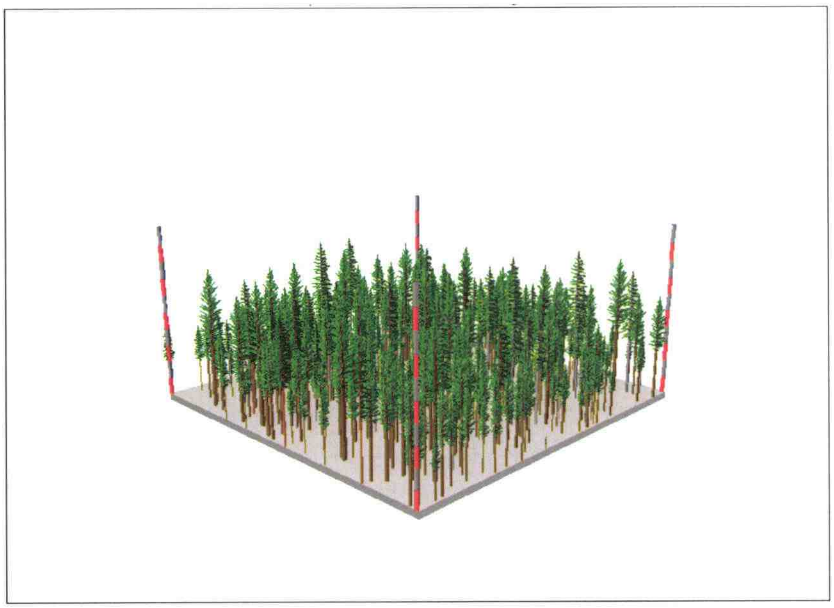
Road 12 & Hwy 20 Junction (before backburn)



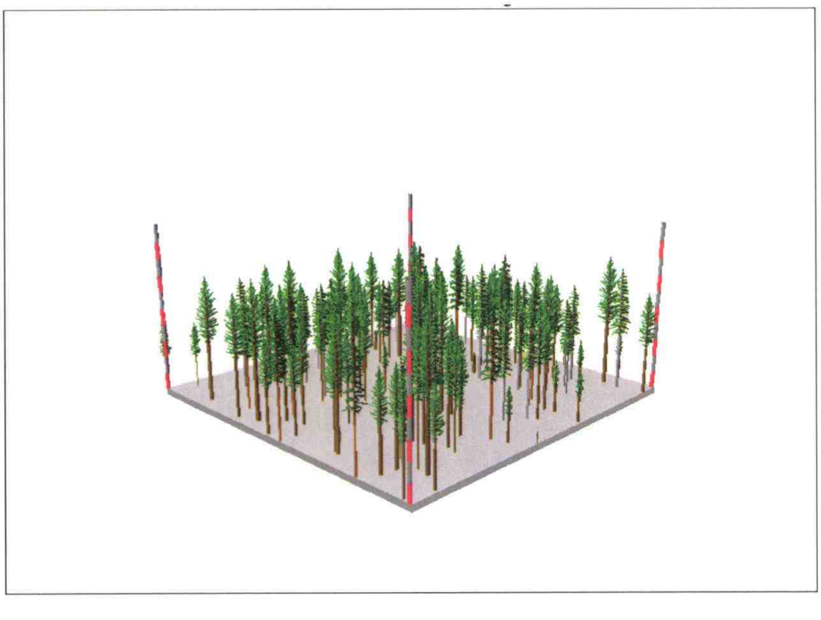
Road 12 & Hwy 20 Junction (after backburn)



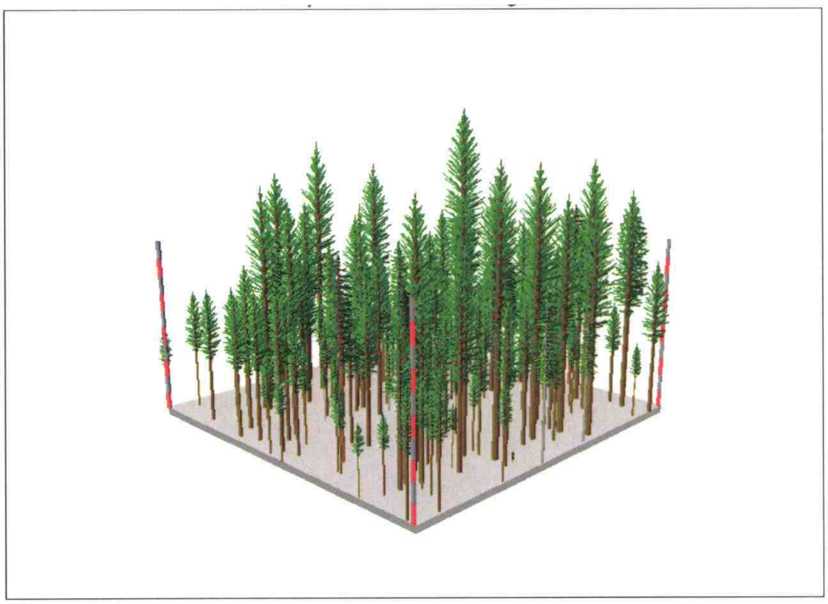
Lower Suttle Lake (*before* thinning treatment & *before* B&B)



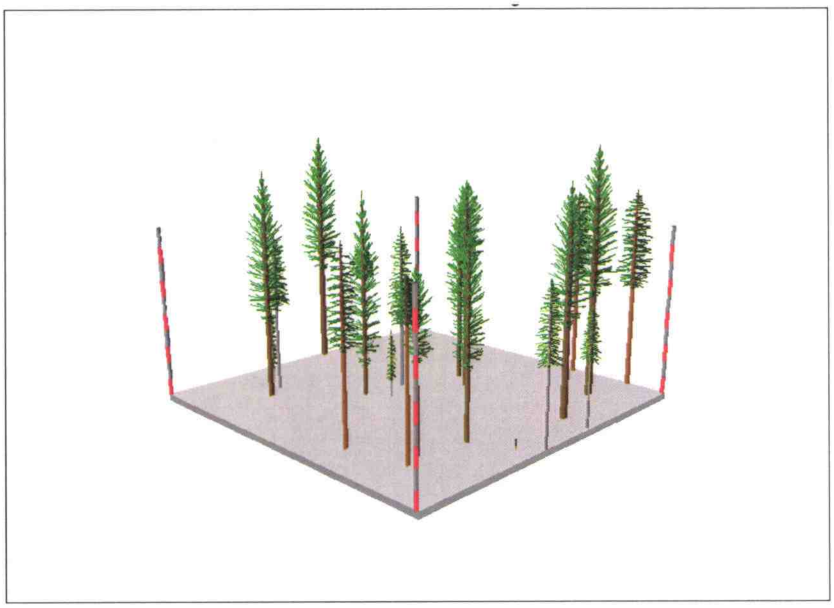
Lower Suttle Lake (*after* thinning treatment & *before* B&B)



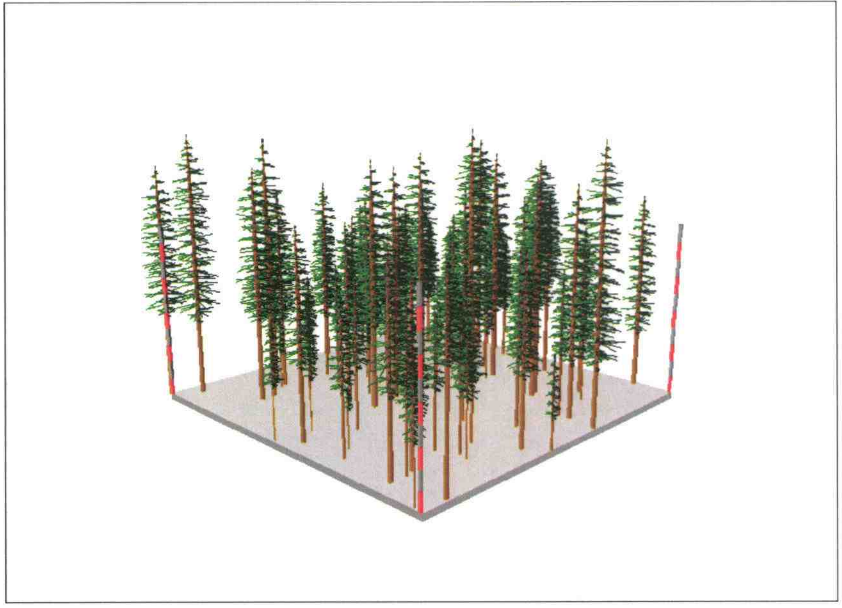
Upper Suttle Lake (*before* thinning treatment)



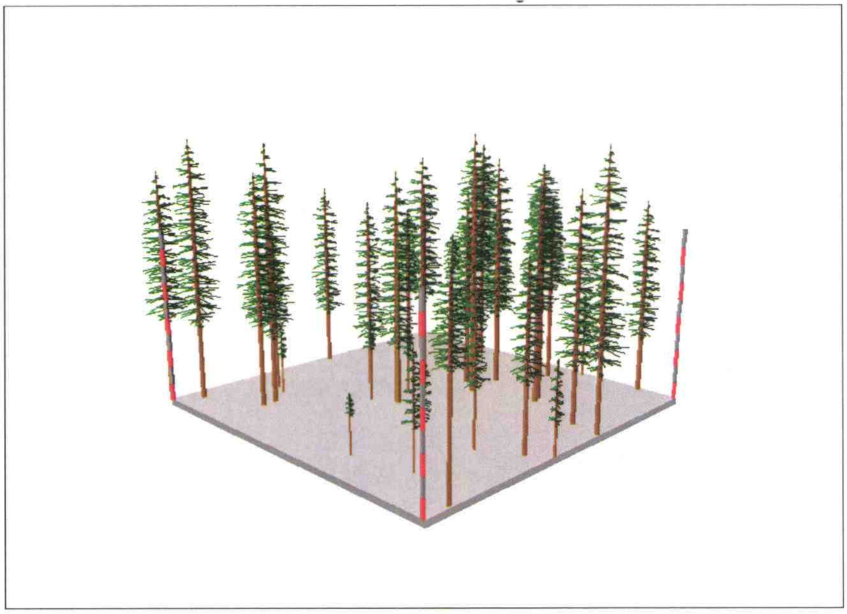
Upper Suttle Lake (*after* thinning treatment)



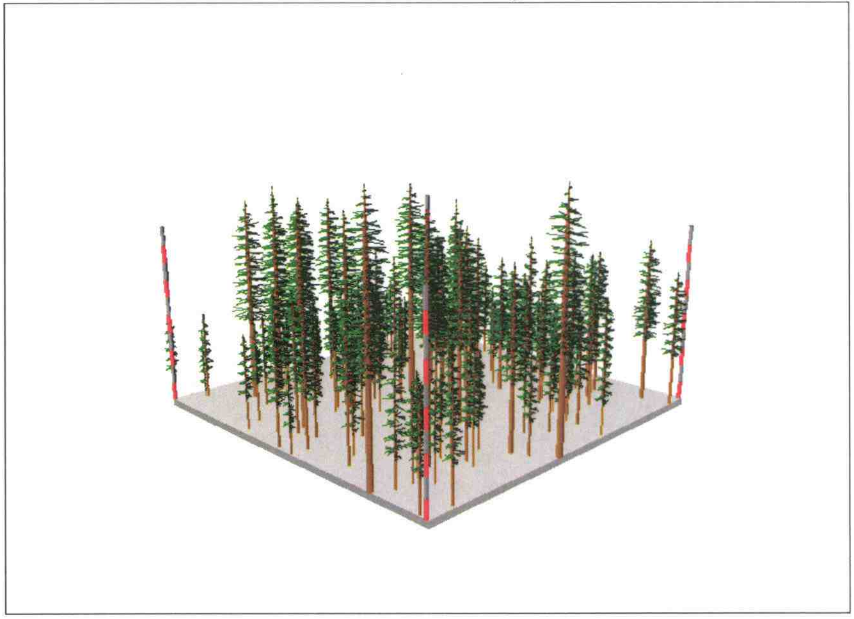
Turn of the Century Forest (*before* thinning treatment)



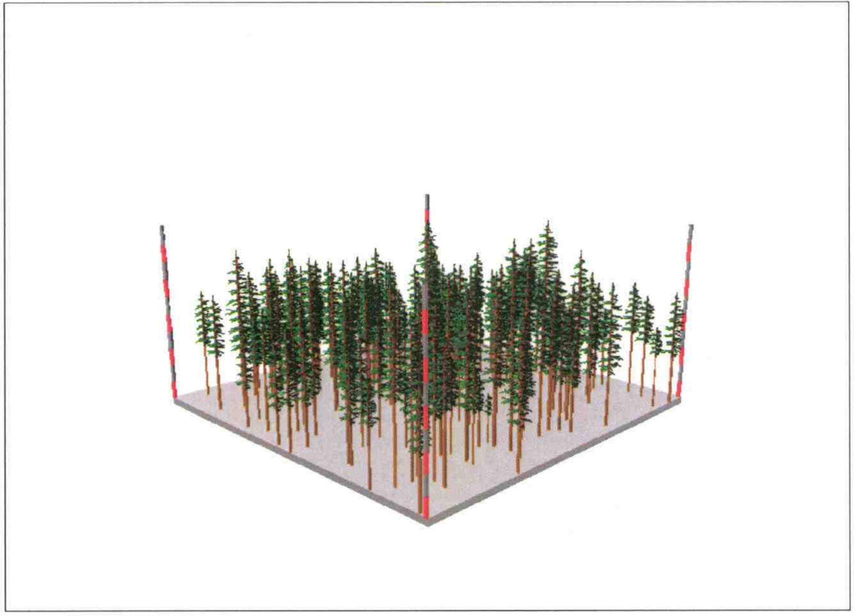
Turn of the Century Forest (*after* thinning treatment)



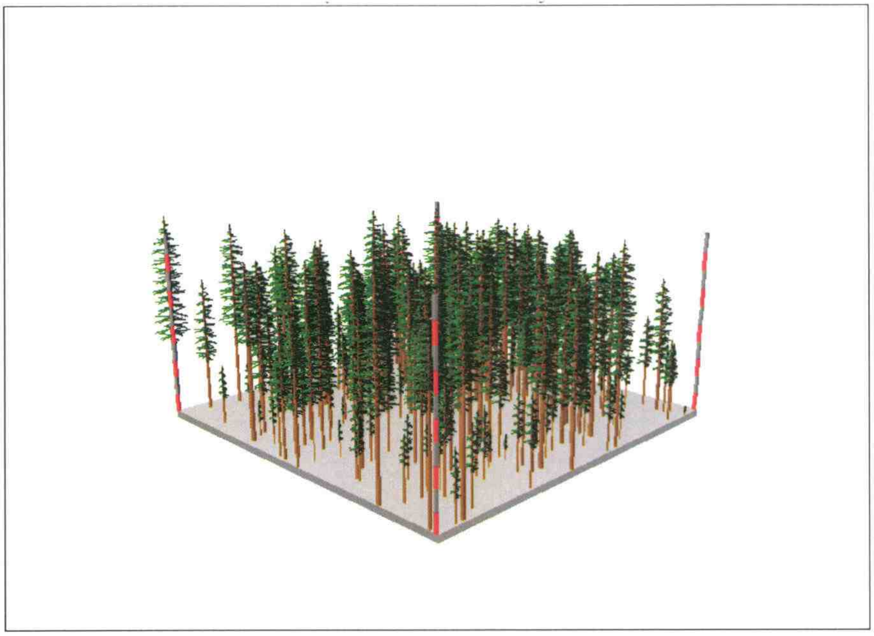
“Untreated” Metolius Demonstration Plot



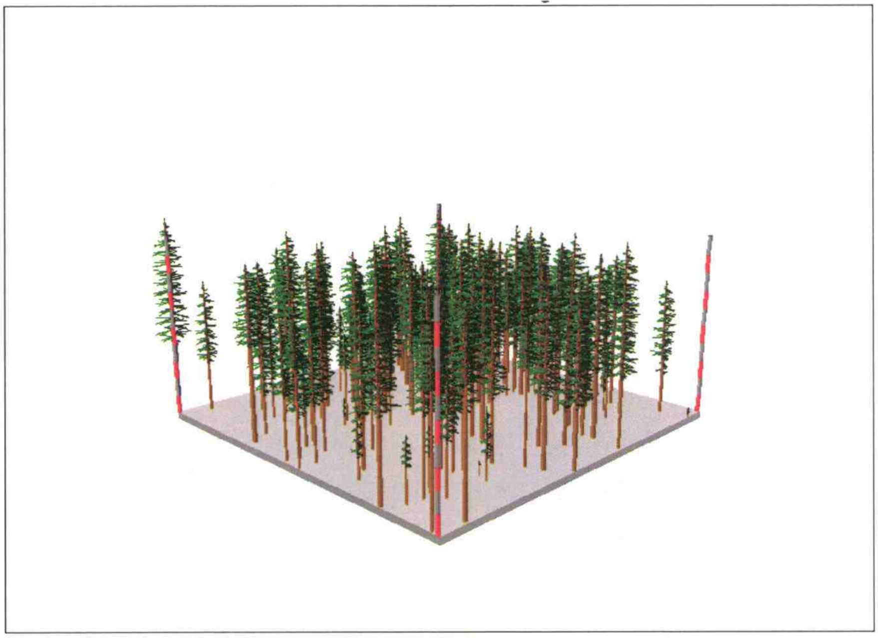
Pole Creek 1



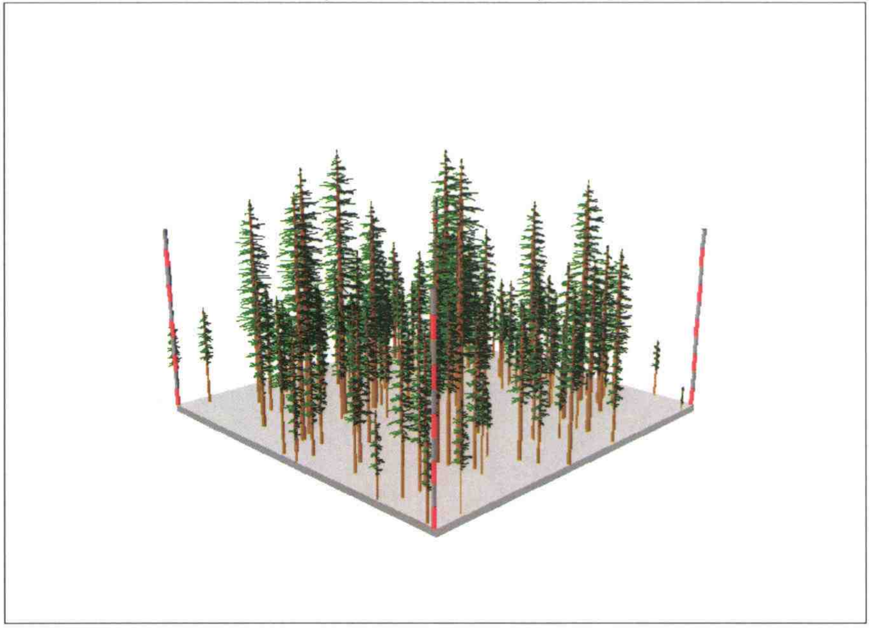
Pole Creek 2 (*before* thinning treatment)



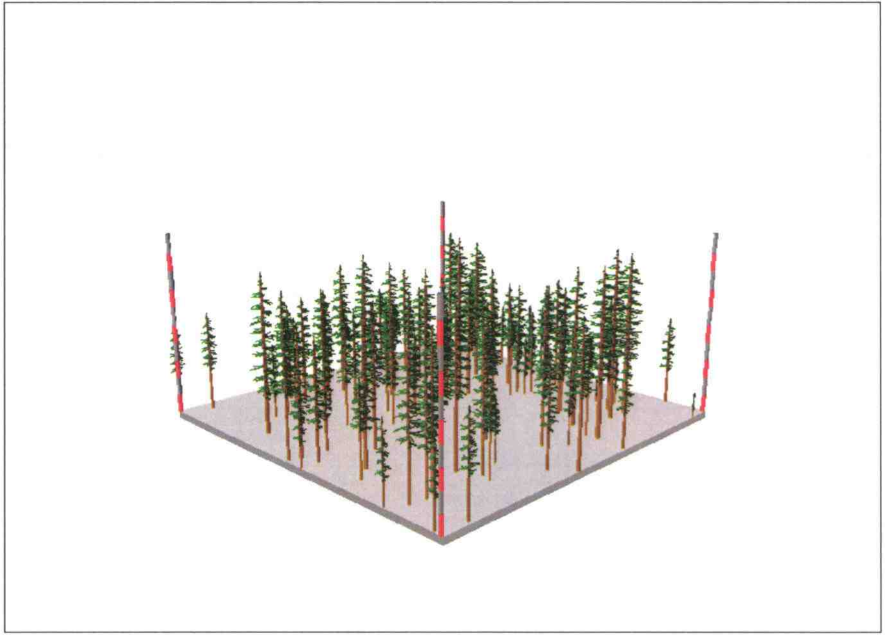
Pole Creek 2 (*after* thinning treatment)



Pole Creek 3 (*before* thinning treatment)



Pole Creek 3 (*after* thinning treatment)



APPENDIX F

Electronic Reference.

On the inside of the back cover of this paper is a CD that contains a digital copy of the project, including Appendices A through D.

The CD also contains copies of GIS data. GIS data may also be obtained directly from the USDA Forest Service. Dorothy Thomas, R6 GIS Data Services Specialist, was extremely helpful in providing GIS data used in this paper. She can be reached in Bend, OR at <dthomas04@fs.fed.us> and (541) 383-5570.