Simulating Historical Disturbance Regimes and Stand Structures in Old-Forest Ponderosa Pine/Douglas-fir Forests

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Abstract—Forest Service land managers, with the collaborative assistance from research, applied a disturbance based restoration strategy to rehabilitate a greatly-altered, high risk Northern Rocky Mountain old-forest ponderosa pine-Douglas-fir stand. Age-class structure and fire history for the site have been documented in two research papers (Arno and others 1995, 1997). Silvicultural treatments using stocking reduction through a normal timber sale offering and prescribed fire to simulate disturbance processes, were used to restore a semblance of historical vegetative conditions. These actions should improve tree vigor of the old-forest and promote ponderosa pine regeneration, while reducing the risk of significant mortality due to wildfire, root disease or bark beetle through reduced competition and open spacing. Other resource objectives were achieved including enhancement of big game winter range and flammulated owl habitat, retention and creation of wildlife snags, stimulation of fire dependent species, improved aesthetics, commodity production, and road closure/rehabilitation. Post harvest re-measurement reflects successful application of disturbance simulations. High prescribed fire severity with resulting mortality, illustrates the risk of restoration activities and the requirement of good xecution. Photographs from four permanent camera points document pre-harvest, post-harvest, and post-burn conditions.

Introduction

Wildland fire, historically and dramatically, influenced the landscapes of the inland west. For example, within the 2.1-million acres (0.85-million ha) Lolo National Forest in Western Montana, 24 percent of the forest area, over 500,000 acres (202,000 ha), burned, on average, every decade prior to active fire suppression of the early twentieth century (USDA FS 1994). Of these acres, two-thirds burned every 10 to 50 years in low-severity fires as defined by fire ecology research (Applegate 1998, Smith and Fischer, 1997). These episodes of wildland fire had a significant effect on basic vegetation structure, composition, pattern and the associated ecological processes that were sustained on the landscape (Williams 1996). The resulting plant communities and canopy structures also provided a critical niche for several wildlife species such as pileated woodpeckers *(Dryocopus pileatus)* and flammulated owls *(Otis flammeolus*).

Ponderosa pine (*Pinus ponderosa*), and western larch/Douglas-fir (*Larix occidentalis*/*Pseudotsuga menziesii*) forest types are adapted to and sustained by these historically frequent low-severity wildland fires (Stickney 1990). Prior to 1900, nearly 50 percent of these low-severity burned sites were dominated by open grown stands of old-forest trees comprised of single-storied, multiaged stands (Arno and Harrington 1998; Losensky 1993). Low-severity fires periodically killed most of the immature trees and occasionally some of the larger mature trees, singley or in groups. Infrequently, tree regeneration survived to maturity, maintaining dominance of fire-adapted conifers.

Today very few open grown old-forest stands remain. For example, recent Lolo National Forest inventory listed ponderosa old-forest at nearly 12,000 acres (4,850 ha) and western larch/Douglas-fir old-forest at 24,000 acres (9,700 ha). Both total only about 6 percent of the old forest ponderosa pine and western larch/Douglas-fir acres that was historically present (USDA Forest Service 1999). As a result of fire exclusion and early-day logging of larger trees, the low-severity fire regime sites have become multi-storied of varying densities of overstory ponderosa pine with dense thickets of understory Douglas-fir or other more shade tolerant species (Fiedler and others 1997).

Many species of wildlife are dependent upon open grown old-forest ponderosa pine/Douglas-fir or western larch/Douglas-fir forests. In upland habitats in the Northern Rockies, pileated woodpeckers nest exclusively in large diameter ponderosa pine or western larch snags (McClelland 1977). Flammulated owls nest in abandoned pileated woodpecker cavities and forage on insects in open understories (Wright 1996). Wright concluded that fire exclusion, which results in increasingly dense understories, might make old-forest ponderosa pine stands unsuitable for flammulated owl foraging.

Other species are not exclusively dependent on old-forest ponderosa pine or larch, but utilize this community type as one of several preferred habitats. These species include black-backed (*Picoides arcticus*) and three-toed (*Picoides tridactylus*) woodpeckers which forage on bark beetles (such as *Dendroctonus, Ips* and *Pityophthorus*) and wood borers (*Cerambycidae* and *Buprestidae*) resulting from periodic

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insect or fire mortality. According to Hutto (1995) exclusion of periodic fire in these communities makes them relatively unsuitable for black-backed and three-toed woodpeckers. Elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) forage on sprouting shrubs occuring after low-intensity burns (Hillis and Applegate 1998). Various studies in the west (Hillis and Applegate 1998, Leege 1978) have shown that periodic burns can increase forage production from 200–2000 percent. While much of the forage for elk on winter ranges is associated with young forests, the scattered large overstory trees of old-forests allow deer and elk to better cope with severe winter weather (Baty and others 1996) due to greater snow interception by old-forest overstories.

These multi-storied stands are now at risk for major disturbances such as disease and insect epidemics and high-severity stand replacing fires. Also at risk are specific habitat niches for many wildlife species that are adapted to the more open grown old-forest character.

Silvicultural prescriptions developed by an interdisciplinary team, implemented through timber harvests, are designed to partially simulate historic fire disturbances. These treatments were designed to achieve desired sustainable ecosystems, meet Forest Plan objectives, and provide amenities and commodities for society. In this paper, we describe a specific silvicultural prescription, representative of many being implemented through timber harvests, to simulate historic disturbances and stand structures thus achieving desired forest conditions within the Lolo National Forest.

Ecosystem Management and National Forest Plans

Ecosystem management has guided National Forest and other agency management since the early 1990's. Ecosystem management reemphasized efforts to provide for sustainable ecosystems and public needs. Generally, ecosystem management uses an ecological approach to achieve management objectives (Robertson 1992). More specifically, ecosystem management employs that ecological approach to meet multiple-use management goals of national forests and grasslands by blending the needs of people and environmental values in such a way that national forests and grasslands represent diverse, healthy, productive, and sustainable ecosystems (Bartuska 1993).

Ecosystems are dynamic. The composition and structure of the plant component are shaped and sustained on the landscape not only by natural succession, but also by disturbances such as fire, wind, drought, insects, pathogens, and humans. Wildland fire not only influenced the pattern and structure of the landscape, it was also significant in determining which plants and animals would dominate, which would be suppressed, and which would be excluded (Agee 1993). Fire is a key process in ecosystem dynamics, function, and sustainability.

Listed within the portion of the Lolo Forest Plan (USDA Forest Service 1986) that covers the landscape historically dominated by frequent, low-severity fires, are many goals and objectives. The goals and objectives are to provide a socially acceptable and healthy environment and diverse ecosystems, and to provide habitat for viable populations of all indigenous wildlife. At the same time, there is specific emphasis to provide quality big game winter range as well as timber production.

Management planning strategies that consider historical conditions and processes appear to have advantages for maintaining biological diversity and ecological processes in the development of treatment alternatives and should appropriately result in recovery of biologically diverse and sustainable ecosystems (Arno and Harrington 1998; Arno 1997; UCRB 1997; Kaufmann 1994).

Research Application

Studies by Arno and others (1995, 1997) have detailed the fire history and resulting age-class and structure on several 2.5-acre (1 ha) plots in old-forest sites on the Lolo and Bitterroot National Forests within historically frequent low-severity fire regimes. Forest restoration on one of these research sites, the Whitehorse area, was planned and executed based on historic stand data and is the focus of this discussion. This project, which includes commercial tree removal and reintroduction of fire, is representative of many forest restoration projects being conducted on the Lolo National Forest.

Additional research on the Whitehorse stands was conducted by Hejl and Woods (1991). Their research focused on identifying songbirds dependent on old-forest ponderosa pine communities. They found a sizable assemblage of songbirds both strongly and weakly associated with old-forest ponderosa pine communities.

The research provided the baseline stand, fire history, and wildlife data. These data were used to develop long-term management strategies which will eventually attain historic stand structures. On both dry and moist sites, the major changes in stand structure between 1900 and the 1990s were an increase in basal area and in the number of trees per acre as well as the development of an understory of shade-tolerant trees (Arno and others 1995). Re-introducing fire alone will not restore most old-forest stands because of unprecedented accumulations of duff and ladder fuels. The dense understories, including many trees whose crowns extend into the overstory canopy, cannot now be killed by fire without damaging the old-forest trees (Harrington 1991). Growth and vigor of the old trees also have declined noticeably in many stands while mortality has increased (Arno and others 1995). To restore a semblance of self-perpetuating pine, it is necessary to reduce the understory mechanically and thereafter control understory development using prescribed fire.

Site Description

The Whitehorse project area is confined to a rather small landscape of approximately 400 acres (162 ha), on the Ninemile Ranger District in the Fish Creek drainage about 35 miles (56 km) west of Missoula, Montana. It is positioned between proposed wilderness and industrial private ownership at mid elevation, 4,000 to 4,800 ft, (1,200-1,500 m) on a steep, mildly convex, south-facing slope. The landform is dissected with minor ridges and draws which create changes in environmental conditions. Consequently, four habitat types (Pfister and others 1977) occur within the old-forest restoration treatments. The research plot (100 m^2 or roughly 2.5 acres) lies on the two most common habitat types, Douglas-fir/blue huckleberry (*Pseudotsuga menziesii* / *Vaccinium globulare*), and Douglas-fir/pinegrass (*P. menziesii* / *Calmagrostis rubescens*), which are moderately warm, dry to moist and cool dry sites.

The mean fire interval has been determined at approximately 26 years beginning in 1636 with no evidence of fire since 1897 (Arno and others 1995). Stand replacement fires were probably rare. This classic dry site fire regime with frequent fires of low-severity would also include the extreme southeast portion of the project area which is Douglas-fir/ninebark ninebark phase (*P. menziesii*/*Physocarpus malvaceus*-*Physocarpus malvaceus*). These three habitat types are in Fire Group 6 with a mean fire interval range of 16 to 42 years (Davis and others 1980; Fischer and Bradley 1987). A fourth habitat type, grand fir/twinflower (*Abies grandis* / *Linnaea borealis*) occurs in a draw along the western edge of the restoration treatment. It is considered a warm moist site depicted by Fire Group 11. Fire intervals in such moist sites are generally longer, though in this case the past fire interval would be influenced by the frequency of the adjacent, more prevalent regime (fig. 1).

Mortality from other disturbances such as bark beetle, root disease or windthrow contributed to large openings within these stands and an increase in fuel loading. A specific example is annosum root disease *(Heterobasidion annosum)*, which can accelerate with harvesting (Hagle 1992).

Prior to treatment, the research plot representing the stand had a predominent, single broad-aged old-forest component with a layered structure of ponderosa pine and Douglas-fir. The oldest individual ponderosa pine on these dry types exceeds 500 years of age (Arno and others 1995).

Most trees in this old-forest became established during a 70-year period (1700–1770) despite intervening surface fires (fig. 1). This major age group became established after surface fires in about 1687 and 1698. Its rapid early growth suggests that these fires (and perhaps associated root disease and bark beetle attacks) may have created openings by killing many of the overstory trees. Before treatment, the plot had 7 live trees and about 4 dead trees/acre (17 live and 10 dead trees/ha) (post-1900 mortality) as well as several older dead trees (1800s mortality) that were established before the late-1600s fires. So, an open "shelterwood" overstory of at least 12 trees/acre survived the 1698 fire, and an age class, 1700–1770, developed beneath it. Some of these pines became suppressed and today are only about 12 inches d.b.h. (30.5 cm) and 40 feet tall (12.2 m) at approximately 250 years of age. This is less than half the diameter and height of the dominant trees in this age group (Arno and others 1995). Stocking levels in excess of 180 ft^2 of basal area/acre (41 m^2/ha) exceed historic conditions. Older age classes of ponderosa pine and western larch exhibit a decline in vigor which is accentuated with increased competition (Arno and others 1995, 1997).

Prior to treatment, the stand was overstocked with many small-diameter old-forest ponderosa pine of 250 or more years of age and younger understory of Douglas-fir. Because of this heavily stocked overstory, understory trees were almost exclusively slow-growing Douglas-fir less than 90 years old. Since 1900 the basal area of the stand had increased from 152 ft^2/acre to 187 ft^2/acre (34.9 to 42.9 m^2/ha) 61 percent of which is Douglas-fir (table 1) (Arno and others 1995).

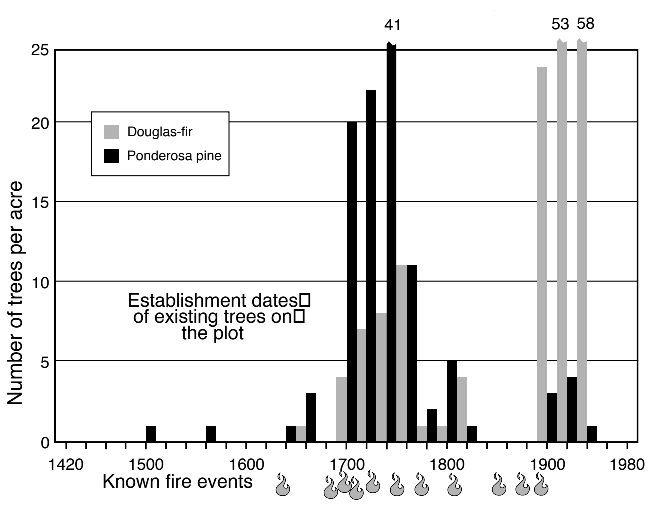

Figure 1—Whitehorse Creek old-growth plot Lolo-3 (adapted from Arno and others 1995).

Restoration Strategy

Based on the philosophy of ecosystem management and direction contained in the Lolo National Forest Plan, specific management objectives for this project area are to restore and maintain ponderosa pine type old-forest character, reduce the risk of stand replacement wildfire, simulate historical disturbance regimes through fire application, and provide for wildlife habitat. The restoration strategy involves stocking reduction and the return of fire (Arno 1988). The silvicultural treatments applied were single tree selection cutting and group tree selection harvests. The high residual stocking level of the single tree selection cutting, with a regeneration goal, could arguably be called intermediate cutting involving both thinning and improvement harvests to remove undesirable trees and reduce stocking density. Group selection harvests are primarily a result of sanitation/salvage cutting Douglas-fir within active armillaria root disease areas (*Armillaria ostoyae*). The group

Table 1—Comparison of overstory tree stocking and species composition expressed as basal area (square feet per acre) in 1900, historic, 1991, pre-harvest and 1997, post-harvest, in the Whitehorse area (Arno and others 1995; unpublished, Rocky Mountain Research Station, Missoula, MT).

Species	1900	1991	1997
PP	113 (73%)	126 (67%)	82 (82%)
DF	39 (27%)	61 (33%)	18 (18%)
Totals	152	187	100

selection was applied on less than 5 percent of the restoration area. These actions were taken to improve tree vigor of the old forest, and promote ponderosa pine regeneration, while reducing the risk of significant mortality due to wildfire, root disease or bark beetles.

The stocking reduction objective was accomplished by removing, through timber harvest, excess understory trees and a portion of the overstory (fig. 2,3). The target was to retain an average of 45 trees/acre (111 trees/ha) of the desired dominant and codominant trees in an irregular

Figure 2—Photo Whitehorse stand prior to treatment.

Figure 3—Photo Whitehorse stand after commercial timber harvest.

spacing averaging 100 ft^2 of basal area/acre (23 m^2/ha). There were fewer old-forest trees in the western most draw occuring on grand fir/twinflower habitat type. Here the target residual basal area was 80 ft^2/acre and about 45 trees/acre (18 m^2 and 111 trees/ha).

The timber sale involved five other units of tractor and skyline yarding and road construction. These other harvests consisted of 13 acres (5 ha) of clearcut with reserves, and 66 acres (27 ha) of shelterwood final cut with reserves. The old-forest restoration involved 70 acres (28 ha) of single tree selection and group tree selection. All of the harvest areas were planned for underburning, with ecosystem maintenance burning planned for an additional 63 acres (26 ha). The overall intent was to accomplish as much of the restoration needs as possible within the small drainage with no subsequent entry for a period of 40 years.

Lab incubation of samples confirmed the presence of annosum root disease in ponderosa pine which appeared more active in a portion of the area that had been salvage logged in the past (Hagle 1992). The concern that this disease would accelerate with harvesting was addressed with a borax stump treatment by the purchaser within eight hours of felling.

The submerchantable excess understory was reduced through slashing and underburning. The partial slashing by the timber purchaser after harvesting augmented the fuel loading to allow better understory mortality during prescribed burning. Approximately 100 stems/acre (247 trees/ha) of understory conifers were left standing with a high level of expected fire mortality. This treatment will better ensure the objective of understory removal is met.

The partial slashing treatment was added in exchange for omitting the leave tree protection requirement. A change largely as a result of conditions created by the purchaser's election to skyline and tractor yard tree length. The yarding technique removed tree tops and limbs that until recently were routinely left on site. Without this material on site, it became imperative to augment the fuel loading with partial slashing of the submerchantible understory. Fuel augmentation is to increase the amount and continuity of drying fuel and expand the season when ignition could take place. At the same time, leave tree protection, which is manual removal of logging debris from the base of leave trees, was not needed.

The tree length yarding practice is a harvesting trend brought about with the increasing occurrence of processing equipment at landings. One faller teamed with a processer can do the work of three fallers that limbed and bucked in the woods. This reduces the purchaser's costs in payroll and state mandated workman's compensation. It also alleviates the difficulty in filling and maintaining logging crews. On the other hand, it creates problems in maintaining woody debris for long term soil productivity, wildlife habitat, and regeneration microsites.

Underburning was applied following timber harvesting and slashing to reduce severe wildfire risk, to rejuvenate shrubs and other fire adapted species, and to provide site preparation for natural regeneration of seral plants (fig. 4). Objectives of the underburn are important to specify so proper burn prescriptions can be developed (Harrington 1991). Specific desired ranges for treatment effects included reducing vegetation litter and duff reduction less than 1/4 inch (0.64 cm) depth spread evenly over 20 percent of the area for natural regeneration of ponderosa pine and western larch. Additionally desired were extensive small woody fuel reduction, 40 to 100 percent top-kill of shrubs, retention of 5 to 10 tons/acre (11.2 to 22.4 megagrams/ha) of woody debris greater than 3 inches (7.6 cm) diameter, and 60–90 percent understory tree mortality, while limiting overstory mortality to less than 10 percent. The burn objectives are achieved at specific fuel and soil mosture contents, plant phenology, and ignition techniques. Improved shrub and grass vigor results as harvesting opens the overstory crown layer allowing more sunlight to reach the forest floor, and underburning stimulates sprouting. Another response from underburning is the resin production that is stimulated at the base of fire-scarred residual ponderosa pine (Smith and Arno 1999). This may increase decay resistence which increases the durability and longevity of future snags.

Restoring stand structures and reintroducing fire to these historically low-severity fire regime ecosystems is not without risk. With the long absence of wildland fire, some old-forest tree mortality is unavoidable due to excessive stress and high fuel loadings (Arno and others 1995). The underburn, which was envisioned as both a site preparation treatment and an ecosystem maintenance burn, was planned for hand igniton under moderate spring conditions.

Results and Discussion

The two-fold, overarching objectives of these treatments are closely related and include: (1) returning these landscape ecosystems to a more sustainable and resilient condition; and (2) simulating historic disturbance regimes, stand densities, species compositions and stand structures. The silvicultural treatments of stocking reduction and underburning have begun the process of ecosystem restoration, the culmination of these objectives.

The commercial timber sale accomplished much of the stocking reduction through single tree selection and group tree selections in 1998. The post harvest overstory remained predominately old-forest ponderosa pine and Douglas-fir (fig. 2,3 and 4). Younger age classes of both species were also still intact but at significantly reduced levels.

The average volume per acre removed was 6,000 board feet per acre. These were mostly understory Douglas-fir trees, but also included some of the overstocked 1700 to 1770 era old-forest ponderosa pine and Douglas-fir. The total stocking, at least within the research plot, was reduced to 100 ft^2/acre (23 $m/^2$ha) (table 1). The sale of 1,467 thousand board feet of sawtimber was sold at $345.52/thousand board foot, sealed bid, in September 1993 with only two bidders. Subsequent timber harvests to maintain this highly valuable old-forest are expected in 40 years to regulate stocking and species composition. Future entries are expected to yield 4,000 to 6,000 board feet/acre. Underburning will be an important companion treatment with timber harvests in replicating the natural disturbance regimes that created and sustained this relatively open old-forest. High aesthetic and wildlife values of large diameter trees of this old-forest remain. Such treatments will also greatly reduce the risk of stand-replacement fire.

Figure 4—Photo Whitehorse stand after fire application.

The successionally elevated numbers of Douglas-fir brought about by fire suppression were removed through timber harvest, partial slashing, and underburning. The timber harvest removed about 55 percent of the trees and about 34 percent of the basal area. Post harvest plot remeasurements (unpublished, Rocky Mountain Research Station, Missoula, MT) show that Douglas-fir composition was reduced from 33 percent to 18 percent (table 1). Stand structure is now predominately single-storied and likely resembles historic conditions, which represents a change from the multi-storied pre-treatment stand (fig. 2,3 and 4).

Reintroducing fire to this site after a 102-year absence was realized with a 1998 spring underburn. Though originally planned for hand ignition, a helicopter equipped with a sphere dispenser was used instead to save time and money. All five units of the timber sale, 149 acres (60.3 ha) and an ecosystem maintenance burn, 63 acres (25.5 ha) were ignited in one day at a cost of $66/acre. Within the old-forest restoration, the prescribed fire treatment resulted in a low-severity burn on 55 acres (22.3 ha) (79 percent) and a mixed to high severity on 15 acres (6.1 ha) (21 percent). The prescribed fire successfully reduced the density of the shade tolerant seedlings, saplings, and immature conifers. However, this fire also caused severe crown scorch in the overstory in 21 percent of the restoration treatment, which represented 12 percent of the immediate contiguous southfacing landscape. Unfortunately, the highest level of overstory mortality occurred within the research plot, truncating the opportunities for further research. Although acceptable at the landscape level, the mixed to high fire severity which was primarily the result of an aggressive ignition pattern, was not desired at the stand level. Ignition strip width and time interval between strips are key controls of prescribed fire intensity. This points out the inherent risks and that any deviation from the burn plan, expected forecast, or estimated fuel loading can result in greater fire impact than desired. In retrospect, objectives would have been better achieved through either hand ignition and/or full slashing of shade tolerant conifers which would require less subsequent fire intensity. However, narrow aerial ignition strips at the proper duration can be successful under these conditions. This experience highlights the varying degrees of control/risk presented by the range of restoration activities, in other words, prescribed fire, timber harvest, and other cultural practices.

Species adapted to and dependent upon frequent low-severity fire benefited by these treatments. Immediately following the prescribed burn the forest floor looked as though a summer wildfire had occurred. The forest floor surface was significantly charred by fire, but the high duff moisture content resulted in partial duff retention. About half the litter layer was consumed, being partially protected by moisture content. Most of the understory vegetation was consumed above ground, but undamaged below ground. This enabled fire-adapted shrubs, grasses and forbs to quickly respond and utilize available nitrogen.

Improved old-forest tree vigor is anticipated with reduced competition and the potential flux of nutrients. Following an initial increased risk of bark beetle infestation to fire-injured trees, this risk should lessen because of reduced stocking. Research on nearby Sawmill Gulch, found that two approximately 800 year-old pines on this site grew slowly (mean annual radial increments of about 0.02 inch or 0.5 mm) for more than 100 years prior to about 1525, followed by accelerated growth (two to three times as fast) for several decades after distrubance (Arno and others 1995).

Snags and snag replacements remain at 4 to 6/acres (10 to 15/ha), somewhat grouped across the landscape. This density of snags and live replacements exceeds the density recommended in the Regional Snag Protocol (Samson and others, in preparation). Cavity nesters such as pileated woodpeckers and flammulated owls should find excellent nesting and foraging opportunities indefinitely, assuming that longterm management will include frequent prescribed underburns.

Both the scattered and concentrated overstory mortality created excellent foraging opportunities for black-backed and three-toed woodpeckers. Both species were observed foraging in the area during the summer of 1999. Research by Caton (1996) suggests the area should provide foraging opportunties for these two species for next 5 to 6 years.

Conclusions

Historic fire and stand structure research has given Lolo National Forest managers an excellent basis to plan and implement scientifically-based silvicultural treatments to simulate historical disturbance regimes and stand structures in old-forest ponderosa pine/Douglas-fir. These in turn have resulted in a greater appreciation of, and enhanced habitat for many low-severity fire adapted and dependent plants and wildlife species.

Interdisciplinary silvicultural prescriptions designed to simulate historical disturbance processes and implemented through commercial timber harvests provide for ecosystem integrity, resiliency and sustainability (Fiedler and Keegan 1997). Although our detaited silvicultural prescriptions are written at the stand level scale, their cumulative effects at the landscape scale determine successful management. At the stand and landscape level initial and maintenance treatments are extremely important ecologically as demonstrated by past successes. These ecosystems in turn will be able to provide amenity and commodity values for society.

The excessive overstory mortality experienced on 15 acres (6 ha) of the project area emphasizes the challenge managers face in reintroducing fire to old-forest ponderosa pine communities. While managers must continually apply adaptive management to avoid undesirable mortality, it should be recognized that some mortality of old ponderosa pine is inevitable. Managers should strive to meet mortality goals at the acre scale, but recognize that successs should also be measured at the stand and landscape scale.

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