Prescribed Fire Effects in the Panhandle Area Crater Lake National Park

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EXECUTIVE SUMMARY

Previous vegetation and fire history studies of the Panhandle area of Crater Lake National Park showed that nearly 80 years of fire suppression had altered the structure and composition of the mixed conifer forests found there (McNeil and Zobel 1981). A program to restore primeval forest conditions in the Panhandle by use of prescribed fire was begun in 1976 and has continued successfully to the present. Although the program has generally been effective at meeting management objectives, a process of delayed mortality of large ponderosa pine, where fire weakened trees succumb to bark beetle attack, had been observed after some Panhandle burns, as well as in nearby Sun Creek.

Park staff requested a study on the level and extent of this type of mortality and the conditions that contributed to it. The research objectives were to: 1) assess mortality of ponderosa pine (>22 cm dbh) relative to tree size, fire severity, timing of burn, and tree vigor, 2) determine duff moisture relationships with National Fire Danger Rating System (NFDRS) moisture estimates, and 3) investigate fire effects after an experimental early season burn.

Ponderosa pine mortality was strongly associated with scorch height, depth of char, and early season burning. The death of a high proportion larger diameter trees, which do not normally die from cambial damage, suggest that other factors

are involved in addition to fire severity. Fine live roots were concentrated in the forest floor and the upper soil layers; both received lethal temperatures. Also, peak standing crop for fine roots was highest at the time of the experimental burn. Although burning strongly reduced live root biomass, no difference was found in moisture stress between burn and unburned trees in the season following the experimental burn. Observation in following years may detect a difference.

Lower duff moisture appears to control consumption of duff and therefore fine root reduction. More data is needed to better define critical levels, but preliminary results suggest that a minimum of 18% fuel moisture for NFDRS-Th should be included in burning prescriptions for early season burns. This restriction would not apply to fall burning in the Panhandle. More research is required to quantify duff moisture and duff reduction relationships, to better predict duff moisture, and to assess longterm mortality patterns. Burning earlier in the spring when duff moisture is higher needs to be examined more thoroughly.

The reintroduction of fire alone will not satisfy management objectives. Mortality levels should be monitored to assess burn effects. Lower intensity initial burns and some protective measures for high risk trees are recommended. Keen's tree class system is an effective tool for identifying high risk trees.

Forest restoration by prescribed fire is difficult, but remains necessary to maintain primeval ecosystem functions. It is also the most cost effective method for reducing fuel hazards. Without prescribed fire, the open mixed-conifer forests dominated by ponderosa pine will disappear from Crater Lake National Park.

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INTRODUCTION

The fire management program in the National Park System is designed to proceed in its execution based on state-of-the-art knowledge, with refinements to come about through site- or problem-specific research (Butts 1985). This study evaluates the mortality of large ponderosa pine for the first decade of a prescribed burning program in the Panhandle area (Fig. 1) of Crater Lake National Park (1976-1986). The goal of this program is to restore forest structure and species composition to what it would have been today, if fire suppression had not occurred, by reintroducing fire under controlled conditions. Preliminary observations and previous scientific studies (Thomas and Agee 1986) indicated that after some burns, large ponderosa pine dominants on Mt. Mazama tephra deposits were uncommonly susceptible to attack from bark beetles. The loss of these large individuals run counter to the intent of the program. Park staff requested better information regarding the level and extent of this type of mortality and a better understanding of the contributing conditions so that burning prescription could be improved.

Research on these questions consisted of three areas of study: 1) determination of mortality levels relative to tree vigor and size, timing of burn, and fire severity, 2) investigation of actual duff moisture for correlation with National Fire Danger Rating System (NFDRS) fuel moisture estimates, and 3) an experimental burn where the impact of low intensity fire on duff reduction, soil heating, fine root growth, and post-fire moisture stress was assessed. All three studies are documented in a University of Washington Master of Science thesis by Michael Swezy (1988), which is being submitted as a technical completion report on the project. The findings of the thesis are summarized in the next section of this report. Recommendations for burning prescriptions, monitoring programs, and further research are included in the following management recommendations section.

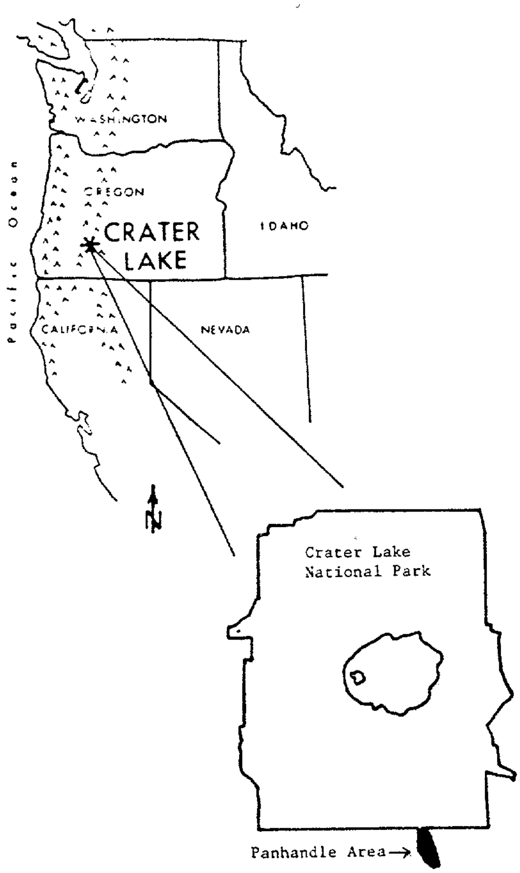

Figure 1. Location of Crater Lake and the Panhandle.

RESEARCH SUMMARY

1. Stand History Maps

A map delineating specific burn units (Fig. 2) was constructed from park fire records, interviews with previous park staff, and through field reconnaissance that included some fire scar analysis. The size and timing of the burns for each unit is summarized in Table 1 and fire behavior data for fires with known dates are presented in Table 2.

2. Ponderosa Pine Mortality Survey

A series of transects covering all of the Panhandle were established to determine mortality of ponderosa pine greater than 22 cm dbh in both burned and unburned areas for a ten-year period. Tree height and diameter, tree vigor/age class as described by Keen (1943) (Fig. 3), and year and season of burn were recorded. In addition, in areas that had been burned, fire severity estimates that included scorch height and ground char (Fig. 4), and other measures of tree vigor indices based on increment cores, were recorded for each tree.

Mortality for the period investigated was higher for burned areas (19.5%) than in unburned areas (6.6%) (Fig. 5). Timing of burns was important in explaining mortality. Early season burns had much higher mortality (37.6% in June and 31.6% in July) than the late season burns (12%) (Fig. 6). Because the same ten-year period was used to assess mortality for all burn units and mortality effects are often

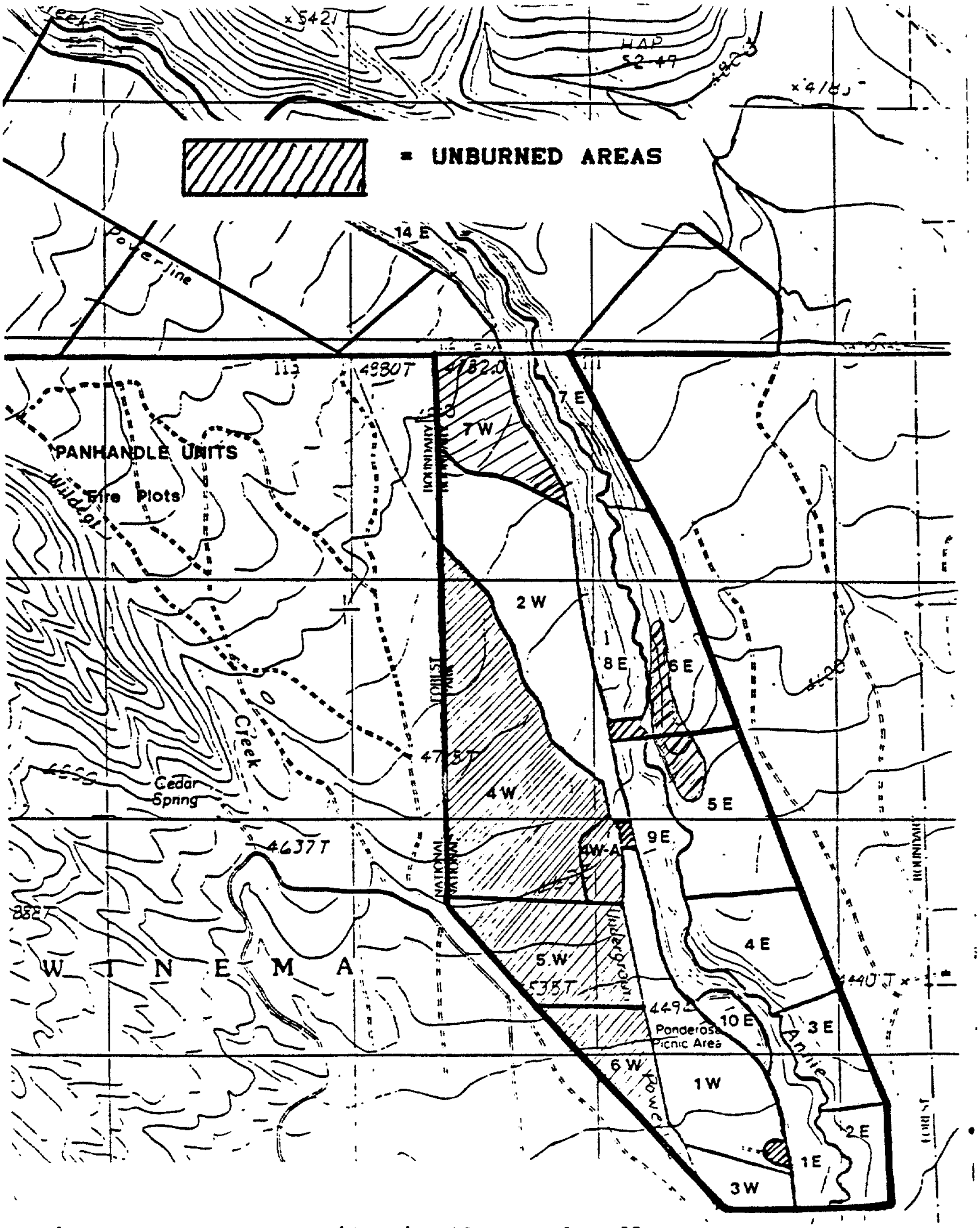

Figure 2. Burn units in the Panhandle.

Table 1. Summary data for units historically burned in the Panhandle.

BURN UNIT	BURN YEAR	BURN MONTH	AREA (HA)
1E*	77 84	SEPT JUNE	13.4.
2E	76	SEPT.	11.7
3E	77	SEPT.	13.0
4E	78	SEPT.	21.9
5E	78	SEPT.	29.1
6E	76	SEPT.	24.7
7E	76	JUNE	10.1
8E	86	JUNE	25.1
9E	78	SEPT.	18.2
10E	UNBURNED	-	6.9
1W	82	SEPT.	32.4
2W	84	JULY	49.0
3W	85	JUNE	7.7
4W	UNBURNED	-	66.0
4W-A**	87	JUNE	4.0
5W	UNBURNED	-	25.9
6W	UNBURNED	-	14.2
7W	UNBURNED	-	19.0
		TOTAL AREA	392.3
		BURNED AREA	260.3
		UNBURNED AREA	132.0

* BURNED TWICE
** STRESS STUDY BURN AREA/SAMPLED FOR MORTALITY BEFORE BURNED.

Table 2. Available fire behavior data for Panhandle burns.

BURN/ BURN UNITS --	/--------- HISTORICAL BURNS			--------/	EXP.
	1W	2W	3W	8E	4A
BURN MO/YR	9/82	7/84	6/85	6/86	6/87
DRY BULB TEMP C	28-30	24-39	19-26	26-31	16-20
RELATIVE HUMIDITY%	37-47	26-39	26-49	58-61	48-52
WIND SPD. (km/hr)	1.2	1.8	1.2	0.6-1.8	0.0-0.6
1-HR % MOIST.	8	6	6	9	7
10-HR	12	7	9	7	12
100-HR	15	14	14	14	15
1000-HR	18	15	20	17	19
FLAME LENGTH(m)	0.5	0.6-1.2	0.6-0.9	0.6-1.2	0.0-0.3
FIRELINE INTENSITY(Kw/m)	45	72-203	131-145	145-413	41-155
BURNING INDEX	17	30	20	24	17

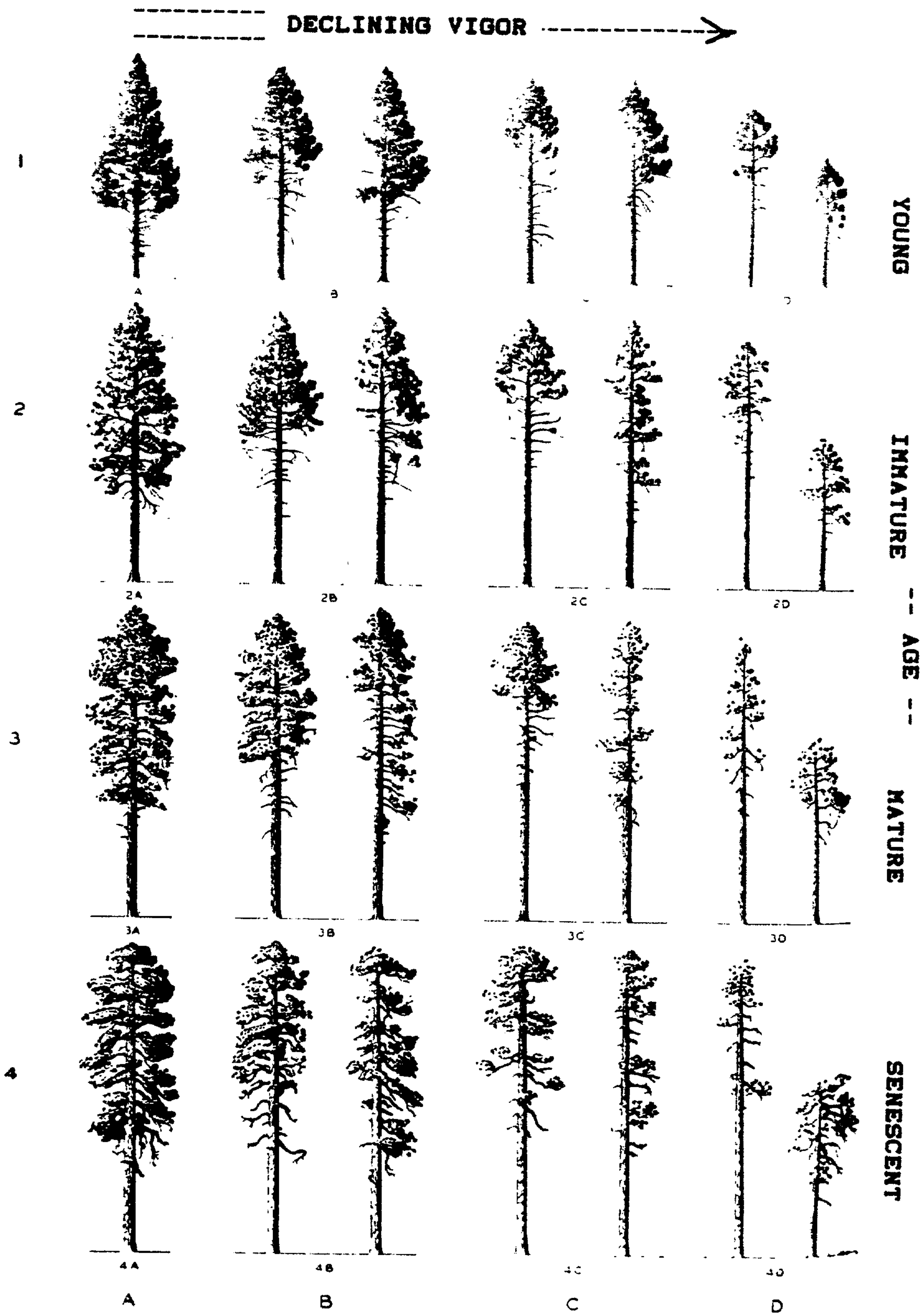

Figure 3. Keen's crown vigor and age classes.

GROUND CHAR CLASSES

1. LIGHT GROUND CHAR

<2 PERCENT OF THE AREA DEEPLY CHARRED
<15 PERCENT MODERATELY CHARRED
REMAINING AREA LIGHTLY CHARRED OR UNBURNED

2. MODERATE GROUND CHAR

<10 PERCENT OF THE AREA DEEPLY CHARRED
>15 PERCENT MODERATELY CHARRED

3. HEAVY GROUND CHAR

>10 PERCENT OF THE AREA DEEPLY CHARRED
>80 PERCENT MODERATELY OR DEEPLY CHARRED
REMAINING AREA LIGHTLY CHARRED

SCORCH HEIGHT CLASSES

SCORCH HEIGHT CLASS	SCORCH HEIGHT RANGE (FT)	CORRESPONDING FLAME LENGTH (FT)
1	0-9	0-2
2	9-24	2-4
3	24-64	4-8
4	64-116	8-12
5	>116	>12

Figure 4. Ground char and scorch height classes.

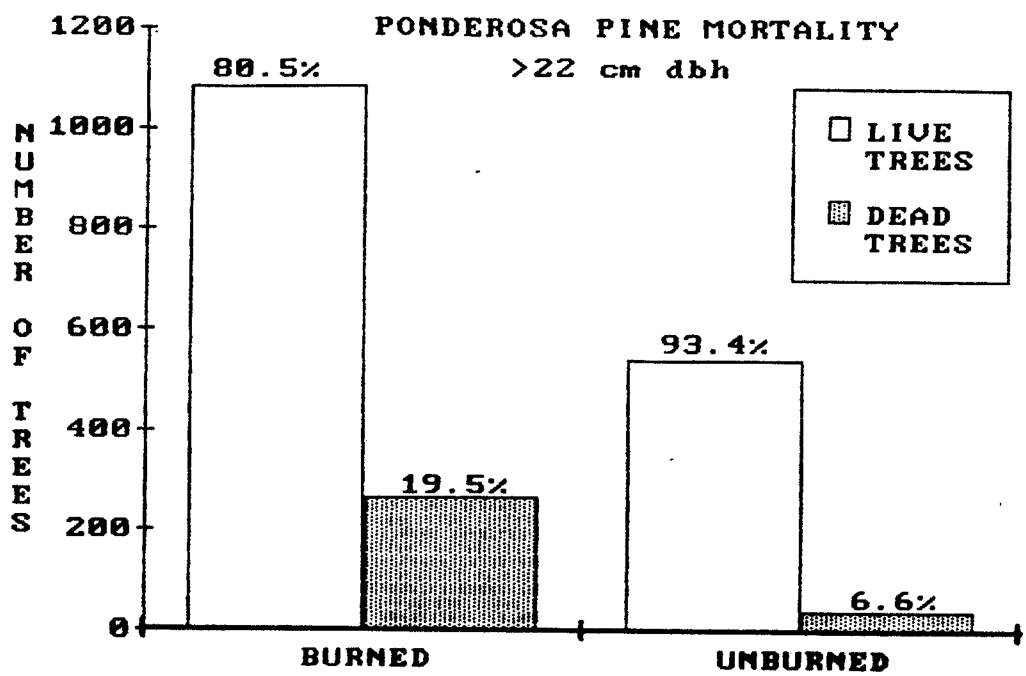

Figure 5. Mortality of trees in burned and unburned areas.

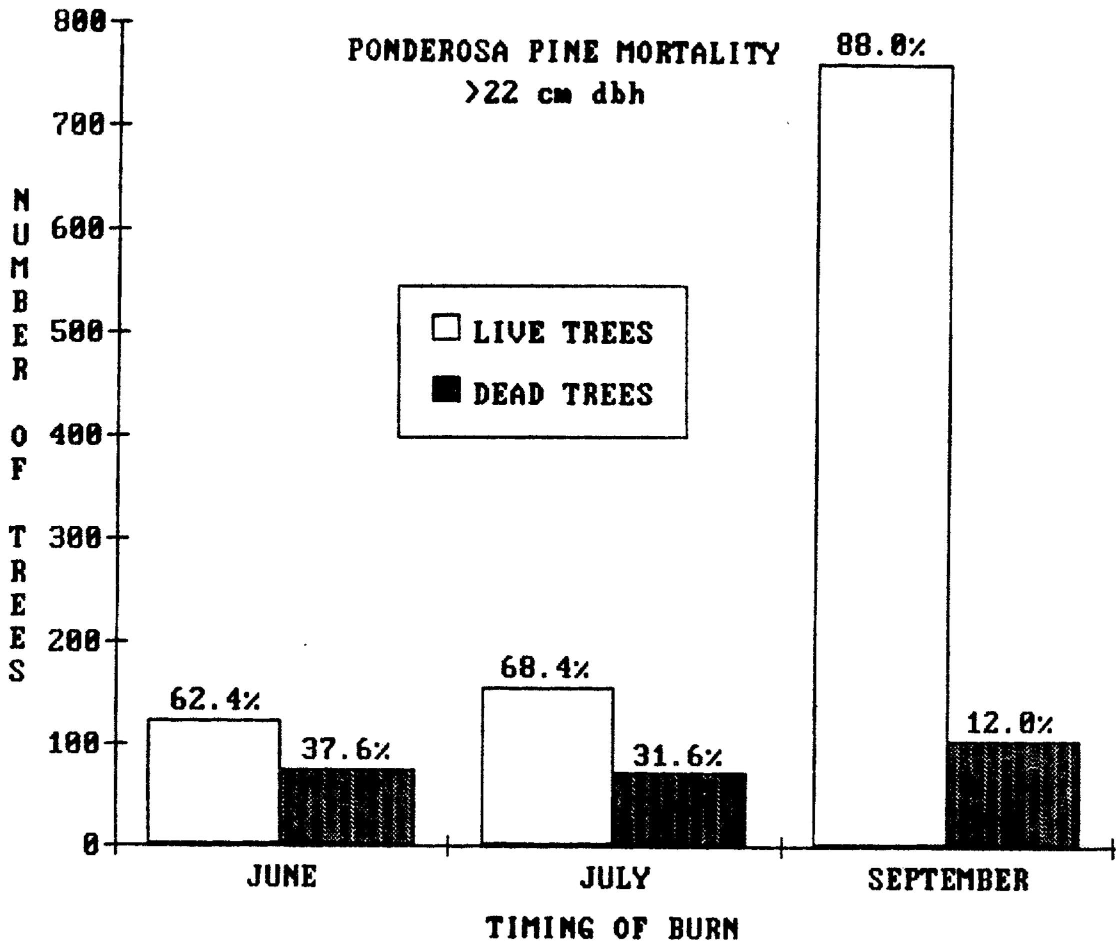

Figure 6. Mortality by month of burn.

delayed 2-5 years, units burned in the last few years (early season burns) may not have fire-related mortality fully expressed. For this reason the difference between early and late season burns may actually be greater than what was observed.

Tree size characteristics showed important relationships with mortality of ponderosa pine. Fire tended to kill a higher proportion of the smaller diameter trees and the very large diameter trees (Fig. 7). Small diameter trees are thin barked and would be expected to be more heat sensitive. Large trees rarely are killed by cambial damage and lethal crown scorch was uncommon. Therefore, other mortality processes are suspected for the large diameter trees. Mortality tended to be highest for the shortest trees, as would be expected for trees whose crowns were close to the ground (Fig. 8).

Keen's crown vigor and age class system proved to very useful for predicting mortality (Fig. 9), i.e. identifying high risk trees after prescribed fire. Using the mortality estimates by crown age/vigor category presented by Keen (1943) for natural stands of mature ponderosa pine and comparing them with the Crater Lake data (Fig. 10), it appears that, proportionally, mortality from prescribed fire roughly mimics that of natural stands. However, the magnitude of Crater Lake mortality on a percentage basis far

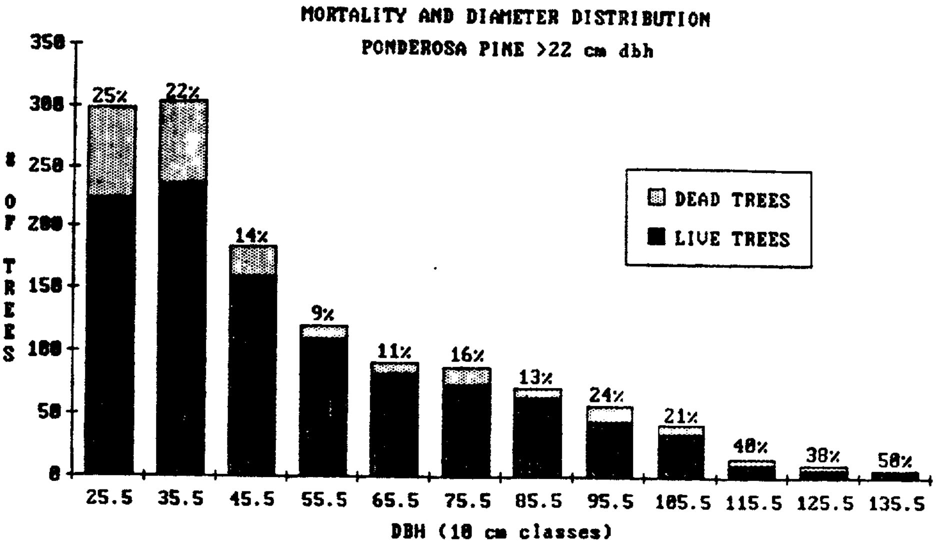

Figure 7. Mortality by diameter class.

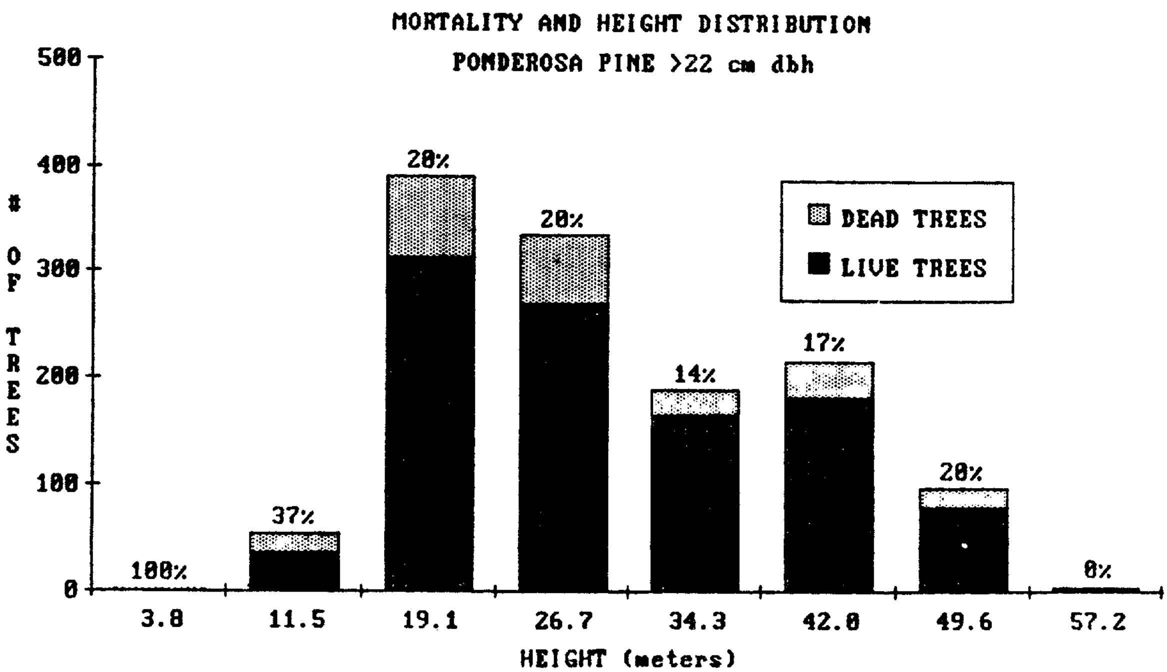

Figure 8. Mortality by height class.

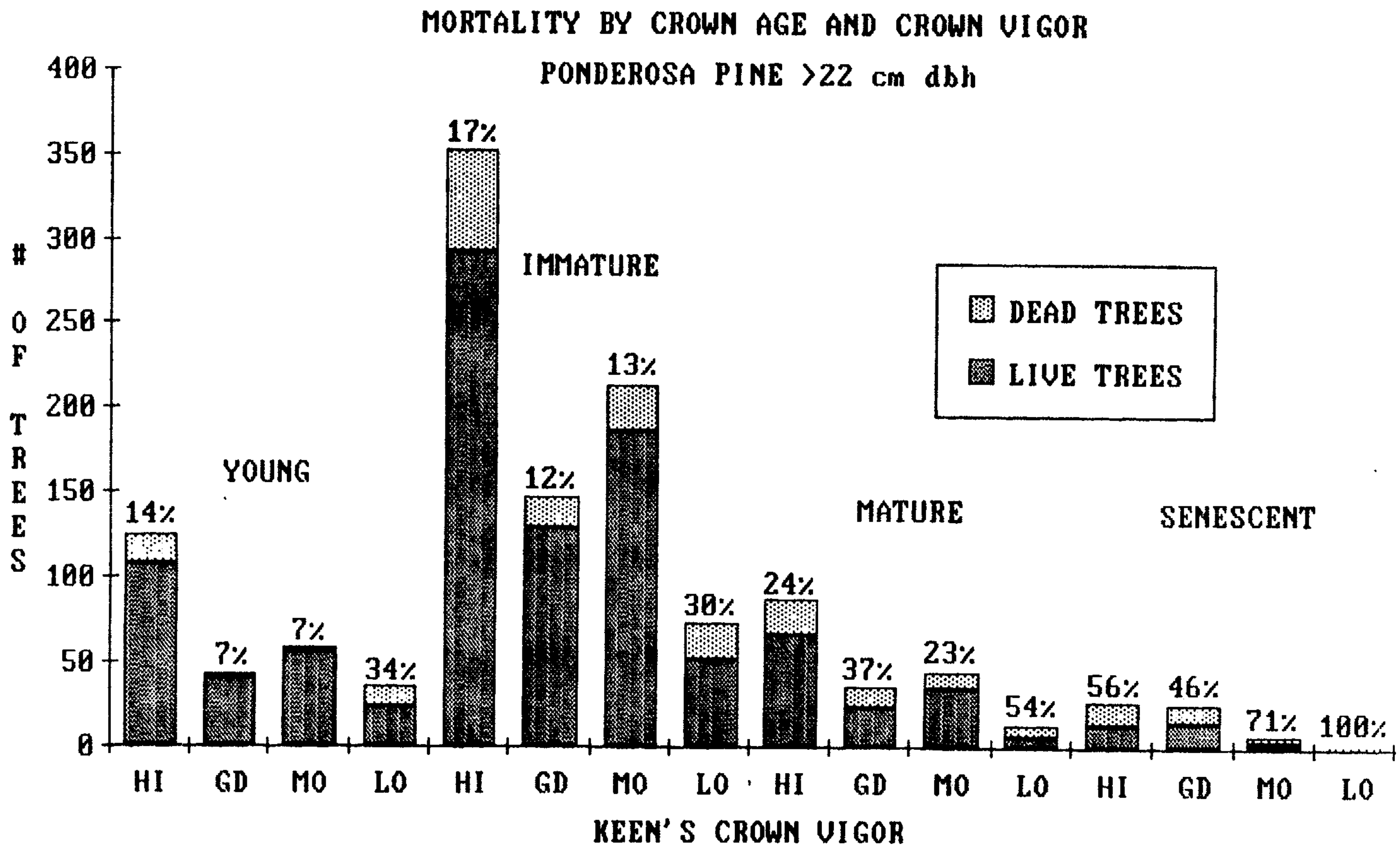

Figure 9. Mortality by Keen's tree classes.

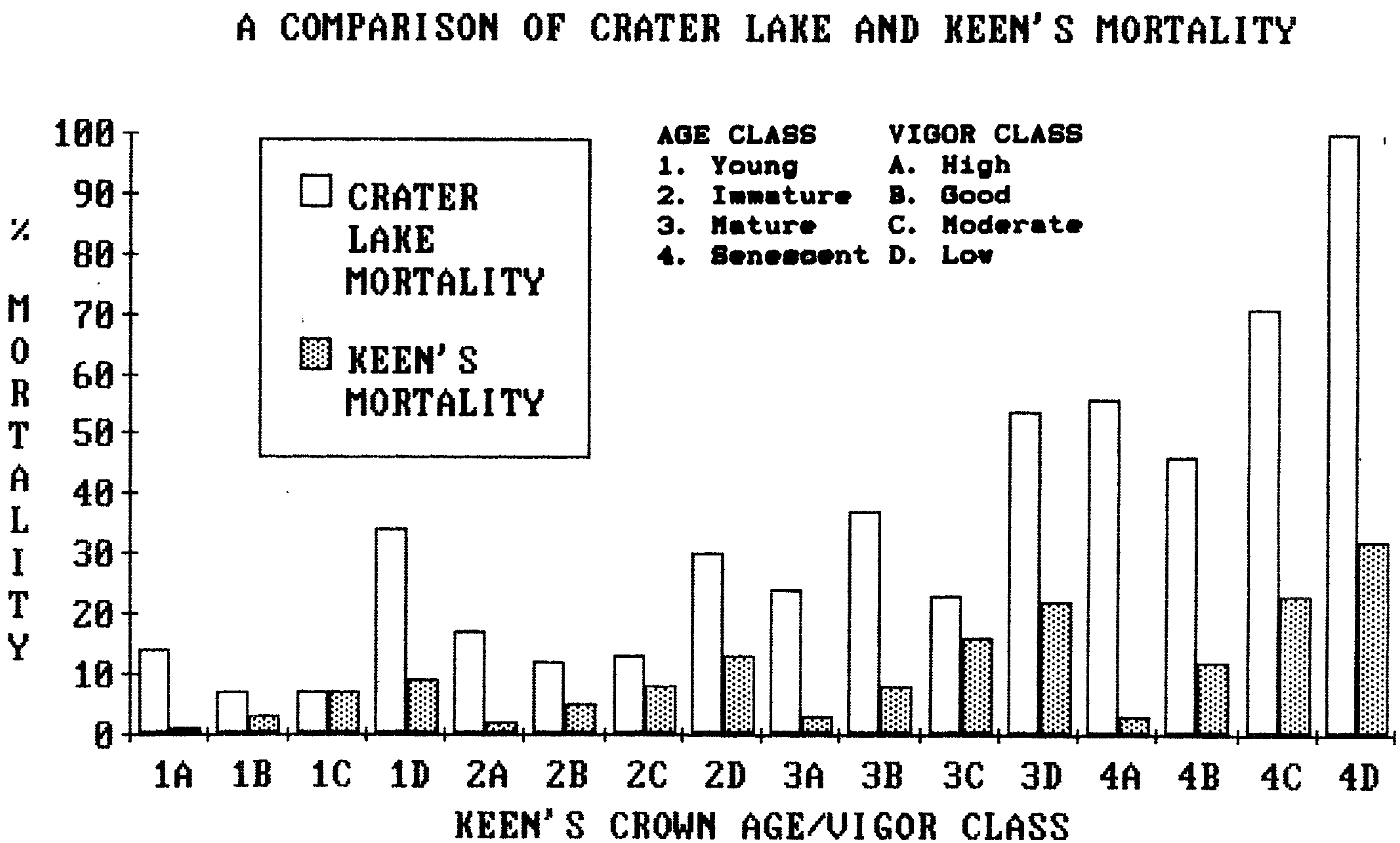

Figure 10. A comparison of Crater Lake fire mortality with Keen's bark beetle-induced mortality.

exceeds that reported by Keen for large scale bark beetle attack in drought affected stands.

Discriminant analysis, a multivariate approach to pattern recognition, is used to predict group membership of an observation based on its measurement values. Using this technique a function was developed that predicted survivorship (live or dead) of ponderosa pine after prescribed fire, based on all vigor indices, tree size, fire severity, and season of burn. Although we were unable to derive a function that predicted mortality with a high level of precision, the technique allowed the variables to be ranked in terms of relative importance (Table 3). Scorch height was the most important variable for predicting mortality. Season of burn was the next most important variable, followed by depth of ground char. If ponderosa pine at Crater Lake can sustain severe crown scorch as reported in other studies, other forms of damage must be occurring to account for the high level of mortality in early season burns. Our hypothesis was that the relationship between fire severity, duff reduction, and tree stress from root mortality begins to explain this seasonal difference.

3. Duff Moisture

Moisture content of the fermentation layer (upper) and the humus layer (lower) of representative duff samples from the Panhandle was determined during the 1986 fire season.

Observed values were then correlated with NFDRS 100-hr and 1000-hr timelag fuels (NFDRS-Hu and NFDRS-Th, respectively) (Table 4) to determine if actual duff moisture could be predicted from the readily available NFDRS values.

A rapid decline in duff moisture, following snow melt, to a fairly constant midsummer trough (Fig. 11) was observed in 1986. This pattern is probably characteristic of most years, where there are only a few weeks when lower duff fuel moistures are above the critical 30% (fires occurring when moisture content is less than 30%, burn nearly all of the duff), yet are dry enough to carry a fire.

Although reasonable correlation was found between observed and NFDRS values, the relationship was not one-to-one. Also, the variation in observed duff fuel moisture, as well as the difference between average observed values and NFDRS values, was greatest in the periods of rapid drying and wetting, i.e. the periods most critical for prediction. Using the derived equation, lower duff moistures at Crater Lake is estimated to be at 30% when NFDRS-Th is at 29%. Sandberg (1980) pegs this critical level at 25% NFDRS-Th for shallow forest floor Douglas-fir stands. Only two measures of duff reduction in relationship to lower duff moisture are available for Crater Lake: 1) the June 25, 1986 burn in Unit 8E, 34% lower duff moisture and 100% duff reduction and 2) the June 20, 1987 burn in Unit 4WA, 53% moisture content and 75% duff reduction. More duff moisture and duff reduction

Table 3. Within-groups correlation with discriminant function.

(Variables ordered by size of correlation within function)

	FUNC 1
SCORCHHT	.85672
BURNSEAS	-.64930
CHARCLAS	.23700
RINGSCM	.20038
CROWNVGR	.18557
GROWINCR	-.10740
HEIGHT	-.08987
DBH	-.06823
CROWNAGE	-.02367

	FUNC 2
SCORCHHT	.91682
BURNSEAS	-.69485
CHARCLAS	.25363

Table 4. Regression equations for duff moisture.

DEPENDENT VARIABLE	INDEPENDENT VARIABLE	EQUATION
F-LAYER	100-HR TL	Y= -.630 + 6.95(100-HR TL) *
H-LAYER	1000-HR TL	log(Y)= -3.67 + 17.5(1000-HR TL)**

* r^2 = .583 P<.000
** r^2 = .671 P<.000

observations in early spring are needed to more adequately assess the usefulness of NFDRS values for improving burning prescriptions.

4. Experimental Burn Effects

The results presented in this section are based on data derived from six trees subjected to low intensity fire during a prescribed burn ignited on June 20, 1987. Duff depth and reduction, and vertical and horizontal distribution of heat was measured on these trees. Litter was raked from around three trees before burning to assess the usefulness of this treatment in reducing duff reduction and root mortality. Fine root biomass and plant moisture stress were measured on the burned trees and three control trees in a nearby unburned stand.

The experimental burn in this study was probably of a lower intensity than previous early season burns (Table 2), both in terms of fireline intensity and downward heat pulse. Despite its low intensity, important relationships between duff depth, duff reduction, and the spatial distribution of heat were illustrated. Lethal temperatures (>60 degrees C) were found at 83% of the samples at the soil surface and at 77% for samples at the 5 cm soil depth. Evaluated in the zone towards the base of the trees, where roots were sampled, lethal temperature frequency approached 100%. This concentration of heat was probably a function of increased duff depth and the resultant increase in duration of

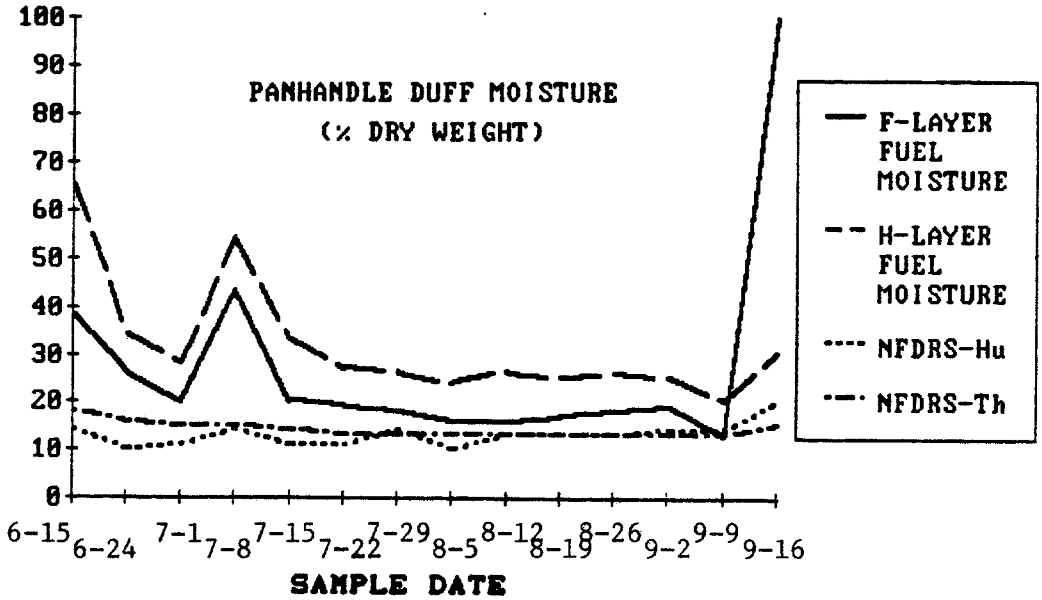

Figure 11. Panhandle duff moisture.

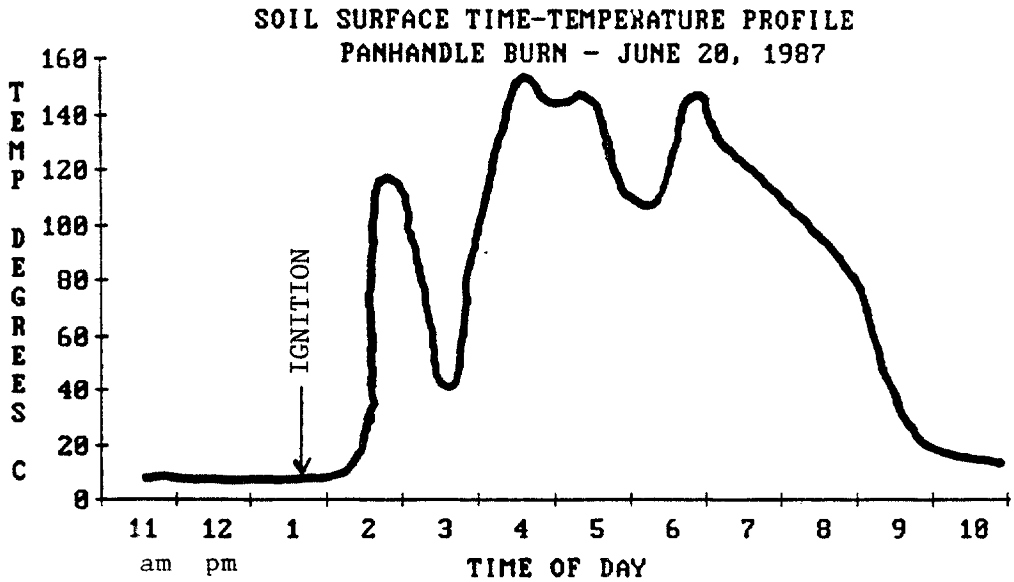

Figure 12. Soil surface time-temperature profile during the experimental burn.

smoldering. It is likely that even in the range of fuel moisture where duff burnoff is complete (<30%), the heat input to the site increases as fuel moisture decreases.

A time temperature profile derived from a thermocouple placed at the soil surface at the base of a large ponderosa pine showed a multi-peak heat pattern (Fig. 12). Temperatures rise as dry fuels combust, drop as moist fuels evaporate moisture, and rise again as this now dry duff smolders. Maximum temperatures ranged between 150 and 160 degrees C for approximately 2 hours. Lower duff moisture was measured at 53% at this tree.

Both duff and litter were greatest at the base of trees and decreased markedly with increased distance from the tree (Figs. 13 and 14). Both percent duff reduction and average duff burnoff showed a similar pattern (Fig. 14). Raking away litter from the base of large ponderosa pines did not provide any significant decrease in duff reduction (Fig. 15) and heat to the site, and may actually increase these effects. This treatment also failed to reduce root mortality (Fig. 16). This should not be interpreted to mean that litter does not contribute to the downward heat pulse or duff reduction. Most likely removal of litter prior to burning allowed the duff to dry somewhat, mitigating the effect of less fuel.

Fine roots (those less than 2mm in diameter) are the size class of roots responsible for water and nutrient uptake.

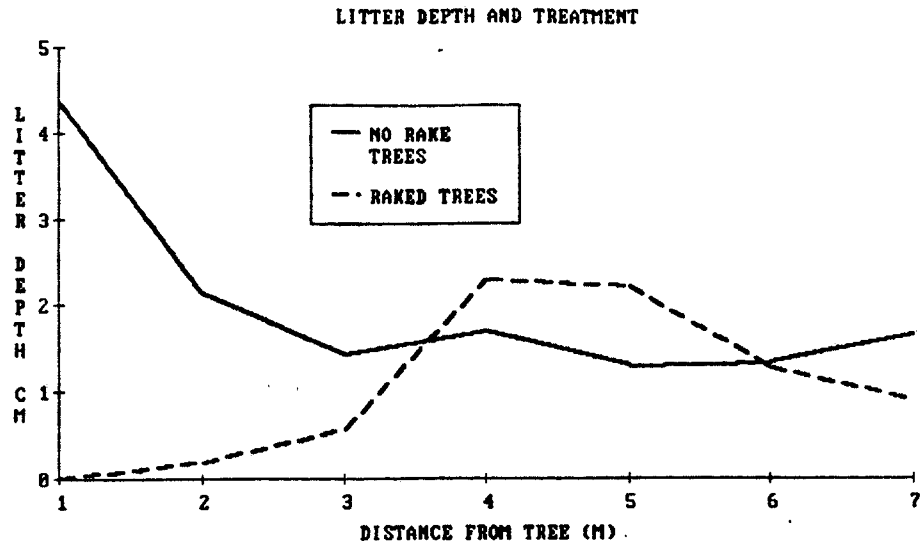

Figure 13. Litter depth by treatment and distance from tree.

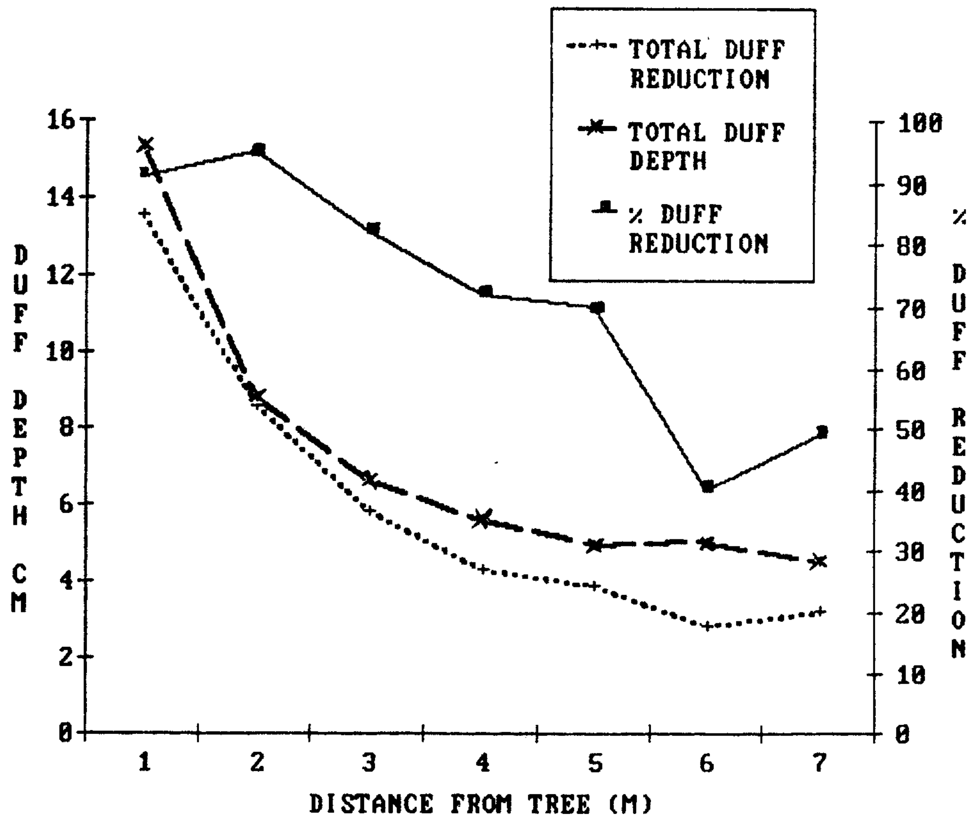

Figure 14. Duff depth, percent duff reduction, and total duff reduction as a function of distance from tree bole.

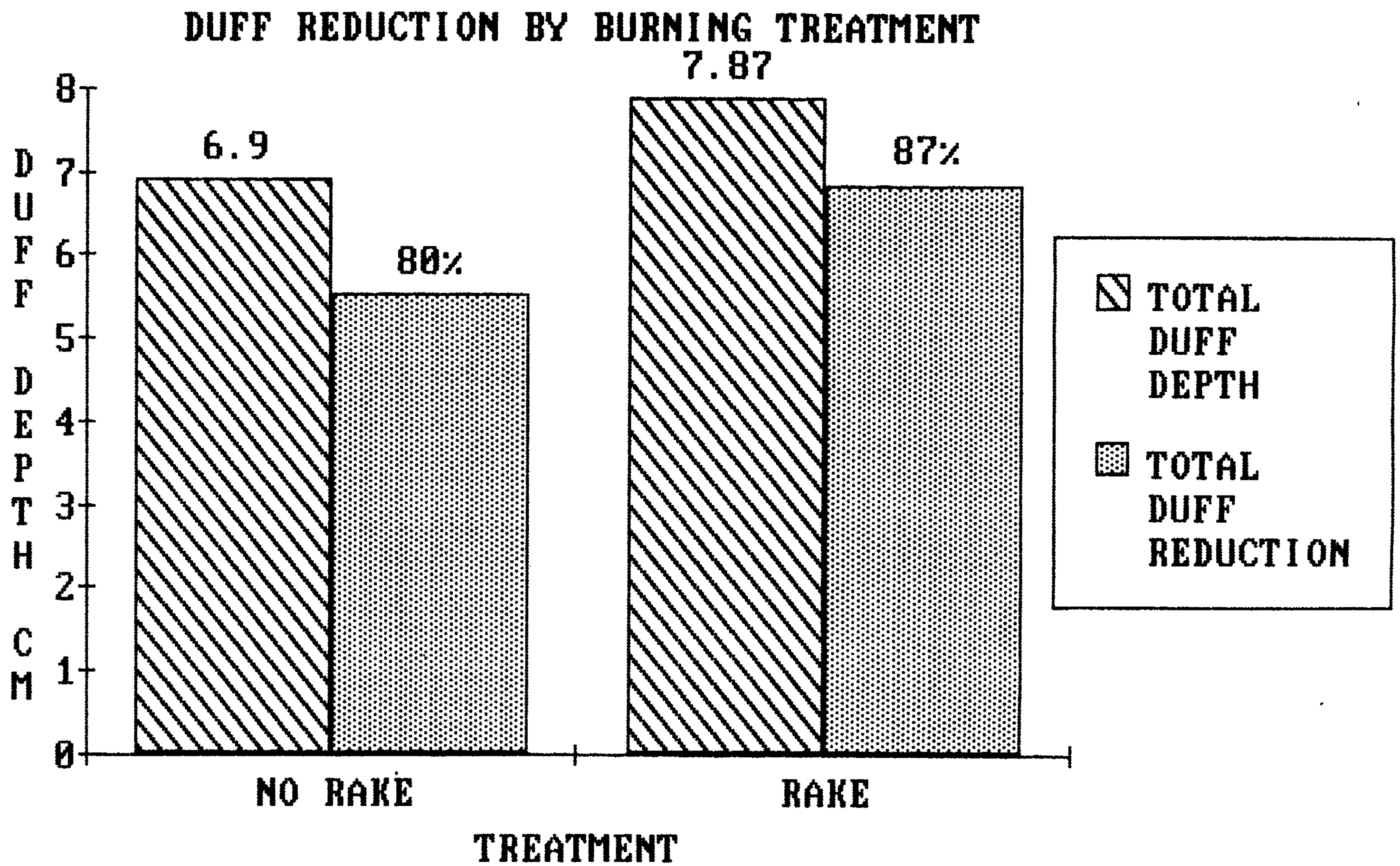

Figure 15. Total duff reduction by burning treatment.

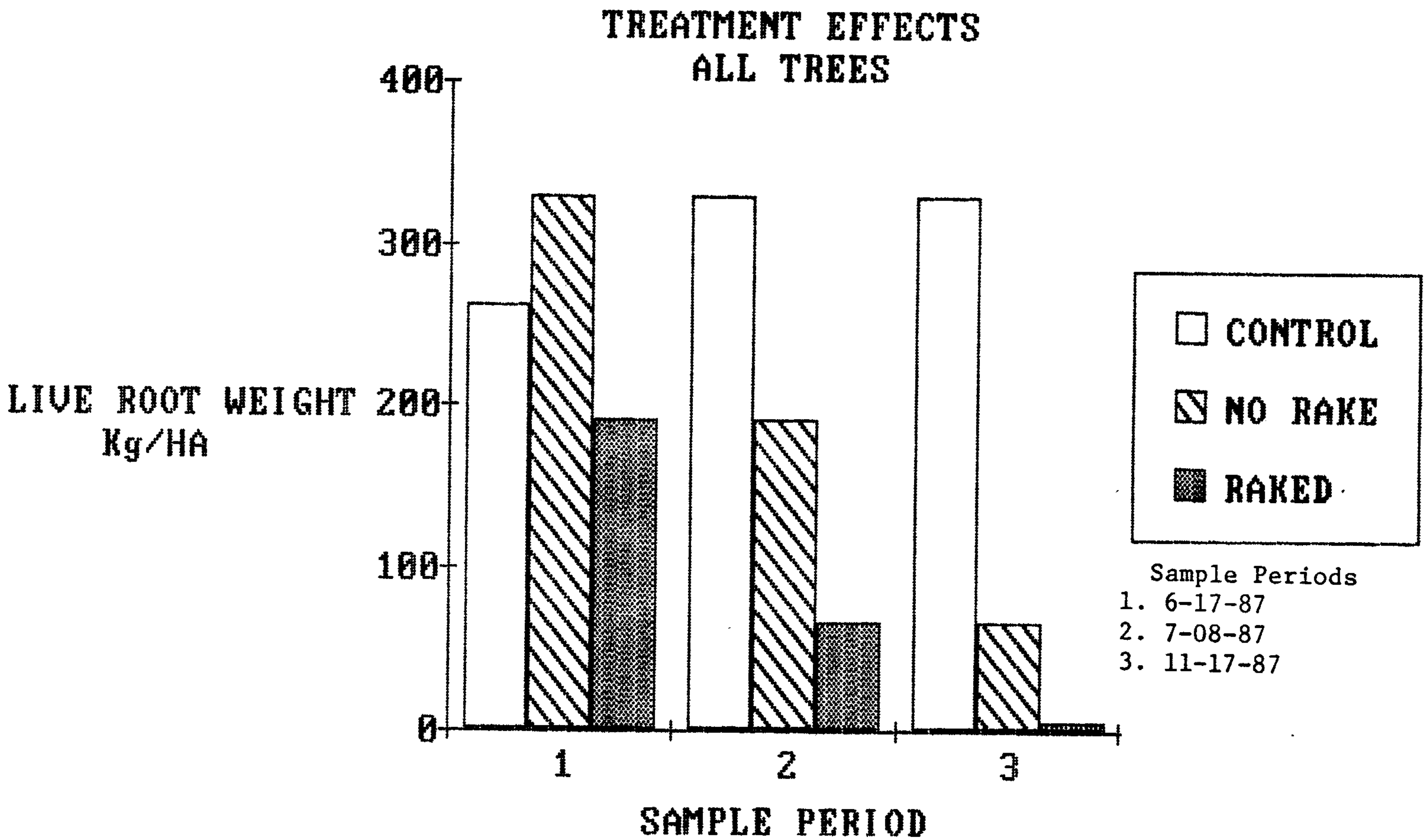

Figure 16. Treatment effects on live roots.

In Pacific silver fir forests in Washington, these 'feeder' roots have been observed to grow most actively in the spring prior to bud break. Although the full depth of the root zone in ponderosa pine at Crater Lake was not sampled, it appears that live fine roots, especially those in the 0-1 mm diameter class, were concentrated in the forest floor and 0-10 cm depth (Fig. 17), both of which received lethal temperatures. McNeil (1975) found that roots of any size were rare below the 60 cm depth in the two soil types found in the study area. Although the peak in standing crop for the 0-1 mm diameter class was observed at the first sample date (June 17), the actual seasonal peak probably occurred before this time when soil moisture was more available. The standing crop of live roots less than 2 mm diameter decreased over the sample period in all soil depths (Fig. 18). Soil surface temperatures rarely exceeded ambient air temperatures. Possible soil heating from a blackened soil surface was mitigated by shade and an ash layer that remained on the soil throughout the summer.

This concentration of roots in upper layers and peak growth activity in the spring suggest higher stress potentials for early season burns. Burning earlier in the season than has been customary, e.g. May, may not constitute a greater risk in root damage, because although the rate of growth and the standing crop of fine roots may be at a maximum, wet duff, especially in the lower layers may keep duff burnoff and soil heating to a minimum. Also, the impact on fine roots

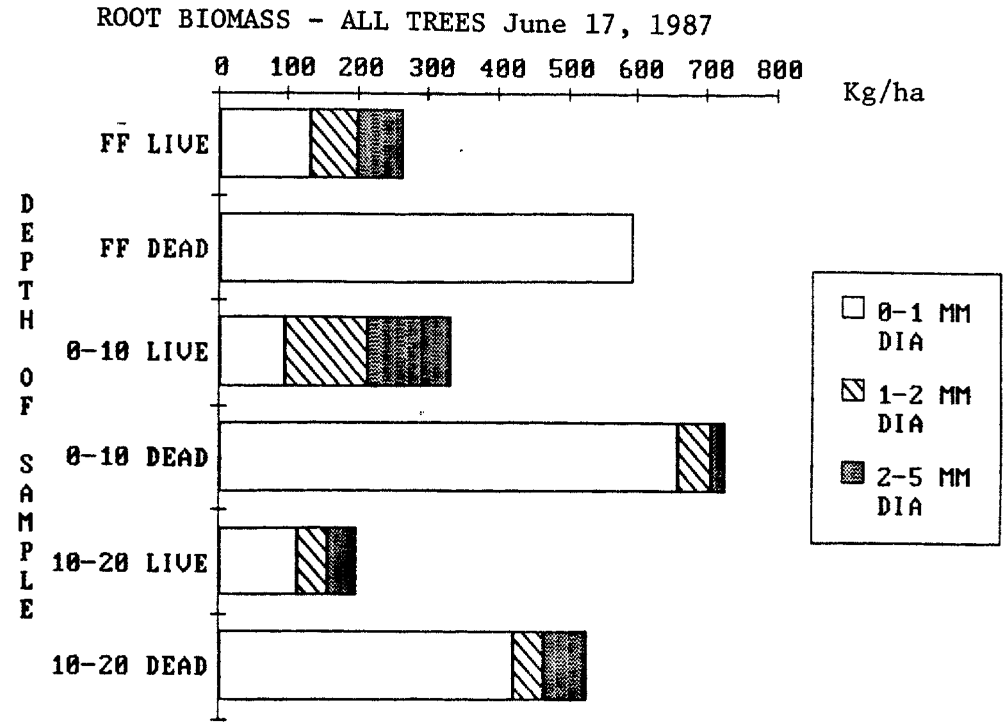

Figure 17. Distribution of live and dead roots by size class and soil depth.

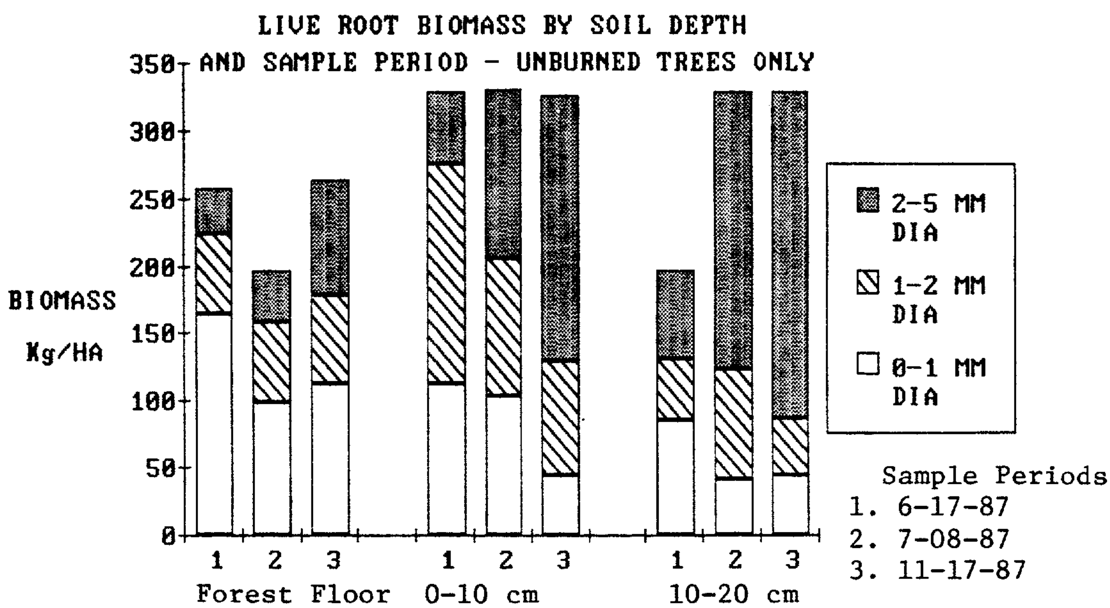

Figure 18. Distribution of live roots by size class and soil depth for three sample periods.

from burning in the fall may not be as high as spring burns for the same level of heat input to the site.

It is believed that this interaction of duff moisture, duff reduction, and fine root mortality may explain seasonal differences in mortality. In delayed or secondary mortality associated with low intensity fires in mixed conifer forests, trees are stressed such that bark beetle attacks have a higher probability of success. A successful attack in one year may weaken a tree so that subsequent attacks, in years following, lead to death. We were unable to show trees with different levels of root damage (two burning treatments vs. unburned control), differed in one physiological indicator of moisture stress (PMS) in the dry season following the burn. Continued observation through subsequent seasons may detect differences, however. Root damage in the spring best explains the seasonal differences in mortality noted in this study.

The level of root damage affects a tree's ability to respond to stresses in the same way a tree's longterm vigor predisposes it to stress. At a stand level, root damage may not result in heavy mortality if moisture conditions were favorable or if bark beetle populations remain at endemic levels. In fact, when bark beetles are epidemic, healthy trees have been observed to succumb to attack. Although conclusive evidence is not available, it appears that this phenomenon is presently occurring in the Panhandle on about a 5 ha patch in Unit 2W next to Highway 62. Another potential influence not assessed in this study is the additional competitive stress posed by the recent development of a white fir understory. This structural change may mean increased competition for moisture and nutrients and reduced vigor for the overstory pines.

MANAGEMENT RECOMMENDATIONS

Two previous scientific studies on role of fire in Crater Lake's forests emphasized the management challenges to fire management programs represented by man-caused disturbances. Agee and Thomas (1982) concluded that prescribed fire alone would not be able to restore the Sun Creek mixed conifer stands to primeval conditions because of the generation of mature white fir created by 80 years of fire suppression. Large wildfires caused by white settlers in the previous century account for the extensive seral stands of lodgepole pine in Crater Lake's Red Fir/Mountain Hemlock Zone (Zobel and Zeigler 1978). Although lightning fires are an important component of this forest type, prescribed burning would only delay the development of mature forest in most cases. The experience of ten years of prescribed burning in the mixed conifer forest of the Panhandle similarly suggest that simple reintroduction of prescribed fire will not fully satisfy fire management objectives.

The overall success of the program is well documented by this report. Most burns achieved desired levels of mortality, reduced fuel hazards, and are beginning to yield the open and expansive landscape views characteristic of forests with an active fire influence. The recommendations listed are a means of limiting the occurrence of excessive mortality found as a result of some of the burns. Recommendations are made for burning intervals, improving burning prescriptions, improvements in burn monitoring, protection measures for high risk trees, and further research.

Burning Intervals

Present fuel arrangement and fuel loads may be too hazardous given existing burn prescriptions. The present system of restoration using prescribed fire requires one initial burn to achieve mortality of understory trees and reduce fuels. A following burn is called the 'restoration burn'; its purpose is to remove the additional fuels accrued from the first burn. All subsequent burns are called 'maintenance burns' and are intended to mimic natural fires. Given that both fuel loads and fuel arrangement are much altered from primeval conditions, fire severity and tree mortality are probably similarly increased. In burn units with higher fuel loads and hazardous fuel arrangements, it may be desirable to reduce burning intensities and increase the number of burns required to reach maintenance conditions. If these fires are not intense enough to yield desired levels of mortality, mechanical means could be selectively employed (felling or girdling) on a one-time basis.

Burning Prescriptions

Air quality restrictions are causing fire managers to focus increasing attention on early season burning to take advantage of more favorable conditions. This study showed that excessive mortality has been associated with early season burning, at least under the range of conditions observed. It appears that few spring burns have been conducted when the lower duff is wet. Further research is needed to determine if burning earlier in the spring would result in the desired understory mortality, yet keep duff reduction and soil heating to low levels. Historically, lightning fires in the Panhandle probably occurred in June and July with little overstory mortality. Therefore, the seasonal difference in mortality may not occur after the fuel loads are reduced.

The present prescription used in the Panhandle specifies fire behavior parameters such as scorch height and fireline intensity, which can be achieved under a range of conditions. Thousand-hour timelag fuel moistures range between 16% and 22%, with a preferred level at 18%. Sandberg (1980) defined 'wet' duff as the moisture level below which duff burned independent of woody material and suggested this occurred at 25% NFDRS-Th for Douglas-fir forests on west slope of the Cascades. We recommend minimum level for NFDRS-Th be raised to 18% for initial spring burns in lieu of more precise data. This restriction would have ruled out all the early season burns with high ponderosa pine mortality, except for the June 1985 burn in Unit 3W. The NFDRS-Th was recorded at 20% for this burn, again emphasizing the unreliability of this method at present. Actual field investigation by hand will give general indications duff moisture and should be used as a check on NFDRS values. Burning when actual duff moisture is greater than 30% is strongly recommended (i.e. burn earlier in the season than late June).

If root phenology and timing of burning is important in explaining mortality as suggested by this study, then lower duff moisture may not be as important for fall burning. The duff moisture guideline suggested above would not apply to a late season burn. A program of fall burning in the Panhandle and early season burning in the Sun Creek units which have few ponderosa pines, would make use of the part of the burning season favored by air quality managers and keep on the burning schedule outlined in the fire management plan.

Monitoring

Early fire managers at Crater Lake initiated an innovative program, yet neglected to leave any written record of their activities. Most fires in the 1980's are well described in terms of fire weather, fuel conditions, and calculated fire behavior characteristics. All of following recommendations were adopted in 1987 by the park's resource management staff and are included here only to serve as a guide for future personnel. Narrative descriptions of lighting patterns, and daily changes in weather and fire behavior were extremely useful for reconstructing prescribed fires. Direct observations of rate of spread and flame length (see Rothermel and Deeming 1980) should be compared with calculated values using the computer program BEHAVE. Some fires in the 1980's had very high observed scorch heights that could not have been achieved from flame lengths derived from BEHAVE calculations (i.e. actual flame lengths were much higher than calculated values).

Tracking the effectiveness of prescribed burning has been recently improved by monitoring fuel loads before and after fires. Mortality levels should be included in the monitoring program to quantify fire effects on stand development. Measurements should include percent cover, basal area, and stems/ha by species for overstory and understory. Tree and shrub cover data recorded from fuel transects could be used to document mortality. Assessing mortality levels between upper canopy levels may not be achievable given present height categories; however, altering the categories would cause difficulties for comparison with previous data.

High Risk Trees and Protective Measures

Keen's crown age and vigor classification system proved to be very useful for identifying high risk trees for prescribed fire mortality. The visual criteria used for rating trees are easy to learn, and efficient for field use. Trees in high risk categories could be protected by various fuel treatment measures. Manual removal of down and dead woody fuels, flammable live surface fuels, and ladder fuels will reduce duff reduction, soil heating, and crown scorch. These measures may be particularly appropriate for trees along Highway 62.

This study suggests that raking litter probably does not reduce duff reduction and heat loads at the base of large trees treated as little as one day before a burn and, therefore, it is not recommended. Raking immediately before burning may reduce the amount of duff drying occurring and may offer somewhat better protection; however, such timing would mean few trees could be treated. Constructing fireline around individual trees is time consuming and probably ineffective since the likelihood of the burn spotting over this perimeter is very high. Fireline construction to mineral soil may also cause the very root damage that we are trying to avoid.

Further Research

As noted earlier more information is required to determine under what conditions early season burning is appropriate. Measuring actual duff moisture is difficult and time consuming, so correlation with NFDRS values has been perceived as an efficient way of incorporating duff moisture in burning prescriptions. More observations of duff moisture are necessary to develop more precise predictive equations, especially in the periods when duff is wet (late spring and after fall rains). Also, the relationship between duff burnoff and duff moisture needs to be quantified. This could be accomplished by a series of small experimental burns (1/4 ha) conducted at different moisture levels after snow melt.

These plots could also provide more precise data for determining the relationship of fire intensity, scorch height, and long term tree mortality.

Summary Comments

The mixed conifer forests of the Panhandle and the nearby Sun Creek area stand as important relatively undisturbed remnants of a forest ecosystem whose range was once extensive. Fire suppression policies in this century have seriously altered forest structure and composition such that some management action is required to perpetuate the presence of ponderosa pine. The use of prescribed fire to achieve these aims is not only the most viable option, it is an important ecosystem process, critical to the maintenance of a 'natural' forest. As a means of reducing the extremely hazardous fuel conditions in the Panhandle, prescribed fire remains the least costly alternative. Suspension of the fire management program would mean continued development of a highly flammable white fir-dominated forest, and the end of open ponderosa pine-dominated forests in Crater Lake National Park. Admittedly, forest restoration is a difficult process, requiring prudent judgment, well developed technical skills, and reliable information. This study should provide the basis for reducing mortality of mature ponderosa pine and continuing improvement in meeting the goals of forest restoration by means of prescribed fire.

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