FINAL REPORT

FOREST RESTORATION OF SUN CREEK

CRATER LAKE NATIONAL PARK

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National Park Service, Pacific Northwest Region

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EXECUTIVE SUMMARY

The Sun Creek area of Crater Lake National Park began to be protected from naturally-occurring, frequent, low intensity surface fires at the beginning of the twentieth century. During the 1930's, the area, which was then a private inholding within the park, was logged: ponderosa and sugar pines were selectively removed. Due to this incompatible use, the area was added to Crater Lake National Park in 1941. It has been protected from disturbances since then.

The park staff requested an assessment of the degree of disturbance caused by logging and fire suppression, and techniques available to restore the area to "natural" conditions. We identified two forest types, and established permanent 0.25 ha plots in both logged and unlogged areas of each type. The objective of detailed plot work was to determine historic and current forest structure, and the immediate effects of the prescribed fire across each plot. Reconnaissance level surveys were done to assess spatial pattern of trees, and the present tree stocking in logged areas.

The results indicated that the forests in the 1800's were predominantly pine forests, and that sugar and ponderosa pine, as well as white fir, tended to grow in clumps. Logging had obvious effects on species composition by removing the overstory pines. Pine regeneration occurred in some areas but not others after logging.

Introduction of prescribed fire as a restorative treatment caused 75-85 percent mortality of trees below 5.5 cm dbh; much less mortality occurred in larger diameter classes. White fir was more sensitive to fire than sugar pine; ponderosa pine appeared to be most resistant. Three management areas were delineated across the Sun Creek area: (1) Understocked Ponderosa Pine Area (355 ha, 875 ac); (2) Stocked Ponderosa Pine Area (190 ha, 465 ac); and (3) Stocked Sugar Pine Area (120 ha, 300 ac). In the first area, the lack of pine regeneration and seed source for pines will require planting of pines as well as reintroduction of fire. For the other two areas, careful reintroduction of fire alone should be sufficient, as pole-size pine are present in the stocked areas and only need selective favoring over white fir. Fire prescriptions and planting recommendations are made for each area.

The restoration will require patience and substantial commitments of time and money. Planting trees in national parks is an unusual treatment but certainly justified to counterbalance past effects of logging. In another century, the Sun Creek landscape can be largely restored to a mimic of wilderness character.

LIST OF FIGURES AND TABLES

INTRODUCTION

Many national parks have implemented fire management programs to restore the natural role of fire to park ecosystems (Kilgore, 1976). Planning for such programs includes documenting the historical role of fire, and evaluating this role in relation to socioeconomic values and the current state of the ecosystem (Agee, 1974). Where the effects of fire suppression have not been major constraints, natural fires have been allowed to burn in some parks; planned ignitions have often been used to incrementally restore other systems or substitute for natural fires.

The Sun Creek area of Crater Lake National Park (Figures 1 and 2) differs from many national park areas in that it was selectively logged (as an inholding) before it came under National Park Service management in 1941. Unlike systems where reintroduction of fire can itself recreate natural patterns, the restoration of Sun Creek will be more complex. Research was undertaken to determine the past architecture of the forest, and the steps necessary to recreate a mimic of these natural conditions.

The research was divided into two parts: (1) a detailed study of the effects of logging, fire suppression, and one prescribed fire on forest species composition, size and age structure, and fuels; and (2) a reconnaissance of the entire logged area to determine stocking and potential management directions. The first part of the research is documented in a Master of Science thesis by Terri Thomas (1982), 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, followed by the

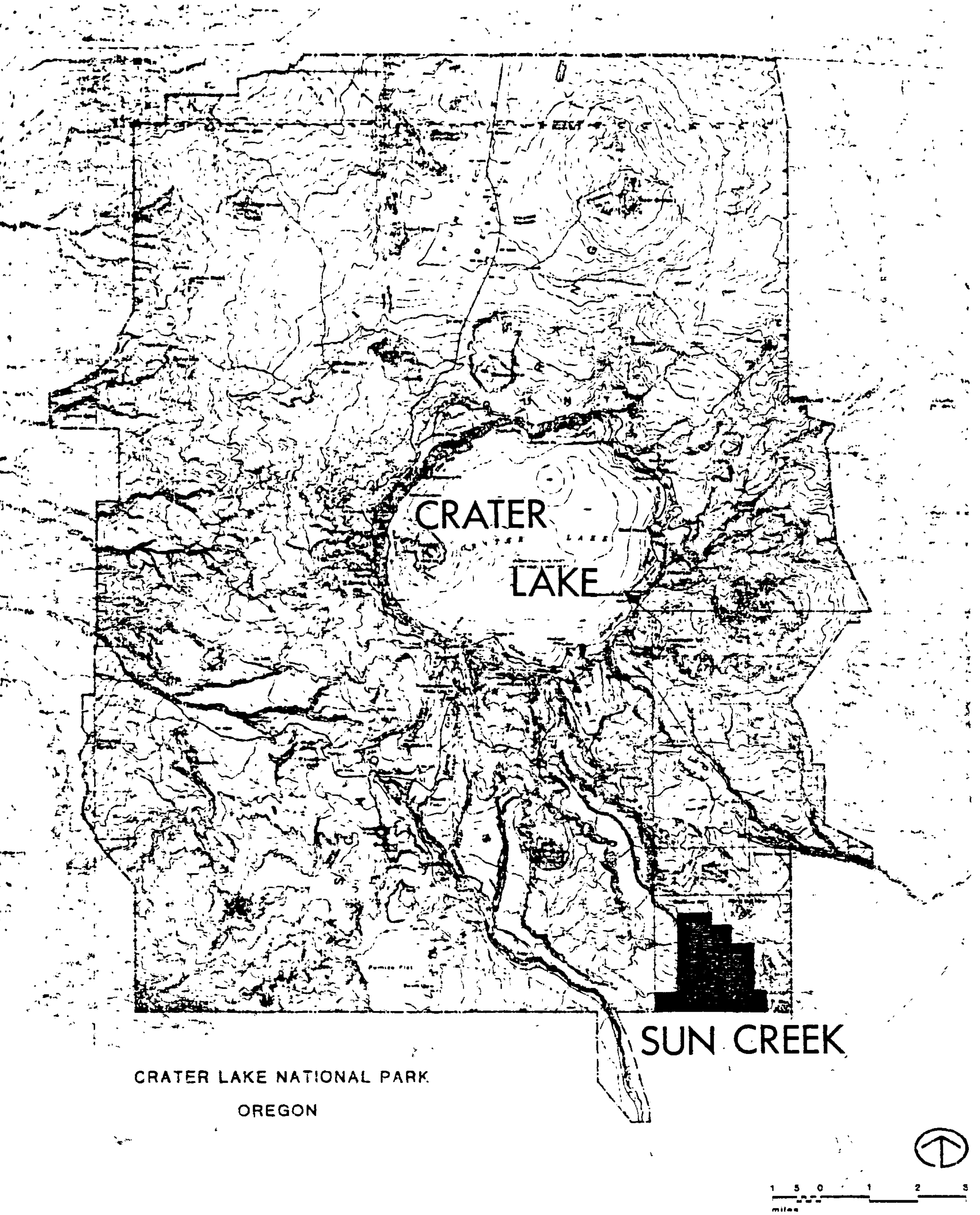
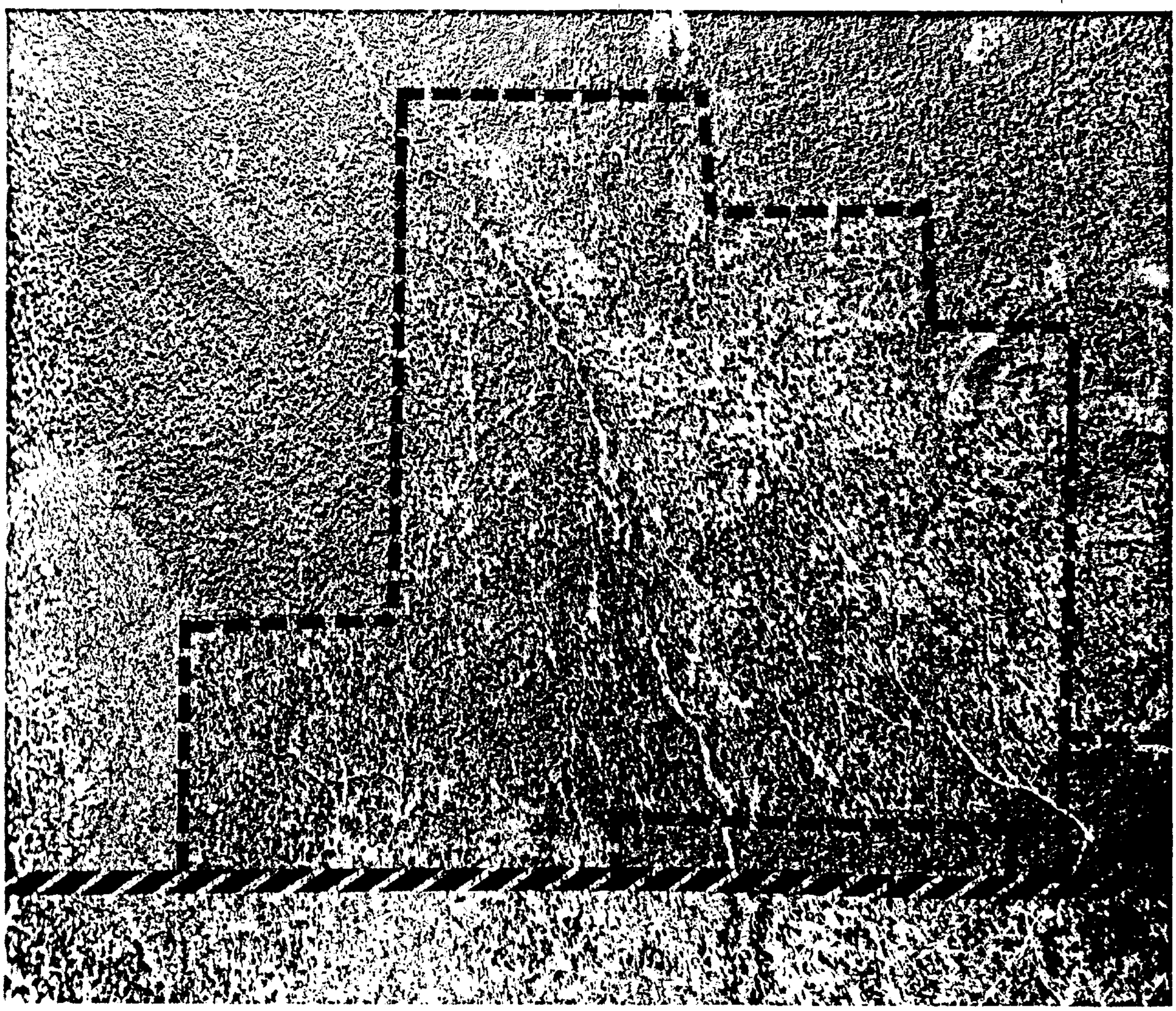


Figure 1. Location of Sun Creek area in southeastern corner of Crater Lake National Park.

Figure 2. Color xerox of Sun Creek logged area (#678-146). Park boundary is thick, diagonal red line at photo bottom; tract boundary is outlined in thin, dashed red line.



reconnaissance level results. An integration of these findings is then applied to future management of these areas.

RESEARCH SUMMARY

Description of Area and Techniques

Four 50 x 50 m (1/4 ha) plots were established: one logged and one unlogged plot in ponderosa pine-white fir and sugar pine-white fir community types. Forest structure was quantified on each plot, and then each plot was burned. Forest structure was measured on each plot. This approach allowed quantification of the effects of (a) fire suppression, (b) logging (in the 1930's), and (c) the immediate effects of one prescribed fire.

Fire Frequency

Fire frequency was measured using fire scar samples cut from sample trees. The method did not allow using composite fire intervals (combining the records of several adjacent scarred trees). In the sugar pine area, all trees located had much of the early record burned out by later fires. In the ponderosa pine area, most of the record was found on stumps cut about 50 years ago, and cross-dating would have been very difficult.

Fire frequency was conservatively estimated at 15-18 years; due to the fact that individual fire scars do not record every fire, true fire frequency is probably in the range of 10-15 years.

The Prescribed Fire

A single prescribed fire was applied to each of the four plots. The prescription is listed in Table 1(a). Fire behavior varied considerably, even though the same prescription was used; it was a wide prescription, and such variation in future management fires is also expected. The characteristics of the fires are listed in Table 1(b).

Table 1(a). The final fire prescription for the Sun Creek prescribed fire Crater Lake National Park, Oregon.

wind	0 - 10 mph
relative humidity	20 - 70 percent
temperature	60 - 70 degrees F
1-hour timelag fuels	6 - 14 percent
10-hour timelag fuels	8 - 15 percent
100-hour timelag fuels	12 - 17 percent
1000-hour timelag fuels	14 - 18 percent
burning index	10 - 40
Max. btu/sec/ft kcal/sec/m	125 103
Max. flame length	1.1 m. with wind .9 without wind
Max. crown scorch height	4.6 m. logged; 6 m. unlogged
firing pattern	strip head fire with shorter strips near fireline and in logged areas with brush

Table 1(b). Fire characteristics.

	SUGAR PINE		PONDEROSA PINE	
	Unlogged	Logged	Unlogged	Logged
Mean flame length (cm)	41	38	20	305
Median rate of spread (cm/min)	30	30	15	38
Median scorch height (m)	6.1	4.6	0.3	9.1
Percent area burned	65	70	55	80

Forest Pattern

In order to determine the spatial pattern of the major forest trees, a technique called "relative dispersion" was employed to see whether species were regularly, randomly, or contagiously dispersed relative to other species present. The effects of logging and presence or absence of fire were measured.

All species had contagious distributions in the nineteenth century. This means that pines were found in discrete groups and firs were also found in separate groups. This clumping of small groups of pure species was not affected by fire suppression, although the forest is now so thick with white fir reproduction that the clumps are not easily identified by sight. Logging removed the clumped pattern of ponderosa pine, but sugar pine, which was also logged, regenerated in a clumped fashion. Prescribed fire had variable effects on species pattern; it tended to restore clumped patterns for ponderosa but reduced clumping for sugar pine.

Forest Structure

Several forest structure characteristics were measured; species composition, tree density, diameter, age, and height distributions. Most of the analyses considered only those trees greater than 5.5 cm dbh, but height analyses considered all trees. Since many of the fire impacts are on smaller diameter, younger, shorter trees, the density, diameter, and age analyses should be interpreted with this in mind.

Forest density (trees greater than 5.5 cm dbh) was high before the fire. The sugar pine plots (per hectare) had more variations (312 unlogged, 964 logged) then ponderosa pine plots (672 unlogged, 692 logged). Most of the mortality due to the fire was in white fir (Table 2). Trees less than 5.5 cm dbh were analyzed as a species undifferentiated group, and mortality ranged from 66 to 95 percent. A map of one 50 x 50 m plot before and after burning illustrates the effects of the fire on forest density (Figure 3).

Table 2. Percent mortality by species on each burned plot (trees above 5.5 cm dbh only).

	Sugar Pine Plots		Ponderosa Pine Plots	
	UNLOGGED	LOGGED	UNLOGGED	LOGGED
Ponderosa Pine	0	9.1	8.3	0
Sugar Pine	2.5	23.1	36.2	0
White Fir	25.4	30.0	36.2	40.4

Diameter analyses were done only for those trees above 5.5 cm dbh. Excluding the smaller trees, significant differences ($p < .01$) in mortality between diameter classes were found on the sugar pine logged plot, the ponderosa unlogged plot, and for all plots combined. This was due to higher mortality in the smaller diameter classes. As shown by Figure 4, white fir showed the most mortality and also showed some mortality in trees up to 110 cm diameter.

Age analyses showed that younger trees tend to suffer more mortality than older trees. However, there was mortality in all age classes of white fir on the sugar pine unlogged plot and the ponderosa pine logged plot. One of the more intriguing results of the age analysis was that white fir began to "invade" the vicinity of the ponderosa pine plots 180-200 years ago. Climatic factors do not appear to be responsible for

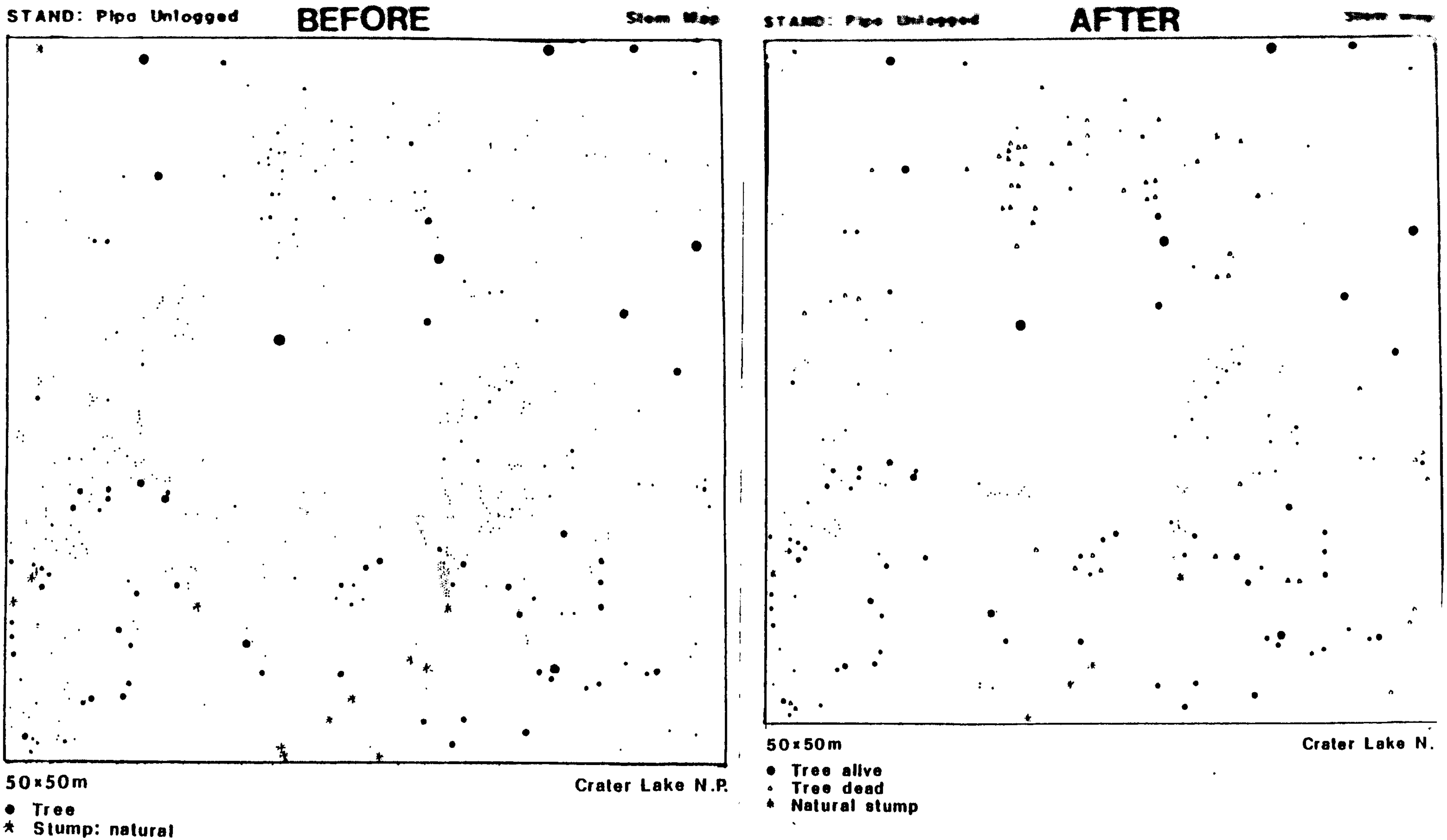


Figure 3. Stem map of unlogged ponderosa pine plot before and after burning. Most of the stem reductions are in the smaller diameter classes.

this invasion, which occurred 80-100 years before possible fire suppression. However, the invasion period is coincident with a fire-free period between 1797 and 1829 in the panhandle area (McNeil and Zobel, 1980) which may have allowed fir to establish some fire resistance before fire again passed through the area.

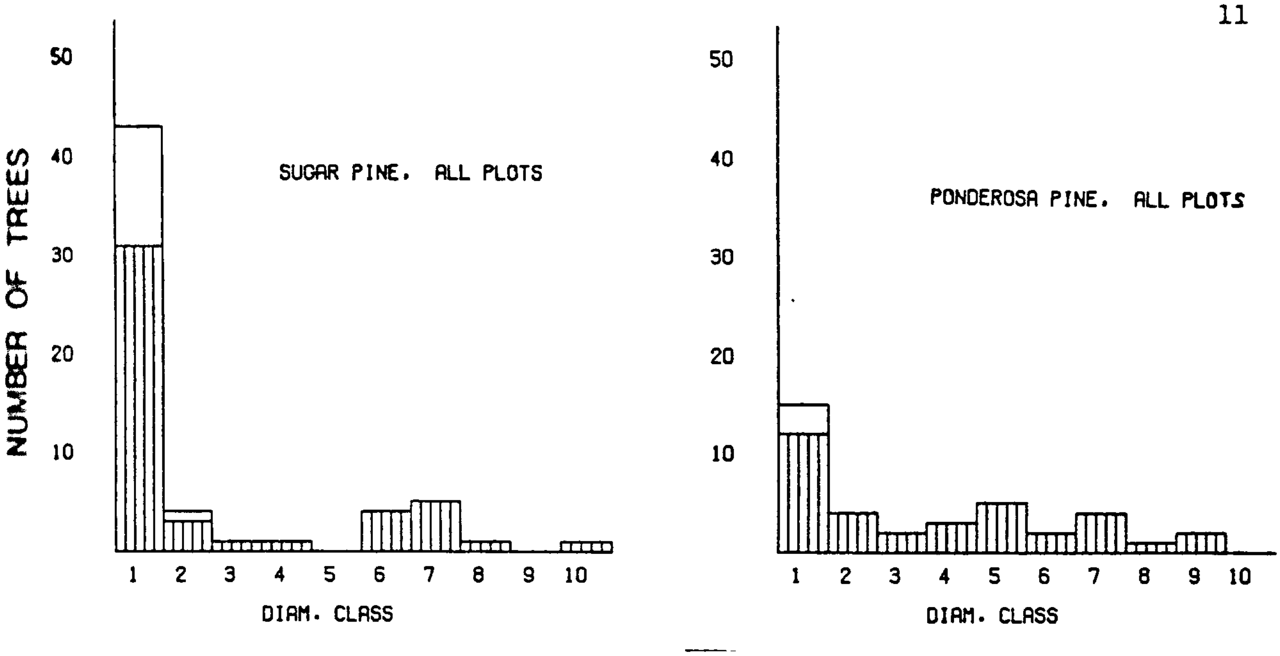
The height analyses were done on two groups of trees: those less and greater than 5.5 cm dbh. In the smaller trees, mortality ranged from 75 to 87 percent; mortality was similar for trees in the 0-1 m and 1-10 m height classes. For the larger diameter trees, taller height classes had significantly less mortality (Figure 5). Again, white fir appeared to be more susceptible in most height classes than the pines.

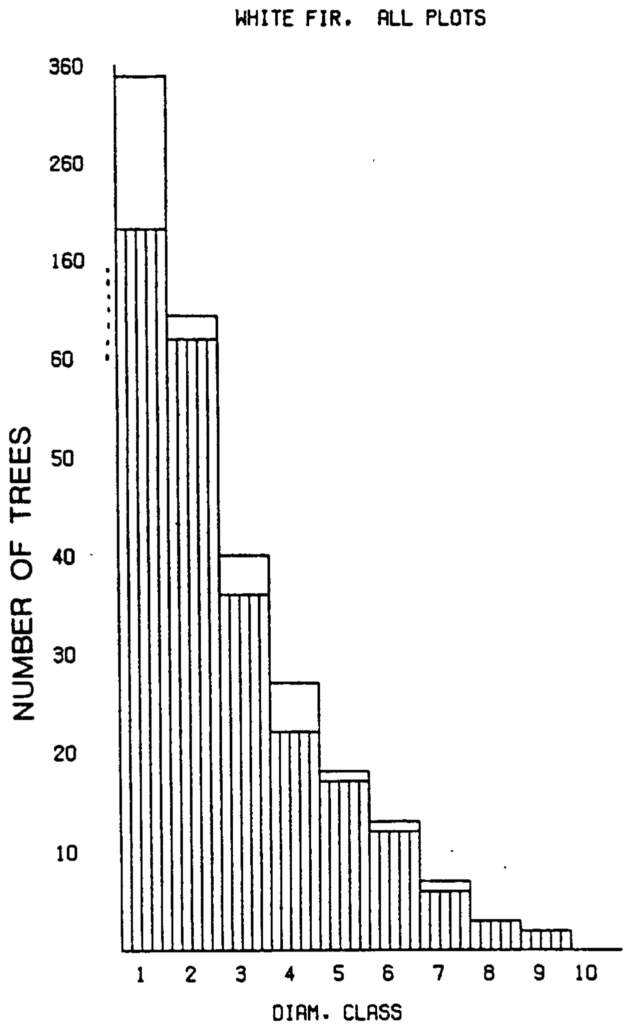
Shrubs and Herbs

Logged areas had more shrub cover before the prescribed fire than unlogged areas. Most of the shrub cover in ponderosa pine areas was snowbrush with some chinquapin. The sugar pine area had more chinquapin and some pinemat manzanita. Fire reduced shrub cover on all plots; a sample shrub/fuel map before and after fire is shown in Figure 6. The ponderosa unlogged plot, which had the slowest moving fire, resulted in the least sprouting the year following the fire. A new shrub genera, *Ribes* (gooseberry), appeared on the plot after the fire. Seeds dormant in the soil were stimulated to germinate after the fire.

Fuels

Fuel effects of the fires were also analyzed. Although 50 to 70 percent of total dead and down fuels were consumed by the fires, there were no





DIAMETER CLASSES

class 1	5.5-20 cm
class 2	21-35 cm
class 3	36-50 cm
class 4	51-65 cm
class 5	66-80 cm
class 6	81-95 cm
class 7	96-110 cm
class 8	111-125 cm
class 9	126-140 cm

Figure 4. Number of stems by diameter classes of trees by species before and after burning. Note the scale change in order to accomodate the smaller diameter classes of white fir. Amounts removed by the fire are shown by white; residual densities are indicated by vertical stripes.

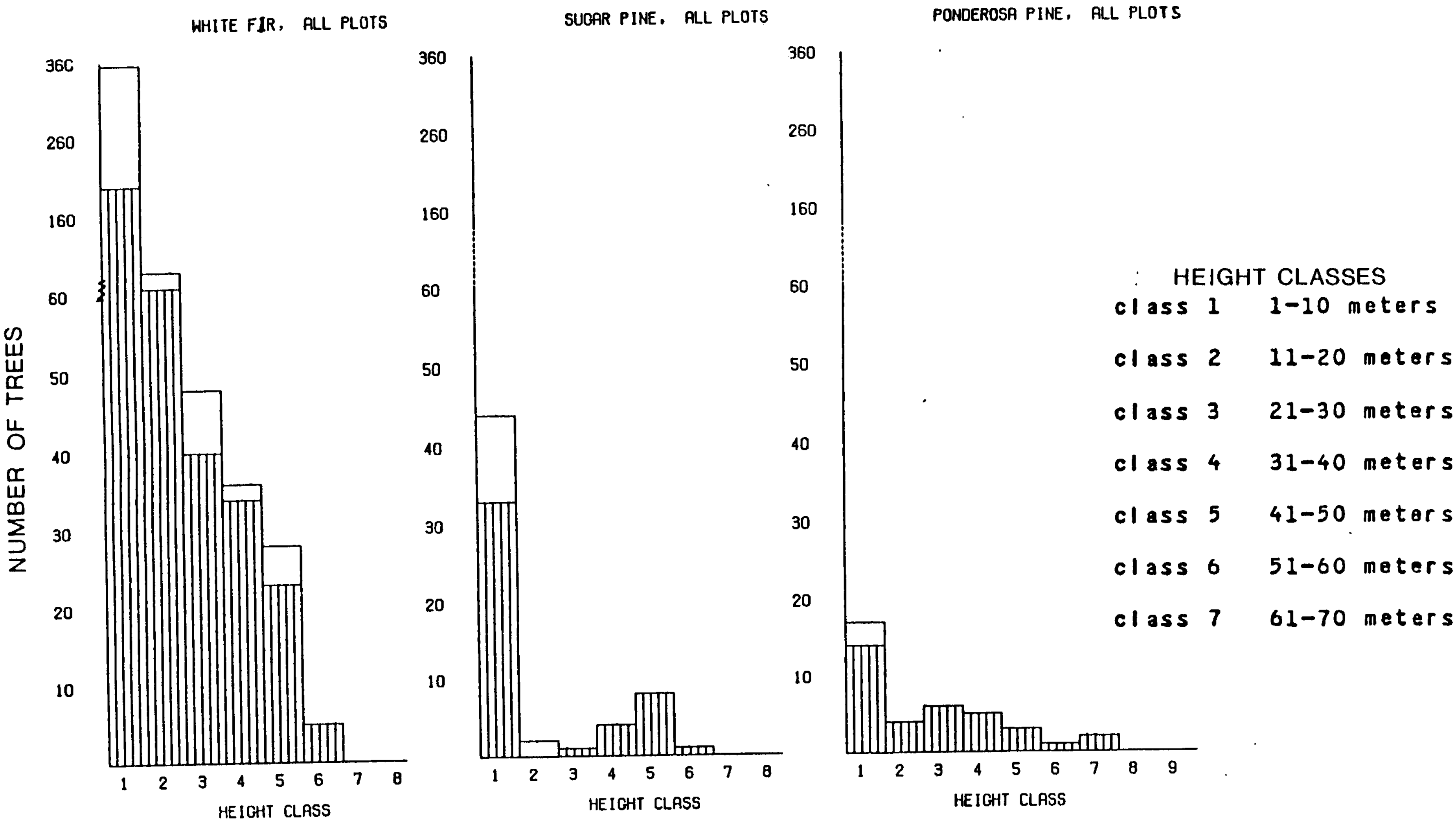


Figure 5. Number of stems by height classes of trees and species before and after burning. Note the scale change in order to accommodate the smaller diameter classes of white fir. Amounts removed by the fire are shown in white; residual densities are indicated by vertical stripes.

statistically significant differences between forest types and logging histories for the large fuel classes. For the smaller fuels (litter/duff and 1-hr timelag fuels) significant differences between plots did occur. More litter/duff was consumed than 1-hr timelag (small twig) fuels, and more litter/duff was consumed in the sugar pine area than in the ponderosa pine area. This was primarily due to higher loads before the prescribed fire, since post-fire levels were relatively equal.

Restoration of Natural Conditions by Fire

The species composition of the pre-logging, pre-fire suppression forest can be roughly reconstructed from the age class data and the dispersion data. The relative overstory species composition (Table 3) is one goal towards which restoration efforts should strive.

The prescribed fires in unlogged areas resulted in progress towards the goal. The pre-fire suppression structure is basically intact, and the effect of fire is mainly in those diameter and height classes of white fir which have invaded since fire was eliminated from the ecosystem.

In logged areas, progress was more variable. In the ponderosa pine area, little progress was made because there was almost no pine on the plot to benefit from reduced white fir densities.

Table 3. Reconstructed overstory species composition of the two forest types.

	Ponderosa Pine Area	Sugar Pine Area
Ponderosa Pine	50	20
Sugar Pine	10	50
White Fir	40	30

On the sugar pine logged plot, some progress was made, but there was sub-

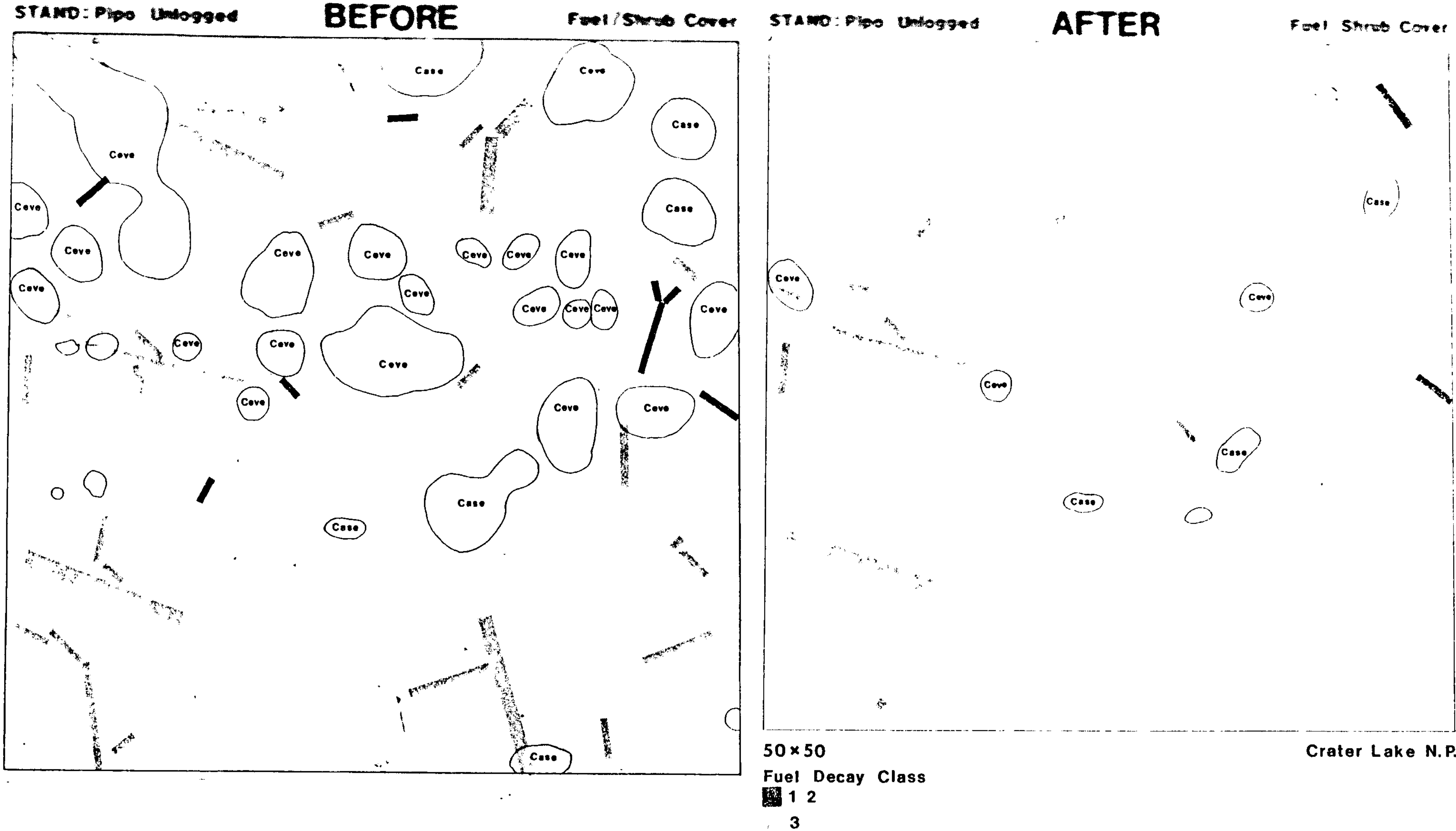


Figure 6. Map of fuel and shrub cover before (left) and after (right) fire. "Case" is chinquapin and "Ceve" is snowbrush; the plot is the unlogged ponderosa pine plot.

stantial sugar pine mortality in the smaller trees.

Much of the future progress in restoring "natural" forest structure to the Sun Creek area depends on delineation of whether plots were logged or not, and if logged, the post-logging success of pine regeneration. The next section of the report looks at stocking of the logged areas on a broader scale, so that the specific recommendations for treatments which follow can be made for each area.

It should be emphasized that the research results give a conservative estimate of the impact of the fire, because they document only first year effects. Root damage due to the fire has created additional summer moisture stress for some trees, and further mortality of some trees through insect attack may be expected. (Ferrell, 1978, Fischer, 1980). Similarly, the environment of the tree seedling establishment has been altered, and new regeneration of pine and fir may result.

RECONNAISSANCE RESULTS

A survey of the logged areas was completed during 1981 to see where the detailed plot information and implications would best apply. A set of 87 plots was uniformly established over the logged areas. From the center point of each plot, stand basal area by species was measured using a 10 factor metric prism. A fixed plot with a 3 m radius was then surveyed at each point. Tree density by species and height class was recorded.

The data were analyzed to determine the adequacy of pine stocking. Areas of adequate or less than adequate stocking were then defined.

Reconnaissance results are summarized in Figures 7 and 8. Three areas were delineated: (1) understocked ponderosa pine area, (2) stocked ponderosa pine area, and (3) stocked sugar pine area.

1. *Understocked Ponderosa Pine* (355 ha, 875 ac). This area does contain some ponderosa pine, but none showed up on the 36 plots in this type. All stocking recorded was white fir. The average stocking is 2642 trees/ha (1069 trees/ac), about two-thirds of which are below 6 m in height. This stand structure has developed from two changes in disturbance factors. Fire suppression after 1900 initiated a wave of white fir regeneration, which then was released once the overstory pines were logged in the late 1930's. Fire management alone cannot be used to restore this area to "natural" conditions.

2. *Stocked Ponderosa Pine* (190 ha, 465 ac). This area contains a number of species of conifers, four of which show up in the sampled plots.

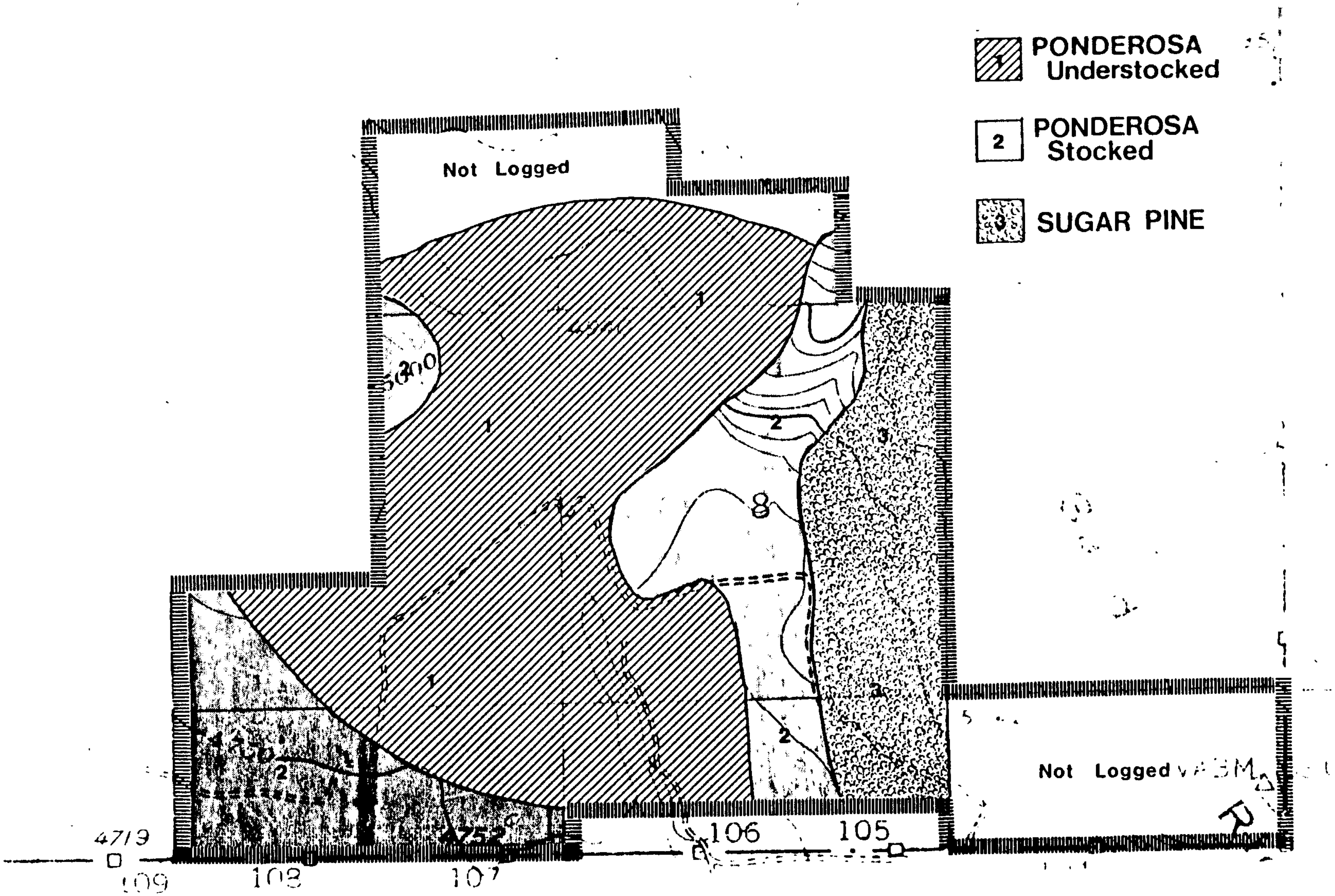


Figure 7. Reconnaissance map of pine stocking in the Sun Creek logged area.

White fir is by far the dominant species represented, but some ponderosa pine is represented in each height class. An occasional sugar pine is present, and some lodgepole pine occurs through the area. This area is both adjacent to both the unlogged areas and the "stocked sugar pine" area. Total stocking is 3036 trees/ha (1229 trees/ac), and over two-thirds of trees are below 6 m height. There is enough ponderosa pine present to produce adequate mature stocking if it can be selectively favored on the site; most of it is in the 6-9 m height class at present. Judicious use of fire can largely restore this area to "natural" conditions.

3. *Stocked Sugar Pine* (120 ha, 300 ac). This area is adjacent to unlogged sugar pine forest, and after the logging both sugar pine and ponderosa pine regenerated. There is adequate stocking to produce a mature "natural" forest, but like the stocked ponderosa pine area, the sugar and ponderosa pine will have to be selectively favored on the site. Fire alone can probably be used to restore this area. Total stocking is 1450 trees/ha (790 trees/ac), less than half of which is in trees below 6 m height.

The reconnaissance plots show current forest structure in three areas of Sun Creek. Based on the dispersion analysis and on the intensive plot data, we have developed an interpretation of how the vertical structure and species composition should appear had fire suppression and logging not occurred (Table 3, Figure 9).

The tree densities shown in Figure 9 are crude representations of historic forest structure in the 1800's. Overstory (>12 m ht) densities for the mid-to-late 1800's reconstruction were determined from trees ex-

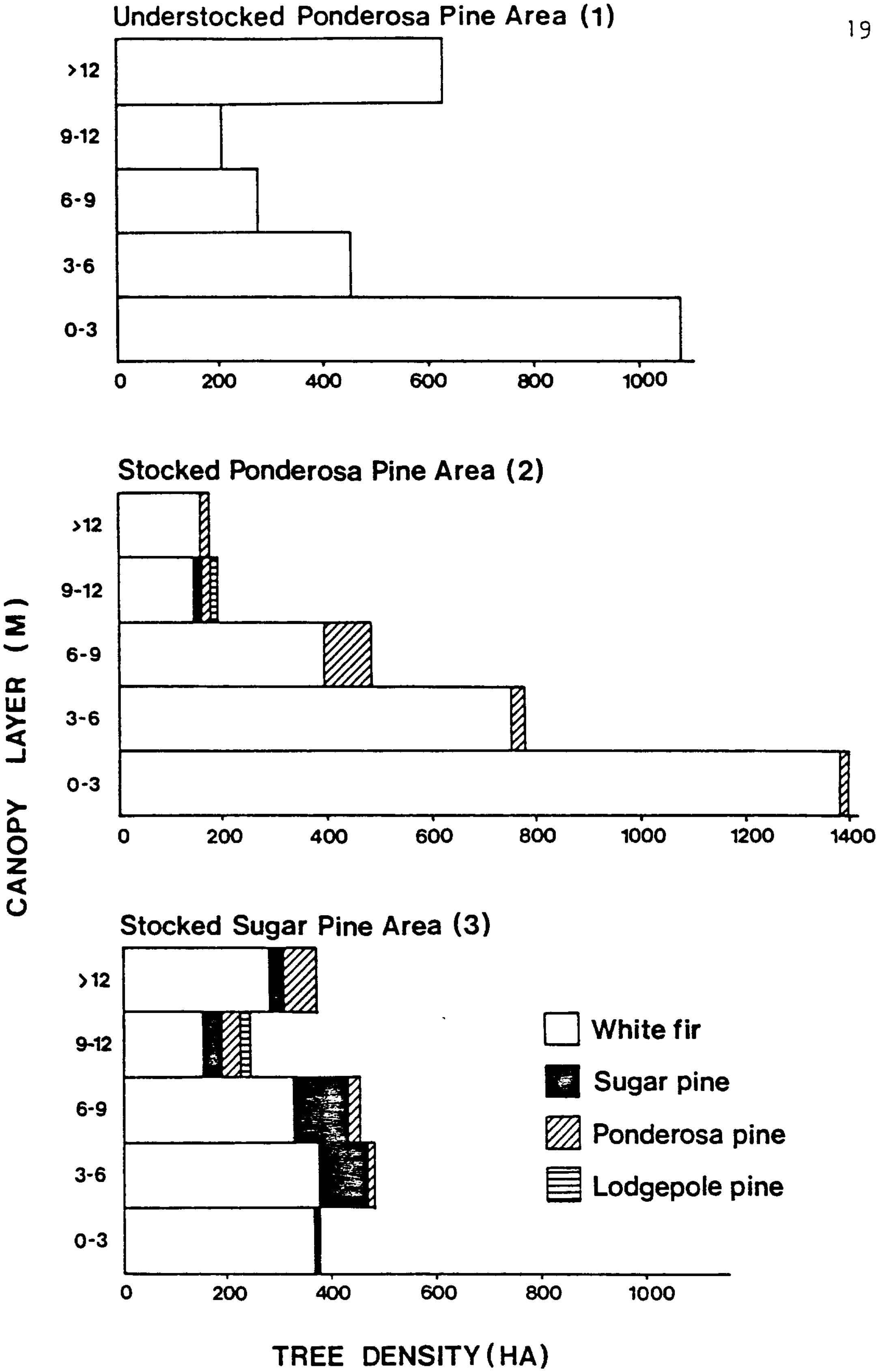


Figure 8. Vertical structure by species in the three areas delineated in Figure 7.

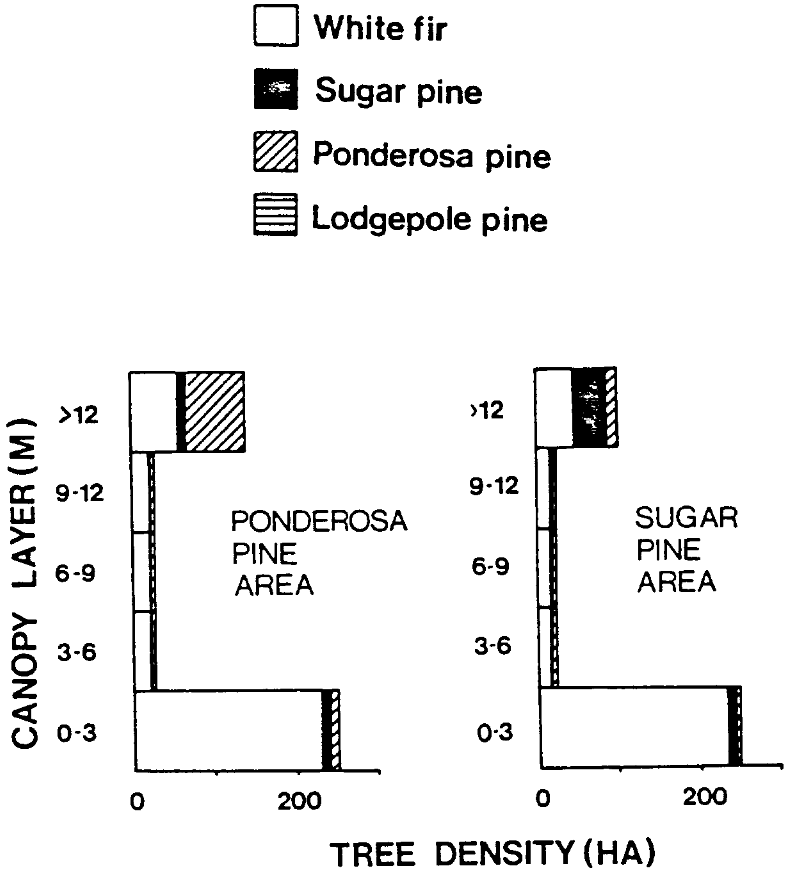


Figure 9. Hypothesized "ideal" forest structure in the ponderosa pine and sugar pine areas. This structure is the goal towards which the structures in Figure 8 should be manipulated. The apparent lack of density in the 3-6, 6-9, and 9-12 m height classes reflects the limited age ranges in the sapling to pole height classes. The 12 m height class includes many different age classes, ranging from young mature to fully mature to senescent, and thus appears "larger" on this graph which lumps all 12 m height classes together. This graph indicates relatively limited recruitment of young trees into a relatively stable overstory canopy. The major fluctuations are in the 0-3 m height class which is periodically reduced by low intensity fire.

ceeding 175 years of age on the plots; densities in the 3-12 m height were determined from trees that germinated between 1805 and 1840, and the 0-3 m height range densities were determined from trees that became established between 1840 and 1875. This underestimates reconstructed density in most classes due to the exclusion of some trees that died before the plots were examined in With the exception of the 0-3 m ht class, though, it is believed that density estimates are within 10-20 percent of actual values. The 0-3 m ht densities fluctuated tremendously, with high mortality after surface fires and substantial regeneration between recurrent fires.

The degree of forest restoration in the logged areas can be assessed by comparing Figures 8 and 9. In the "Understocked Ponderosa Pine Area," adjustments in density and species composition are needed. In the "Stocked Ponderosa Pine Area" and "Stocked Sugar Pine Area," density adjustment of white fir only is needed. In unlogged areas (not graphed), similar density adjustments of white fir are needed.

The restoration goal is not to recreate the ecosystems of the 1800's. It is to recreate what would have existed there today had we not interfered with natural processes. In our opinion, the two goals in this specific case are synonymous. We have no evidence to suggest major shifts in forest structure would have otherwise occurred in unmanaged forests subject to recurring fires over the last century in this area. Therefore, using the late 1800 ecosystem state as a mimic of what should be today's state is an acceptable assumption for these forests. It would not be as applicable in subalpine forests of the park, where the 1920-1940 drought apparently initiated some significant tree invasion into meadow environments.

MANAGEMENT RECOMMENDATIONS

Techniques to restore the Sun Creek area are as important as knowing what degree of restoration is needed. When and how should the work be done? We closely analyzed the first year effects of one prescribed fire in these areas, but it was clear before we began that fire alone might not be sufficient to restore natural forest structure, and the total effects of the single fire would not be available just one year after the fire. In the following sections we use our results plus some interpretation to provide some specific planning guidelines for unlogged areas. The phased implementation suggested will allow fine-tuning to occur as the operational aspects of the project proceed, and subsequent effects of the prescribed fires are documented.

Unlogged Areas

The Short Run

A significant proportion of the pre-fire suppression forest structure is still present in these areas. Reintroducing prescribed fire at low intensities will reduce fuels and much of the white fir density, particularly in the smaller height and diameter classes. The techniques suggested here are fairly standard and comparable to other mixed conifer recommendations (Van Wagtendonk, 1974). A prescription for these areas is presented in Table 4. In the sugar pine area, a backing fire is recommended for the short run fires. In the ponderosa pine area, which has a gentler slope, strip headfires with strips 2-7 meters apart are recommended. Two fires in the next decade are recommended; the first will consume much dead fuel and kill much of the understory, and the second will consume the fuels created by the first fire and largely recreate a mimic of natural forest structure.

The Long Run

These areas are near the park boundary. Prescribed fire may be needed in the long run to simulate natural fires for two reasons. First, natural fires near the boundary may be somewhat unpredictable and require excessive monitoring. Second, some of the past natural ignitions came from outside the park, and these have been eliminated by current land use policies in those areas. A prescribed fire frequency should mimic the natural fire range of frequencies. For example, the average frequency was about 15 years. After the first two short run fires, this average frequency should prevail. Instead of a fire every 17.5 years, however, the intervals for the next 100 years should vary around the average: 20, 10, 15, 5, 25, 12, 18, etc., in a normal distribution.

The long run ecological consequences of this plan are illustrated by Figure 10. Under "A. Fire Exclusion" the present shift toward overstory and understory dominance by white fir will continue. Under "B. Fire Reintroduction," an eventual shift back to natural conditions (the relative numbers in 1880, far left) will occur. The primary reason the overstory will take so long to recover is the current presence of large post-fire suppression white fir which will be only slightly affected by the reintroduced prescribed fires. The understory, once fire is reintroduced, will show a cyclic stability, with white fir relatively increasing between fires and pines relatively increasing at and right after fires.

Table 4. Fire prescription for unlogged areas.

wind	1-10 mph
relative humidity	25-70 percent
temperature (F)	60-70
1-hr. timelag fuel moisture	8-14 percent
10 hr "	11-15 percent
100 hr "	12-17 percent
1000 "	14-18 percent
burning index	10-40
fireline intensity	
Btu/sec/ft	125
Keal/sec/m	103
max flame length	.7 m (with wind)
max scorch ht	4 m (13 ft)

It should be noted that Figures 10, 11 and 13 are schematic in nature, and the future timeframes are not meant to be precise. They are suggested as long-term trends and goals towards which management actions should point.

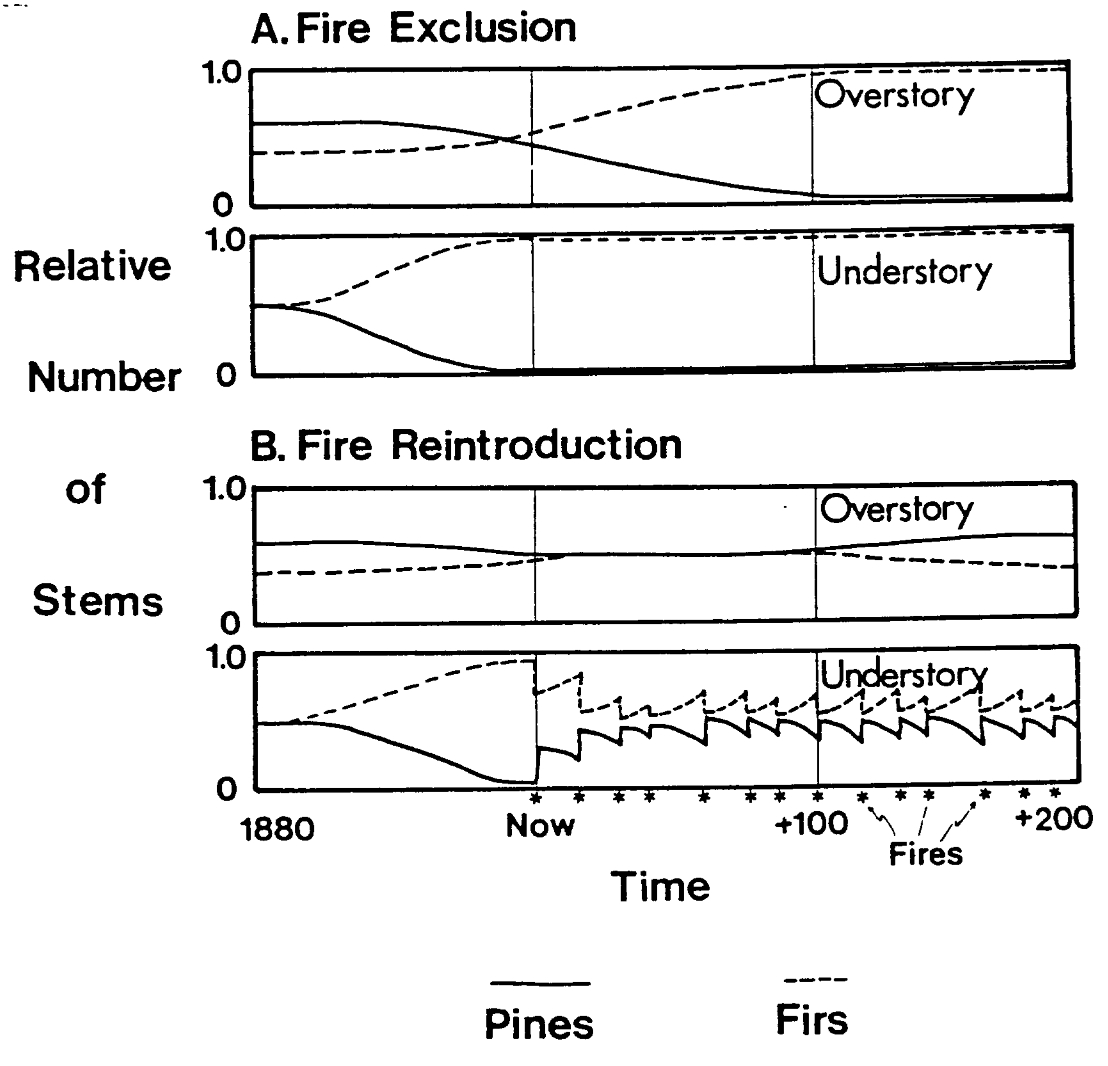


Figure 10. Long term effects of management in unlogged areas. Under "A", fire exclusion remains in effect. Under "B", fire is reintroduced to the environment.

Stocked Sugar Pine and Stocked Ponderosa Pine Logged Areas

The Short Run

Although logging significantly altered forest structure in these areas, subsequent regeneration of both pine species occurred. The pines only need selective survival over white fir in future years, and therefore fire can be used to restore "natural" forest structure in these areas. The same prescription recommended for unlogged areas (Table 4) can be used, but backing fires rather than strip headfires are recommended. A strip headfire might cause too much crown scorch on the pines, so a conservative application of fire is recommended. This should still reduce white fir density considerably, but protect the pines until they are larger and more fire resistant. This is particularly important for sugar pine logged areas, which contain moderately sensitive sugar pine poles on moderate to steep slopes.

Two fires about ten years apart are recommended. This will allow settling of dead fuels created by the first fire before the second fire.

The Long Run

As with unlogged areas, total restoration of "natural" structure within one forest generation will not be possible with the use of fire alone. Some of the trees in the post-fire suppression white fir age class are already large enough that they are as fire resistant as trees in the post-loggi pine age class, which are 40-60 years younger. However, restoration of natural fire intervals as suggested for unlogged areas will in the long run favor pines in future generations.

The long run consequences of fire restoration in the logged but adequately stocked areas are shown in Figure 11. Under "A. Log/Fire Exclusion," the wave of pine regeneration initiated by the logging will decrease over time. Some individuals will reach the overstory, but eventually a relatively pure white fir overstory and understory will develop. The scenario under "B. Log/Fire Reintroduction" will eventually produce a "natural" forest structure. The post-logging wave of pine regeneration will be augmented by continued pine establishment as understories will be opened and fir will be selectively killed. The overstory, which shifted to almost pure white fir after logging, will eventually readjust to a pine-dominated overstory with a substantial white fir component, similar to the structure at the 1880 (far left) time period.

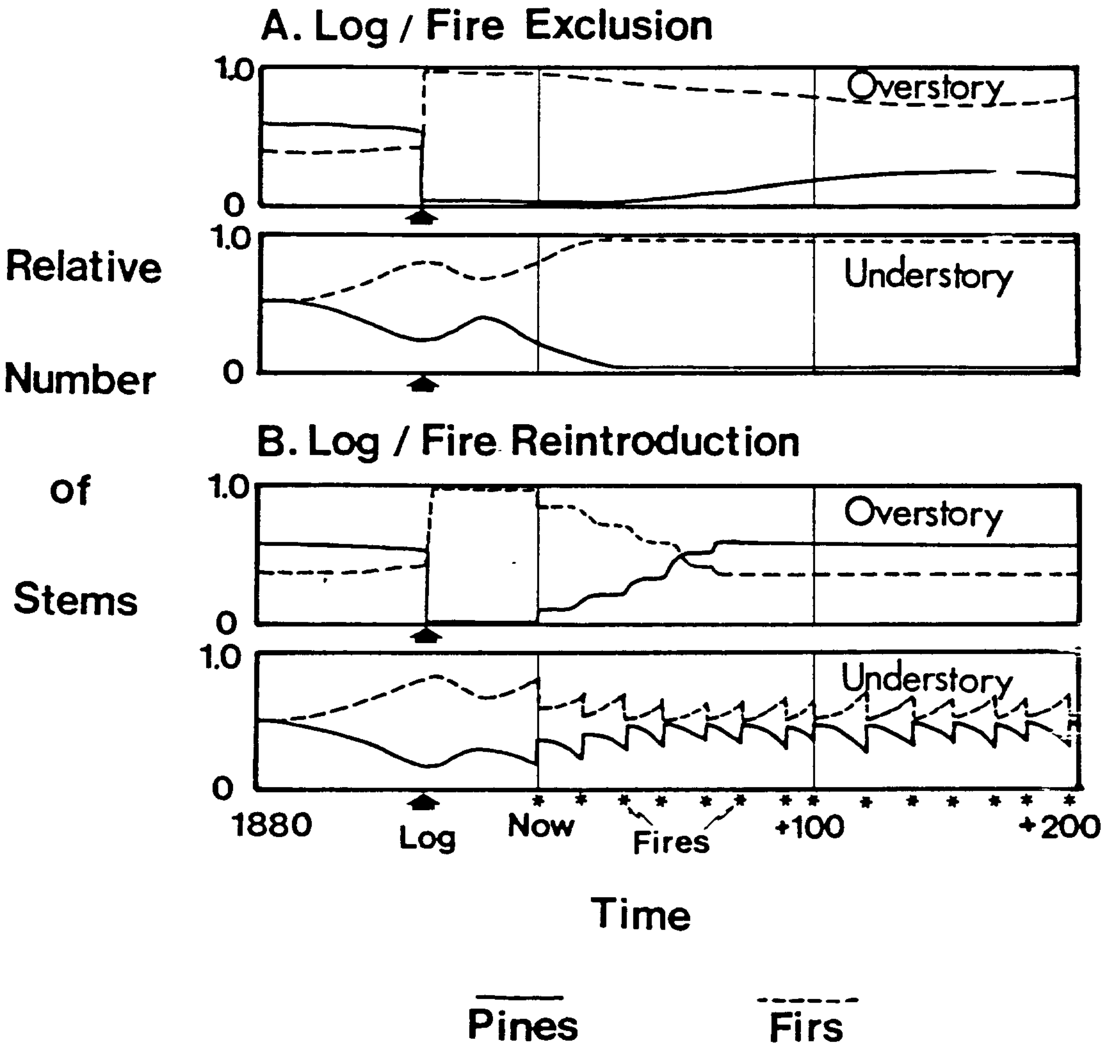


Figure 11. Long term effects of management in logged but restocked areas. Under "A", fire exclusion after logging remains in effect. Under "B", fire is reintroduced to the environment.

Understocked Ponderosa Pine Areas

The Short Run

This area is now dominated by white fir in all size classes. The short-term goal in this area is to initiate regeneration of ponderosa pine while reducing the density of white fir. This can be accomplished with a combination of tree removal by saw or fire plus planting of pines. Much of the white fir to be removed is not of commercial size; cutting the smaller material would be very expensive and its disposal would be a problem. Although the area is laced with existing old skid trails and haul roads, a manual operation does not appear feasible.

If fire is used, the fuel creation problem caused by manual removal is avoided. However, the larger post-suppression white fir will not be removed by the intensities of fires proposed below. This will result in a continued dominance of white fir for at least the next "forest cycle" in this area. This may well be the cost associated with using a natural disturbance agent, fire, for a silvicultural treatment for which it is not perfectly suited. Fire thins from below, and to thin the larger size classes significantly will require fire behavior bordering on erratic, or a more selective manual removal. The timeframe for these treatments is a function of continued white fir occupation of growing space. Each year's delay, while seemingly insignificant, makes the eventual treatment more difficult. The initial treatment should have been done forty years ago. We recommend completing all prescribed fire and planting treatments within the next fifteen years.

Prescribed fire treatments. The proposed short run treatment in this area is two prescribed fires over a period of 5 years, with subsequent planting of native ponderosa pines in selected areas. Protection of planted areas for 20 years is recommended, followed by recurrent prescribed fires with the pre-disturbance ranges of fire frequency and intensity.

The number of acres treated per year depends on the number of blocks and the number of years. If, for example, 9 blocks are chosen over a 15-year period (Table 5), then about 40 ha (100 acres) per year would be treated. This could be done in a single area or spread out over several smaller blocks of the understocked area.

The two prescribed fires will: (1) reduce white fir density over the area, (2) reduce long-term fuel accumulations and much of the dead fuel created by the first fire, and (3) reduce shrub density and biomass. Opening the area will create growing space for ponderosa pine and result in manageable fuel loads in the area after the 20 year protection period.

Planting. In the understocked area, the major species removed by logging was ponderosa pine. There was very little sugar pine in this area and white fir was not removed. Therefore, ponderosa pine is the major species that needs to be considered for planting; minor amounts of sugar pine will be needed.

Planting stock should be obtained from local seed sources of both species. Due to the potential variability of ponderosa in the area and its potential hybridization with Jeffrey pine, all seed collection should be restricted to the Sun Creek area of the park. Cones should be selected

Block	Year 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	F					F	P								
2		F					F	P							
3			F					F	P						
4				F					F	P					
5					F					F	P				
6						F					F	P			
7							F					F	P		
8								F					F	P	
9									F					F	P

F = FIRE P=PLANT

Table 5. An example of the treatments applied to Sun Creek logged area assuming that nine blocks are to be treated within a fifteen year timeframe. Five years elapse between the initial fire treatments; after planting, areas are protected from fire for twenty years.

to include genetic variability at the site: good and poor form, limbing and limbless boles, a range of bark colors, etc. Good seed years occur on the average every 2-3 years, and several years' worth of seed can be collected in one good seed year, if properly stored.

Seedling production can be contracted to local nurseries. Because of the importance of good initial growth, large planting stock (2-0 or 2-1 stock) should be requested. This means that the seed must enter the production schedule at least two years before planting occurs.

Planting at relatively low stocking is recommended. Although about 50-60 mature trees per ha (20-25 per acre) are desired, mortality due to planting shock, drought, animal damage, and subsequent fires requires higher planting densities. Planting densities of 170 per ha (70 per acre) are suggested, which would require about 7000 seedlings per year from the nursery (assuming a 15 year plan).

Since both the sugar and ponderosa pine are dispersed, they should be planted in pure clusters. In any area, there will usually be mature white fir clusters around or between which the pine clusters can be planted. Planted clusters should be centered in open areas, with spacing varying from a modified 3 x 3 m (10 x 10 ft) to 5 x 5 m (17 x 17 ft). If the entire hectare were planted in a uniform pattern with 170 trees, spacing would instead be about 7.5 x 7.5 m (25 x 25 ft), so the intent is to cluster seedlings in groups without crowding them within a group. Nine of every ten planted clusters should be ponderosa pine (Figure 12). Since our tree pattern data did not produce pattern size estimates, these spacings are an educated guess. The eventual pattern will be a result of seedling survival and subsequent fire effects.

The best planting time is usually April and May, just as soon as the snow melts and while soils are still moist. Planting after June 1 almost guarantees substantial seedling mortality. Even though the sites have been prepared by two prescribed fires, seedling planting sites should be scalped (clearing away litter, duff, and especially grass/sedge tops and roots). Proper planting is essential: digging a proper hole, preventing turned roots, and proper repacking of the hole with moist soil. Several good manuals (Schubert and Adams, 1971, Cleary et al, 1978) with planting guidelines are available for specific techniques.

Once each area has been burned twice and planted, a period of protection against fire will be needed. The time interval will depend upon tree height growth rates, the buildup of other fuels on the site, and the intended fire intensity of the next fire. A 20-year protection period should allow trees to reach about 6 m (20 ft) height. A low intensity fire ($\leq$ 50 kcal/m/sec or 60 Btu/sec/ft) with little to no wind should scorch less than 50 percent of the tree height and reduce much of the competing vegetation. At that point, long-term strategies for natural fire maintenance should be considered.

The Long Run

The long run consequences of no treatment, exclusive use of fire, and use of fire plus planting are shown in Figure 13. Under "A. Log/Fire Exclusion" the failure of pine to regenerate after logging will continue, resulting in a relatively pure white fir forest. Under "B. Log/Reintroduce Fire," sufficient growing space for pine is created, but the absence of seed source results in essentially the same relative forest structure

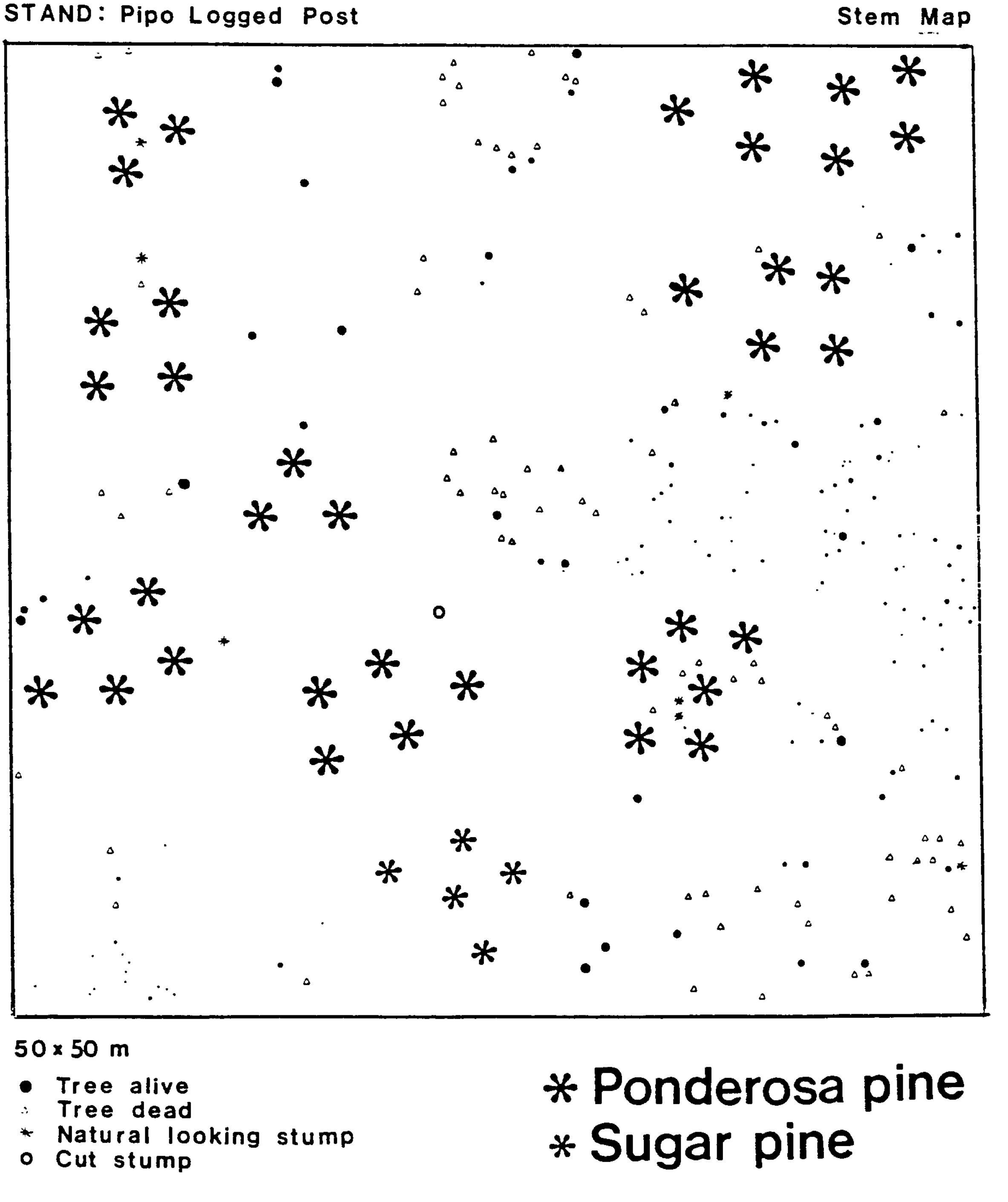


Figure 12. An example of the cluster planting of ponderosa and sugar pine in the logged, unstocked ponderosa area. The large out-of-scale stars represent ponderosa pine seedlings and the small out-of-scale stars represent sugar pine seedlings. Other stems are to scale on the 50X50 m plot.

over time as "A." The proposed plan is shown under "C. Log/Reintroduce Fire/Plant." Through a continued selective favoring by fire of planted pines, they will eventually dominate the overstory and be adequately represented in the understory.

One potential problem with the proposed planting scheme is that planted seedlings will be even-aged in clusters within the logged areas. There is no clear evidence that this occurred in the pre-fire suppression era; our plot data did not conclusively show any single or nearby groups of clusters to be even-aged. However, even if somewhat unnatural in terms of age structure, it will visually be a mimic of natural structure. Maintenance of periodic fire over a generation of trees should complete the restoration process.

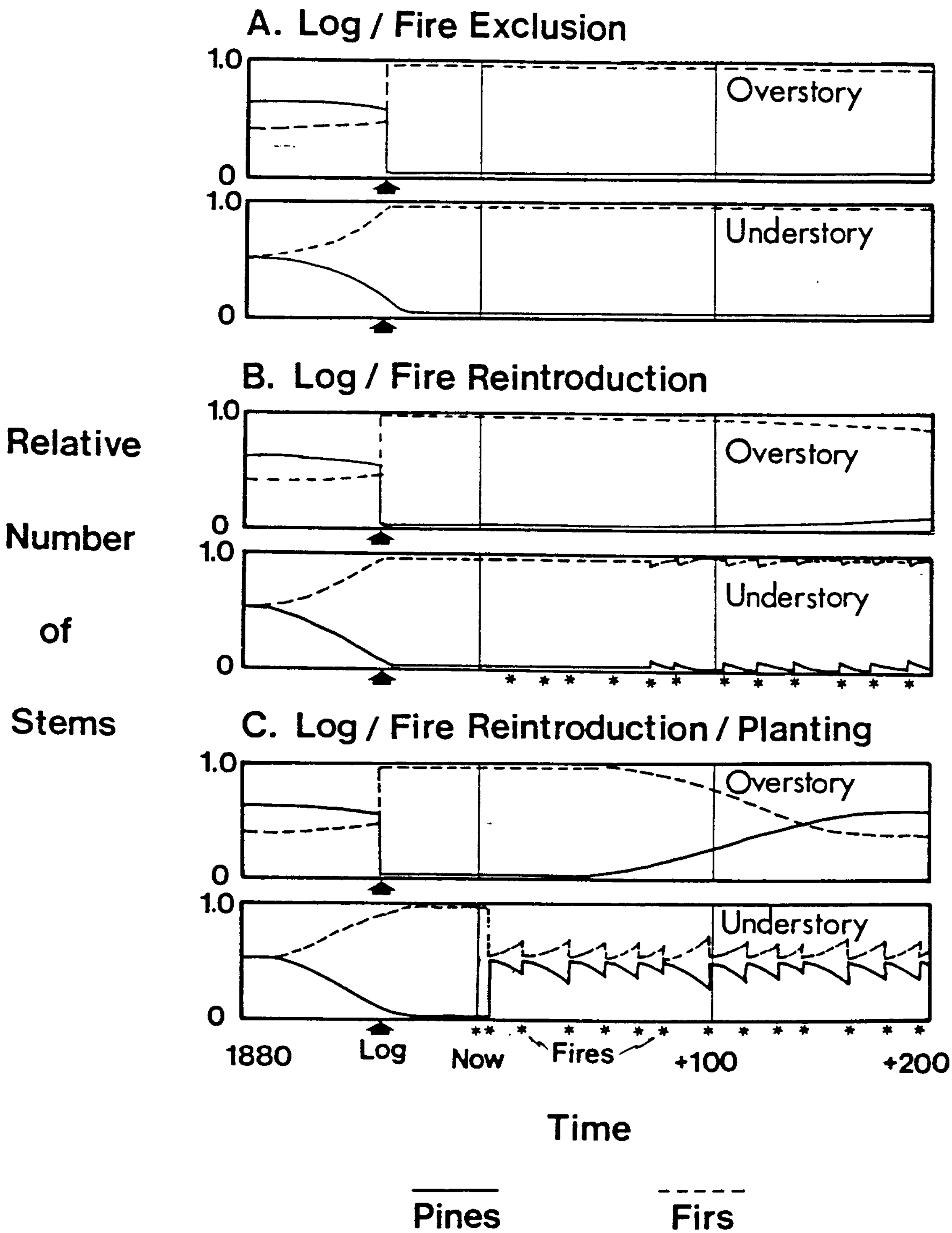


Figure 13. Long term effects of management in logged, unstocked areas. Under "A", fire exclusion after logging remains in effect. Under "B", fire is reintroduced after logging. Under "C", fire and tree planting are both part of the post-logging (after 40 years) management.

CONCLUSION

The restoration of the mixed conifer forests of Sun Creek will require patience and a substantial commitment of time and money. The unlogged forests and those logged that have naturally restocked with pines will be fairly easy to restore. Fire restoration in those communities can be done using techniques that have been applied elsewhere at Crater Lake National Park.

The logged but unstocked areas will require an unusual treatment for a National Park area, but one justified by past effects of modern humans. As with most silvicultural operations, there are chances of planting mortality or fires that are too hot that may cause localized failures. We recommend a monitoring program for the planting/fire operations so these techniques can be refined as they are applied.

The first monitoring element is remeasurement of the established permanent plots over time to more precisely evaluate the initial prescribed fire effects. Subsequent monitoring of planted seedling survival and effects of fires should become a routine part of the restoration process. In another century, through careful management, the effects of the logging of pines and unnatural protection from fire will be largely erased from the landscape.

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