Mortality as a Source of Coarse Woody Debris in Managed Stands[1]

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Abstract

Mortality was recorded annually over a 15-year period after thinning in each of three even-aged stands (one ponderosa pine and two ponderosa pine/Douglas-fir/western larch), and after individual tree selection cutting in two uneven-aged ponderosa pine stands. Highest mortality occurred in the controls in both the even- and uneven-aged stands, primarily due to suppression, while weather was the leading mortality agent in the thinning and selection cutting treatments. Beetles were the primary killer of ponderosa pine, and western spruce budworm of Douglas-fir. Mortality of trees ≥25 cm diameter was negligible in all silvicultural cutting treatments. Absent low-intensity fires that historically promoted open pine stands and large-tree development, active management will likely be needed to create desired live tree and dead wood stand components in the future.

Introduction

A primary objective of prescribing and implementing silvicultural cutting treatments in forest management is to achieve a desired future condition in the stand while ensuring long-term site productivity. These treatments typically involve directing site resources toward fewer trees—usually trees of desired species, form, and vigor—thus increasing the growth rate of residual trees. A secondary but traditionally welcome effect of treatment is reduced levels of tree mortality. However, recent insights into ecosystem health suggest that stands consisting only of live trees may not provide the range of conditions needed to support the full suite of life-forms required for sustained ecological function (Cazares and Trappe 1999). Dead trees, either standing or down, are important as food sources (Haverty and Shea 1999, Ross 1999), as refugia for a variety of animal species (Herder and Jackson 2002, Laudenslayer 2002), as substrate for mycorrhizal infection (Harvey and others 1981, Harvey and others 1987), and as a primary source of nutrients and large organic matter for soil development and maintenance (Prescott and Laiho 2002). Therefore, the causes, timing, and distribution of tree mortality, along with silvicultural prescriptions that maintain and/or create relatively large trees on-site, need to be addressed.

This paper reports amounts and causes of tree mortality by diameter, species, and treatment for the first 15 years after various silvicultural cuttings in even- and uneven-aged stands in west-central Montana. Tree mortality has traditionally been

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sampled on relatively small (0.04- or 0.08-ha) plots—plots designed to sample growth of trees, not mortality pattern as part of a larger population. Because tree mortality is often clustered (Dale 1999, Lutes 2002) and episodic, sampling small fixed plots at 5- or 10-year intervals may not be appropriate for discerning mortality relationships and trends. Hence, a combination of small plots (to reflect stand density and structure of live trees) and a complete census of dead trees on much larger plots (to capture the full range of species, distribution, and diameters) was incorporated into this mortality study.

Methods

Tree mortality was monitored in five stands on The University of Montana's Lubrecht Experimental Forest in west-central Montana: a pure, even-aged ponderosa pine *(Pinus ponderosa)* stand; two even-aged ponderosa pine/Douglas-fir *(Pseudotsuga menziesii)*/western larch *(Larix occidentalis)* stands; and two uneven-aged ponderosa pine stands. A thinning demonstration was implemented in 1983 in each of the three even-aged stands to evaluate growth and mortality among three residual densities (6x6, 4x4, and 3x3-m nominal tree spacing) and an unthinned control. A second study was installed in the two uneven-aged ponderosa pine stands in 1984. In this study, growth and mortality were compared among two management treatments—selection cutting with and without underburning—and an untreated control. In the even-aged stands, the thinned units and the control were each about 1.5 ha in size, for a total area of about 6 ha per stand. In the two uneven-aged stands, the selection cutting units and the control were each 1 ha in size, for a total area of 3 ha per stand. This paper reports the amounts and causes of mortality by treatment, species, and diameter for the first 15 years after treatment in each stand.

All five stands are within about 10 km of each other and at nearly the same elevation—1,200 m. At the time the study was initiated, the even-aged ponderosa pine stand was about 80 years old, with 2,620 trees per hectare (tpha), and a basal area density of 45.9 m^2/ha in the control. This stand occupies a site classified as a Douglas-fir/snowberry *(Pseudotsuga menziesii/Symphoricarpus albus)* habitat type (h.t.) (Pfister and others 1977). The two mixed ponderosa pine/Douglas-fir/western larch stands were also about 80 years old at the beginning of the study, with an average of 1,300 tpha, and an average basal area density of 36.7 m^2/ha in the controls. These stands occur on sites classified as Douglas-fir/snowberry h.t. (Pfister and others 1977). Trees in the two uneven-aged ponderosa pine stands ranged in size from seedlings to old-growth trees >75 cm dbh, and from 1 to about 400 years old. One of the uneven-aged stands occurs on a site classified as a Douglas-fir/snowberry h.t., while the other is classified within the Douglas-fir/dwarf huckleberry *(Pseudotsuga menziesii/Vaccinium caespitosum)* h.t. (Pfister and others 1977). At the beginning of the study, the uneven-aged controls supported an average of 950 tpha with an average basal area density of about 23.0 m^2/ha, while basal area density was reduced to 13.8 m^2/ha in the treated stands.

In each stand, all standing dead trees were marked with spray paint at the beginning of the study so that they would not be counted as subsequent mortality. Each autumn, a complete survey (census) of all trees in each stand was conducted to identify trees that had died during the preceding year. Each dead tree was recorded as to species, dbh, and cause of death, and then marked to prevent counting again in subsequent years.

Mortality patterns were similar between the two mixed ponderosa pine/Douglas-fir/western larch stands and between the two uneven-aged ponderosa pine stands; hence results were combined in each case for simplicity of presentation and interpretation. Mortality data from the even-aged stands were combined into 5.0-cm dbh classes for greater resolution in the relatively small range of tree diameters (2.5-45.7 cm), while uneven-aged mortality data were grouped by 10.0-cm dbh classes because of the larger diameter range (2.5-76.2 cm).

Results

Even-aged Ponderosa Pine Stand

Mortality in the pure, even-aged ponderosa pine stand occurred primarily in the uncut control *(fig. 1).* There were 2,620 live tpha in the control at the beginning of the study; however, only 1,774 tpha remained alive at the 15-year remeasurement. Among the three thinning treatments, mortality was greatest in the treatment with 3x3-m nominal spacing, where 35 tpha died in the 15-year period. The 4x4 treatment lost only 15 tpha, and the 6x6 treatment had no mortality. The smallest diameter classes represented in each of the treatments contained the majority of the mortality, while little or no mortality occurred among the largest size classes present in each of the treatments. In the control, 699 tpha died among trees <15.2 cm. The 3x3 treatment lost 27 tpha among trees 7.6-17.8 cm dbh, while the 4x4 treatment lost 15 tpha 12.7-22.9 cm in diameter.

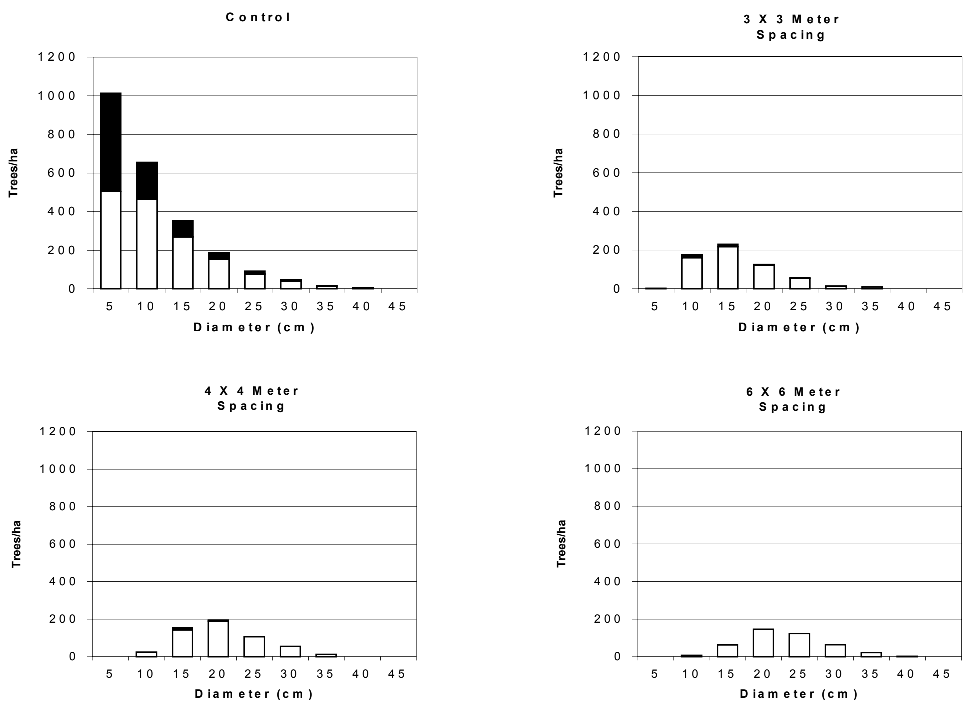

Figure 1—Live trees per hectare by diameter class at the beginning and end of the period 1983–1998 in an even-aged ponderosa pine stand with three thinning treatments and a control. Total bar height indicates live trees in 1983, the shaded portion of each bar indicates trees that died during the 15-year period, and the unshaded portion indicates live trees in 1998.

Causes of mortality in the even-aged ponderosa pine stand varied greatly by tree diameter and treatment *(fig. 2)*. In general, suppression was the primary cause of death in trees <10.2 cm, while bark beetles were the leading cause of mortality among trees >12.7 cm in diameter. Mountain pine beetle *(Dendroctonus ponderosa)* was the primary mortality agent in the 3x3 and 4x4 treatments, accounting for 27 dead tpha in the 10 to 25-cm diameter classes in the 3x3 treatment, and 12 tpha in the 15 and 20-cm diameter classes in the 4x4 treatment. Beetles also killed a total of 252 tpha in the control, primarily among trees 5.1-22.9 cm. Pockets of tree mortality due to mountain pine beetle are common in second-growth ponderosa pine stands, particularly in high-density areas within these stands (Olsen and others 1996). Over the 15-year period, the leading cause of mortality in the control was suppression, killing a total of 682 tpha <12.7 cm. Weather and other agents were minor contributors to mortality across a range of diameters in the control and 3x3 treatment.

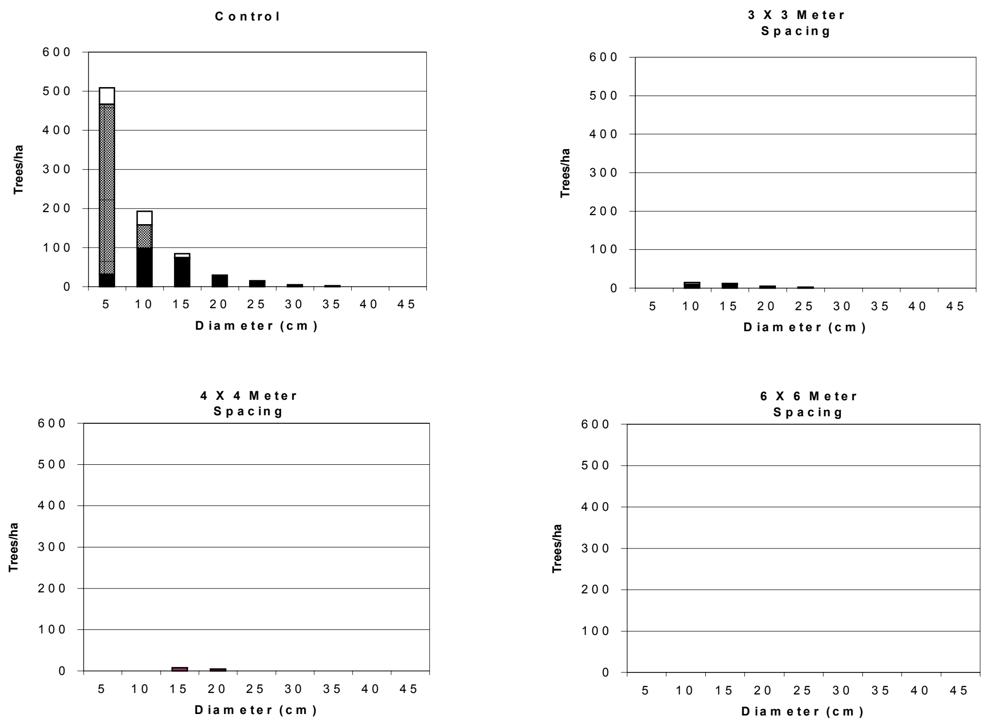

Figure 2—Mortality by diameter class and cause for the period 1983–1998 in an even-aged ponderosa pine stand with three thinning treatments and a control. Dark shading indicates trees killed by bark beetles, stippling indicates trees killed by suppression, and the unshaded portion of each bar indicates trees killed by other causes (primarily weather).

Even-aged Ponderosa Pine/Douglas-Fir/Western Larch Stands

Mortality in the even-aged ponderosa pine/Douglas-fir/western larch stands also occurred primarily in the uncut control *(fig. 3).* There was an average of 1,298 live tpha in the controls at the beginning of the study, which dropped to 954 live tpha at the end of the 15-year period. Among the three thinning treatments, mortality was greatest in the 4x4, with 20 tpha dying in the 15-year period, reducing mean stand density from 467 tpha to 447 tpha. The 3x3 treatments lost an average of 12 tpha, and the 6x6 treatments lost only 5 tpha. Among the treatments in the even-aged mixed conifer stands, the intermediate diameter classes accounted for the majority of the mortality. The 3x3 treatment lost 2 tpha in each 5-cm class from 5.0 to 30.5 cm, while the 4x4 treatment lost 20 tpha in the 10 to 35-cm classes. In the control, mortality was most prevalent among the smaller diameter classes, with an average of 133 tpha and 121 tpha dying in the 5- and 10-cm dbh classes, respectively.

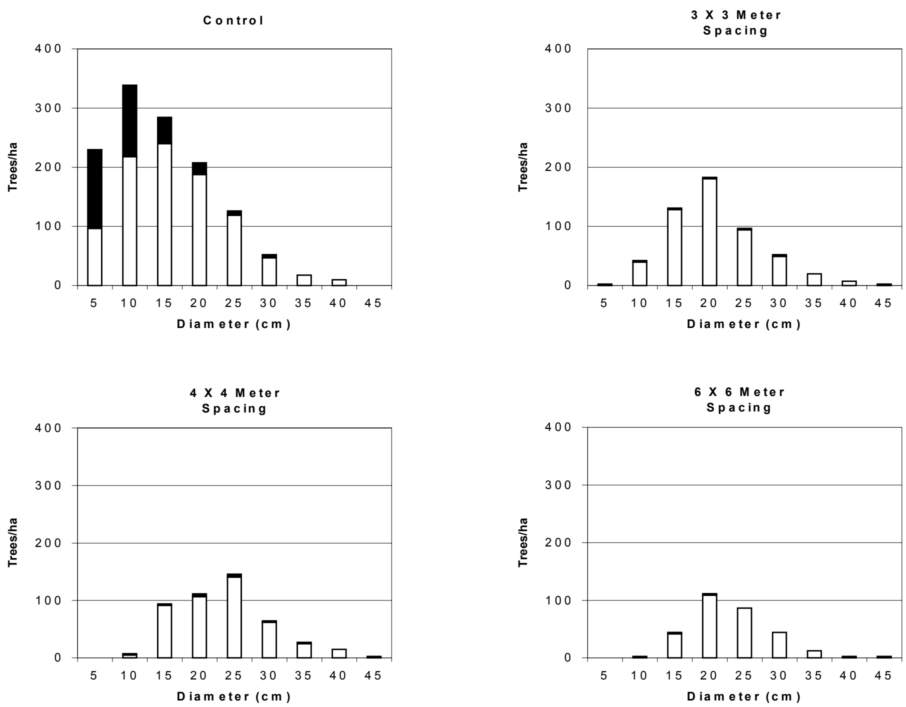

Figure 3—Live trees per hectare by diameter class at the beginning and end of the period 1983–1998 averaged for two even-aged mixed-conifer stands with three thinning treatments and a control. Total bar height indicates live trees in 1983, the shaded portion of each bar indicates trees that died during the 15-year period, and the unshaded portion indicates live trees in 1998.

Causes of mortality in the even-aged ponderosa pine/Douglas-fir/western larch stands varied by tree species, diameter, and treatment *(fig. 4).* Suppression and western spruce budworm *(Choristoneura occidentalis)* were the primary causes of death of Douglas-fir in the controls, whereas mountain pine beetle was the primary killer of ponderosa pine. Virtually no western larch died in either of the mixed-species stands. In general, suppression was the leading cause of mortality in the controls, while weather and beetles were primarily responsible for mortality in the 3x3 and 4x4 nominal spacing treatments. In the controls, suppression killed an average of 156 tpha <20.3 cm, while beetles and weather led to the death of 124 tpha 5.1-35.6 cm in diameter. Western spruce budworm also accounted for the death of 62 tpha <25.4 cm in the control, where the host species (Douglas-fir) was more abundant, the trees were over-stocked and stressed, and a multistoried canopy provided better larval habitat (Carlson and Wulf 1989). Neither suppression nor budworm was an agent of mortality in the thinning treatments, where beetles and weather were responsible for the mortality of 5 tpha in the 3x3 treatment and 12 tpha in the 4x4 treatment.

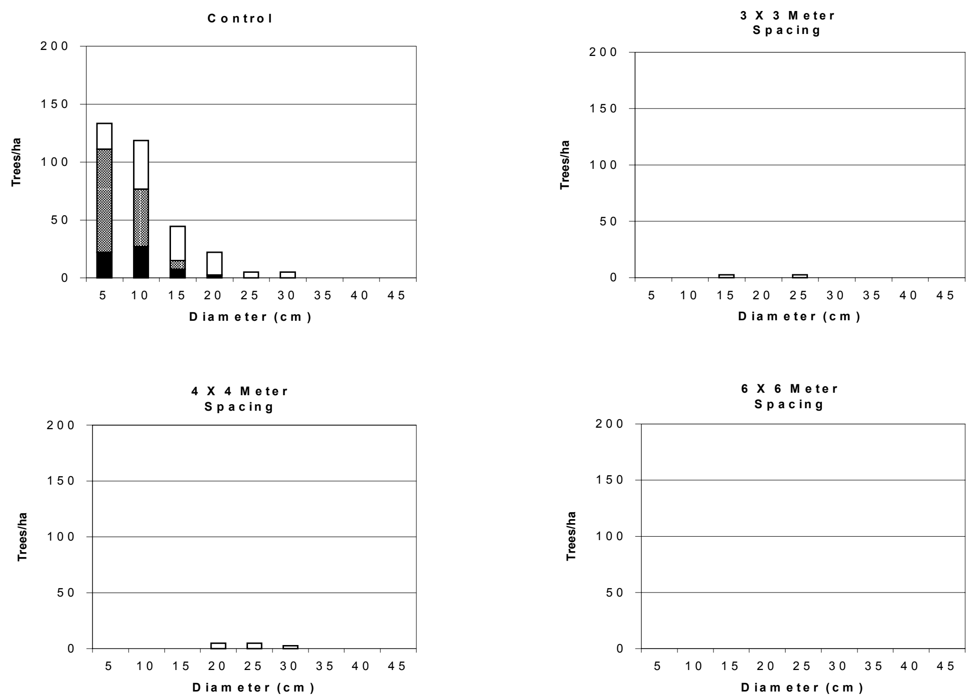

Figure 4—Mortality by diameter class and cause for the period 1983–1998 averaged for two even-aged mixed-conifer stands with three thinning treatments and a control. Dark shading indicates trees killed by budworm, stippling indicates trees killed by suppression, and the unshaded portion of each bar indicates trees killed by other causes (primarily weather and bark beetles).

Uneven-aged Ponderosa Pine Stands

Mortality in the uneven-aged ponderosa pine stands was greatest in the uncut controls *(fig. 5)*. There was an average of 951 live tpha in the controls at the beginning of the study, and 759 live tpha at the end of the 15-year period. In the two selection cutting treatments, mortality was greatest in the cut/burn treatment, with an average of 59 tpha dying in the 15-year period, reducing mean stand density from 326 tpha to 267 tpha. The cut/no-burn treatment lost 30 tpha, reducing stand density from 353 tpha to 323 tpha. The smallest diameter classes contained the majority of the mortality in the two selection cutting treatments. The cut/burn treatment lost an average of 54 tpha <25.4 cm, while the cut/no-burn treatment lost only 25 tpha <25.4 cm. In the control, mortality was also highest among the smaller diameter classes, with an average of 156 tpha <25.4 cm dying in the 15-year period. Fewer than 2 tpha ≥35.6 cm died in either of the selection treatments, while more than 5 tpha died among similarly sized trees in the control.

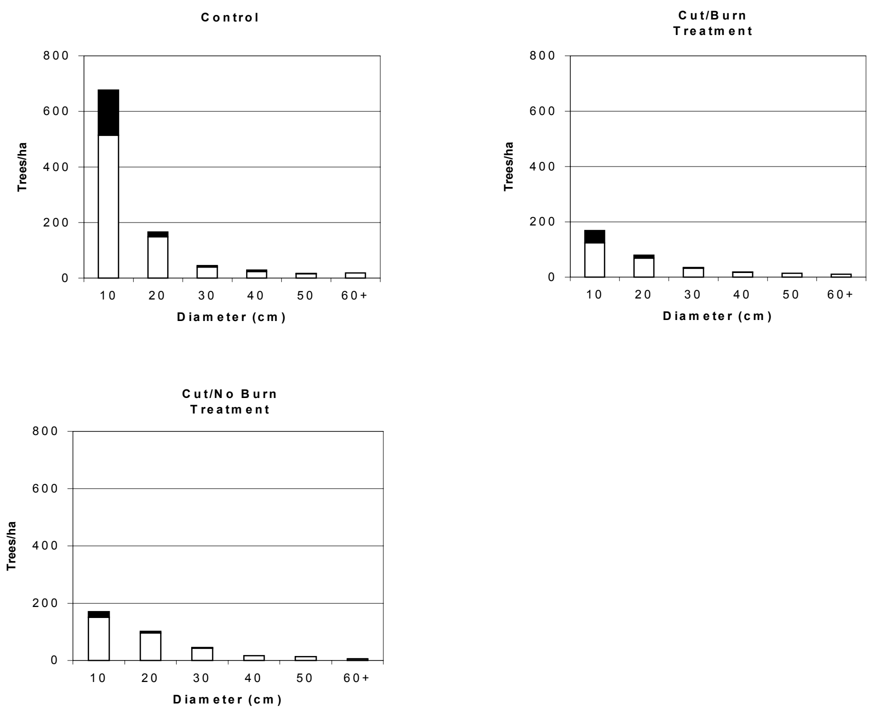

Figure 5—Live trees per hectare by diameter class at the beginning and end of the period 1984–1999 averaged for two uneven-aged ponderosa pine stands with two selection cutting treatments (with and without burning) and a control. Total bar height indicates live trees in 1984, the shaded portion of each bar indicates trees that died during the 15-year period, and the unshaded portion indicates live trees in 1999.

Causes of mortality in the uneven-aged ponderosa pine stands varied primarily by treatment *(fig. 6).* In general, suppression was the dominant cause of mortality in the controls, fire was the leading cause of mortality in the cut/burn treatments, and weather was the primary agent in the cut/no-burn treatments. Mortality due to bark beetles was present in both treated and untreated portions of the stands, though it was much higher in the untreated portions, where higher densities created conditions more favorable for beetles. In the controls, suppression killed an average of 99 tpha <15.2 cm, while beetles caused the death of 52 tpha <45.7 cm. Weather accounted for an average of 44 dead tpha <25.4 cm in the control, 15 dead tpha <25.4 cm in the cut/burn treatment, and 20 dead tpha <35.6 cm in the cut/no-burn treatment. Fire killed an average of 32 tpha <15.2 cm and 5 tpha between 15.2 and 25.4 cm in the cut/burn treatment. Beetles accounted for the death of 7 tpha <35.6 cm in the cut/burn treatment and 5 tpha <25.4 cm in the cut/no-burn treatment. Other agents, including root rot, budworm, and animals, killed an average of 3 tpha <15.2 cm among the cut/no-burn treatments.

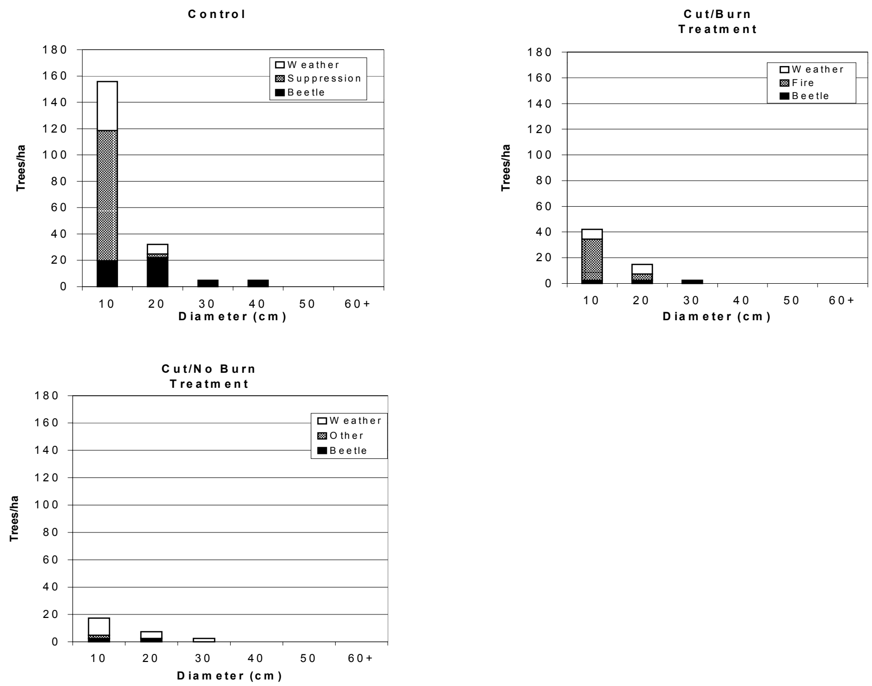

Figure 6—Mortality by diameter class and cause for the period 1984–1999 averaged for two uneven-aged ponderosa pine stands with two selection cutting treatments (with and without burning) and a control. Dark shading indicates trees killed by bark beetles; stippling indicates trees killed by suppression, fire, or other causes (according to treatment); and the unshaded portion of each bar indicates trees killed by weather.

Discussion

Mortality for the 15-year period was greatest in the untreated controls for both the even- and uneven-aged stands. Mortality in the even-aged stands was lowest in the low-density (6x6 nominal spacing) thinning treatment. In the uneven-aged stands, mortality was lowest in the cut/no-burn treatment. Suppression was the leading cause of mortality among the uncut controls in all stands, primarily affecting trees in the smallest diameter classes, while beetles were the leading cause of mortality among the larger size classes in the ponderosa pine stands.

These findings indicate that the thinnings and selection cuttings tended to reduce total mortality. However, this reduction in mortality was not distributed evenly across the diameter classes. Mortality levels among small-diameter trees in the treatments were consistently much lower than mortality levels of small-diameter trees in the controls. However, mortality differences among treatments and controls were not as significant for the large-tree stand component. Although overall mortality of large trees was reduced by treatment, mortality of large trees was not entirely prevented by treatment. The susceptibility of larger pines to bark beetle attack was likely reduced by the increased tree vigor resulting from thinning or selection cutting. However, scorch from prescribed burning likely stressed some residual trees in the selection cut/burn treatment, and may have increased susceptibility to beetle attack. Untreated forest with favorable habitat for pests near treated areas may have allowed insects access to those larger trees stressed by prescribed burning.

One important observation over the 15-year monitoring period was the relatively low mortality of small trees after prescribed underburning in the individual tree selection study. Prescribed burning has been questioned as an appropriate treatment in uneven-aged stands because of the potential to incinerate trees in the smaller diameter classes. However, over the 15-year period, fewer than 20 percent of the trees in the 10-cm class died as a result of burning, and only about 25 percent died from any cause. These results indicate that judicious use of prescribed burning can achieve a variety of management objectives, such as preparing seedbeds, killing small firs, reducing activity fuels, and stimulating growth of important wildlife forage species (e.g., willow *(Salix* spp.) and bitterbrush *(Purshia tridentata)* [Ayers and others 1999]), while limiting mortality of small pines to acceptable levels.

Conclusions

The two types of silvicultural cuttings evaluated in this study—thinning and selection cutting—were found to reduce mortality in even-aged and uneven-aged ponderosa pine stands, respectively. This would be considered a positive outcome from a timber production point of view. However, it may be less desirable when viewed in the broader context of maintaining conditions favorable to indigenous fauna and flora in managed ponderosa pine and drier mixed conifer ecosystems. Because mortality was highest in the smallest diameter classes in all stands, relatively large snags and downed logs may need to be manufactured in managed stands when desired for wildlife or other ecological considerations.

Standing dead wood may be created by girdling live trees with an axe or chainsaw, baiting with pheromones, inoculating with decay fungi, or burning to kill either the cambium at the base of the tree, the roots, or the foliage and terminal bud. However, as several investigators (Boleyn and others 2002, Parks 1999, Shea and others 2002) reported at this symposium, not all dead trees are created equal. For example, woodpecker foraging occurred primarily in the younger age classes of snags (Farris and others 2002). Huss and others (2002) found that woodpecker nest trees were frequently infected by the red-belted conk fungus *(Fomitopsis pinicola),* and Laudenslayer (2002) noted that snags with historical and active nests of cavity-nesting birds tended to be taller and had greater diameters than those without nests. In addition to the size of snag and time since death, how a tree dies may have profound effects on how long it remains standing and what function(s) it may serve (Bull 1983, Bull and Partridge 1986, Keen 1955). Thus, habitat suitability of dead trees and logs for various wildlife species should be considered when selecting which trees are to be killed and how to kill them (Bull and others 1980).

Maintaining desired amounts of large snags and logs both in the near and distant future may require silvicultural stand interventions that not only kill and remove trees from the stand but also leave some dead trees (Ffolliott 1983). The large live and dead trees present in today's ponderosa pine stands developed under stand densities widely documented to be more open than current conditions (Arno and others 1995, Covington and Moore 1994). The low-intensity fires that historically accomplished thinning are often not possible under current stand conditions, given heavy down-fuel loading and the presence of sapling and pole ladder fuels (Fiedler and others 1998). Historically, periodic low-intensity fires commonly created open stand structures, lowered fuel loadings, and favored survival and development of large-diameter, fire-resistant pines. Absent this natural process to reduce density and discriminate against Douglas-fir/true firs, development of large pines in the future will likely require well-designed silvicultural cuttings to release trees, reduce ladder fuels, and simultaneously create desired standing and down coarse woody debris structures. Such cuttings have been shown to significantly increase diameter growth across the full range of tree diameters (including old-growth trees) in uneven-aged ponderosa pine stands (Fiedler 2000). It seems unlikely that productive, ecologically functional, and sustainable ponderosa pine ecosystems will attain these desired conditions without actively managing both live-tree and dead wood stand components.

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