Lodgepole Pine at Crater Lake:

History and Management of the Forest Structure*

by

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I. Introduction:

Since the advent of white man, biotic conditions in Crater Lake National Park have been modified considerably from those of its primeval state. A return toward primeval conditions recently has become a goal of Park management policy. Thus, knowing what types of changes white man's influence has wrought, and where (and when possible, why) these have occurred, has become of great importance to the Park managers. In 1976-77 we conducted a study of the lodgepole pine forests, with the goal of providing this information. We described the state of present lodgepole forests, and gathered evidence for the importance of several processes which affect its characteristics. We attempted to establish what the primeval forest structure was, to infer the changes since white man arrived, to determine what caused these changes, to predict the future course of forest development, and thereby to suggest the appropriate ways to return these forests to their primeval condition.

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Lodgepole pine occurs throughout much of the Park. Areas included in our study were those in which lodgepole comprises more than 50% of the tree layer. We find that the lodgepole pine forest is more complex than we anticipated, with several distinct types of ecosystems represented. The different lodgepole communities have different histories, futures, and environments. Likewise, management policy will need to vary with the forest type. The model for managing forests of ponderosa pine is inappropriate except for a minority of the lodgepole forest. Some lodgepole communities have changed little, and most altered communities will return toward their primeval state without any positive action of management, given a natural fire policy.

Our conclusions have been based on a combination of appropriate information from the literature and on our description of the forests at Crater Lake. The details and our conclusions about all but the management procedures are presented in R. S. Zeigler. 1978. The vegetation dynamics of _Pinus contorta_ forest, Crater Lake National Park, Oregon. Masters Thesis, Oregon State University. 182 p. Copies of the thesis have been presented to the Park Service.

A summary of the information from the thesis upon which we based our suggestions for management is presented in this report, along with those suggested procedures and a map of the management units for which each is appropriate. In instances where information from the literature or our data is incomplete or even conflicting, what we present here represents what we believe to be the most probable case. Evidence and argument for many of these points are presented by Zeigler (1978).

II. Important Characteristics of Lodgepole Pine:

Lodgepole pine at Crater Lake is _Pinus contorta_ subspecies _murrayana_. Some of its ecological characteristics important here are: (1) it is a relatively small, short-lived conifer with sparse foliage; (2) it appears to tolerate a variety of harsh environments (wet, cold, low nutrients) which few other trees can, but (3) its growth is considerably slowed by such conditions; (4) it is intolerant of heavy shade; (5) its small, winged seeds are released soon after the cones mature; (6) it is very susceptible to dwarf mistletoe, although few trees die as a direct result of infection; (7) it is quickly killed by mountain pine beetle; (8) it has very thin bark, even when an old tree, rendering it susceptible to kill by fires of low intensity; (9) trees are very subject to heart rot introduced through wounds such as fire scars; (10) fire-affected trees appear to be very susceptible to secondary bark beetle attack; and (11) dead trees lose their bark rapidly and form a hard sheath, and thus logs appear to decay relatively slowly.

Our lodgepole pine thus differs considerably from ponderosa pine, which has thick bark even when young, gets much larger and survives much longer, appears to be more resistant to bark beetles and can be scarred repeatedly without rotting. It also differs significantly from its relative in the Rocky Mountains, P. contorta ssp. latifolia in at least one way of importance to our study (no. 5 above): many Rocky Mountain trees are serotinous, having cones which remain closed for years until subjected to a high temperature, usually from fire. Thus, in the Northern Rockies, the seed crop of many years is released directly on a site following fire in lodgepole pine. In our area, seed for regeneration must be dispersed from surviving trees or the edge of the burn, only one year's crop at a time. This probably results in slower, more sporadic regeneration in this area than in the Rockies, especially near the center of large burns.

III. Characteristics of Lodgepole Pine Forests

In Crater Lake National Park there exists a wide variety of plant communities presently dominated by lodgepole pine. Some communities have only a single age-class of lodgepole pine, which includes almost all the trees. Others have several distinct age-classes, or have age structures that indicate that reproduction occurs more or less continuously rather than as a short-term response to disturbance. Some communities include other species of trees in the overstory or understory; others are essentially pure lodgepole pine. From this type of information we inferred what type of succession occurs in the various forests.

Some forests are obviously seral, with lodgepole eventually being replaced by other tree species. In some seral communities, lodgepole pine reproduces little and the replacement is rapid, with only one generation of lodgepole occupying a site before the more shade tolerant trees take over almost complete dominance. Of course, some catastrophe may at any time destroy the forest, allowing lodgepole pine to return.

In one seral community the complete replacement of lodgepole pine is delayed, apparently indefinitely, by periodic light ground fires which burn the area incompletely. In two others, invasion of other tree species is slow even without fire, requiring two or more generations of lodgepole pine before the invaders gain dominance.

The lodgepole communities also vary in their understory layers, from almost absent to relatively dense. In two communities, at least, we think the understory plays an important role in delaying tree invasion. Managers can use understory composition to determine the type of forest by using the key in Appendix B; this is more accurate than the maps (Fig. 2, Appendix C) in most situations and can be applied to unmapped areas. Knowing the community, one can determine our management recommendations from section VIII below.

The environments of the various communities are very similar in many ways. Lodgepole forests usually occur on glowing avalanche deposits on relatively gentle topography. Soils are almost all of the Steiger series. We found no evidence of serious moisture stress in any lodgepole forest. Elevations range from the lowest in the Park to over 2000 m.

However, we have identified some differences reflecting the pattern in the forest communities. Topographic basins usually support climax lodgepole forests toward the center, the more sparse and species-poor ones being closest to the middle. These very depauperate forests have the lowest moisture stress but do not usually include small streams and usually seem to be the farthest from outcrops of rocks other than pumice or scoria. In contrast the seral forests with the densest ground vegetation have considerable andesite, dacite, or weathered material in the parent material or nearby upslope, include many streams, have the greatest soil profile development but yet have the greatest moisture stress on the saplings of lodgepole pine. Elevation correlates with some community differences, and continuity with ponderosa pine forest is characteristic of some types.

Such a variety of forest types, with their various environments, histories and potentialities, cannot be managed as a single system. Whether intervention by man is even necessary depends on the type of forest community present; where intervention is desirable, the appropriate type of management will be different depending on the community.

In compiling the community histories presented below, and thus in developing management recommendations, we had variable amounts of data. Many stands date from fires caused by white man and thus provide no direct information about the primeval forest; beetle infestations remove most older trees on many sites; fire scars are rare or absent in most communities and are usually rotten or record only one or two fires. The community histories we present in section VI are what we consider to be the most probable situations, although we have, in many cases, few direct data about primeval forest conditions.

IV. Parasitic Plants Affecting Forest Structure

Dwarf mistletoe (Arceuthobium americanum) is a higher plant which grows as a parasite in the stem and branches of lodgepole pine, from which it receives the water and most of the carbohydrates it needs. It causes swelling of branches and, as it grows, causes abnormal branching above the infection, forming "witches brooms." Tree height and density of the upper crown are reduced in heavily infected trees at Crater Lake, and diameter and root growth may be likewise affected. One hypothesis states that thickness and food content of the phloem tissue may be reduced by heavy mistletoe infection, rendering those trees less susceptible to mortality from bark beetles. Trees with heavy dwarf mistletoe infection often have dead tops. Heavy infection in a young tree may prevent its development to mature size and form. Infection is often inconspicuous when the parasite does not produce aerial shoots or does not cause "witches broom" formation.

These mistletoe effects on growth and form of individual trees seem to result in a more open canopy in heavily infected stands. On severe sites, the largest, oldest trees are almost all heavily infected with dwarf mistletoe. Perhaps they reach their size chiefly as a result of their lower ability to support bark beetle attack.

This species of mistletoe, of which the primary host is lodgepole pine, disappears from a site when the host is totally destroyed or replaced by fir or hemlock. Thus it must be reintroduced to a new population of pine. It moves into an uninfected stand slowly, about 0.7 m yr^{-1}, primarily by short-range mechanical seed dispersal, although long-distance transport by birds occasionally occurs. Thus, areas from which lodgepole is periodically absent tend to have less infection than those where the tree can reproduce without catastrophic destruction. In these all-aged forests with large mistletoe populations few new trees reach the overstory without considerable mistletoe infection. These forests which are open enough to allow continuous reproduction of lodgepole pine have very low and discontinuous surface fuels. Most fires would have been confined to local pockets of continuous fuel, small enough to have their new trees immediately reinfected by seeds from plants on adjacent infected trees. Dwarf mistletoe is not reponsible for the sparse nature of the stands where primeval lodgepole pine continuously reproduced. We believe heavy infections have always been present; management to reduce mistletoe on these sites is not necessary.

Western gall rust (Peredermium harknessii) infects many lodgepole pine stands. Trees with a stem infection often snap off at the canker. In some spots this may cause small openings in the forest canopy and speed fuel buildup on the forest floor, perhaps allowing lodgepole reproduction, or releasing small trees of shade tolerant species, such as fir and hemlock.

V. Primary Causes of Death of Lodgepole Pine

Very few lodgepole pines reach the age and size of which they are capable; most probably die at a relatively young age following either fire or infestation by mountain pine beetle (Dendroctanus ponderosae).

A. Mountain Pine Beetle

Mountain pine beetles often attack lodgepole pines. The female bores through the outer bark and lays her eggs in the inner bark; after hatching, the larvae feed on the phloem tissue. A heavy attack quickly results in death.

After an initial attack the females may abandon a tree if conditions are unsuitable. Suitability is apparently associated with phloem thickness; phloem thickness increases with tree diameter; thus beetles preferentially attack larger trees, which suffer the greatest mortality. Trees with thin phloem, due to their small size (or, in cases, perhaps due to heavy mistletoe infection), are relatively immune. The usual diameter of susceptibility is 25-35 cm in the Rocky Mountains and seems similar here.

At the elevations encountered in the Park mountain pine beetle populations are food-limited. Under endemic conditions beetle populations are low, selectively removing only a few large individuals from a susceptible stand each year. The populations may be kept at endemic levels for several reasons: there may not be enough large trees to support increasing numbers of beetles; the trees may be vigorous enough to successfully resist attack; environmental conditions may be too severe (e.g. low temperature) to permit large scale brood survival. At Crater Lake conditions restricting beetle population buildup may be encountered in a multi-aged lodgepole stand where there are only a few trees of susceptible size at any given time. There are apparently no stands at Crater Lake that are either vigorous enough to perpetually resist attack or at high enough elevations so that environmental extremes always restrict beetle activity.

Epidemic conditions arise when the available food supply is large and environmental conditions (both physical and biotic) permit large-scale brood survival. Populations increase as the beetles successfully attack most of the large trees, each of which produces large numbers of adults. Thus, epidemics are more likely to occur, and impact is most severe, in single-aged stands where most individuals reach a susceptible size at about the same time. As most of the large trees are killed the beetles are forced to attack trees as small as 10 cm dbh. These trees with thin phloem are incapable of supporting large numbers of brood. As the brood starve to death in the smaller trees, and disease and predators increase, the beetle population declines.

Following an epidemic, activity may remain low for years until surviving trees reach the most susceptible size class. In a lodgepole climax stand, openings from beetle-caused mortality permit increased lodgepole reproduction. As this age class reaches susceptible size and conditions permit, another bark beetle epidemic is likely. In seral stands the shade tolerant species are released and replace the pine unless fire recycles the stand to lodgepole. In both cases epidemics greatly increase the amount of fuel on the forest floor.

No known control method for mountain pine beetle is effective over large areas. The last attempts at control at Crater Lake were abandoned several years ago. Beetle activity, since it is affected by the number of susceptible trees, will probably continue to be high as the lodgepole stands which originated in 1850-1900 reach susceptible size. Then the level will probably wane somewhat as some seral stands are replaced by fir and hemlock.

B. Fire

Lodgepole pine is easily killed by fire, as it has thin bark even when old. Trees affected by fire but not killed directly succumbed in 10-12 months to bark beetles (*Ips pini* and *Dendroctanus ponderosae*) in the 1976 Panhandle control burn. Fire decreases the seed availability on the site, because cones are not serotinous. However, removal of overstory shade and litter enhances seedling survival. Major tree competitors, western white pine, the firs and mountain hemlock, are all very susceptible to fire when young, but develop thicker bark with age, and become more resistant than lodgepole. Many understory plants such as grasses and sedges may recover rapidly after fire and some may increase with repeated fires (see Appendix D). Others may be reduced in importance or eliminated at least temporarily. Thus, response of tree regeneration to fire may vary with the ground cover present, as a result of its interference with seedling establishment.

Although fire will reduce the litter on the forest floor, the dead lodgepole needles and twigs will rapidly replenish the fine litter and, as the snags fall, heavy fuels may become very dense. (In the Rocky Mountains, half the snags fall in about 15 years). The usual increase in fuels following fire in lodgepole is in sharp contrast to the fuel reduction which occurred after fire in the primeval ponderosa pine forests, where most of the overstory survived. Fire scar and age class data indicate that some areas which burned in the primeval forest were reburned within twenty to thirty years.

Evidence for the fire history of lodgepole forests comes from several sources: (1) Fire scars are rare. The few are mostly in one community. Those on other species in lodgepole forests are also rare, with the most common, on western white pine, having a record of only two fires. (2) Charcoal is present in variable amounts in the forests. Surface charcoal collected in many stands was identified as lodgepole pine, or white pine, or non-pine species. This can separate stands where fir and hemlock were previously present from those which were only lodgepole pine. (3) Presence of very common age classes may indicate an origin after fire; they may also indicate disturbance by bark beetles or wind effects, or simply the coincidence of heavy seed years with very favorable conditions for seedling establishment, in some communities. (4) Reports by the early qualified observers (e.g. Leiberg 1900), histories of Indian activity, and park records of lightning fires provide much pertinant information.

Lightning fires are common (7 per year recently) in the Crater Lake area and were almost certainly the major ignition source in primeval lodgepole pine forests. Although some low elevation stands were probably burned by Indian-caused fires moving up slope, there was little Indian activity at high elevations where most lodgepole forests are. This situation changed drastically with the arrival of white man in the area about 1855. Fires were used in roadbuilding and caused by visitors and hunters. Grazing on the west slope was accompanied by extensive burning. Considerable fir and hemlock forest was converted to lodgepole pine by this burning, which certainly also burned some of the lodgepole already present. Our age data confirm the historical reports, with many lodgepole stands originating between 1855 and 1900, and many older ones having large age classes established then. These are particularly evident in the areas of greatest activity by white man, the west slope, Pinnacles Valley, and the general route of the Union Creek - Fort Klamath road. With fire suppression, man-caused fires and the size of lightning fires were greatly reduced. These activities of white man have thus resulted in differences from the amounts of lodgepole forest one would have expected with primeval conditions; there is more area of 75 to 120 year old stands and less of younger stands than there would have been.

C. Fire - Bark Beetle Interactions

The effects of fire and bark beetles are not independent of each other. Lodgepole trees which survive fire seem very susceptible to bark beetles, perhaps capable of triggering an epidemic. Trees killed by bark beetles quickly become fuel to support more intense fires. Fire allows another generation of lodgepole pine, which can eventually support more beetles. In contrast, beetle kill of lodgepole in seral forests opens the canopy and thus accelerates growth of the fir and hemlock and the transition to the more fire-proof fir-hemlock forest. The long term effect of beetles thus may be to decrease chance of fire earlier than otherwise, _if_ the stage of high fuel loads passes without fire.

In many northern Rocky Mountain forests, fire suppression led to abnormally large areas of old lodgepole pine with resulting massive beetle kills, much larger than would have occurred in the primeval condition. At Crater Lake, some seral forests have recently reached the size of susceptibility to beetles; recycling them to new, beetle-proof stands with controlled fire might seem a logical thing to do. However, this appears NOT to be appropriate. Many of these stands were converted from fir-hemlock to lodgepole by fires caused by white man and a return to primeval conditions requires some area of lodgepole forest be allowed to revert to fir-hemlock. Furthermore, controlled burning in lodgepole reduces fuel loads only temporarily, since the overstory is usually killed, producing extremely high ground fuels as the debris falls, and probably requiring a reburn for safety. In the resulting lodgepole stand, fire danger and beetle susceptibility eventually will be high again. Thus, a general program of controlled burning in seral stands is ruled out by (1) the policy to return to primeval forest, which requires conversion of some lodgepole forest to fir-hemlock, and (2) long-range safety considerations, i.e., allowing stands to develop naturally to fir-hemlock and thus reducing the fire danger permanently at no management cost. A present period of widespread beetle kills and the resultant high fire danger appear to be the price of a return toward primeval conditions in several of the seral communities.

VI. Types of Forest History and Dynamics

The lodgepole forests in Crater Lake National Park have several apparent types of stand history: Type 1) Those seral lodgepole forests which are rapidly replaced by fir and hemlock need to be considered as a part of the larger complex of fir-hemlock forests. At any one time, part of this complex is in mature fir-hemlock forest, part in seral lodgepole stands, and part in transition (Fig. 1).

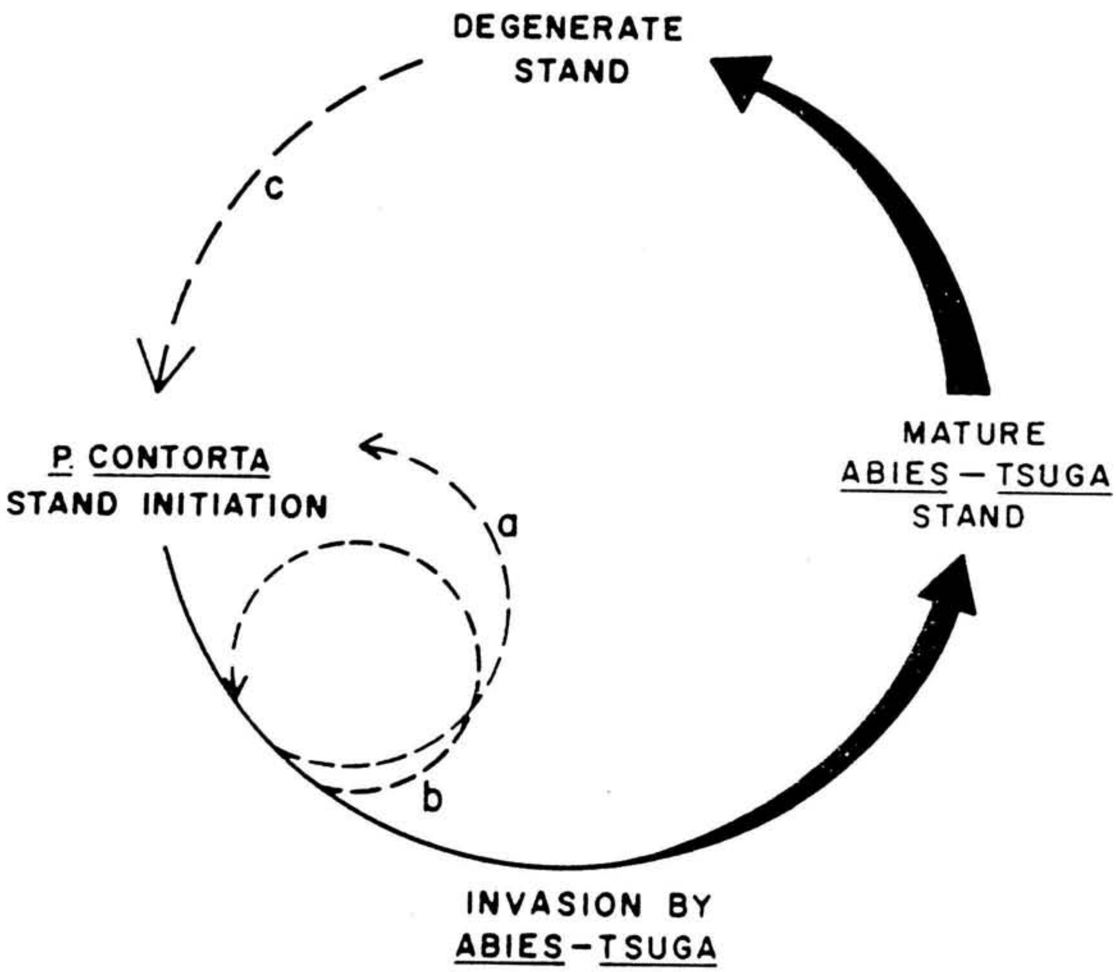


Figure 1. A proposed model of stand development in areas supporting seral P. contorta forest on pumice soils. Heavy arcs indicate phases in which intense fires are unlikely. Solid fine curves indicate phases in which intense fires are more probable. Broken lines signify fires. Fire types a and c are intense enough to initiate a new P. contorta stand. Fire type b may initiate a new age class or only burn the understory and tree reproduction. (from Zeigler, 1978).

Intense fires, which kill the fir and hemlock, create new lodgepole forests, which may then develop into fir-hemlock with time. The lodgepole reproduces poorly in these dense seral forests and beetle kill hastens its demise. Litter is heavy; a reburn would probably kill most of the lodgepole but would also produce a new lodgepole forest. In most stands of this type, the major age class originated after white man arrived. From historical records it seems that a larger proportion of the area which can potentially support fir-hemlock is now in lodgepole than there was in primeval conditions. This resulted from the many fires in 1855 to 1900, some of which burned in mature forest. Type 2) Some areas which can support fir-hemlock are invaded by trees only slowly after forest destruction by fire, probably due to a relatively dense herbaceous cover. Gradually the lodgepole pine increases in number, with most reproduction being near older trees, forming islands of forest in which fir and hemlock become established. These tree islands gradually spread into the meadow between, and, probably after two or more generations of lodgepole without a major disturbance, a closed forest may form. In the meantime, however, some individual tree islands were probably destroyed or thinned by local fires and by bark beetles, delaying forest closure. Tree growth is very rapid once trees finally become established, and they reach beetle-susceptible size at a relatively young age. Type 3) In some lower elevation areas, contiguous to the ponderosa pine forest, periodic ground fires probably maintained a mixed forest of lodgepole, white pine, fir and hemlock. Fuel loads are low, and the burns were probably small or patchy, and of low intensity. Large trees, even lodgepoles, were scarred without dying, but most of the reproduction in the burns would have been killed, and lodgepole reproduction increased in the openings. One fire, which increased the fuel load as dead trees fell, probably led to a greater chance of a later reburn there. If a long enough time passed without fire, an intense fire, killing most trees, could probably have been supported by the accumulated fuel. Lodgepole re-invasion could have led to another forest maintained by periodic ground fires. The burning interval between the only two fires recorded on scars was 30 years, but now, 80 years later, fuel loads still appear too low to allow other than patchy fires. Type 4) Some areas appear to be lodgepole pine climax, where fir and hemlock rarely establish. In the better sites, an open or patchy lodgepole forest gradually may become a quite dense thicket, stopping lodgepole reproduction at least in spots. In the patchy phase fires were probably small or of low intensity due to discontinuous or light cover of litter. These small fires and beetle kills delayed the development of closed forest. After the forest closed, and most likely following heavy beetle kill, intense fires occurred, killing all trees and beginning the cycle again. After 75 years of fire protection, some of these forests have developed densities and fuel loads which are very conducive to intense fire and probably equal or exceed the maximum present under primeval conditions. Type 5) Some climax lodgepole forests are very sparse in all layers, and grow in habitats which appear incapable of supporting denser forest. Fire would be confined to very small patches of continuous fuel. It seems unlikely that extensive fires of any type could have been supported. Reproduction occurs more or less continuously. Beetle kill or local fires remove the older trees; however, some with heavy mistletoe survive longer than any trees in other communities. In these forests, fire effects appear minor, the stands are in more or less a steady state, and further stand development will be a process of primary succession, occurring only over many generations of trees.

VII. Plant Communities in Lodgepole Pine Forest

Eleven communities were defined in the lodgepole pine forest. These communities are named after the apparent climax tree species and dominant shrubs and herbaceous species. A key for the identification of the communities in the field accompanies this report as Appendix B. The general distribution of these communities is shown in a type map (Appendix C). We strongly urge that the map be used only for general orientation and that the key be used when deciding management policies for any particular location in the field.

In general, we found that no one community can be said to result entirely from man's activities, though some types apparently prospered as a result of the numerous fires that accompanied the white man's arrival in the area. One community appears to have experienced fairly frequent ground fires, as well as quite severe fires. Contrary to the popular belief that lodgepole pine is usually seral, we have found three communities where lodgepole pine is the only tree even in old stands, and is reproducing in large numbers.

Brief community descriptions are given below. Accompanying data are presented in Appendices E, F and G. Included in these descriptions are what we believe to be the disturbance histories and the consequences of a fire at the present time. For more complete community description and the facts upon which this summary is based the reader is referred to Robert Zeigler's Masters Thesis. The number in parentheses beside the community name corresponds to the number of the community on the type map (Appendix C).

(1) Incense Cedar/Manzanita

This community is found on steep rocky slopes along Annie Creek Valley. The vegetation includes sparse forest with numerous herbs and shrubs growing among the rocks. Ages indicate that the fires that probably infrequently burned this type likely originated in lodgepole stands downslope from it.

(2) Lodgepole Pine/Bitterbrush/Sedge

Stands of this type are found in the northeast quarter of the Park between

Sharp Peak and Desert Creek at elevations between 1650 m and 1750 m. The herbaceous vegetation is similar to community 3, with the addition of a shrub layer of bitterbrush and, to a lesser extent, rabbitbrush goldenweed. These generally open stands are composed of almost pure lodgepole pine. The apparent successful reproduction by lodgepole pine in the absence of fire, and that all charcoal is from lodgepole pine, indicate that this community is a true lodgepole climax.

There is evidence of past mountain pine beetle activity, though litter accumulation is still fairly light. Because of the patchy nature of the ground cover, light ground fires were probably not extensive. Fairly infrequent intense fires probably recycled the stand after heavy fuel buildup. Most of the areas occupied by this community are probably incapable of supporting either kind of fire at present.

(3) Lodgepole Pine/Sedge-Needlegrass

This community is found on flat areas and depressions with deep pumice and/or scoria deposits at elevations from 1570 m to 2000 m. The largest examples are in Pumice Flat, around the Pumice Desert and on the west side of Sand Creek. The ground vegetation in this type is characteristically depauperate, consisting mainly of a sparse, patchy cover of sedges and grasses. There are very few, if any, shrubs. Though there may be some hemlock and white pine near other communities, lodgepole pine is usually the only tree species present in all layers. Therefore, this community is considered a true lodgepole climax.

Most stands were extensively thinned by mountain pine beetle epidemics in the first half of the century. The thinned stands support relatively vigorous lodgepole regeneration. Most older trees are severely infected with dwarf mistletoe. Considering the present fairly abundant reproduction, this will probably lead to stands being heavily infected with dwarf mistletoe; this was likely also the case in the primeval forest.

Stands in this community probably burned only rarely and then only over small areas. The litter accumulation, even after 70+ years without fire, is very patchy with islands of heavy fuels separated by large areas of mineral soil. Openings in the stand permitting lodgepole regeneration probably resulted from beetle kills. Any fire starting in this type would probably be quite small--limited to one snag or a locally heavy collection of litter. That fire was relatively unimportant in the community in pre-white man times is further supported by the great ages of the stands and the scarcity of charcoal on the forest floor. All charcoal is from lodgepole pine.

(4) Lodgepole Pine/Sedge-Lupine

This third lodgepole pine climax community is found in extensive areas about the Park. It is most accessible on the west side of Sand Creek. Other large stands may be seen northeast of Cascade Spring, southwest of Sharp Peak, west of Timber Crater and southeast of Bald Crater. Stands of this type, found between 1700 m and 1980 m, are recognized by the presence of pine (Anderson's) lupine. In some areas goldenweed and squaw current may be present.

Areas supporting this type were probably visited by intense fires in the past as suggested by the presence of only one or two age classes in all but 2 of 13 sample plots. Recent high bark beetle activity and apparent ice breakage have led to very heavy litter accumulations in some areas. This natural buildup has been increased by locally dense reproduction, resulting in areas of apparently very high flamability. These areas are also characteristically severely infected with dwarf mistletoe. It seems likely that areas such as these would have burned before now without fire suppression. Fire in the area would probably result in nearly 100% tree mortality with a short term reduction in fuel. Dwarf mistletoe in the stand would be eliminated or greatly reduced. As mortality from the fire fell the fuel load would again increase. Another fire, consuming this post-fire fuel and corresponding reproduction, would probably permit the establishment of a stand of vigorously growing trees in an open meadow-like environment.

The closed, highly flammable areas of this community are found between the North Entrance Road and Timber Crater and at the southeastern end of the Pinnacles Valley. Open stands, whose origins are likely those hypothesized above, are found in the upper western Pinnacles Valley, the area southwest of Sharp Peak, and west and north of Desert Cone.

(5) White Fir /California Brome-Lupine

This community is found only in a small area northeast of the Panhandle and west of Sun Creek at elevation 1460 m. White fir is the dominant tree in the understory. There is extreme accumulation of litter from past bark beetle epidemics in some areas. Age data indicate that this type existed prior to the white man's arrival in the area. Following 1855, fires may have increased the area occupied by this type. A fire at present would probably destroy most of the stand in some areas, with lodgepole pine re-establishing itself following fire.

(6) Subalpine Fir/Collomia-Peavine

This community is found in very wet areas near the headwaters of Bybee Creek and Copeland Creek at about 1700 m. The community is best distinguished by the presence of collomia and peavine, though very wet sites may contain a rich flora. Lodgepole pine grows very rapidly on these sites and both Shasta red fir and subalpine fir occur. The dynamics of this type are probably quite similar to the subalpine fir/goldenweed/aster-blue wildrye type (no. 7 below), though tree invasion is even slower because of intense competition with herbaceous species.

(7) Subalpine Fir/Goldenweed/Aster-Blue Wildrye

This relatively lush seral community is found between 1540 and 1920 m in the vicinity of streams and at the base of steep ridges. The most extensive stands are on the west slope of Mount Mazama, Munson Valley, and along upper Sand Creek. Smaller stands occur near Sphagnum Bog, Crater Springs and Pole Bridge Creek. Floristically, this type differs from others in the presence of Cascade aster, blue wildrye, Green's rabbitbrush and/or Rydberg's penstemon. Subalpine fir is also present in almost all areas. Rather than being a true forest, the community is a forest-meadow mosaic. Patches of relatively dense trees of all sizes are separated by relatively lush meadows of lupines, grasses and sedges. The islands of tree reproduction appear to be slowly spreading into the meadow areas. Heavy litter accumulations occur only in the tree islands. In older, nearly closed stands, such as those found in upper Munson Valley, tree mortality from mountain pine beetle has been and continues to be quite high among older, larger trees.

Most of these areas were burned before 1900 by ranchers, to improve grazing for their herds. Age analysis indicates that most of the west slope stands are of post-white man origin while those in Munson Valley contain pre-white man age classes. Charcoal data indicate that some earlier stands contained predominantly fir and hemlock. Fires in this type, at present, would probably be limited to a few tree "islands" and the intervening meadow-like areas. In the primeval forest, intense fires through nearly closed forests of this type probably resulted in very open forest-meadow mosaics. These mosaics gradually closed over several generations of trees, with closure retarded or temporarily reversed by periodic light or small fires. The closed forests either burned again or developed to pure fir-hemlock stands.

(8) Shasta Fir-Mountain Hemlock/Sedge-Lupine

This widespread seral community is found between 1690 m and 2080 m throughout the Park. Extensive stands may be found in the northwest quarter of the Park, on the slopes of Timber Crater and in Castle Creek Valley. This community is recognized by the presence of pine and/or broadleaf lupine in an understory of conspicuous and apparently vigorous fir and hemlock reproduction.

Bark beetle activity and breakage at galls on the main stems of trees have contributed to a heavy accumulation of lodgepole pine litter. Fires in this community would probably result in nearly 100% tree mortality and a post-fire forest of lodgepole pine. However, litter loads would again be high within a decade or two after the fire as fire-killed trees fell.

Age analysis of stands comprising this community reveals that only half of the stands contain trees which germinated before 1855. Charcoal from some of the stands indicates that the sites were occupied earlier by fir and hemlock forests. In addition, many stands contain old, unburned logs and stumps that were obviously quite old firs and hemlocks from a previous forest. Some stands contain surviving large trees of these species. Other stands of almost pure medium-sized fir and hemlock contain a few very large lodgepole pines and have considerable lodgepole mortality on the forest floor.

These data and observations in this community suggest that:

1) A natural cycle exists where lodgepole pine forests are created from mature fir-hemlock forests by fire. Lodgepole pine forests created in this manner may be maintained as lodgepole by repeated fire for a period of time before developing to fir-hemlock again (Fig. 1).

2) Fires caused by white man in the late 19th century increased the area of this community and created areas of lodgepole that were previously in fir-hemlock. Thus, the area of this community is larger now than in the primeval situation.

(9) Mixed Conifer/Manzanita-Bitterbrush/Sedge

This community is found only in steep slopes northeast of Mazama Rock at elevations around 1770 m. It is similar in structure and composition to the Mixed Conifer/Manzanita community. It apparently experiences periodic ground fire. Severe fires are probably infrequent.

(10) Mountain Hemlock/Grouse Huckleberry

This seral community, found between 1600 m and 1770 m, is recognized by patches of grouse huckleberry in an otherwise depauperate understory. Tree reproduction is mixed hemlock and fir with the former usually dominant. The litter accumulation, age structure and apparent history of this type are similar to the Fir-Hemlock/Sedge-Lupine community (number 8).

(11) Mixed Conifer/Manzanita

This is one of the communities of lodgepole pine that probably experiences fairly frequent ground fires. It grows in small areas throughout the Park between elevations of 1570 and 1900 m. The sparse understory is dominated by pinemat manzanita and/or greenleaf manzanita. Tree reproduction is well represented by Shasta red fir, western white pine and lodgepole pine. Ponderosa pine may be found in stands on the east side of the Park. A sizeable stand is found along Highway 62 north of the Panhandle. Other stands may be found along the East Fork of Annie Creek, the east side of Sand Creek, northeast of Mazama Rock and west of Bald Crater.

These stands are typically quite old and heavily infected with dwarf mistletoe. Bark beetle mortality is apparently continuous. Many trees exhibit fire scars with the interval between scars on white pine being between 30 and 40 years. This community probably experiences several light fires between the infrequent severe fires which would be responsible for stand destruction. These light, patchy fires would allow continued reproduction by lodgepole pine.

VIII. Suggestions for Management

The forests of lodgepole pine in Crater Lake National Park vary in their characteristics, their environment, their potential for supporting fir-hemlock forest, and their apparent history. This variability existed previous to white man's influence and must be reflected in the specific management plans prepared for each area.

We feel that the only management tool reasonably available to the park is the control or use of fire. Direct control of bark beetles and dwarf mistletoe is neither desirable nor feasible for the large areas involved; following a return to a natural fire regime, any deviations from primeval levels in these biological factors should again eventually decrease.

We have divided the lodgepole pine communities discussed above into five management units, each of which requires separate attention. Almost throughout, the differences from the ponderosa pine system are extreme. The species differ (long-lived and fire proof vs. short-lived and fire susceptible) and their fire histories are usually different (frequent ground fire vs. the five types, only one of which is like ponderosa). Thus management policy cannot be transferred from ponderosa to lodgepole forests. Specifically, controlled ground fire designed to release larger trees seems appropriate for only one type of lodgepole forest, and even there only in patches. There are several reasons for this.

Such fires would be very difficult to produce with all but the lightest fuel loads; most surviving lodgepole pines will be killed by bark beetles or eventually succumb to heart rot. If it did prove possible, a series of this type of fire would allow large mistletoe-infected trees to remain, insuring heavy infection of most fire-stimulated reproduction and its subsequent deformity. Indeed, in the one community where repeated light fires apparently did occur the forest is in precisely this condition, and probably was so in the primeval state. In other types, when fire occurred it killed the overstory, removing the dwarf mistletoe from the site.

Fire seems also to be inappropriate to simulate or anticipate beetle-caused mortality. Beetle kill and fire will produce very different effects on the forest. Beetles "thin from above," killing the largest trees and opening the canopy, accelerating growth of smaller trees, but not removing the litter. A light controlled fire "thins from below" (any trees which survive are likely to be the largest), killing reproduction of all species and removing the litter, encouraging lodgepole reproduction.

The adoption of the "natural fire policy" by the park will greatly reduce the need for man-initiated fire in the management of lodgepole pine forest, since lightning was the predominant ignition source in most primeval lodgepole in the Park.

The most obvious deviations from primeval structure were caused by white man's promiscuous use of fire, so the suppression of man-caused fires has already served as one very large step toward returning the primeval processes. We suggest that fires obviously of man-caused origin continue to be suppressed in all areas of the Park. They have been in areas and forest types in a pattern which shows little correlation with natural iginition (see Fig. 1 in the Park Fire Management Plan). Another large step has now been taken in the decision to let some natural fires burn. In only a few types has the suppression of all fires resulted in large enough deviations from the primeval conditions to justify prescribed fire. In some other spots outside the natural fire area, it may be necessary to prescribe fire to substitute for the absence of natural fire, but these should be relatively few.

Some general suggestions for management we feel might be helpful are given below; specifics for each area follow: (1) In much of the lodgepole pine forest, the time between primeval fires greatly exceeded that in the ponderosa area. Plans for management must encompass long time spans, and perhaps provide for the chance that natural fires are not solving all problems, on a long term basis. (2) Any prescribed burning should be preceeded by small scale, experimental burns, whose effects need to be evaluated, probably for several years, before management burning. There is no need to rush the return toward primeval conditions in any case, and less in the lodgepole than in the ponderosa. We were disappointed that the slow, cautious, experimental approach suggested for ponderosa was not followed, and hope it will be here. Simply transporting the philosophy, methods and haste used in the ponderosa management to lodgepole would, for about 90% of the area, cause more deviation from the primeval conditions in a short time than all the man-caused perturbations of the last 120 years. It is important to remember that repeatedly burning ponderosa pine lightly will eventually reduce fuel loads; burning lodgepole will probably always eventually increase them. (3) Since lodgepole pine at Crater Lake does not have serotinous cones, seed supply may limit the rate of reforestation. Since prescribed burning will probably kill most lodgepole, directly or indirectly, small burning units with mature forest between would help aid reforestation. Reports for lodgepole pine/sedge-needlegrass communities elsewhere in Oregon indicate that regeneration will be sufficient (for forestry purposes) only one tree height's distance into a clearing. (4) Much of the danger associated with heavy roadside fuel loads (e.g. along Hwy 62 in Castle Creek Valley) could be alleviated by keeping the wide shoulders of the roads as fireproof as possible. Removing wood chips, grass, and trees which invade there all would help. (5) Providing fire-ecology and fire-management information to visitors and local residents is important, and should be even more vigorously pursued. (6) Some major changes in vegetation since white man's arrival are probably natural. For example, much lodgepole invasion of the Pumice Desert and meadows occurred some years ago and trees are now large enough to be obvious. Elsewhere in the Cascades, a similar wave of tree invasion has been related to the dry period of late 1920s to late 1930s. It seems inappropriate to us to eliminate such changes from the primeval which are not caused by man, in response to the Leopold Report.

Specific Recommendations

Natural Fire Areas - Units I and II

In the discussion below, units I, II and III refer to the Park Fire Management Plan; unit I has natural fire, unit II has natural fire except with high fire danger, and in unit III all fires are suppressed.

A key to the five Management Types we suggest is given in Table 1. Their general location in the Park is shown in Figure 2.

Given the natural fire policy, prescribed burning is neither necessary nor justified for three of the five management types in units I and II, where natural fires will burn.

Table 1. Key to Management Types listed on pp. 32-37. Suggestions for management may vary depending on whether the type is inside or outside the boundary of the natural fire area as shown on the Fire Management Plan. See the text for details.

A. Less than 10% of tree reproduction is fir and hemlock.

- I. Forest is quite open; fuels are generally discontinuous. ....MANAGEMENT TYPE <u>C</u>
- II. Thickets of lodgepole pine are common; fuels are often continuous and heavy. ....MANAGEMENT TYPE <u>E</u>

AA. Greater than 10% of tree reproduction is fir and hemlock.

- I. Subalpine fir is conspicuous ....MANAGEMENT TYPE <u>B</u>
- II. Subalpine fir is rare or absent.
  - 1. Overstory is dense, primarily of lodgepole pine. Fuels are heavy and often continuous. ....MANAGEMENT TYPE <u>A</u>
  - 11. Overstory is relatively open, including other pines or shasta fir. Fuels are discontinuous. Pinemat manzanita is often conspicuous. ....MANAGEMENT TYPE <u>D</u>

Figure 2. Approximate location of lodgepole forests in Crater Lake National Park, with suggested Management Type (A-E) noted. See text for definitions. X = non-lodgepole type surrounded by lodgepole. The heavy line which more-or-less parallels the park boundary is the inner limit of the fire suppression zone, as shown on the Park's Fire Management Plan.

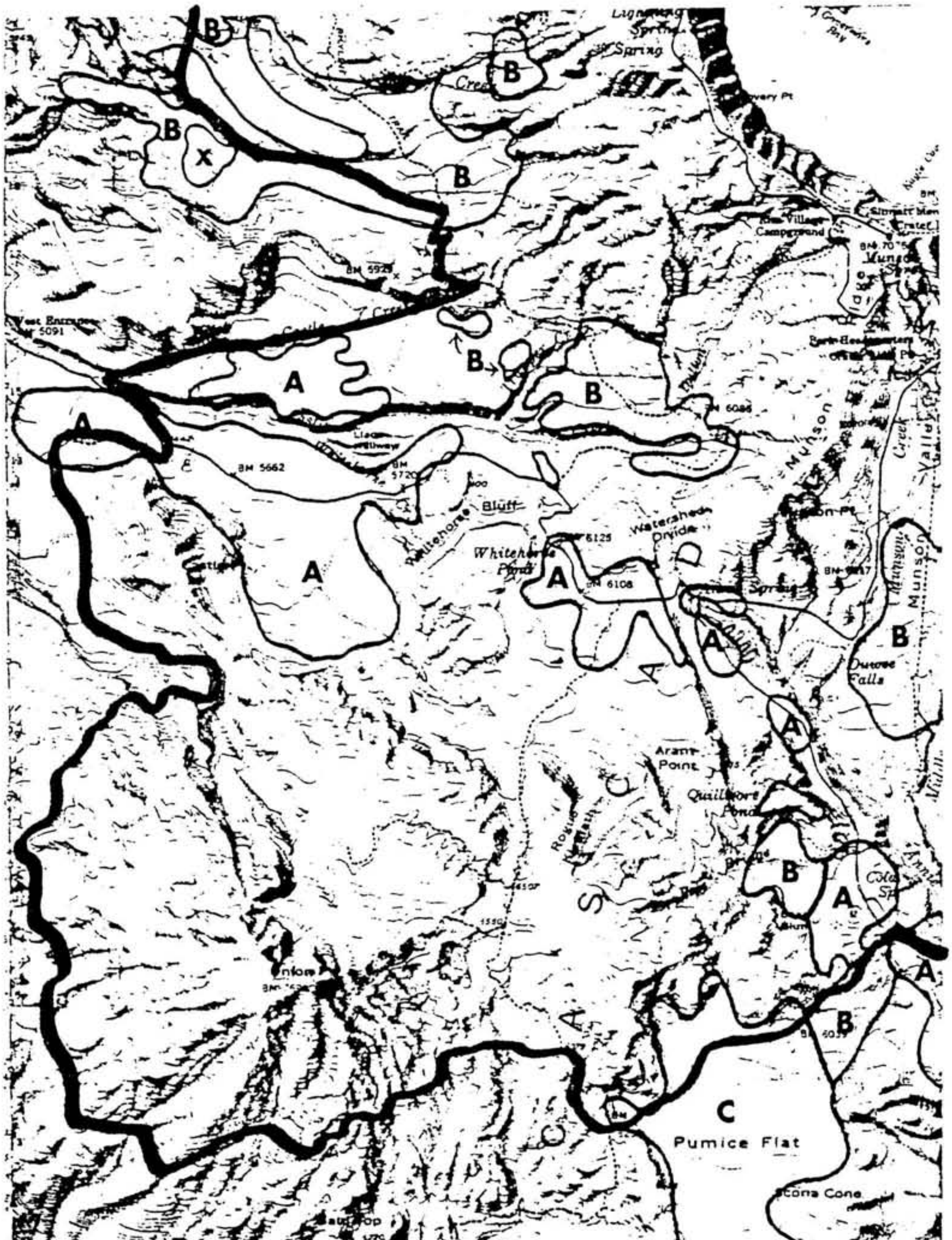


Fig. 2. (Continued)

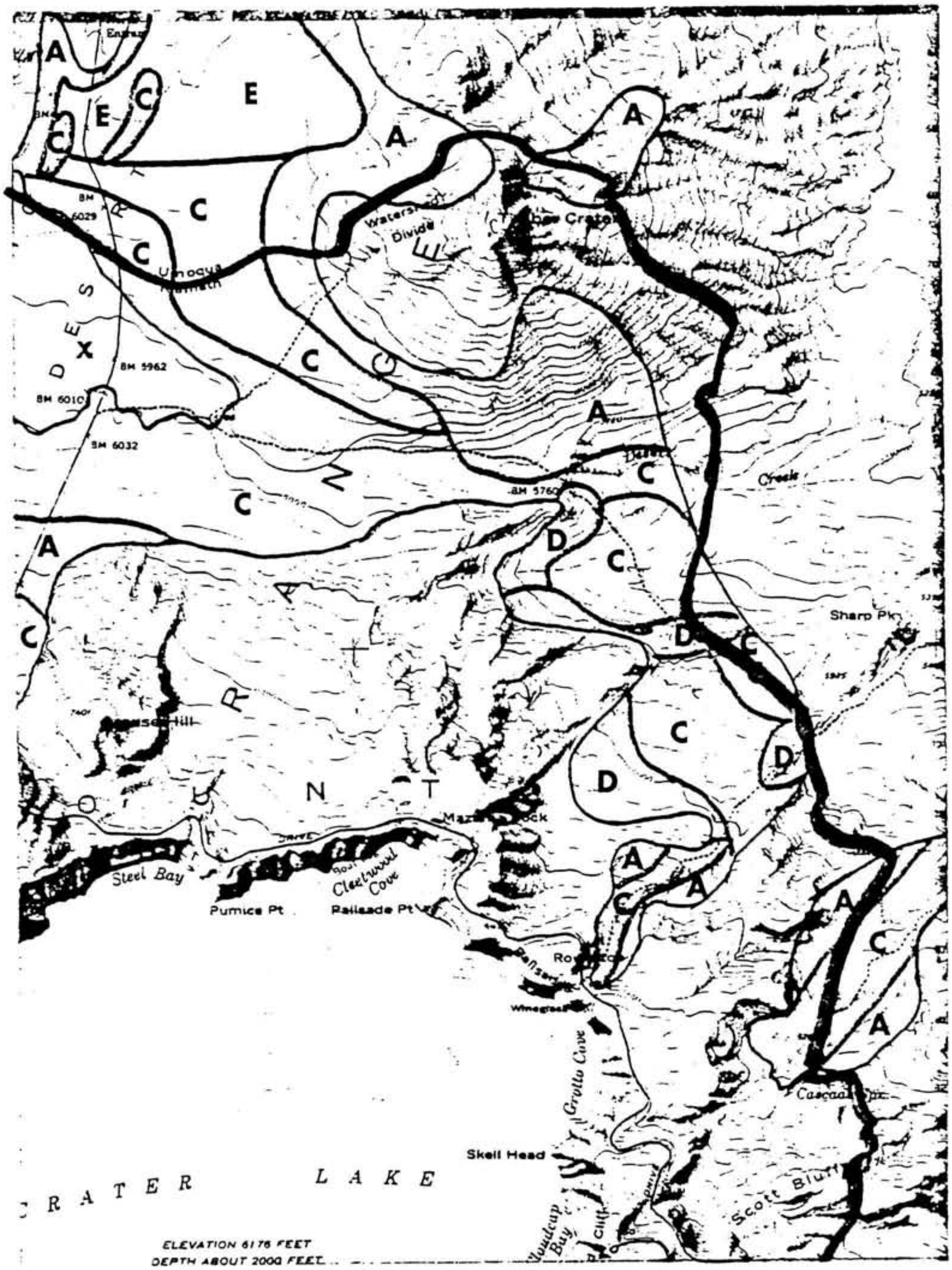


Fig. 2. (Continued)

Fig. 2. (Continued)

Type A:

Fire history type (1)

Communities: a) Shasta Fir-Mountain Hemlock/Sedge-Lupine
b) Mountain Hemlock/Grouse Huckleberry

Suggestions: No prescribed burning necessary.

Reasons: Presently, more of the park that can support fir-hemlock is in lodgepole than during primeval time. Through time, lack of man-caused fire will allow the balance of fir-hemlock to lodgepole to return toward an equilibrium to be determined by the natural fire regime. Exactly what this balance was in primeval times we cannot determine, but we are sure there was less lodgepole pine. Use of fire to reduce the heavy fuel loads in these types is not justified--the resulting dead lodgepole would raise ground fuels to even greater levels within a few years. The fire danger and beetle kill now associated with these stands is the price to be paid for a return toward primeval conditions.

Type B:

Fire history type (2)

Communities: a) Subalpine Fir/Goldenweed/Aster-Blue Wildrye
b) Subalpine Fir/Collomia-Peavine

Suggestions: No prescribed burning necessary.

Reasons: Much of this area, on the west slope and in the Pinnacles Valley, was burned since 1855, and is thus relatively early in its development. A gradual encroachment of forest on meadow is probably the "natural" condition, with small fires periodically eliminating some tree islands and meadow reproduction. Hopefully, natural fire will fill this role. Our interpretation of this system's dynamics is open to considerable question, but unless a detailed re-examination shows it to be erroneous, no use of prescribed fire should be necessary. In perhaps 30-60 years the situation should be reassessed if these areas are not following the patterns we predict or if natural fire has not occurred in at least some spots.

Type C:

Fire history type (5)

Communities: a) Lodgepole Pine/Sedge-Needlegrass
b) Lodgepole Pine/Bitterbrush/Sedge
c) Portions of Lodgepole Pine/Sedge-Lupine
The more open areas, best represented in the following locations:
1) South and West of Timber Crater
2) SW of Sharp Peak
3) Upper Western Pinnacles Valley

Suggestions: No prescribed fire necessary.

Reasons: These forests are somewhat to very open, with light and discontinuous fuel. It is doubtful that (1) fires have ever been large or severe and (2) these areas will produce enough fuel to support such fires in the foreseeable future.

Type D:

Fire history type (3)

Communities: a) Mixed Conifer/Manzanita
b) Mixed Conifer/Bitterbrush-Manzanita/Sedge

Suggestions: Prescribed burning should be carried out in the not-too-distant future, perhaps following the higher priority areas in the ponderosa pine (after priority 4). The fire should be a low-intensity ground fire; it should miss many areas and be intense enough to scar, but not kill, some lodgepole (if possible) and white pine. The ignition pattern should not be so all-encompassing that all pockets of fuel burn in any one fire. This type should be burned over a long period--perhaps 30 years--to produce a variety of age classes. Fires could be repeated at 30-50 year intervals in any given area. Areas burned by natural fire need no treatment.

Reasons: This area has low fuel loads except in spots. Small scars on living lodgepole give evidence of ground fires. The only scars with 2 fires, on white pine, had a 30-year interval. The relatively great ages and heavy dwarf mistletoe of these stands indicate that fires which destroy the entire stand are rare.

Type E:

Fire history type (4)

Community: Denser parts of Lodgepole Pine/Lupine-Sedge, best represented at:
a) East of North Entrance
b) Lower Western Pinnacles Valley
c) ESE of Bald Crater

Suggestions: Prescribed fire appears justified and desirable in some of this type, with a goal of its all burning (by nature or prescription) within the next 70 to 100 years. The first burns (following preliminary experimental work) could begin any time, and should be aimed at breaking the extensive areas of this type (1) between Timber Crater and the north entrance road, and (2) in lower Pinnacles Valley into smaller units, to decrease the hazard of very large, intense fires. After that, burning should be periodic, in Unit III first, to fulfill the 70-100 year burning cycle and provide a mosaic of stands of several different ages. After the first burning cycle, in which prescribed fire will help remove the accumulated fuel and thickets that fire suppression has allowed, a natural fire regime should be sufficient. Even now, prescribed burning should be applied only as necessary to assure that new stands are generated more or less evenly over the next 70-100 years, assuring that areas of high fire danger remain relatively small and discontinuous at any one time. Prescribe-burning large areas, or the whole area within a few years, will only result in a probably unnatural concentration of fire danger both now (large expanses of dead fuel) and at some future date (extensive thickets of mature forest again). Reburning after snags fall (10-20 years) will be necessary to keep fire danger low. Extreme caution will be necessary.

Reasons: It appears that these areas burned in intense fires in primeval conditions, destroying the old lodgepole forest, and replacing it with a young one. Fuel loads are very heavy in extensive areas; prescribed burning to break up the expanse will reduce the danger of a wild fire here moving over large areas or out of the Park. Only in this type has the fire suppression since 1902 allowed fuel build-up to exceed our perception of primeval conditions in a lodgepole type whose area does not need to be reduced.

Fire Suppression Area - Unit III

We suggest that prescribed burning in Unit III be concentrated at first in the ponderosa and lodgepole pine types, in a pattern which isolates Units I and II from surrounding lands. This should eventually allow the expansion of Units I and II and thus reduce the amounts of prescribed burning necessary in most types. Recall that, in lodgepole (1) a repeat burn will be necessary after snags fall and (2) living fuel loads will rapidly increase after fire in the dense seral stands, even though ground fuels will be reduced.

Type A (Unit III only):

Communities: a) Fir-Hemlock/Sedge-Lupine
b) Hemlock/Grouse Huckleberry
c) White Fir/California Brome-Lupine

Suggestions: There is no way to estimate the exact proportion of the whole area capable of supporting fir-hemlock which really was lodgepole in primeval times. We are certain, however, that it was smaller than at present. We feel that prescribed burning should be kept to a minimum for the present. Clearing of heavy ground fuels (for firewood) might help reduce fire danger along highways. Assessment of the role of natural fire in these forests will be possible after a long enough time under the natural fire policy. Some reconversion of primeval lodgepole to lodgepole certainly occurred; this gives a natural rationale for some prescribed burning in these lodgepole types.

Type A is represented in Unit III at many places. (1) Several are small and away from the boundary; we suggest no treatment; (2) In the following areas, burning across the narrow spots in the types near the Park boundary should be sufficient: S of Castle Creek, NE of Bald Crater, E of the North Entrance (where burns should coordinate with those in Type E). (3) Along Hwy 62 S of Cold Spring, between the highway and the canyon, seems a good place to experiment with fire in this type. It might also serve as a visitor exhibit. (4) The White Fir community NE of the panhandle should be treated only along the boundary, also.

Type B (Unit III only):

Communities: a) Subalpine Fir/Goldenweed/Aster-Blue Wildrye
b) Subalpine Fir/Collomia-Peavine

Suggestions: In Unit III, this type is quite young, and the forest patchy. No treatment is necessary at present, except perhaps in its denser parts which are right along the Park boundary. Later assessment of community change, as in Units I and II, will be necessary.

Type C (Unit III only):

Communities: a) Lodgepole Pine/Sedge-Needlegrass
b) Open areas of Lodgepole Pine/Sedge-Lupine

Suggestions: These have very sparse litter. As long as this remains true, no treatment is necessary.

Type D and Type E:

Prescribed burning should proceed as in Units I and II. Unit III should have higher priority.

APPENDIX A

Common and Scientific Names of Plant Species in Lodgepole Pine Forest, Crater Lake National Park

Scientific Name	Common Name
TREES	
Abies concolor (Gord. & Glend.) Lindl.	White fir
Abies lasiocarpa (Hook.) Nutt.	Subalpine fir
Abies magnifica Murr. var. shastensis Lem.	Shasta red fir
Calocedrus decurrens (Torr.) Florin	Incense cedar
Pinus albicaulis Engelm.	Whitebark pine
Pinus contorta Dougl. var. murrayana	Lodgepole pine
Pinus monticola Dougl.	Western white pine
Pinus ponderosa Dougl.	Ponderosa pine
Tsuga mertensiana (Bong.) Carr.	Mountain hemlock
SHRUBS	
Arctostaphylos nevadensis Gray	Pinemat manzanita
Arctostaphylos patula Greene	Green-leaf manzanita
Castanopsis chrysophylla (Dougl.) A.D.C.	Golden chinquapin
C. sempervirens (Kell.) Dudl.	Bush chinquapin
Ceanothus prostratus Benth.	Squawcarpet
Ceanothus velutinus Dougl.	Snowbrush
Haplopappus bloomeri Gray	Rabbitbrush goldenweed
H. greenei Gray	Greenes goldenweed
Purshia tridentata (Pursh.) D.C.	Antelope bitterbrush
Ribes cereum Dougl. var. cereum	Squaw current
R. lacustre (Pers.) Poir.	Prickly current
Symphoricarpos albus (L.) Blake var. laevigatus Fern.	Snowberry
S. mollis Nutt.	Creeping snowberry
Vaccinium scoparium Leiburg	Grouse huckleberry
GRASSES	
Agrostis scabra Wild.	Rough bentgrass
Bromus carinatus Hook. & Arn.	California brome
Calamagrostis canadensis (Michx.) Beauv.	Bluejoint reedgrass
Elymus glaucus Buckl.	Blue wildrye
Melica subulata (Griseb.) Scribn.	Melic
Muhlenbergia filiformis (Thurb.) Rudb.	Pullup muhly
Sitanion hystrix (Nutt.) Smith var. hordeoides (Susksd.) Hit.	Bottlebrush squirreltail
Stipa occidentalis Thurb. var. californica (Merr. & Davy) Hitchc.	California needlegrass
S. occidentalis Thurb. var. occidentalis	Western needlegrass
S. thurberiana Piper	Thurber needlegrass

Scientific Name	Common Name
SEDGES and RUSHES	
Carex abrupta Mkze.	
Carex halliana Bailey	Hall's sedge
Carex pensylvanica Lam.	Long stolon sedge
Juncus parryi Engelm.	Drummond rush
Luzula hitchcockii Hamet-Ahti	Smooth woodrush
FORBS	
Agoseris spp.	Agoseris
Anaphilis margaritacea (L.) B. & H.	Pearly-everlasting
Anemone lyallii Britt.	Lyall's anemone
Antennaria alpina (L.) Gaertn.	Alpine pussytoes
Arabis platysperma Gray	Broadseed rockcress
Arenaria pumicola Coville & Leiburg	Pumice sandwort
Aster chilensis Nees ssp. *adscendens* (Lindl.) Cronq.	Long-leaved aster
Aster ledophyllus Gray var. *Covillei* (Greene) Cronq.	Cascades aster
Castilleja applegatei Fern. var. *fragilis* (Zeile) N. Holmgr.	Applegate paintbrush
C. miniata Dougl. var. *miniata* Hitchc.	Scarlet paintbrush
Chimaphila menziesii (R.Br.) Spreng.	Little prince's-pine
Chimaphila umbellata (L.) Bart.	Prince's-pine
Claytonia lanceolata Pursh. var. *multiscapa* (Rydb.) Hitchc.	Lanceleaf springbeauty
Collomia mazama Cov.	Mazama collomia
Epilobium angustifolium L.	Fireweed
Erigeron peregrinus (Pursh.) Greene ssp. *callianthemus* (Greene) Cronq. var. *eucallianthemus* Cronq.	Wandering fleabane
Eriogonum marifolium T. & G.	Mountain buckwheat
Fragaria virginiana Duchasne var. *platypetala* (Rydb.) Hall	Broadpetal strawberry
Gilia aggregata (Pursh.) Spreng. var. *aggregata*	Scarlet gilia
Hieracium albiflorum Hook.	White hawkweed
H. cynoglossoides Arv.-Touv.	Houndstongue hawkweed
Kelloggia galioides Torr.	Kelloggia
Lathyrus nevadensis Wats.	Peavine
Ligusticum grayi Coult. & Rose	Gray's licorice-root
Lomatium martindalei Coult. & Rose var. *martindalei*	Barestem lomatium
L. triternatum (Pursh.) Coult. & Rose	Nineleaf lomatium
Lupinus albicaulis Dougl.	Pine (Anderson's) lupine
L. latifolius Agerdh. var. *latifolius* Hitchc.	Broadleaf lupine
L. lepidus Dougl. var. *lobii* (Gray) Hitchc.	Least lupine
Microseris alpestris (Gray) Jones ex Cronq.	Alpine lake agoseris
Orthocarpus imbricatus Torr.	Mountain owl-clover
Osmorhiza chilensis H. & A.	Mountain sweet-root
Penstemon rydbergii A. Nels. var. *varians* (A. Nels.) Cronq.	Rydberg's penstemon
Phlox caespitosa Nutt.	Tufted phlox

Scientific Name	Common Name
FORBS (continued)	
Polygonum newberryi Small var. newberryi	Newberry's fleeceflower
Pterospora andromeda Nutt.	Woodland pinedrops
Pyrola picta Smith	Whitevein pyrola
P. secunda L.	Sidebells pyrola
Ranunculus occidentalis Nutt. var. dissectus Hend.	Western buttercup
Senecio integerrimus Nutt.	Western groundsel
S. triangularis Hook.	Arrowleaf groundsel
Smilacina stellata (L.) Desf.	Starry solomon plume
Solidago canadensis L. var. salebrosa (Piper) Jones	Meadow golden rod
Spraguea umbellata Torr. var. caudicifera Gray	Umbellate pussypaws
Stachys rigida Nutt.	Rigid betony
Stephanomeria lactucina Gray	Skeleton weed
Trifolium longipes Nutt.	Longstem clover
T. repens L.	White clover
Veratrum viridae Ait.	Green false hellebore
Vicia americana Muhl.	Vetch
Viola praemorsa (Dougl.) Wats.	Upland yellow violet
MOSSES	
Brachythecium sp. B.S.G.	
Ceratodon purpureus (Hedw.) Brid.	
Polytrichum juniperinum Hedw.	

APPENDIX B

Key to the Plant Communities in the *Pinus contorta* Forest of Crater Lake National Park, Oregon (from Zeigler, 1978)

(*Pinus contorta* must comprise at least 50% of the canopy, and is usually much more important. The key species must be within 15 m of the observer. The descriptions following the dash are simply aids to the field worker. The number in parentheses following the community name corresponds to the community number in the text and in Appendix C.)

A. Abies-Tsuga reproduction less than 10% of total reproduction

I. *Calocedrus decurrens* present in canopy and as reproduction - steep rocky slopes; *Arctostaphylos* spp. and *Ceanothus* spp. common

CALOCEDRUS DECURRENS/ARCTOSTAPHYLOS (1)

II. *Calocedrus decurrens* absent

1 - *Purshia tridentata* present in understory - east side; *Carex pensylvanica*, *Stipa occidentalis*, *Lupinus lepidus* and *Haplopappus bloomeri* present

PINUS CONTORTA/PURSHIA/CAREX (2)

11 - *Purshia tridentata* absent

a *Lupinus albicaulis* present

- understory of *C. pensylvanica*, *Stipa*, *Sitanion hystrix*; *Ribes cereum* and *Haplopappus bloomeri* may be present

PINUS CONTORTA/CAREX-LUPINUS (4)

aa *Lupinus albicaulis* absent

- depauperate understory with *Carex*, *Stipa* and *Lupinus lepidus* present; *Eriogonum marifolium* and *Spraguea umbellata* may be present.

PINUS CONTORTA/CAREX-STIPA (3)

AA. Abies-Tsuga reproduction greater than 10% of total reproduction (conspicuous)

I. Lupinus albicaulis and/or L. latifolius present

1 Abies concolor reproduction more abundant than A. magnifica var. shastensis.

- Bromus carinatus, Haplopappus bloomeri, Carex, Stipa and Sitanion hystrix may be present.

ABIES CONCOLOR/BROMUS CARINATUS-LUPINUS (5)

11 Abies concolor less abundant (usually absent or rare) than A. magnifica var. shastensis or A. lasiocarpa

a Lathyrus nevadensis and Collomia mazama present

- Solidago, Trifolium, Ranunculus species, Senecio triangularis, Veratrum viridae as well as numerous other species may be present; forest-meadow mosaic.

ABIES LASIOCARPA/COLLOMIA-LATHYRUS (6)

aa Lathyrus and Collomia absent

i at least two of the following species present: Elymus glaucus, Aster ledophyllous, Haplopappus greenei, Penstemon rydbergii

- Forest-meadow mosaic.

ABIES LASIOCARPA/HAPLOPAPPUS/ASTER-ELYMUS (7)

ii above combination of species absent.

- A. magnifica var. shastensis and T. mertensiana reproduction abundant; Elymus glaucus may be present.

ABIES MAGNIFICA VAR. SHASTENSIS-TSUGA MERTENSIANA/CAREX-LUPINUS (8)

II. Lupinus albicaulis and L. latifolius absent

1 Purshia tridentata present

- east side; steeper slopes; A. magnifica var. shastensis, Pinus ponderosa, P. monticola, Arctostaphylos spp. may be present.

MIXED CONIFER/ARCTOSTAPHYLOS-PURSHIA/STIPA (9)

11 Purshia tridentata absent

a Vaccinium scoparium present

- cooler moister areas, T. mertensiana present, depauperate understory.

TSUGA MERTENSIANA/VACCINIUM (10)

aa Vaccinium scoparium absent

- Arctostaphylos spp. present, P. monticola and A. magnifica var. shastensis present in quantity and may be quite large. Tsuga mertensiana rare.

MIXED CONIFER/ARCTOSTAPHYLOS (11)

APPENDIX C

Distribution of plant communities in Pinus contorta forest in Crater Lake National Park. Heavy black lines correspond to the boundaries of the principal P. contorta stands. "X" signifies non-P. contorta surrounded by P. contorta. Each grid unit in the eastern part of the Park is one mile square. All maps are to the same scale (from Zeigler, 1978).

Communities:

1 = Calocedrus decurrens/Arctostophylos

2 = Pinus contorta/Purshia/Carex

3 = Pinus contorta/Carex-Stipa

4 = Pinus contorta/Carex-Lupinus

5 = Abies concolor/Bromus carinatus - Lupinus

6 = Abies lasiocarpa/Collomia-Lathyrus

7 = Abies lasiocarpa/Haplopappus/Aster-Elymus

8 = Abies magnifica var. shastensis - Tsuga mertensiana/Carex-Lupinus

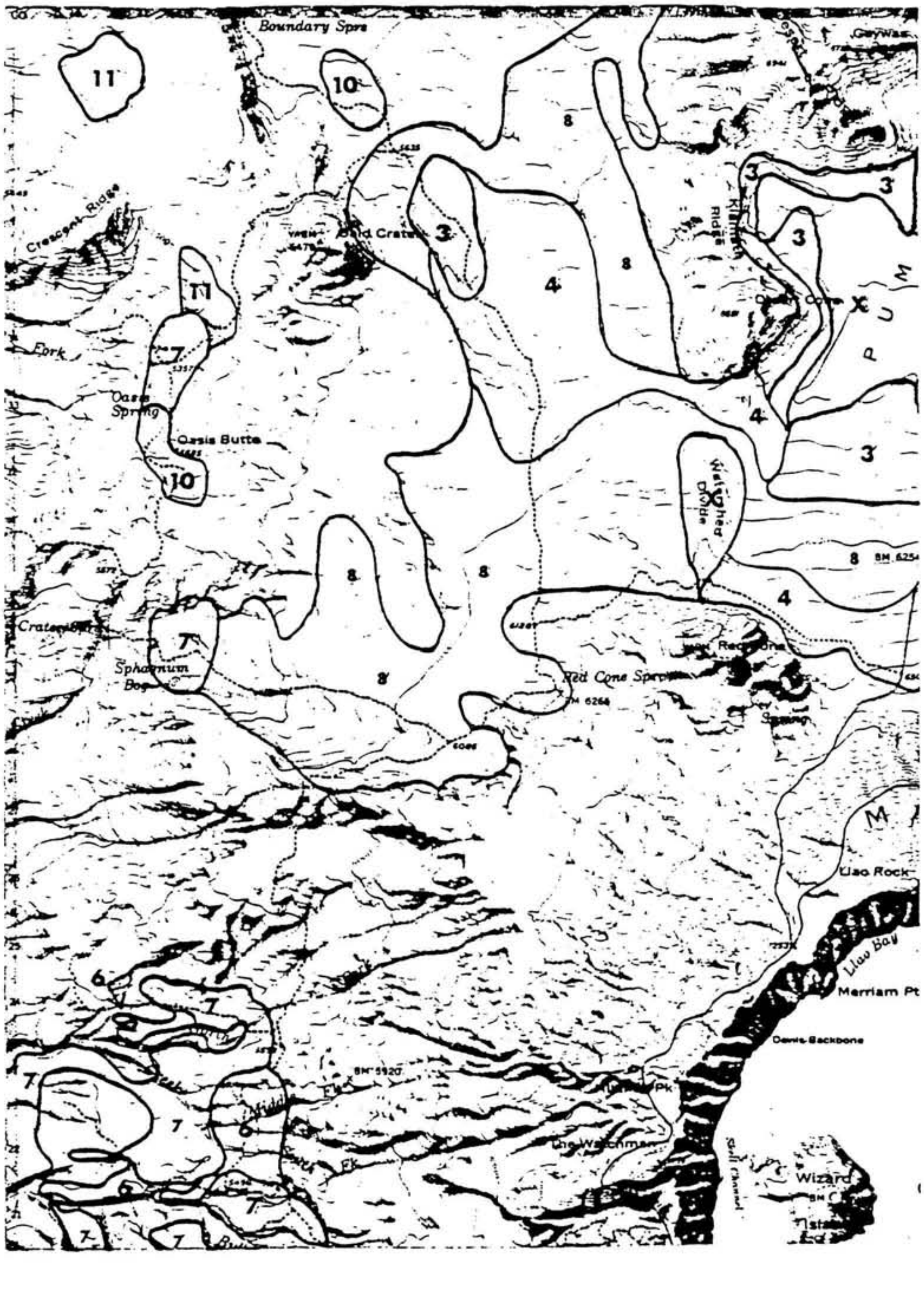
9 = Mixed Conifer/Arctostaphylos-Purshia/Carex

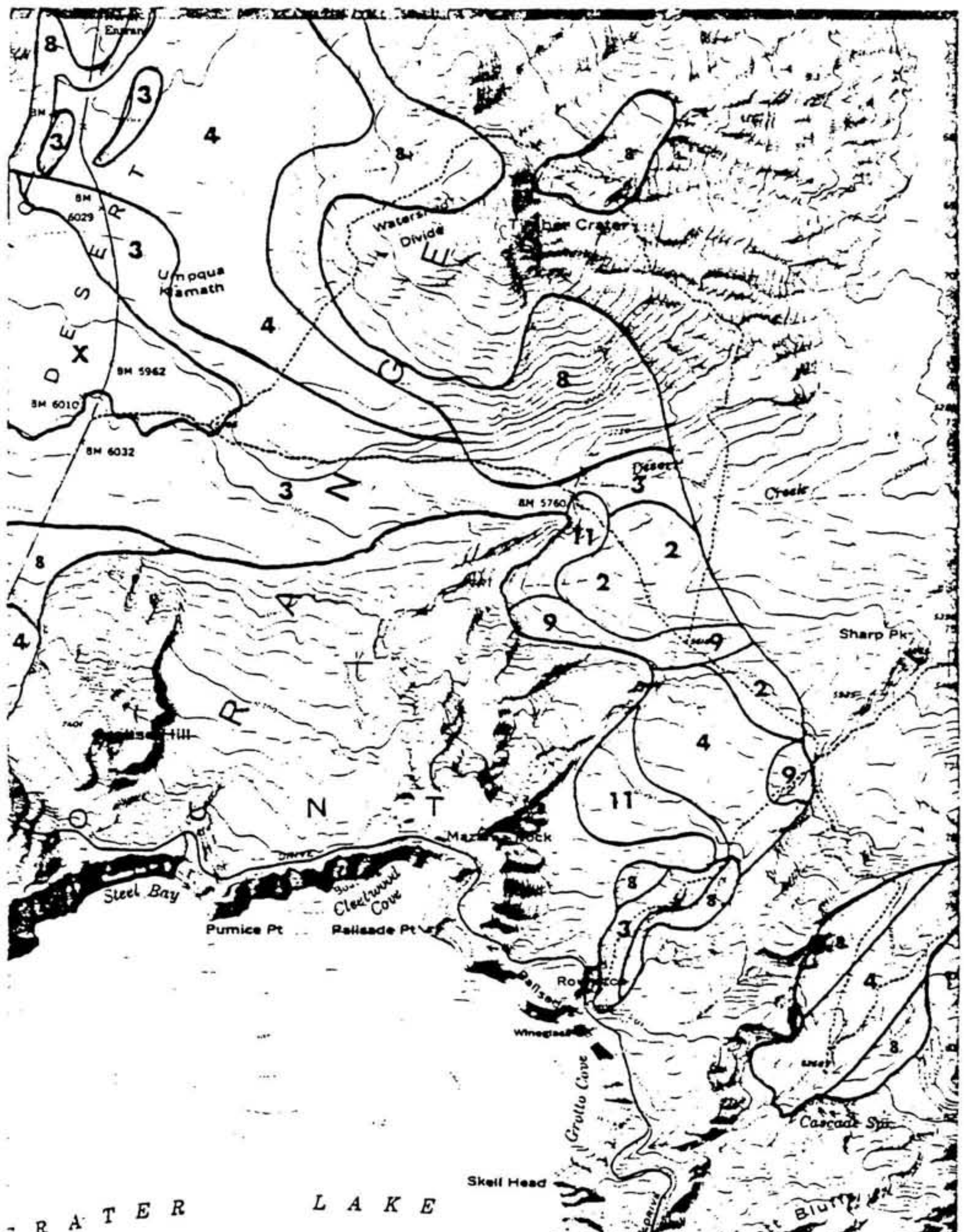
10 = Tsuga mertensiana/Vaccinium

11 = Mixed Conifer/Arctostaphylos

Cloudcap
Sentinel Rock
Castle Rock
Danger Bay
Eagle Pt
Phantom Ship
Chaski Bay
Kerr Notch
Anderson Spr
Kerr Valley
Sun Notch
Applegate
Sun Meadow
Sand
Lost Cr
Wheeler
Tututni Pass
Pinnacle
Sun Creek
Maklaks Pass
The Pinnacles
Valley
Entrance Closed
Maklaks Spr
Maklaks Crater
Creek
Annie Falls
Fork
8
7
11
3
4
5
10


Castle
Whitehorse Bluff
Whitehorse Pond
Watershed Divide
Arant Point
Pumice Flat
Munson
Munson Valley
BM 5662
BM 6039
10
8
7
3


Boundary Spr
Crescent Ridge
Bald Crater
Fork
Oasis Spring
Oasis Butte
Klamath Ridge
Watershed Divide
Sphagnum Bog
Red Cone Spring
Llao Rock
Llao Bay
Merriam Pt
Devils Backbone
The Watchman
Wizard
11
10
3
4
8
7
6
P
U
M



Timber Crater
Divide
Umpqua
Klamath
BM 6029
BM 5962
BM 6010
BM 6032
BM 5760
Creek
Sharp Pk
Steel Bay
Cleetwood Cove
Pumice Pt
Palisade Pt
Skell Head
Grotto Cove
Cloudcap Bay
Cascade Spr
CRATER LAKE
ELEVATION 6176 FEET
DEPTH ABOUT 2000 FEET

APPENDIX D

Probable post-fire status of some important plant species of *P. contorta* communities (from Zeigler, 1978).

Species	Post-Fire Status	Author
SHRUBS		
Arctostaphylos nevadensis	Resprout**	Sweeney, 1967
A. patula	Resprout	Sweeney, 1967
Chimaphila umbellata	Rhizomatous spread	McLean, 1967
Haplopappus species	Resprout**	
Purshia tridentata	Dead**	Daubenmire and Daubenmire, 1968
Ribes cereum	Resprout	Kilgore, 1971
Vaccinium scoparium	Resprout	McLean, 1969
HERBS		
Aster ledophyllos	Rhizomotous spread*	
Carex pensylvanica	Rhizomotous spread	Volland, 1976
Elymus glaucus	Unknown	
Lupinus albicaulis	Resprout*	
L. lepidus	Resprout*	
Penstemon rydbergii	Rhizomotous spread*	
Sitanion hystrix	Resprout	Wright, 1971
Spraguea umbellata	Resprout*	
Stipa occidentalis	Resprout	Wright, 1971

* Prediction based on root characteristics following McLean (1969).
**Field observation.

APPENDIX E (1)

Abundance and cover summaries for tree, shrub and herbaceous species in sampled communities. Numbers in parentheses represent that portion of the mean number of trees per plot that is Pinus contorta. + = less than 0.1% cover (from Zeigler, 1978).

Community	No. Plots	Total No. Tree Species	Mean No. Tree Species Per Plot	Mean No. Trees Per Plot	Total No. Shrub Species	Mean No. Shrub Species Per Plot	Mean Cover of Shrub Species	Total No. Herbaceous Species	Mean No. Herbaceous Species Per Plot	Mean Percent Cover of Herbaceous Species	Total No. of Species	Mean No. of Species Per Plot
Pinus contorta/ Carex-Stipa	15	5	1.8	234 (.96)	2	<.1	+	20	6	6	27	7.8
Pinus contorta/ Carex-Lupinus	14	5	1.9	210 (.97)	3	1.0	2	21	7	25	29	9.9
Pinus contorta/ Purshia/Stipa	1	1	1	168 (1.0)	1	1	4	6	6	15	8	8
Abies magnifica var. shastensis-Tsuga mertensiana/ Carex-Lupinus	20	3	2.7	295 (.52)	3	0.4	1	30	7.5	24	36	10.6
Abies lasiocarpa/ Haplopappus/ Aster-Elymus	16	4	3.5	283 (.61)	5	1.8	4	30	9.3	50	39	14.6
Abies lasiocarpa/ Collomia-Lathyrus	1	3	3	95 (.63)	3	3	+	22	22	92	30	28
Tsuga mertensiana/ Vaccinium	6	4	3.5	293 (.69)	3	1.7	13	12	4.5	5	19	9.7
Mixed Conifer/ Arctostaphylos	5	5	3.0	117 (.80)	1	1	17	7	3.2	5	13	7.2
Mixed Conifer/ Arctostaphylos-Purshia/Carex	1	4	4	79 (.78)	2	2	7	6	6	21	12	12
Abies concolor/ Bromus carinatus-Lupinus	2	3	2.5	278 (.49)	3	2.5	11	17	12	47	23	17

APPENDIX E (2)

Comparison of age structure of the principal plant communities. Mean interval between classes was calculated as the mean of the intervals between two consecutive P. contorta age classes at least one of which antedates 1850. Community 3 = P. contorta/Carex - Stipa; 4 = P. contorta/Carex - Lupinus; 8 = A. magnifica var. shastensis - T. mertensiana/Carex - Lupinus; 7 = A. lasiocarpa/Haplopappus/Aster - Elymus; 10 = T. mertensiana/Vaccinum; 11 = Mixed Conifer/Arctostaphylos.

Community	Mean Stand Age	Mean Age of Latest Class	Mean No. Classes Per Plot	Mean Interval Between Classes* (Years)
3	175	131	2.4	60
4	115	96	1.7	48
8	122	109	1.6	40
7	112	98	1.5	48
10	128	115	1.4	27
11	151	141	1.7	25

*Only plots with multiple age classes.

Mean Stand Age

3>4, 3>7, 3>8 (p = .01)
3>10 (p = .05)
11>4, 11>7, 11>8 (p = .05)

Mean Class Interval

Not significantly different

Mean Age of Latest Class

3>4, 3>7 (p = .01)
3>8 (p = .05)
8>4, 8>7 (p = .01)
11>4, 11>8, 11>7 (p = .01)
11>10 (p = .05)

Mean No. Classes Per Plot

3>8 (p = .01)
3>4, 3>10, 3>7 (p = .05)
11>10 (p = .05)

APPENDIX F

Cover (A) and constancy (B) of selected species of shrubs and herbs in the principal communities. Communities sampled by only one or two plots are not included. Numbers are percent; + is < 0.05% (from Zeigler, 1978).

	Pinus contorta/ *Carex*-*Stipa*		*Pinus contorta*/ *Carex*-*Lupinus*		*Abies magnifica* var. *shastensis*-*Tsuga mertensiana*/ *Carex*-*Lupinus*		*Abies lasiocarpa*/ *Haplopappus*/ *Aster*-*Elymus*		*Tsuga mertensiana*/ *Vaccinium*		Mixed conifer/ *Arctostaphylos*	
	A	B	A	B	A	B	A	B	A	B	A	B
Lupinus albicaulis			2.6	100	4.2	90						
Haplopappus bloomeri	+	13	.9	50	+	5						
Eriogonum marifolium	.1	67	.2	71	+	10	+	6				
Viola praemorsa	+	13	.1	43	+	5			+	17		
Microseris alpestris	+	7	+	36	+	10						
Spraguea umbellata	.1	73	.4	14	+	10						
Lupinus lepidus var. *lobii*	.1	33	+	+	+	10						
Luzula hitchcockii	+	7	.1	7	.9	40	.6	19				
Phlox caespitosa			.2	14	.5	25	1.1	38	+	14		
Lupinus latifolius					1.1	5	11.0	100	4.4	50		
Elymus glaucus					.2	5	3.3	81				
Haplopappus greenei							.8	75				
Aster ledophyllus var. *covillei*					+	5	.6	56				
Penstemon rydbergii							.8	50				
Arctostaphylos nevadensis	+	7					.3	25	3.2	50	17.2	100
Vaccinium scoparium					+	10	.6	25	9.6	100		
Claytonia lanceolata			+	14	.3	25						

Tree density (stems/ha) by size classes for ten plant communities (from Zeigler, 1978)

Species Diameter Class (cm)	Community: Pinus contorta/ Carex- Stipa	Pinus contorta/ Carex- Lupinus	Abies magnifica var. shastensis- Tsuga mentensiana/ Carex-Lupinus	Abies lasiocarpa/ Haplopappus/ Aster-Elymus	Tsuga mertensiana/ Vaccinium	Mixed Conifer/ Arctostaphylos	Abies concolor/ Bromus carinatus- Lupinus	Mixed Conifer/ Arctostaphylos- Purshia/Carex	Abies lasiocarpa/ Collomia- Lathyrus	Pinus contorta/ Purshia/ Stipa
Pinus contorta										
0-4.9	3460	2678	1672	2406	2959	916	1950	660	560	1440
5.0-9.9	480	622	534	364	429	312	240	180	300	520
10.0-19.9	440	512	436	336	450	428	220	160	180	920
20.0-29.9	186	222	266	216	166	180	150	100	40	440
30.0-44.9	86	82	154	136	80	36	130	140	40	
>45.0	19	1	220	24					80	
Abies magnifica var. shastensis										
0-4.9	19	30	1760	1938	783	192	10	60	540	
5.0-9.9			52	54	37	48			80	
10.0-19.9		3	26	16	7	24			60	
20.0-29.9				11	7	8			20	
30.0-44.9				2						
>45.0										
Tsuga mertensiana										
0-4.9	89	38	750	136	307	81				
10.0-19.9	24	3	154	6	53	12				
20.0-29.9	29		52	12	103	12				
30.0-44.9	5		1	2	53	4				
>45.0			1		20	12				
Pinus albicaulus										
0-4.9	46	7								
5.0-9.9		9								
10.0-19.9	1									
Pinus monticola										
0-4.9		3			86	20		20		
5.0-9.9						24				
10.0-19.9					7	16				
20.0-29.9						12				
30.0-44.9						4				
>45.0						4				
Abies concolor										
0-4.9						4	2690			
5.0-9.9							70			
10.0-19.9							20			
Pinus ponderosa										
0-4.9								260		