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Donald B. Zobel

This thesis describes the composition of and some of the environmental controls of the vegetation of a 7.5 km^2 area in Crater Lake National Park, Oregon. It also gives the approximate dates and locations of most fires that burned in the area between 1750 and 1974.

The vegetation was sampled in 68 plots, which were 15 m x 25 m. Trees were tallied by size classes and coverage of herbs and shrubs was recorded. The soil profile was described at selected plots. The vegetation was classified by using three techniques: (1) Daubenmire's habitat type approach, (2) Braun-Blanquet's table sorting, and (3) an ordination. This resulted in a two-level classification in which 16 communities were grouped into six habitat types. The fire history was found by cutting wedges from fire scars and counting the rings outside the sears left by individual fires. This was done for two trees within 100 m of each other at each of 24 spots. The dates from these two trees were combined to give dates for a single sample.

Two different soil parent materials support different habitat types. Alluvial material supports the relatively dry *Abies concolor*/*Symphoricarpos mollis* habitat type, which includes the *Populus*, *Senecio*, and *Melica* communities. The *Populus* and *Senecio* may be the driest and are the most recently disturbed communities, and *A. concolor* may not be the climax dominant. The *Melica* community is somewhat moister and much less disturbed. The second type of soil parent material is pumice. This supports *Abies concolor*/*Chimaphila umbellata* and *Abies magnifica* var. *shastensis* habitat types and a Mesic Species community. The Mesic Species community occurs in areas with the water table near the surface in the spring, and provides enough moisture to stop some fires. The *A. concolor*/*C. umbellata* habitat type can be subdivided on the basis of the importance of *Ceanothus velutinus* and other criteria. The two subdivisions are generally located on different sides of the Mesic Species community fire break, and some of the differences between them are probably due to different frequencies of fires before 1902 as well as the climatic changes associated with elevation. Other communities occur only in special topographic or edaphic situations.

Fires occurred at sampling spots at intervals from three or less to more than 50 years, with the mean interval at a spot ranging from nine to 42 years. The intervals between fires generally lengthened with increased elevation.

A rough estimate of the composition of the forest was gained by combining age-size data with vegetation data.

Most of the study area is not near maturity, and probably never has been due to the frequent recurrence of fire. The vegetation has apparently been changing since fire suppression became effective. As the forest matures, the canopy will probably close some more, resulting in less *Pinus ponderosa* and decreased importance of shrubs. Reintroduction of fire can probably reverse these trends to some extent.

Vegetation and Fire History of a Ponderosa Pine-White Fir Forest in Crater Lake National Park

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Robert Curlan McNeil

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in charge of major

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Chairman of Department of Botany and Plant Pathology

Redacted for Privacy

Dean of Graduate School

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INTRODUCTION

Several recent studies and reviews (Fahnstock 1973, Habeck and Mutch 1973, Heinselman 1973, Kilgore 1973a, Weaver 1968, Wright and Heinselman 1973) have emphasized that in many of the coniferous forests in North America, fire is an important process. In many cases fire appears to be necessary, under natural conditions, for the continued existence of the ecosystem. The role of fire in the ecosystem is complex because the ecosystem is complex, and fire has strong, direct interaction with two other major subsystems, the vegetation and the organic horizons of the soil. Because of this complexity, it is not surprising that the older literature includes conflicting reports about the effects of fire on such things as soil physical properties, erosion, plant growth, and soil chemical properties (Ahlgren and Ahlgren 1960). But, it appears that fire generally causes conditions typical of classical early succession. Thus Wright and Heinselman (1973) and others think that some of the usual effects of fire are: 1) to release nutrients to the soil or atmosphere directly, and possibly by increasing decomposition rates and mineral weathering rate; 2) to increase insolation to the vegetation and soil, thereby changing such things as the surface temperature; 3) to stimulate germination and flowering in some plant species; 4) to expose a seedbed; 5) to influence age distribution of perennials; 6) to increase the amount of herbs and shrubs; 7) to change habitat patterns; and 8) to kill plants, sometimes selectively (between species), favoring the survivors by reduced competition. They also note that fire can change the susceptibility of forests to subsequent fires (by changing fuel and microclimatic conditions) and to insects and disease (by affecting the susceptibility of individual hosts, or by destroying the hosts). Fire also can change soil physical properties and stimulate erosion (Agee 1973).

The realization that fire is an integral part of many ecosystems, rather than an externally applied perturbation, has led to the formation of two hypotheses based on evolutionary considerations. Mutch (1970) hypothesized that the species in a fire-dependent community, as contrasted with those from a community not dependent on fire, tend to have characteristics that promote fire, to insure that fire remains part of the environment. Loucks (1970) suggested that ecosystems progressing through secondary succession tend to pass through a period of maximum diversity and production at a time related to the frequency of perturbations with which that ecosystem has evolved. In this way the system persists by repeating the same sequence of changes, rather than by reaching a steady state.

Lightning and man are the two ignition sources for fire. Indians possibly used fire to increase forage and berry production and to clear understory vegetation (Leiberg 1900) for cultivation, hunting, and warfare. They probably also set fires accidentally. Early settlers may have set fires for about the same reasons. There are accounts of Indians in the Sierra Nevada of California deliberately setting fires, but Wagener (1961) concluded that over most of the Sierra, lightning was the main ignition source. He found no change in the frequency of fires after Indian influence had been eliminated. This also led him to conclude, contrary to some reports, that the early settlers increased the frequency of fires little or none. However, Heinselman (1973) did find an increase in the frequency of fires after settlement in northern Minnesota.

One of the important factors regulating the effect of fire is fire behavior (i.e., severity, frequency, and area). Of course, fire behavior and the effects of a given behavior depend on the state of the rest of the system, especially factors such as weather, topography, vegetation, fuels, and soil. In turn, the states of vegetation, fuels, and soil depend upon fire. Some of these relationships will be explored in the following review, outlining the major roles of fire in ecosystems.

Probably the most important variable associated with fire is its severity, which can be measured by the temperature, intensity, or energy released. The importance of some of the differences between crown and surface fires are readily apparent. However, surface fires of different intensities can have significantly different effects. For instance, Kilgore (1973b) found that hotter fires killed larger trees creating larger openings in the canopy, more surface fuels were oxidized, the seedbed was better for Sequoiadendron, the resulting habitat was less diverse, and more particulate matter was probably lost from the site as ash. The temperature of a fire can vary hundreds of $^{\circ}$C over a few meters, and the temperature gradients in the soil are hundreds of $^{\circ}$C over decimeters. The horizontal variation is associated with the hot fires in heavy fuels (Kilgore 1973b). On slash burns in the western Cascades, severely burned sites subsequently had less cover than lightly burned sites (Dyrness 1973).

The frequency of fires is important because it influences such things as whether perennials become old enough to produce seed (Biswell and Schultz 1958), fuel accumulation and fuel type (and thus severity of subsequent fires), whether trees get bark thick enough to survive fires, and how much time nutrients are in labile forms. The mean interval between fires, found by examining fire scars, varied from every 7 to 50 years in western North America (Table 1).

Wind, temperature, and humidity influence fire behavior (Wright and Heinselman 1973). Heinselman (1973) found that in Minnesota the dates of small fires had little relation to weather, but

Table 1 . Mean interval between fires in various coniferous forests.

Location	Tree dominant	Mean interval between fires (years)	Reference
Watkins Butte, Central Oregon	*Pinus ponderosa*	17	Keen (1937)
Black Butte, Central Oregon	*P. ponderosa* to *Abies grandis* & *A. lasiocarpa*	12	Sherman (1969)
Warm Springs Indian Reservation, Central Oregon	*P. ponderosa* *P. ponderosa* to *A. grandis*	14 to 16[1] 25 to 30[1]	Soeriaatamadja (1965)
Upper Williamson River Basin, Klamath County, Oregon	*P. ponderosa* to *Abies concolor*	30 to 50[2]	Volland (1963)
Middle Elevation Sierra Nevada, California	Mixed Conifer	7 to 10	Wagener (1961)
Kings Canyon National Park, California	*Sequoiadendron*, *A. concolor*, *Pinus lambertiana*	8 to 9	Kilgore (1973a)
Yosemite National Park, California	*Sequoiadendron*	24	Presnall (1933, cited in Agee, 1973)
Yellowstone National Park, Wyoming	*Pinus contorta* and *Pseudotsuga*	17 to 26	Houston (1973)
Boundary Waters Canoe Area, Minnesota	*Pinus resinosa* & *Pinus strobus*	36[3]	Heinselman (1973)

[1] Interval between sears on individual trees.

[2] No supporting data given.

[3] "Certainly there were also many light surface fires for which no evidence remains."

that the seasons in which most of the area burned were drought years. He also stated that in spring, high temperatures do not go as far into the soil and heavy fuels will not burn as well, because of the greater moisture content; whereas, in the fall, fires burn hotter and oxidize more fuel because of lower fuel moistures. But the effect of weather can be greatly complicated by interaction with other parts of the system. For instance, Soeriaatmadja (1965) reports that an extensive fire burned in part of central Oregon after unusually dense stands of grasses developed due to unusually high precipitation during the growth of the grasses. Moisture and litter type can interact in unexpected ways (Agee 1973). The vegetation affects wind velocity and drying conditions. Snow can compact the fuel (Swedburg 1961). Topographic position influences fire behavior through topographic influence on climate.

In central Oregon fires were more frequent and less severe at low elevations than high (Soeriaatmadja 1965), so that at high elevations many of the fires were intense enough to kill all the trees present (Sherman 1964). The greater severity at high elevations may be due to more accumulation of fuel, steep topography and closed stands having greater chance of crowning (Soeriaatmadja 1965). Ridges often have more severe (Show and Kotok 1924) or more frequent fires (Heinselman 1973) than valleys. Lakes, streams, swamps, bedrock exposures, ridges, valleys and soil texture can affect fire behavior directly or through the vegetation. The effectiveness of natural firebreaks is related to the wind during fires. Narrow breaks can stop the flank, but not the head of a fire (Heinselman 1973).

The above discussion shows the effect of climate and topography on fire often is exerted indirectly through the effects of these factors on fuels. Fuel variables that influence fire behavior include quantity, quality, arrangement, surface to volume ratio, fuel bed porosity, chemical composition, and mineral content (Kilgore 1973). The increasing quantity of fuel in former *Pinus ponderosa*-grass savannahs in Glacier National Park, which now have *Pseudotsuga* and *Picea* understories, would have endangered the *P. ponderosa* if fire had been immediately reintroduced (Habeck and Mutch 1973). The small amount of mortality in *P. ponderosa* forests in southern Oregon during fires may have been due to the small amounts of litter and humus found in them (Leiberg 1900). Fuel size plays a role in determining whether it helps to spread the flame front or results in longer term fires. Dense, matted litter found under *Abies concolor* and *Sequoidendron* does not burn as well as the spongy litter beneath *Pinus ponderosa* and *Calocedrus* under prescribed burning conditions (Agee 1973). Dense fuel does not dry as fast, and does not permit as great a flow of oxygen during combustion. Sometimes *Abies concolor* and *A. magnifica* slash retains enough water that it will not burn during the summer it was created (Gordon 1973). Tree reproduction and shrubs can form ladder fuels to the crown (Leiberg 1900, Lunan and Habeck 1973, Wright and Heinselman 1973). In pine stands in California, the worst crown scorch was above shrubs (Show and Kotok 1924).

Fire often decreases the fuels on a site (Agee 1973, Kilgore 1971, 1973b, Weaver 1968), but not always immediately. Leiberg (1900) and Show and Kotok (1924) thought that fires generally increase the danger and quantity of the fuels. Fire kills many trees without consuming them, creating much new dead fuel, especially jackstraws or standing snags. The shrub and herb growth is stimulated and produces more fuel. The conclusion that fire increases fire hazard was reached despite observation that in the California pine forests "The virgin forest is uneven-aged, or at best even-aged by small groups and is patchy and broken; hence it is fairly immune from extensive devastating crown fires" (Show and Kotok 1924, p. 31). However, in mature stands there is more above ground biomass, there are more ladder fuels due to suppressed trees, and there is much dead fuel due to the death of mature trees, susceptible to such things as pests and wind-throw (Heinselman 1973). With fire protection, trees die anyway sooner or later, increasing the fuel gradually, instead of suddenly. Probably the only way that fire could increase the amount of fuel over the long run is by increasing net primary productivity or decreasing decomposition enough to counterbalance destruction of fuel by fire. This interpretation of fire's effect on amount of fuel is supported by Van Wagtendonk's (1972, cited by Agee 1973) model and the finding that *Pinus ponderosa* stands in the northern Rockies that last burned less than 40 years ago have less fuel than stands that last burned more than 60 years ago (Lunan and Habeck 1973). Of course, this probable reduction in fuel quantity does not necessarily mean that fire hazard is reduced; hazard also depends on such things as litter type (*P. ponderosa* vs. *A. concolor*), fuel arrangement (suppressed understory vs. shrubs, jackstraws, and standing snags), and microclimate.

The most direct effect that fire has on vegetation is to kill and injure plants by heat. Both the temperature and the duration of heating are important in the survival of the plants (Kayll 1968). Several factors might permit one plant to survive a fire that will kill another, including the plant's initial temperature, insulation, growth form, sprouting ability, flammability, and its state of dormancy or cold and drought hardiness (Hare 1961). Dormant tree seedlings are more heat tolerant than active ones (Kayll 1960). Growth form determines what part of the plant is exposed to intense heat in surface fires. Seedling trees are exposed to the same hazards in surface fires as the rest of the understory, and suffer greater damage than larger trees due to their thinner bark and lower foliage (Agee 1973, Keen 1937; Kilgore 1971). Released Pinus palustris seedlings were less likely to die from a fire than suppressed ones (however, suppressed trees also had more litter around them), and seedlings on average sites were less likely to die than those on poor sites (Boyer 1974). Fires in the California pine region did not destroy all reproduction (Show and Kotok 1924). Insulation of trees is provided by bark, seed coat, fruit or cone, bud scales, and soil (Hare 1961). The effectiveness of bark as an insulator depends mainly on its thickness, but its composition also has some effect. On large trees of some species, bark is effective enough that often crown scorch is a greater factor in injury than cambial death (Kilgore 1973b, Lynch 1959, Van Wagner 1973). Most trees do not seem to be seriously hurt by a fire scar directly (Hare 1961). However, each subsequent fire tends to enlarge the scar, and this can eventually cause the tree to fall (Show and Kotok 1924). Fire scars might increase the resistance to water flow to the crowns of Sequoiadendron (Rundel 1973). The flammability of the whole stand is important in the survival of the individual tree. For instance, the thick bark of Pseudotsuga in the northern Rockies does not provide much protection from fire because the dense stands it grows in are susceptible to crown fires (Habeck and Mutch 1973).

Fire prepares a seedbed by removing litter. Where the canopy was undisturbed, more A. concolor and Sequoiadendron survived on small seedbeds prepared by fire than on nearby unburned substrate (Agee and Biswell 1969). Possible reasons for the greater survival are: 1) mineral soil stays damp longer than litter; 2) softer burned soil permits deeper seed burial; 3) less competition, and 4) destruction of pathogens and alleopathic substances (Hartesvedt and Harvey 1968). Fire can also indirectly change vegetation through its effects on insects (Show and Kotok 1924), small mammals (Christensen and Muller 1975), microbiota (Renbuss, Chilvers, and Pryor 1973), and the soil.

In many mixed conifer forests, fire favors Pinus over Abies, Calocedrus, and Pseudotsuga (Bock and Bock 1969, Kilgore 1973b, Lunan and Habeck 1973, Show and Kotok 1924, Weaver 1968, West 1964). A. concolor appears to be damaged more than other species by fire (Leiberg 1900). However, as A. concolor become larger, they become less susceptible to fire damage (Kilgore 1973a). Show and Kotok (1924) also felt that A. concolor and Calocedrus were more susceptible than P. ponderosa and P. lambertiana because of greater flammability, more foliage near the ground, and buds that were more exposed. Another factor accounting for the greater susceptibility of A. concolor is its relatively thin bark. In the township where the present study was located, 50% of the A. concolor had rot associated with fire scars (Leiberg 1900). The resin in P. ponderosa and P. lambertiana fire scars helps prevent the entry of decay organisms by waterproofing the wood (Hare 1961). The reason that *A. concolor* becomes the most important reproducing species in the absence of fire is apparently its greater shade tolerance (Barker 1973, Atzet and Waring 1970). *A. grandis*, *A. concolor*, and *A. magnifica* survive best in the shade, at least for the first year or two (Gordon 1970, Seidel and Cooley 1974). Keen (1937), working in old growth *P. ponderosa* forests in south-central Oregon, observed,

> Many trees showed an early period of suppressed growth at their centers. Apparently, while in the seedling stage, these trees stagnated owing to competition for a period of 50 to 75 years and in some cases for 150 years. Then with a release from competition, probably as a result of forest fires, they suddenly began to grow at normal rates. . . .

In areas where *P. ponderosa* is a seral species, careful management is necessary to maintain its dominance (Dyrness 1960).

Understory plants also use insulation, sprouting ability, flammability, and dormancy to survive fires. For instance, herbs and shrubs use the soil for insulation. Plants with only fibrous root systems or stolons are generally more susceptible to fire than plants with rhizomes 1.5-5 cm deep, which are generally more susceptible than plants with tap roots or rhizomes more than 5 cm deep (McLean 1969). In an area where one burn rapidly follows another, sprouting species will be favored since those that depend on seed will not have enough time to produce many seed (Heinselman 1973). *Sitanion hystrix* is hurt less by fire than *Stipa comata* because of its dormancy and lower flammability (Wright 1971). However, if a plant is burned just after dormancy is broken, its chances of survival decrease greatly, because its food reserve is often low at that time (Hare 1961). One common method of surviving fire is as seed, especially that for which heat is necessary for germination. Ceanothus velutinus and Arctostaphylos patula are examples of this. Even fire-susceptible plants can be important in the post fire vegetation, if the seeds are easily dispersed (McLean 1969). Litter removal and more light on the ground often help the understory. Logging and slash burning in the western Cascades initially decreased the cover of the shrub and herb layer, but it rapidly recovered and soon exceeded its former value (Dyrness 1973).

Typically, after fires there is a quick increase in herbaceous plants, especially annuals, followed by a more gradual rise in importance of the shrub and tree layers, which depresses the herb layer (Dyrness 1973, Lunan and Habeck 1973, Sweeny 1956, Weaver 1968, West 1964), but there are many exceptions. The herbaceous cover on prescribed burns can be about the same as unburned areas (Kilgore 1973a). Repeated burns can cause an increase in either shrubs (Show and Kotok 1924) or grasses (Soeriaatamadja 1965, Weaver 1968). This relation might depend on elevation (Leiberg 1900).

Sometimes plants growing in pots of soil from burned areas grow better than those growing in soil from unburned areas. This is often attributed to a possible increase in fertility (Ahlgren 1960, Vlamis and Gowans 1961). The main effect that fire has on soil chemistry is the release of nutrients from the organic horizons to the atmosphere (either volatilized or as particulate matter) and mineral horizons. There are also less direct effects, such as possible decreased uptake due to plant mortality (Grier 1972), addition of organic matter by dead roots, and changed microbiological activity. The type of soil, the climate, the vegetation and the intensity of the burn interact with fire to produce different effects (Wells 1971). The depth to which the organic matter is oxidized can range from less than the thickness of the organic horizons to several centimeters deep (Ralston and Hatchell 1971). At least in poorly drained, very acidic soils, burning can lead to an increase in organic matter in the soil (Wells 1971). Usually a fire releases the cations held by the organic matter, and this causes an increase in the pH and concentration of cations in the upper parts of the soil (Grier and Cole 1971, Lewis 1974, Wells 1971). The pH change may depend on the cation exchange capacity as well as the amount of cations released by burning (Wells 1971). This effect may disappear after the first rains (Sweeny 1956) or it may remain for years (Ahlgren 1960). However, the relation between the amount of fuel consumed and cations released is not a simple one. For instance, Wells (1971) found that while repeated burns decreased the amount of P, K, Ca, and Mg in the organic horizons, only P, Ca, and Mg appeared to be in greater concentrations in the soil, so it appears that some K may have been lost from the soil. More water soluble P and K was in P. ponderosa litter heated to 200°C than in litter heated above or below this temperature (White, Thompson, and Gartner 1973). The decrease in K above 200°C may be due to volatization or formation of a complex with ions released from the organic matter. Beneath a slash burn in Washington, the concentration of Ca decreased, probably because of the increase in pH; phosphate increased beneath light burns, but decreased beneath heavy burns (Grier and Cole 1971). The increased solubility of these elements may cause them to be leached from the site. After a severe wildfire, between 35% and 95% of the cations in the ash leached into the soil. Over 90% of the Ca, Mg and K were retained in the top 19 cm of the soil, with a larger amount of Na being lost, probably due to displacement from exchange sites. Leaching loss was less than the loss that occurred within two weeks of the time the area burned. Even when a fire is not very severe, there may be some nutrient export due to ash movement by wind (Lewis 1974).

Almost any time organic matter is lost by fire much of the nitrogen in it is volatilized as N_2 (DeBell and Ralston 1970, Grier 1972, Klemmedson et al. 1963, Knight 1966, Lewis 1974, White et al.

1973). Often the concentration of N in the remaining litter and soil is higher than before the burn (Knight 1966), but not always (Grier and Cole 1971). Nitrogen may also increase after fire due to increased nitrogen fixing activity, and nitrate may increase as a result of increased nitrification due to the pH change. Nitrogen export by leaching can decrease after a fire (Grier 1972).

The influence if any of nutrients released by fire on the nutrition of plants in the field has apparently been neglected. Potassium or nitrogen deficiencies in the soil may be corrected by burning, but this is not clear cut, and the data are open to alternative interpretations (Vlamis, Biswell, and Schultz 1955, Vlamis and Gowans 1961). Despite an increase in soil N, pot-grown plants may take up less N (Wells 1971).

To understand either fire or the vegetation, information about much of the ecosystem is desirable. Data on natural fires are difficult to gather, due to the present exclusion of fires. Although fire scar size has been used as an index to fire severity (Soeria-atmadja 1965), the validity of this method has not been established. However, fire frequency can be estimated relatively accurately by dendrochronology. The vegetation is important and easily observed. It integrates the influence of much of its environment, including fire, and it influences fire and its effect on an area. These considerations suggested that a study of the vegetation (accompanied by observations on the soil) and of the fire history would provide the maximum insight into the system studied in the time available.

THE STUDY AREA

Location

The study area is approximately 7.5 km^2, located on both sides of Annie Creek and Oregon Highway 62 just inside the south boundary of Crater Lake National Park in Klamath County, Oregon (Fig. 1). It is in parts of Sections 11, 12, 13, 14, 15, 23, 24, and 25 of T. 32S, R. 6E, about 122°04' West longitude and 42°47' North latitude.

Physiography and Geology

The study area slopes at 3.5% from 1340 m to 1540 m in elevation. Annie Creek runs through a narrow canyon, 15 m to 60 m deep, within the study area.

The study area is near the boundary of the volcanic High Cascades physiographic province to the west and north, and the Basin and Range physiographic province to the east and south (Baldwin 1964).

Williams (1942) gives an excellent account of the geology of the study area, as well as the rest of the National Park. At a great depth, pre-Mazama basalts and basaltic andesites from the Union Peak volcano probably underlie the study area, rather than Mazama lavas. However, the ridge that defines the northeast boundary of the study

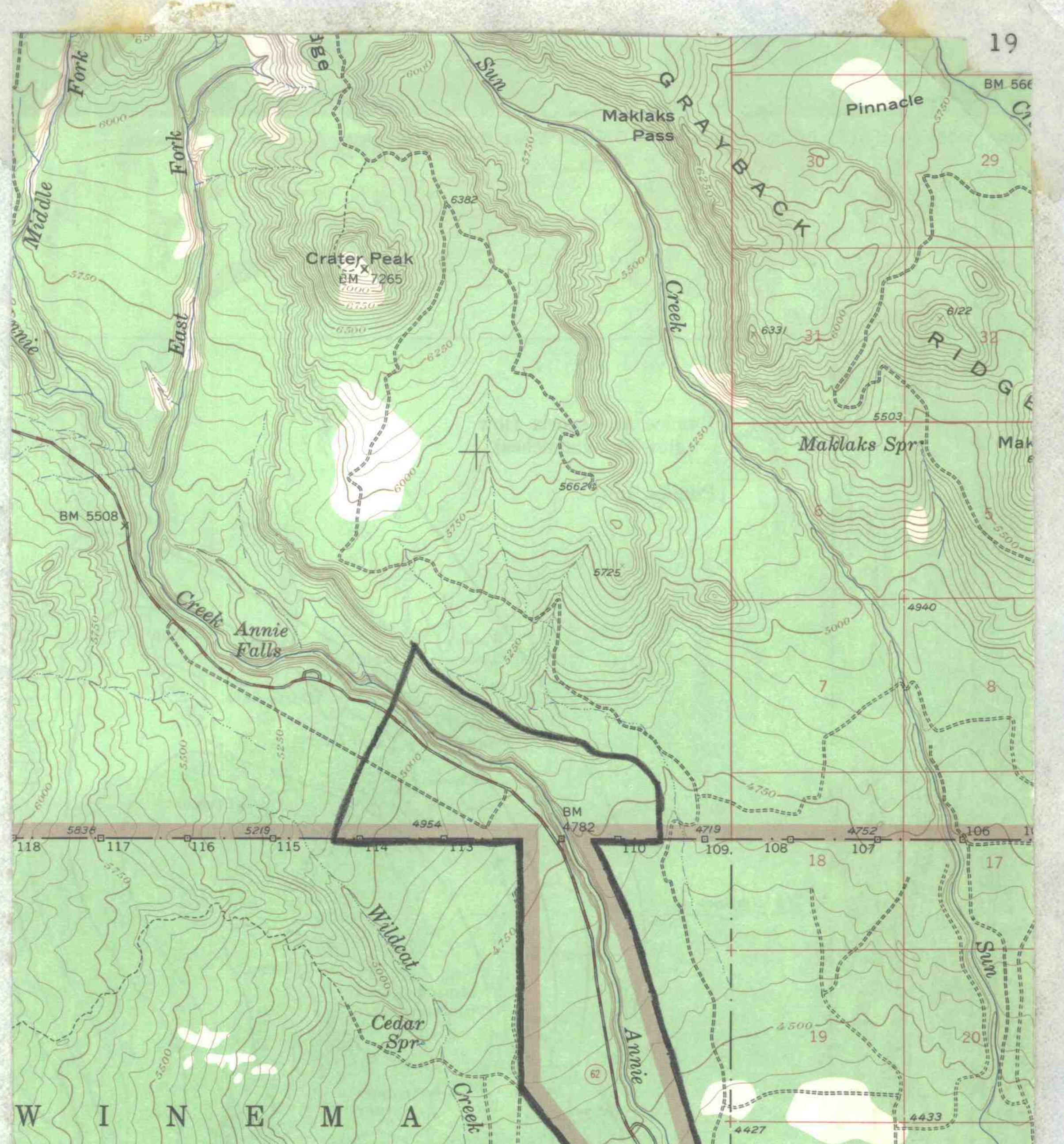


Fig. 1. The study area and environs. The study area is the area inside the heavy black line. Scale is 1:62,500. Elevations are in feet.

area is Mazama dacite, erupted from lateral vents. These eruptions occurred before the maximum glaciation of Mt. Mazama in the Pleistocene Epoch. At their maximum, glaciers probably extended down Annie Creek through the study area. Evidence of this can be seen in moraines on the ridge in the northeast part of the study area, and along sections of Annie Creek. The moraines in Annie Creek canyon are sites of many springs; apparently the morainal material is less permeable to water than that above it.

Most of the soils in the study area have developed in parent material deposited during or after the culminating eruptions that occurred just before the collapse of Mt. Mazama. The culminating pumice eruptions had two phases, the pumice fall and the pumice flow. In the pumice fall, gravel-sized pumice was thrown high into the air and fell back to earth. In the pumice flows (which followed the pumice fall), larger blocks were thrown just out of the volcano, and avalanched down the slopes, resulting in deposits of sandy ash mixed with cobbles and gravel. These are called glowing avalanches or nuees ardentes, as well as pumice flows. The pumice flows were followed by similar flows composed of scoria instead of pumice. The culminating eruptions apparently occurred with few or no interruptions. The pumice fall deposits are found mostly over wide areas to the east and northeast of Mazama, due to the winds during the eruptions, but there is a deposit in the study area (see Results chapter). The pumice and scoria flows were able to travel great distances because of the release of trapped or dissolved gas as the frothing rocks collided with each other and other objects, providing a cushion over which the flow traveled, and because the forest was less dense than at present. However, at least some trees extended well above the site of the study area. The pumice flows followed the topography, occupying the glacial valley, and extended to Fort Klamath 7 km southeast of the study area or beyond. The abrasion and internal explosions in the pumice flows resulted in deposits of subrounded cobbles and gravel, which are irregularly mixed with a matrix of sand. According to Williams, there is generally no stratification in the pumice and scoria flows, except occasional lenses of fine tuff. The scoria flows were similar to the pumice flows, except that they did not travel as far--often no farther than the boundaries of the park--and they did not spread as widely--only occupying the central depressions in the pumice. The scoria has a higher proportion of crystalline materials in it, although even the "pumice" parent material ranges to over half crystalline and lithic fragments. Along the creeks, Williams reports that an ash layer, resulting from the settling of ash thrown into the air by the turbulence of the glowing avalanches, overlies the pumice and scoria flows. This layer is restricted to the central part of the valleys of the creeks. I did not learn to distinguish this layer from true pumice flow material, and will refer to both the pumice flow and the ash as pumice flow.

Since the culminating eruptions, about 6600 years ago (Rubin and Alexander 1960), Annie Creek has deposited sandy alluvium over parts of the study area (see Results section).

Soils

Since much of the soil in the study area is derived from Mazama pumice, it might be expected that this soil is similar in some respects to other soils in the same type of parent material. Franklin and Dyrness (1973) point out that vegetation on pumice soils has a depauperate herb layer, lower total cover, and more schlerophyllous shrubs than vegetation on other types of soil. Many of the pumice soils belong to the Lapine series, derived from the pumice fall, and others belong to the Steiger series on pumice flow material. Dyrness (1960) describes the Lapine series, and U.S. Bureau of Indian Affairs, USDA Soil Conservation Service, and Oregon State College (1958) describes both pumice flow and pumice fall soils. Since these soils developed so recently, the soil-forming factors of climate, biota, and topography have not affected them much. The A_1 and AC horizons of the Steiger and Lapine soils are similar (Table 2). However, the Lapine lacks cobbles and generally has more gravel. The C horizon of the Steiger ranges from a fine sandy loam to a loamy sand, with gravel and cobbles ranging to 60% and extends to great depth. The C horizon of the Lapine is substantially different. It is divided into a gravel or gravelly sand C_1, 8-90 cm thick and a gravel to coarse sand C_2, 18-90 cm thick. The gravel in these unweathered

Table 2. Comparison of A and AC horizons of Lapine and Steiger soils (after Dyrness 1960, U.S. Bureau of Indian Affairs *et al.* 1958).

	Parent material	A horizon				AC horizon			
		Thickness (cm)	Texture	Structure	Gravel and cobbles (%)	Thickness (cm)	Texture	Structure	Gravel and cobbles (%)
Lapine	Pumice fall	3-9	Loamy sand, sandy loam	Weak medium or fine granular	10-15	10-33	Loamy sand	Single grained	20-30
Steiger	Pumice flow	3-7	Sandy loam	Weak, platy or granular	0-40	5-30	Fine sandy loam	Structureless to weak, subangular blocky	0-60

Table 3. Some properties of pumice soils and "typical" sandy soils. Dashes indicate quantities that are poorly correlated with texture (after Youngberg and Dyrness 1964, Buckman and Brady 1969).

	Sand (%)	Silt (%)	Clay (%)	Mean particle density (g/cm^3)	Bulk density (g/cm^3)	Porosity (%)	Moisture held at -.33 atm minus moisture held at -15 atm (%)	pH	Cation exchange capacity (me/100 g)		N %	
									A_1	C	A_1	C
Pumice	64-83	9-27	8-14	2.61	0.5-0.9	73	10-27	6.0-6.8	12[1]	6[1]	0.13[2]	0.03[2]
Typical sandy	>50	<50	<50	2.60-2.75	1.2-1.8	35-50	3-10	-	2-17		-	

[1] Lapine

[2] Steiger

horizons is often angular, as opposed to the subangular gravel and cobbles in the Stieger. Also, the Lapine C_1 and C_2 lack the sandy matrix found in the C of the Steiger. The C_1 and C_2 of the Lapine overlies a IIC_3, which is the soil buried when Mazama erupted. Occasionally, the IIC_3 horizon is mixed with the C_1 and C_2. Roots rarely proliferate in the C_1 or C_2 horizon, usually being confined to the A, AC, IIC_3 and the mixed areas. Dyrness (1960) and Youngberg and Dyrness (1964) also investigated the physical and chemical properties of pumice soils (Table 3). The high porosity of pumice soils gives them a much higher water holding capacity than one might expect from the texture. Most of the available water is held between -0.1 atm and -1 atm. Since the porosity is inherent in the pumice particles, a finer texture does not necessarily mean an increased available water holding capacity. Unsaturated water flow in pumice is very slow. This may help account for the generally greater amount of soil water after snowmelt than is held at equilibrium at -0.1 atm. The slow unsaturated flow might reduce the amount of water available to a plant that is transpiring rapidly. Youngberg and Dyrness also had difficulty in wetting soil samples.

Plant roots are important in the weathering of the C horizon (Dyrness 1960), and the organic matter and the rate of weathering are two principal factors governing the fertility of pumice soil (Dyrness and Youngberg 1966). Organic matter is important because of its nutrient holding capacity and its effect in accelerating weathering. A large part of the cation exchange capacity is due to the gravel, rather than colloidal material. Since the fertility depends on the organic matter, it is not surprising to find the concentrations of P, K, Ca, Mg, and total N in the A and AC are higher than in the C in a Lapine. In a Steiger, there is less difference between the horizons, with only P, Ca, and total N being higher in the upper horizons, and there is a smaller concentration difference between horizons for these three nutrients. They pointed out that in order for these numbers to be comparable to other soils, the concentrations should be expressed on a volumetric, rather than per weight basis, because of the low bulk density of the pumice soils. The Lapine and Shanahan soils studied by Dyrness (1960) had an unusually high C/N ratio, compared to non-pumice soils. Nitrogen is probably the most important limiting nutrient, but P and S are also limiting, whereas K and Ca are not (Youngberg and Dyrness 1965).

Soil properties can be modified to some extent by single plants. Dyrness (1960) found that, under shrubs, the soil moisture is not depleted quite as rapidly as in the open, and there is more K, Ca, Mg, and N.

The soil developed in the alluvial material on the study area might be expected to have physical and chemical properties closer to "typical" values for sandy soils (Table 3).

Climate

Sternes (1963) thinks that the climate of much of the lower elevations in Crater Lake National Park is intermediate between the climate at Park Headquarters and that at Chemult (Table 4). The climate of the study area is probably closer to that of Chemult, because of the elevation and position east of the Cascades. However, the area lies on a strong gradient (e.g., compare Ft. Klamath and Park Headquarters) so it is difficult to be certain. The macroclimate undoubtedly changes even within the study area. The Park, like the rest of the Northwest, has a winter rainfall climate. About 70% of the total precipitation falls during the five months of November through March, and less than 10% falls in June through August. The difference in precipitation between Park headquarters and other stations is due to the rain shadow in the lee of the Cascades. If the water content of snow is 10% (volume/volume), 86% of the precipitation at Park Headquarters, and 61% of the precipitation at Chemult falls as snow. In the study area, on March 21, 1974 the snow varied from 170 cm deep with 62 cm of water to 270 cm deep with 110 cm of water. The winter of 1973-74 had near record precipitation. Regardless of the precipitation, it is probably safe to assume that the soil is at field capacity shortly after snow melt, and soil moisture progressively declines through the summer. So maximum plant moisture stress

Table 4. Climatic statistics for some stations near the study area (after Sternes 1963, Johnsgard 1963).

Station	Mean annual precip. (cm)	Mean temperatures (°C)				Distance and direction from study area	Elevation (m)	Period used
		January		July				
		daily max.	daily min.	daily max.	daily min.			
Crater Lake National Park Headquarters	171	1.4	-8.1	21.3	5.6	12 km northwest	2001	1924-1961
Chemult	67	3.3	-10.9	28.2	2.5	54 km northeast	1498	1937-1961
Sand Creek Station	71	2.4	-10.8	27.3	3.5	22 km northeast	1425	1931-1952
Fort Klamath	55	mean = -3.6		mean = 16.5		9 km southeast	1280	1864-1898 Discon.

may depend more on the length of the rainless season and evapotranspiration through the summer than on the total precipitation.

Some of the summer precipitation accompanies thunderstorms. These thunderstorms often have little rain and result in fires. Morris (1934) indicates that lightning storms occur less frequently in the study area than to the west, east or north, but they are still common. Most of the fires are set by storms that cover a wide area on a single day, and set multiple fires. Despite his finding that lightning fires are equally likely to occur at any altitude with equal frequency of storms and equal fuel conditions, in the Park, lightning fires appear to be more likely to be set near the tops of ridges (Fire Atlas, Park Headquarters). In the period 1964-1973, in the whole Park, there were four lightning fires set in June, 13 in July, 25 in August, and 3 in September.

Keen (1937) found in south central Oregon that the climate, as reflected by the width of annual rings of P. ponderosa trees on drier sites, has shown no long-term trends in the past 650 years. However, there have been periods averaging about 13 years long with above or below average growth.

The reasons that Chemult, at lower elevation, has lower minimum temperatures are 1) cold air drainage, 2) arctic air masses moving from the east stopping at the Cascades, and 3) marine air masses from the west riding over the cold air east of the Cascades

(Sternes 1963). Frost probably can occur any night of the year in the study area.

History

There is little indication that Indians used most of the area occupied by Crater Lake National Park for anything more than occasional hunting (National Park Service Files, Park Headquarters). Good (1941) reports that trappers first entered Klamath County around 1825, and probably occasionally returned thereafter. However, Fremont was still exploring when he passed through in 1843 and 1846 and Crater Lake was not discovered until 1853. There was no American settlement in the area until Fort Klamath was established in 1864, when a treaty established the Klamath Indian Reservation. In conjunction with establishment of Fort Klamath, a road was built in 1863 and rebuilt in 1865, from Jacksonville by way of Union Creek, probably through the study area. Early road builders often set fires to clear brush (Leiberg 1900). The Cascade Forest Reserve, which included the study area, was established in 1893. Leiberg (1900) stated that forest fires were more frequent and larger during settlement, especially 25 to 40 years before his observations (compare with Results). In the early 1900's, fire control became effective. Crater Lake National Park was established in 1902, except for the panhandle, which was added in 1932, and some private inholdings which were acquired later. The southern tip of the panhandle was logged in 1909, 1910, 1911, and 1917 (U.S. Forest Service Records, Klamath Ranger District). The part of the panhandle east of Annie Creek was logged in 1923 and 1927. Between 1923 and 1933, there was an extensive outbreak of the Mountain pine beetle (Dendroctonus monticolae) in Pinus contorta. The outbreak moved through the Park from north to south, with the south entrance area becoming infested about 1930. In 1925 the beetles were killing an estimated 200,000 trees north of the Park. In order to control this outbreak, over 64,000 trees were felled and the beetles in them killed by heat from the sun or burning. Often, these attacks speeded succession to forests of Abies or Tsuga. There were limited bark beetle buildups in 1946 - 1948 and 1957. Limited chemical control of beetles in P. ponderosa, mostly near the road, was done through the 1960's (National Park Service Files).

Previous Vegetation Studies

Much work has been done on the vegetation of central Oregon (Dyrness 1960, Sherman 1969, Swedburg 1961, Volland 1963, West 1964). These and other studies are reviewed by Franklin and Dyrness (1973). The reader is referred to their treatment, especially the section on Abies concolor and Abies magnifica shastensis zones of southwestern Oregon and the Pinus ponderosa and Abies grandis zones of eastern Oregon and Washington, for a comprehensive and coherent account. Even though the vegetation in the study area could be called Mixed Conifer, it is substantially different from that of the Mixed Conifer zone of southwestern Oregon. In this section, I will mention some of the findings of studies that specifically included the study area. However, the early studies often concerned a large area and it is difficult to know how well the study area fits their generalizations.

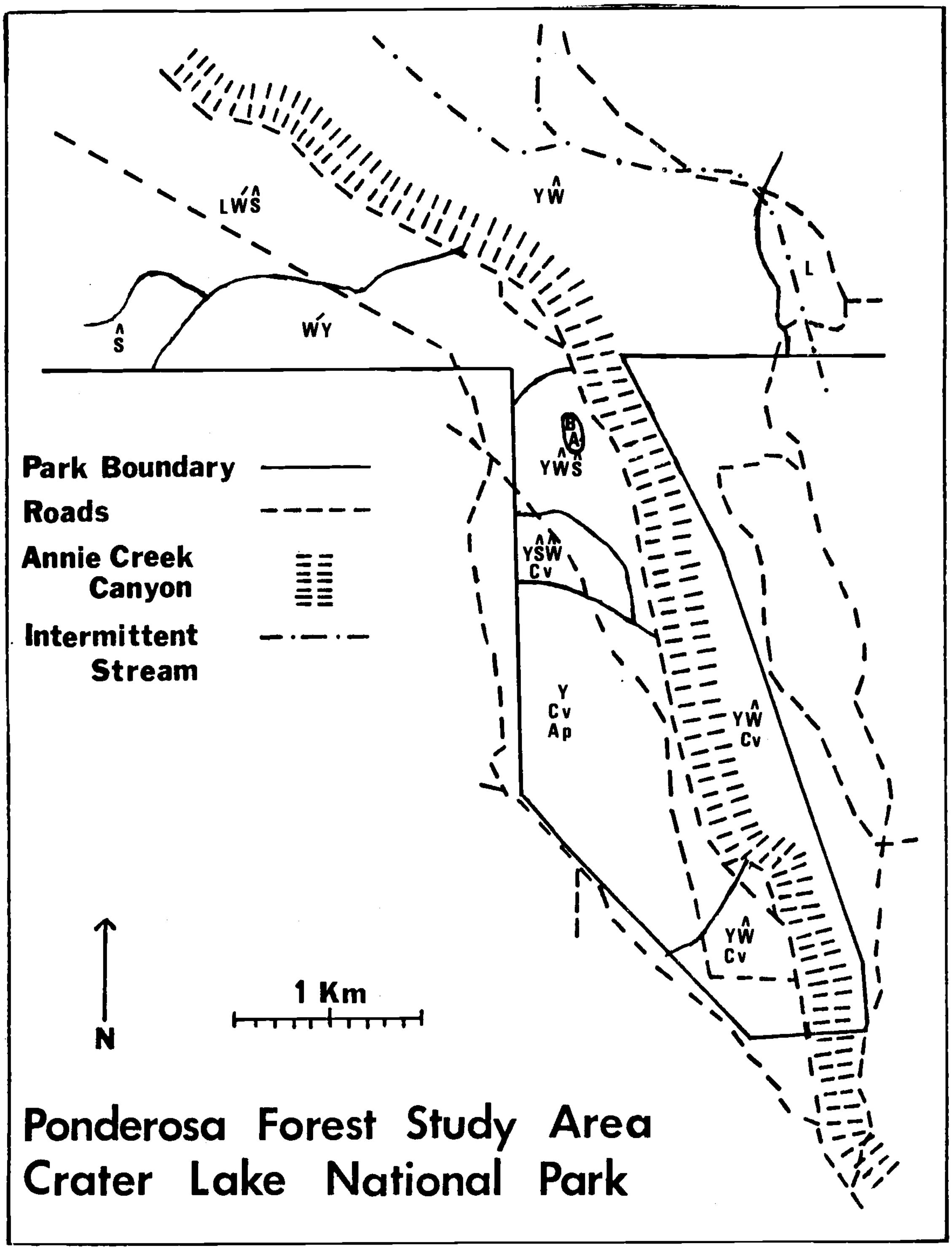
Leiberg (1900) described the vegetation of T. 32S, R. 6E as being of the _Pinus ponderosa_ and _Tsuga mertensiana_ forest types. He said (p. 350) that part of the township carried "... open and scattered growth of yellow and lodgepole pine. There is a thin sward of grass and sedge among the trees, and the land is at present utilized for cattle range." He also says (p. 350), "The stands of yellow-pine type have been grievously thinned by the fires and dense masses of underbrush, composed almost exclusively of the vellum-leaved ceanothus, have occupied the place of the burned forest." And in speaking of _A. concolor_ (p. 292), "It reproduction is generally good, but in some locations... as T. 32S, R. 6E, brush growths are replacing burned or partially burned stands of the white fir." In making generalizations about the _P. ponderosa_ forests throughout southern Oregon, he said (p.248-249), "The aspect of the type is that of an open forest with a minimum of undergrowth and seedling or sapling growth . . . due to frequently repeated forest fires more than to any other cause. The forest floor in the type is covered with a thin layer of humus. . . where the humus covering is most conspicuous, it is never more than a fraction of an inch in thickness, just enough to supply the requisite material for the spread of forest fires ."

In 1936 a vegetation cover type map was prepared for Crater Lake National Park (Fig. 2). Much of the panhandle was dominated exclusively by *P. ponderosa*, with a *Ceanothus velutinus* and *Arctostaphylos patula* understory. The trees were widely enough scattered that the shrubs probably could be seen from above the canopy. At higher elevations, *A. concolor* and *A. magnifica shastensis* became more important, and the canopy closed. Annie Creek canyon was dominated by *Pseudotsuga* and *A. concolor* and a small area in the northern part of the panhandle was dominated by *Populus trichocarpa* and *Populus tremuloides*. East of Annie Creek and near the lower tip of the panhandle *P. ponderosa* shared dominance with *A. concolor*. The report that accompanies the map combined the Y/Cv/Ap type with some *P. ponderosa* habitat type in the northeastern part of the Park to form a Ponderosa Pine type. This report states that this type was generally open and parklike, but there are places where there was an accumulation of dead material.

Wynd (1941) analyzed the Park's vegetation in terms of Merriam's life zone concept. He included most of the study area in the transition zone, along with the *P. ponderosa* habitat type. The shrub layer had a thick growth of *Ceanothus velutinus* , with *Prunus*

Fig. 2. Vegetation type map, 1936, from National Park Service Files. Species are listed in order of decreasing density. The species listed are those that would probably be seen from above the canopy, and so do not include the reproduction. The accompanying report states "In tree types a pure stand is one which contains approximately 20% or more of a single species by number of stems." This probably is a mistake, and actually means 80% or more. Also, the *Pinus monticola* associated with *P. ponderosa* north of the old boundary is probably a mistake, and should be *A. concolor*. *Pseudotsuga* and *A. concolor* are the indicated vegetation in Annie Creek Canyon.

A = *Populus tricocarpa*; Ap = *Arctostaphylos patula*; B = *Populus tremuloides*; Cv = *Ceanothus velutinus*; L = *Pinus contorta*; Ŝ = *Abies magnifica shastensis*; W′ = *Pinus monticola*; Ŵ = *Abies concolor*; Y = *Pinus ponderosa*



Ponderosa Forest Study Area
Crater Lake National Park

emarginata, *Salix scouleriana*, and *Salix sitchensis* common. *Chimaphila umbellata* was the most common herb, with a large number of grasses, and *Fragaria virginiana*, *Smilacina racemosa*, and *Arctostaphylos nevadensis* in sunny spots. He also included Annie Creek canyon with some canyons west of the Cascade crest in the transition zone. *Pseudotsuga* was the most typical species, with a relatively mesophytic shrub and herb layers, with such species as *Acer glabrum*, *Rubus parviflorus*, and *Clintonia uniflora*.

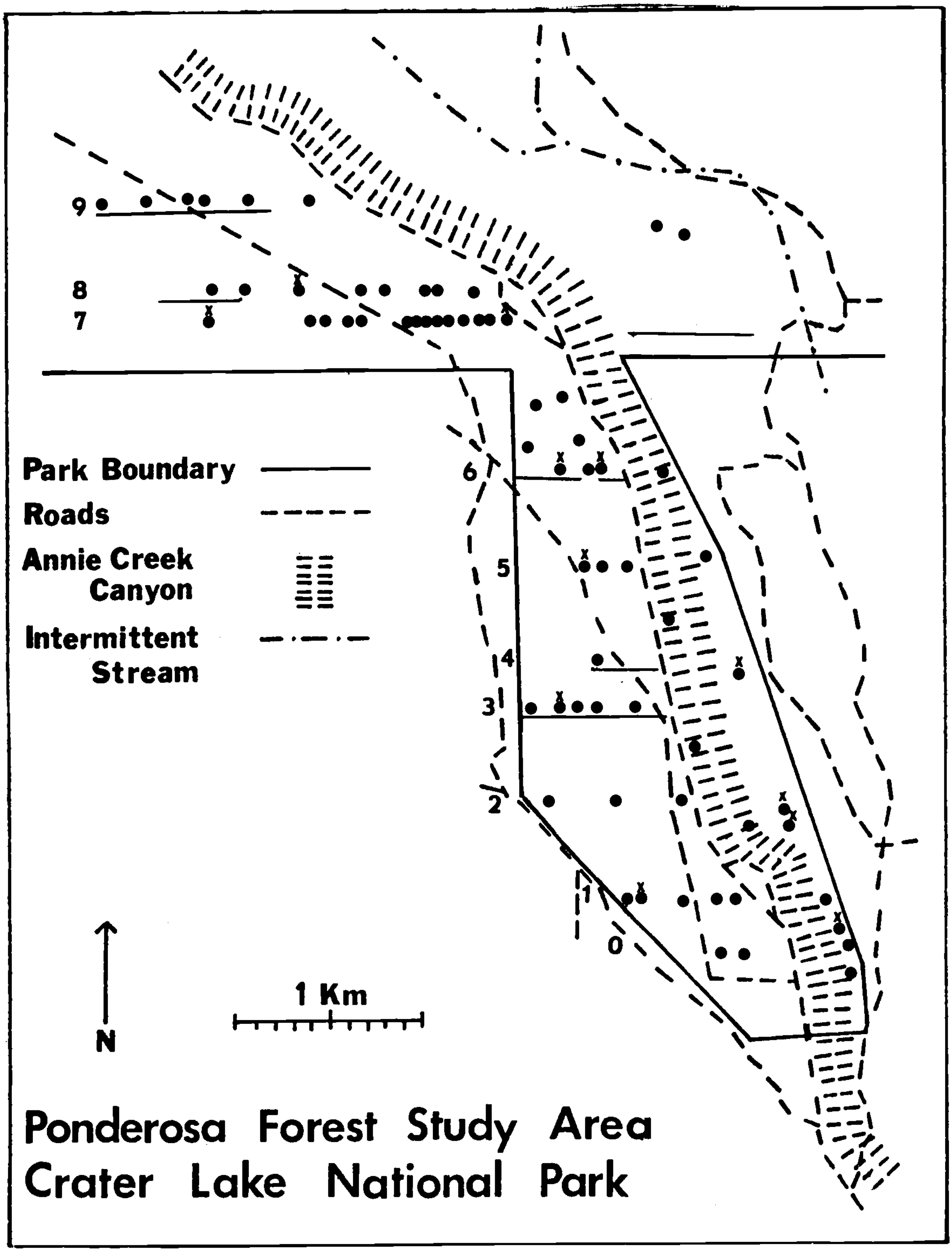
METHODS

Vegetation Sampling

The vegetation was sampled in 68 plots (Fig. 3). Fifty plots were located along 10 east-west transects through the portion of the study area west of Oregon Highway 62. Eighteen plots were located throughout the area as needed to sample all of the vegetation units recognized in a reconnaissance. Only two plots were located in the portion of the area east of Annie Creek and north of the original boundary. The reconnaissance indicated that the same communities exist on both sides of the creek.

The 10 east-west transects were located by dividing a north-south line extending the length of the area into 10 equal segments, and randomly choosing an east-west transect through each segment. The plots were located along the transects at intervals chosen by multiplying a random number between 0 and 99 by a factor. The factor increased from 1.8 to 5 m for different transects as sampling progressed, because total length of transect to be sampled was initially underestimated. This interval between plots was measured by tape measure. I thought that this method of placement would result in more or less random location of plots. However, it resulted in a tendency for the plots to be located too close together (Fig. 3). The

Fig. 3. Sampling locations. Dots indicate vegetation plots. The x's show plots at which soil pits were dug. Underlined transects indicate locations of age-size sampling. The numerals to the left of the transects designate the transect. The individual plots are designated by numerals with 1 being the western most plot. The 10 plots east of Annie Creek Canyon are designated by E followed by a numeral, with 1 being the southern most. The four plots in Annie Creek canyon are designated by C followed by a numeral, with 1 as the southern most. The four plots between transects 6 and 7 are designated by M followed by a numeral, with the south-western most plot being 1, and numbering in a clockwise direction.



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eighteen plots not on transects were located by pacing a random distance along a baseline, such as a road, park boundary, or ridgetop, that bordered the vegetation unit to be sampled, and measuring a randomly determined distance into the vegetation unit. In both methods of plot location, if two plots overlapped, one was arbitrarily eliminated. At each location the precise orientation of the plot was randomly chosen from 16 possible orientations. If a plot extended into a disturbed area, such as the powerline, or into another vegetation unit, such as over the canyon edge, the orientation was adjusted to exclude the non-conforming area. On steep slopes the orientation was adjusted so that the long axis of the plot was parallel to the contour lines.

The data collected at each were similar to those of Daubenmire and Daubenmire (1968). Each plot is a 15 m x 25 m rectangle divided into three 5 m x 25 m rectangles. All trees over 20 cm tall in the large plot were tallied by size class. Size was measured as diameter at breast height. The divisions between size classes occur at 5 cm, 10 cm, 15 cm, 20 cm, 25 cm, 35 cm, 45 cm, 55 cm, etc. Canopy coverage of the shrub and herb layers was recorded as the canopy coverage class of each shrub or herb in 50, 20 cm x 50 cm microplots, placed at one meter intervals along both of the long sides of the central 5 m x 25 m plot. The divisions between classes are 5%, 25%, 50%, 75%, and 95%. Two additional lists were made--one of the species that occurred in the central plot but not in the microplots, and the other of species that occurred in the plot but not in the central plot.

Nomenclature follows Hitchcock *et al*. (1969) and Peck (1961) for the few species not in Hitchcock *et al*.

Vegetation Analysis

Three different approaches to classifying the vegetation were used. These were: (1) Daubenmire's habitat type approach, (2) Braun-Blanquet's table sorting, and (3) an ordination.

Daubenmire's approach (Daubenmire and Daubenmire 1968) is to classify vegetation mostly on the dominants of the climax community that would occupy a site in the absence of disturbance. The part of the study area that has gone longest without disturbance was last burned by a surface fire in 1846, and most of the lower elevations have burned in the 1900's (see Results). So there is little area that may be considered near climax, and this is not well distributed. The main evidence about what the climax tree dominants probably would be is the number of small trees of the various species present. Over much of the area, this indicates that *Abies concolor* or *Abies magnifica* var. *shastensis* will be the principal climax dominant. In the drier and more disturbed parts of the area, there are many small *Pinus contorta* and *Pinus ponderosa*. These two species are not shade tolerant (Fowells 1965) and Daubenmire and Daubenmire (1968) conclude that in the northern Rockies neither of these species is climax where another tree species is present. This leads me to conclude that even where *Pinus contorta* and *Pinus ponderosa* presently dominate the smaller size classes, *Abies concolor* would be the primary climax species. This conclusion is supported by the apparent poor health of all of the smaller *Pinus ponderosa* in unlogged areas (they have few living branches and grow very slowly). However, without the mature stands to study, there is a substantial chance for error in this judgement.

To decide on the probable climax dominants of the herbaceous layer, I observed what species dominated these layers beneath a closed or nearly closed canopy of *Abies*. This method of assessing the probable climax composition assumes, of course, that at climax there will be a nearly closed canopy of *Abies*. There is also some danger, in an area that has been as recently disturbed as this, that the most mature stands are in the "stagnation stage" of development described by Daubenmire and Daubenmire (1968, p. 6), in which "Shade from the crowded tree canopies now becomes so dense that all but the most sciophytic undergrowth plants (these chiefly the highly mycotrophic members of the *Ericaceae* and *Orchidaceae*) are eliminated. Sometimes even these die out, leaving only a carpet of brown needles on the forest floor." Following this stage, the climax herbs and shrubs reinvade as some mature trees die. It is possible that even the least disturbed part of the study area, which last burned in 1846, is still in the stagnation stage, rather than near climax.

Daubenmire's system is difficult to apply because of lack of knowledge of successional relationships and climax vegetation. In the present study these can only be estimated. However, the habitat-type concept has been useful in other parts of the Northwest, and was also in this study (see Results).

The table sorting of Braun-Blanquet was done as described by Shimwell (1971, Chapter 6) and Mueller-Dombois and Ellenberg (1974, Chapter 9). First the data were put in a "raw table," with vegetation plots along one axis and species along the other; then the species with intermediate constancy were put in a "constancy table." The species and the plots were rearranged to obtain an "ordinated partial table." This showed that clearly some plots should be grouped together because of their similarity to each other and dissimilarity to the rest of the plots. But most of the plots seemed to lie, more or less, along a gradient of gradual change in composition, apparently associated with elevation. There were no sudden changes in species composition, but there were somewhat sharper, but more difficult to interpret, changes in the dominant species.

At this point, I used an ordination as Franklin, Dyrness, and Moir (1970) did. The ordination was a modification of the SIMORD program presented in Dick-Peddie and Moir (1970). This program calculates the similarity between stands as:

$$\frac{1}{n'} \sum_{k=1}^{L} \left(\frac{2\min(a_{ik}, a_{jk})}{a_{ik} + a_{jk}} \right); \quad \text{for } a_{ik} \text{ or } a_{jk} \geq b$$

where n' is the number of species satisfying the inequality, L is the number of species used in the ordination, a_{ik} and a_{jk} are the importance of the k^{th} species in the stands, i and j, being compared, and b is an arbitrary value chosen by the investigator as the minimum below which the contribution of a species to the vegetation is deemed to be negligible. I set b = 0.5% rather than 3% because of the low coverage of many species and the low number of species. I entered the tree species twice, by using the number of trees less than 10 cm and the number of trees greater than 10 cm as two separate "species," instead of only one number for the coverage of each species. This division also placed relatively more weight on the smaller size classes. This set L = 48, even though only 38 species were actually used, because there were 10 tree species. The 38 species used include all the species with more than 0.5% cover in any of the plots for which ordination was used to classify the vegetation.

The distance between stands i and j is calculated as:

$$\text{distance } (i, j) = 1 - \text{similarity } (i, j)$$

and the ordination distance of stand i along the x or y axis is calculated as:

$$50 + 50\ [(\mathrm{distance}(i,R1)^2 - (\mathrm{distance}(i, R2)^2\ ]$$

where R1 and R2 are the end stands of the axis.

The development of the classification was similar to that outlined by Franklin, Dyrness and Moir (1971). First the similarity matrix was studied for the relationships it revealed. I chose the end stands because they seemed typical of a certain community type or typical of one end of the elevation or successional gradient, as indicated by the subjective classification and the similarity matrix. Several different end stands were tried on subsequent runs, but the results generally agreed with the first run, or did not seem to make much ecological sense, so I depended on the first run for the ordination, using the others only for the information gained by their failure to produce meaningfully different results. The relations shown by examining the similarity matrix and the ordinations were compared to the subjective classification, and adjustments were made in the subjective classification by transferring plots from one community to another, and by abandoning some of the communities that had been considered.

Finally, the classification was checked in the field to see if the communities were recognizable and could be mapped. The changes made following field checking resulted in the final community classification.

Soils

I described soils at 11 plots (Soil Survey Staff 1951) selected to include all the important soil types found in the study area (Fig. 3). Samples were taken from each horizon and textural analysis was done on the 2 mm portion. This analysis was done using the reading at 70 seconds on pumice soils and the reading at 40 seconds for non-pumice soils to determine sand content (Youngberg and Dyrness 1964).

Fire Frequency

In the following discussion, the term scar or fire scar means the "cat-face" or the whole wound caused by several fires on the tree, and the term sear means the wound on the face of a scar caused by an individual fire.

The study area was searched for the fire scars with many visible individual sears. From these trees with a relatively high number of sears, several were chosen for sampling (Fig. 4). Factors considered in choosing which trees to sample were as follows: (1) Ease of relocation. The tree had to be within 200 m of a boundary, transect, or road. (2) Location in the area being sampled. The samples were as widely dispersed over the sampled area as possible, considering the location of the suitable scars. (3) Amount of damage that would be done to the tree. The fire scar had to be of such size

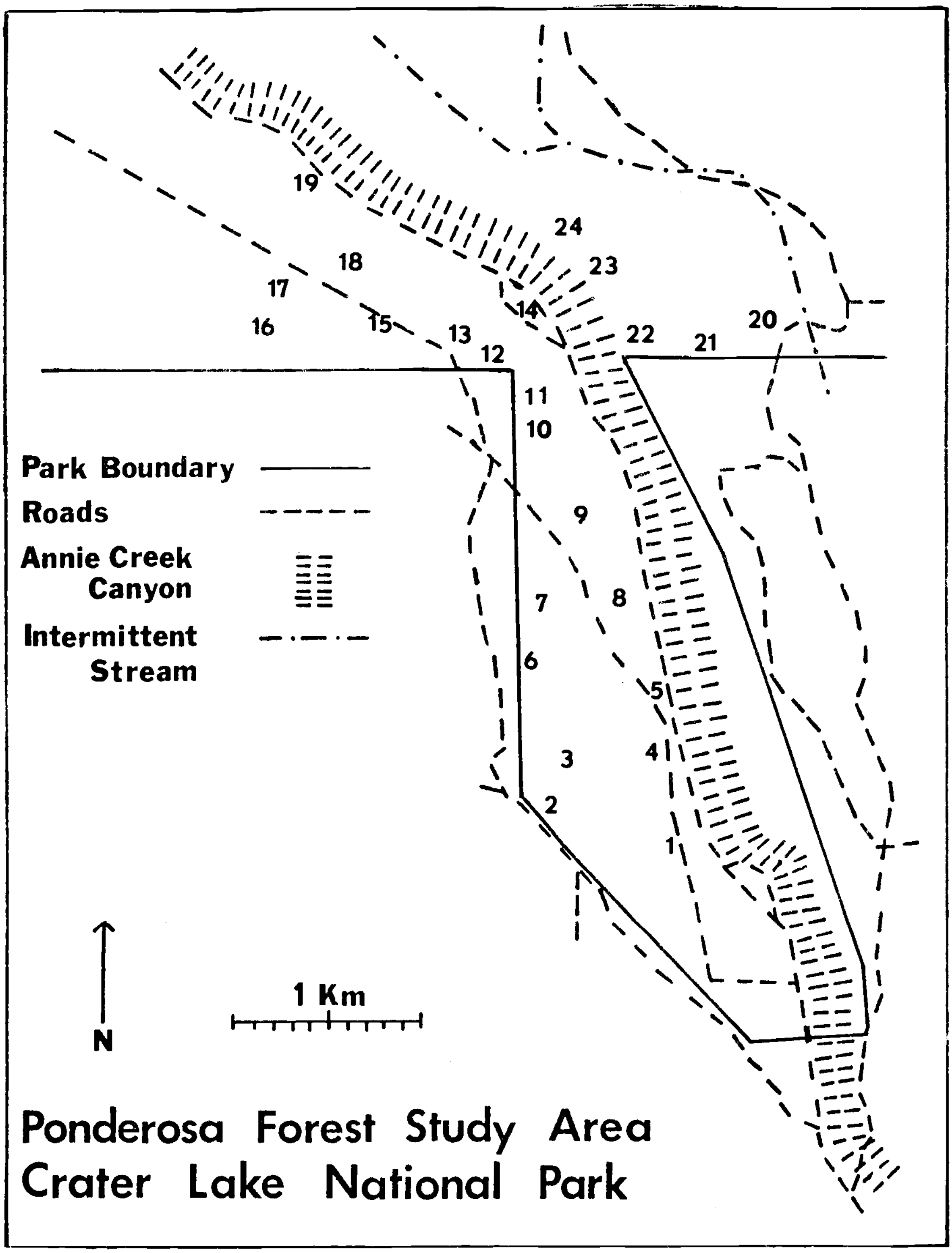

Fig. 4. Spots where fire scars were sampled. The number is a designation for later reference.

and location that, in my judgment, removal of a wedge from it would not substantially increase the chances of the tree falling due to direct structural damage from sampling.

The area within 100 m of each suitable tree was searched intensively for a second fire scar to be sampled. This second sample at each spot was selected on the basis of number of scars and amount of damage to the tree. At three spots the two trees are somewhat farther than 100 m apart; where the second fire scar was substantially better than any within 100 m of the first tree.

Two trees were sampled at each spot because every fire does not leave a record on all fire scars. All fires do not burn up to all trees (Fredrick Hall, U.S. Forest Service, Region 6, personal communication), and later fires sometimes burn deeply enough to erase scars that are on the scarred area. I arbitrarily chose 100 m as a small enough distance so that each spot of two trees could be treated as a single sample; that is, the dates from the two scars will be combined to find the fire frequency for a single point. To check the assumption that the two trees are sufficient, three scars were sampled at one spot.

Even though I chose the scars with the greatest number of scars visible, I am assuming that the relatively high number results from such factors as the age of the scar and the growth of the particular tree or the fuels around the tree, rather than these particular spots having a higher fire frequency. There is no apparent reason that any particular small area would have a higher fire frequency than the neighboring areas. There are no points that rise above the general terrain that would attract more lightning.

The fire scar sample is a wedge cut from it with a chain saw, as in Fig. 5. The wedges were long enough to remove all the scars on one side of the scar. The inside end of the wedge was loosened with a chisel. The wound was painted with a compound to prevent infection.

With the exception of a *Pinus lambertiana* and a *P. monticola*, all the samples were taken from *Pinus ponderosa*. Other species rarely had a comparable number of visible scars. Also *Abies* spp. and *Pinus contorta* usually rotted around their scars.

The number of rings outside the scars were counted using a dissecting microscope. In many cases this was necessary to obtain even an approximately accurate count; most of the trees sampled presently are growing very slowly. Even with the dissecting microscope, two samples could not be counted. Usually counting was facilitated by a growth rate decrease that occurred the year of the fire or the year after the fire. This decrease may be localized around the scar or extend around the tree, and lasted one to several years. In counting, there were problems with narrow, missing, or indistinct rings, pitch, insect holes, decay, and later fires destroying evidence

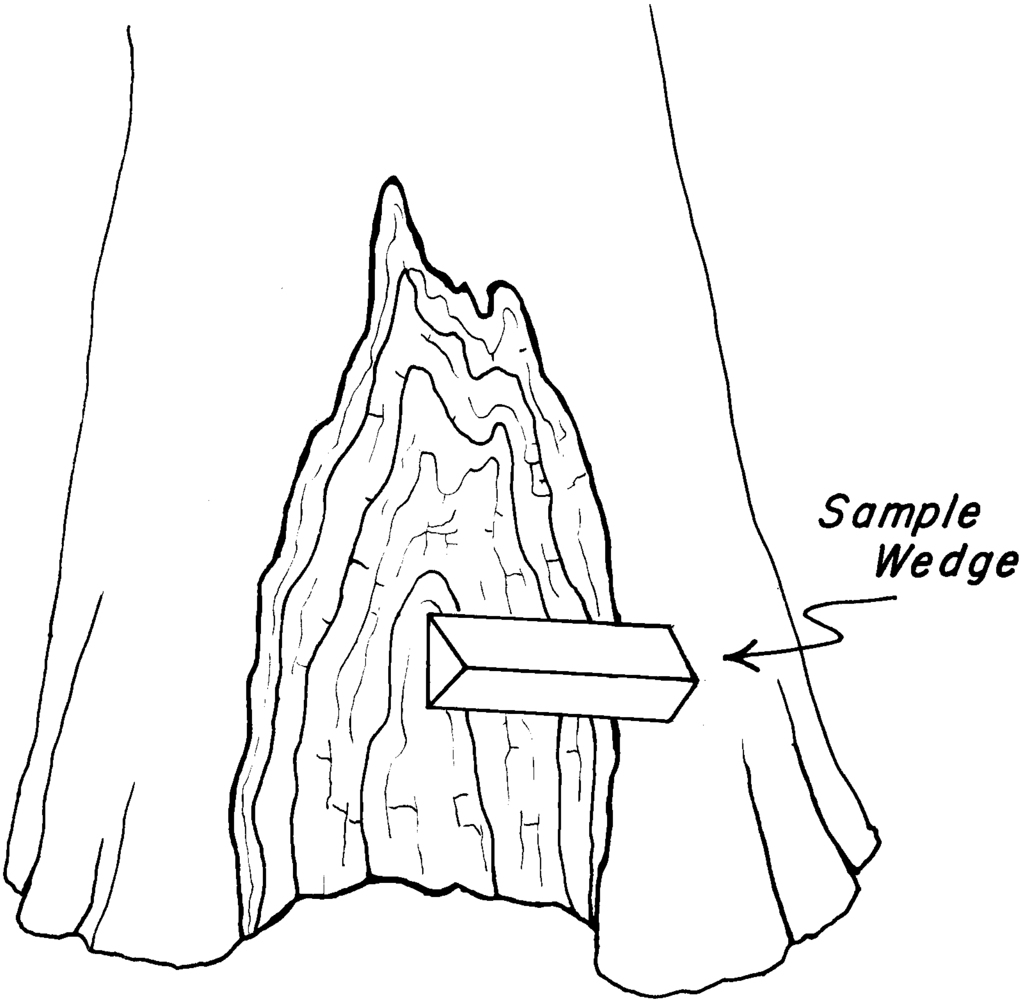

Fig. 5. Method of sampling fire scars.

of earlier sears. Alcohol usually washed pitch out of the top layer of early wood tracheids, increasing the contrast of early and late wood. Insect holes and decay were a problem usually only within about 5 cm of the face of the scar, so they did not hurt the cumulative count but sometimes made it impossible to tell which ring a sear was associated with. Because of these errors, I recorded an estimate of the accuracy of the date for each fire. Even the most accurate dates could be off 2% of the difference between the date of the fire and 1974. There were sometimes inconclusive indications that a fire may have occurred, usually a growth rate decrease, and some hint on the face of the scar that there was a sear there at one time. If this was the case, I recorded "possible fire" that year. Occasionally growth rate decreased without any sign of a sear. If this was during an unusually long interval without a fire, I recorded a "growth rate decrease."

To find the dates of the fires, I took the counts that appeared most accurate to the earliest date, and tried to match the intervals between fires on other scars with these most accurate ones. I made special efforts to insure that no single fire at any one spot that was recorded on both trees at that spot was counted as two different fires. For instance, in the panhandle, there were three scars on which I counted the following dates:

3A	1902	1892	1883	1870	1864			1841			1812 ± 2
9A		1892	1879		1864		1846	1841		1818 ± 2	
9B	1902	1892	1881	1872	1867	1858	(1849)	1844	1829	1821	1815 ± 6

(Parentheses mean there was possibly a fire that date.)

The count of 3A and 9A are most accurate, so I took their dates at face value, but since 9B was less accurate, I subtracted three years from the dates before 1872 to make them match the dates on the more accurate trees, and subtracted two years from 1881 and 1872 to make them match. The validity of this procedure is supported by the fact that 9A and 9B are at the same spot. The procedure gives accurate dates for widespread fires, but smaller fires are more liable to be placed in the wrong years. Cross dating fires is probably not as accurate as cross dating ring widths, and is only useful if the fires are widespread. However, except in the driest habitats (which were logged) the P. ponderosa trees in the study area are probably complacent, and their growth is probably affected only by extreme climatic fluctuations. This would make cross dating ring width difficult.

In order to calculate the fire frequency, it is not necessary to know the precise dates of the fires, but only the intervals between them. The only danger of not knowing the correct date for each sear is that in some cases a fire that sears both trees at a spot might be counted as two fires, or that two fires might be counted as one.

Tree Age-size Relationships

In order to determine the probable approximate forest composition when fires still burned through the area, a relation between age and density was determined, by combining the vegetation data with data on the relation between age and size of the trees. This permits an estimation of the number of trees that are still alive that were also alive at some specified time in the past. To estimate probable relative past composition one has to assume that all the species concerned had approximately the same age-specific death rate. This assumption seems unlikely to be true, for instance, for competing P. ponderosa and A. concolor seedlings, or for a comparison of A. concolor, of which 50% have fire scars, with P. ponderosa, or for a comparison of either species with P. contorta, with its shorter life span. However, this procedure can probably give a rough estimate.

The sampling and data analysis to find the relation between tree age and size was done for each important species in each of four areas. This sampling was independent of that done on the same species on the other three areas and independent of that for other species in the same area. For each tree sampled, the dbh was recorded. For the trees greater than 5 cm dbh an increment core was taken approximately 20 cm above the ground. Trees less than 5 cm dbh were cut at ground level and a section of stem removed. The sampling was done on transects in four different habitat types (Fig. 3). The population of each species in each area was divided into four or five size classes above 5 cm dbh, based on the vegetation data. Five trees were sampled in each of these size classes, and 10 trees less than 5 cm dbh were sampled, for a total of about 30 trees sampled. However, the actual sample size is usually smaller because some cores were lost, trees less than 0 cm dbh could not be assigned a negative dbh, and the cores from some of the large trees did not get close to the center.

The sampling was done at 10 stations in each area. The size classes to be sampled at each station were preselected; the selection was based on what had been sampled at previous stations and a desire to space the samples of the same size class as widely as possible. The stations west of Annie Creek were rectangles 10 m or 20 m wide, and 30 m to 75 m long. The transect extended through the middle, parallel to the long sides; adjacent rectangles touched. The individuals sampled were the ones which were in the preselected size classes furthest west. In each area, all rectangles were approximately the same size. East of Annie Creek, each station was a circle 20 m in radius, and the individuals sampled were the ones in the preselected size classes nearest the center. No tree over 80 cm dbh was sampled. When counting the rings on the increment cores in which the pith was missed, an estimate was made of the number of rings missing, and this was added to the counted number. Seven years were added to the age of all trees greater than 5 cm dbh, to approximately compensate for the amount of time it took the tree to reach 20 cm.

When age was plotted against size, it was apparent that the variance of age increased with size. A square root transformation seemed to make the variance more constant. In order to estimate the age of trees of a certain size, I did a least squares regression of the square root of age against size.

Any size is associated with an age by the regression equation. Also, vegetation data associate certain size classes with the corresponding density of trees. To find the relation between age and density I entered the sizes that bounded the size classes (0 cm, 5 cm, 10 cm, etc.) into the regression equation and used the resulting estimated ages as bounds on age classes, each associated with the same density of trees as the corresponding size class was. There are several sources of error in this procedure. First there is sampling error in the vegetation data and the age-size data. This can only be reduced by increasing the sample size. Second, there may be error due to using the wrong type of equation to relate age and size. The square root transformation was arrived at empirically, and is subject to some error. Third, associating the same density in a size class with the corresponding age class gives a biased estimate of the density in the age class. This bias arises because if a size, x, corresponding to age y, separates two size classes associated with density i in the size class smaller than x and density j for larger trees, a certain proportion of i will be older than y, and a certain proportion of j will be younger than y. If i and j are not equal, or the proportions are not equal, in general, the errors will not balance out. Of course, i and j are usually not equal. In order to correct this bias, I would have to estimate the proportion of i and j that are in error. To calculate this net error I would have to know or assume how the variance of age changed with size (this implies I know or could assume the distribution of ages at a given size), and I would have to know or assume the distribution of sizes within the size classes. With my data, the size of the correction of the bias would probably depend as much on the assumptions as on the data. Because of this, and because of difficulty in locating a statistical treatment of these problems, I have chosen to ignore the bias.

RESULTS AND DISCUSSION

Soils

The soils fall into two major groups, those derived from pumice and those derived from alluvium from Annie Creek. A minor portion of the area is on soil derived from colluvial and possibly morainal material on the ridge on the northeast boundary of the study area. All of these soils are weakly developed, with an A_1 horizon overlying an AC or a C horizon. Their texture is sand or loamy sand in the A_1 and sand in the AC and C (Table 5). They are somewhat excessively or excessively drained. The structure in all of them is weak granular or subangular blocky. Most of them have water repellant A_1 and AC horizons and contain some pumice. Detailed soil profile descriptions are given in Appendix A.

Soils formed from both pumice fall and pumice flow occur. Lapine soil is found east of Annie Creek, about halfway up the panhandle, covering about 25 ha. It overlies a small ridge that rises 5 to 15 m above the surrounding pumice flow and alluvium. The Steiger covers about 415 ha, including most of the area west of Annie Creek canyon. The Steiger often has some scoria in it. The Steiger soil in the study area differs from the description by U.S. Bureau of Indian Affairs _et al._ (1958) in that it is not transported outwash from the

Table 5. Average particle size distribution in the 2 mm fraction of soils formed in two parent materials. The glowing avalanche deposit was sampled at plots 1-2, 3-2, 5-1, 6-1, 7-1, and 8-3. The alluvium was sampled at plots E-3, E-5, and E-6.

Horizon	Depth (cm)	% Sand	% Silt	% Clay
		<u>Glowing avalanche deposit</u> (n = 6)		
A	0-15	78.9	16.7	2.7
AC	15-50	87.7	10.1	2.3
C	50+	89.6	8.4	2.1
		<u>Alluvium</u> (n = 3)		
A_{11}	0-15	90.0	5.6	4.4
A_{12}	15-35	89.0	5.5	4.5
C_1	35-55	92.0	5.7	2.3
C_2	55+	91.5	4.8	3.7

pumice flow, but developed on the flow itself. In the study area it also appears to have more gravel and cobbles and a coarser texture than the Steiger on the Klamath Indian Reservation, although the amount of coarse fragments is highly variable. Both the Steiger and the Lapine seem to have thicker A_1 (usually over 10 cm) and AC (usually over 35 cm) horizons than reported for other areas (Bureau of Indian Affairs et al. 1958, Dyrness and Youngberg 1966). This may either be an actual difference or it may be due to a difference in interpretation of what constitutes the horizon.

The alluvial material deposited after the culminating eruptions contains varying proportions of pumice, scoria, and different kinds of harder rocks and it is possible that soil properties vary over short distances, due to deposits of different materials as the stream meandered. The harder rock is subangular, but the pumice and scoria are rounded. In most of the profiles of this material, no stratification is evident. However, in a gravel pit 0.7 km south of the Park, stratification is evident, as it is in the soil pit at plot 7-14. In the gravel pit, the alluvium overlies pumice flow material. These deposits are nearly level, except for terrace edges.

Two different soils formed in the alluvium. One is found principally in the *Melica* community covering about 105 ha. It is similar to the pumice soils in color, texture, structure, and, to a lesser extent, horizon thickness. The A_1 is up to 7 cm thick. The other kind of soil developing in the alluvium is found in the Senecio and Populus communities, covering about 45 ha. It differs in having a darker A_1 which is usually 30-35 cm thick. It also seems to have a lower proportion of pumice in it.

The top horizon of soil in Annie Creek canyon is usually derived from this alluvial material.

The water table at transect six was within a few centimeters of the surface in the first week of June in 1974 and 1975, but has dropped to more than 120 cm below the surface by the second week in July. On this transect, the structure of the A_1 is somewhat stronger than elsewhere, and tends toward angular blocky. It is not clear whether the parent material at plot 5-3 is alluvium or glowing avalanche.

Vegetation

I recognized 16 communities in six habitat types (Tables 6 to 9, Figures 6 and 7, and Appendix B). Each habitat type is the area that would support the same tree and understory dominants at climax. I defined communities so that they would not cross habitat type boundaries. The communities are areas with relatively homogeneous vegetation at the present. A key was developed for field identification of the communities (Appendix C).

Table 6 . Density of trees in 16 communities (trees/ha).

Habitat type:	Calocedrus decurrens/ Arctostaphylos patula	Abies concolor/ Symphoricarpos mollis			Abies concolor/Chimaphila							Abies magnifica var. shastensis/ Chimaphila umbellata		Abies concolor/ Mesic Species		Alnus incana/ Elymus glaucus
Community:		Populus	Senecio	Melica	Logged P. ponderosa	Logged P. contorta	Ceanothus	Chimaphila	Ceanothus-Carex	Carex	Chimaphila-Pyrola	A. magnifica var. shastensis-P. ponderosa	A. magnifica var. shastensis/ Chimaphila	Mesic species^2	Castinopsis	
Plots:	E-9, E-10	E-2, E-3	0-2, E-1 E-4, E-5 E-6, E-8	7-12, 7-13 7-14, 8-8	0-1, 1-4 1-5, E-7	1-1, 1-2 1-3	2-1, 2-2 2-3, 3-1 3-2, 3-3 3-4	3-5, 4-1 5-1	5-2, 5-3	7-6, 7-7 7-8, 7-9 7-10, 7-11 8-5, 8-6 8-7, 9-1	7-3, 7-4 7-5, 8-3 8-4	7-1, 9-2, 9-4, 9-5	7-2, 8-1 8-2, 9-1 9-3	6-1, 6-3 M-1, M-2 M-3	C-1, C-2 C-3, C-4	6-2, M-4
Calocedrus decurrens																
55-75	13															
35-55	13															
20-35	0															
10-20	40															
0-17	1160						27									
Populus tremuloides																
35-55																26
20-35		13														13
10-20		253			27											0
0-10		3320	76		226									128		1093
Pinus lambertiana																
95+							4									
75-95							0									
55-75						9	0									
35-55						0	0									
20-35						0	4									
10-20						9	11	9							7^1	
0-10					7	27	102	107	13						33^1	
Pinus contorta																
35-55					7	18	4	9			48	13	21			13
20-35					54	196	53	18		5	32	26	101	106		40
10-20					14	365	304	187	40	38	0	60	59	27		13
0-10					93	391	659	347	174	138	21	407	272	0		0
Abies magnifica var. shastensis																
95+												13				
75-95												4	16			
55-75												27	16			
35-55										5		7	48			
20-35										5	5	14	75			
10-20									40	8	5	87	224			
0-10				7					453	328	458	3153	4624	10		
Pinus monticola																
20-35													5			
10-20											5		10			
0-10										21	32	160	234	5		

(Continued on next page)

Table 6. (Continued)

Habitat type:	Calocedrus decurrens/ Arctostaphylos patula	Abies concolor/ Symphoricarpos mollis			Abies concolor/Chimaphila							Abies magnifica var. shastensis/ Chimaphila umbellata		Abies concolor/ Mesic Species		Alnus incana/ Elymus glaucus
Community:		Populus	Senecio	Melica	Logged P. ponderosa	Logged P. contorta	Ceanothus	Chimaphila	Ceanothus-Carex	Carex	Chimaphila-Pyrola	A. magnifica var. shastensis-P. ponderosa	A. magnifica var. shastensis/ Chimaphila	Mesic species[2]	Castinopsis	
Plots:	E-9, E-10	E-2, E-3	0-2, E-1 E-4, E-5 E-6, E-8	7-12, 7-13 7-14, 8-8	0-1, 1-4 1-5, E-7	1-1, 1-2 1-3	2-1, 2-2 2-3, 3-1 3-2, 3-3 3-4	3-5, 4-1 5-1	5-2, 5-3	7-6, 7-7 7-8, 7-9 7-10, 7-11 8-5, 8-6 8-7, 9-1	7-3, 7-4 7-5, 8-3 8-4	7-1, 9-2 9-4, 9-5	7-2, 8-1 8-2, 9-1 9-3	6-1, 6-3 M-1, M-2 M-3	C-1, C-2 C-3, C-4	6-2, M-4
Tsuga mertensiana																
0-10													5			
10-20							9				21	13	75		7	
Pseudotsuga menziesii																
95+															20	
75-95															26	
55-75	13														27	
35-55	13														14	
20-35	0														0	
10-20	0										5				0	
0-10	0		13				8	62			0				107	
Populus trichocarpa																
85-75															13	
35-55															13	
20-35															0	
10-20															0	
0-10															40	
Pinus ponderosa																
95+				7			8	27	27	14	5	20	5	21		
75-95	13			0	7		22	0	0	22	0	20	0	10		
55-75	13		35	7	7	36	8	9	0	3	0	0	0	0	7	
35-55	0	27	36	0	47	9	4	9	0	0	0	0	0	5	0	
20-35	0	213	63	0	147	54	15	0	0	0	0	0	0	0	7	
10-20	40	294	120	0	133	54	4	0	13	0	0	0	0	0	7	
0-10	454	507	204	0	313	222	676	125	1120	19	0	0	0	0	7	40
Abies concolor																
95+								9			5	7			7	
75-95				7			4	0		8	0	0		5	27	
55-75			4	47			0	0		13	5	7	5	26	53	
35-55			36	87	14	18	8	9		59	85	7	5	70	7	
20-35			76	193	67	27	8	45	26	94	204	27	48	112	50	26
10-20	27	53	267	247	147	124	99	391	320	323	369	80	112	373	86	240
0-10	294	294	1613	2687	1406	499	1246	3786	2213	6135	3083	2620	3557	2592	1687	400

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[1] May include some Pinus monticola.

[2] For Picea engelmanii data, see Appendix B, plot M-1.

Table 7. Cover (a) and constancy (b) of selected species of shrubs and herbs in 7 communities. Species are in same order as in ordinated partial table. Numbers are percent. + = < 0.05%.

Community	Calocedrus/ Arctostaphylos		Populus		Senecio		Melica		Logged P. ponderosa		Logged P. contorta		Ceanothus	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Grimmia	0.2	100												
Ceanothus prostratus	1.3	100												
Arctostaphylos patula	21.4	100			+	17			+	25	0.2	67	+	43
Senecio integerrimus	0.6	100	+	50	+	50								
Poa nervosa	+	50	0.2	100	0.5	67								
Lonicera conjugalis			1.9	100	0.1	50								
Lupinus albicaulis			2.0	100	0.1	67								
Symphoricarpos mollis			0.9	100	3.7	83	1.4	100	+	25				
Stipa occidentalis var. californica			0.2	100	+	33								
Purshia tridentata			2.5	100	+	67								
Festuca idahoensis			+	50	+	17								
Gilia aggregata			+	50	+	17								
Erigonum umbellatum			+	100	+	17								
Hieracium albiflorum + H. cynoglossoides	+	50	4.6	100	0.4	100	+	73	+	25	+	33		
Melica aristata					0.7	67	0.5	50						
Amelanchier alnifolia					3.7	50	0.2	25	+	25			+	14
Phacelia heterophylla			0.2	100	+	50	+	25	+	25				
Bromus spp.			3.3	100	2.0	67			+	50				
Collomia tinctoria			0.1	50	0.1	33			+	25				
Cynoglossum occidentale			+	50	+	83			+	50				
Stephanomeria lactucina					0.1	100	+	25	0.3	75				
Happlopappus bloomeri			5.2	100	0.7	100			1.0	50	0.1	33		
Ribes cereum			6.1	100	1.3	83			7.8	100	+	33		
Sitanion hystrix			8.3	100	1.1	83	+	50	2.0	100	+	67		
Fragaria virginiana			2.1	100	0.6	100	0.3	100	2.1	100	0.4	100	+	29
Chimaphila menziesii			+	50	0.1	50	0.2	100	+	25	+	100	+	29
Carex pensylvanica + C. brainerdii	9.8	100	26.1	100	44.3	100	27.2	100	20.8	100	12.6	100	+	43
Epilobium angustifolium			0.1	50	0.1	50	0.1	75	1.1	100	0.6	100	0.9	100
Stipa occidentalis var. occidentalis			7.8	100	3.8	67	+	50	7.3	100	1.7	100	1.0	86
Ceanothus velutinus	3.0	50	1.2	50	15.5	83	2.4	50	28.5	100	18.9	100	18.9	100
Kelloggia galioides			0.9	100	0.8	83	0.2	100	0.1	75	0.6	100	0.1	86
Apocynum androsaemifolium					0.1	33	0.7	75	0.1	100	0.1	100	2.9	100

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Table 7. (Continued)

Community	*Calocedrus*/ *Arctostaphylos*		*Populus*		*Senecio*		*Melica*		Logged *P. ponderosa*		Logged *P. contorta*		*Ceanothus*	
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
Salix scouleriana									3.7	50	4.9	100	2.7	100
Chimaphila umbellata					+	17	0.5	75	0.2	100	0.4	100	1.1	100
Arctostaphylos nevadensis	2.5	50					1.9	25					10.3	86
Pyrola secunda							+	50	+	25	+	67		
Smilacina spp.					+	50	+	50						
Adenocaulon bicolor							+	50						
Ozmorhiza chilensis			+	100	+	17	+	25						
Galium triflorum							+	25						
Rosa gymnocarpa					+	17								
Castinopsis sempervirens	+	50			+	17							0.6	43
Pteridium aquilium					+	17								
Elymus glaucus			0.4	100	0.2	17	0.7	50					+	14
Pyrola dentata					+	17	+	50	+	75	+	67	+	57
Pyrola picta					+	50	+	25	+	50	+	33	+	57
Brachythecium leibergii + *Pohlia nutans*					+	17	0.3	50	0.1	75	+	67	+	57
Polytrichum juniperinum	+	100					+	25	0.4	75	0.4	33	+	14
Gayophytum nuttallii					1.0	17			+	50				
Phlox caespitosa					0.1	17			0.1	25	+	33		
Antennaria rosea			0.5	100	+	17								
Arabis holboellii					+	17			+	25				
Lomatium triternatum					+	17								
Aster canescens					+	17			+	25				
Custilleja applegatei					+	17								
Arnica cordifolia					+	17								
Pachistima myrsinites					+	17								
Ribes viscossium							+	50						
Listera caurina							+	25						
Corylus cornuta	+	50												
Polystichum munitum var. *imbricans*	+	50												
Melica subulata					+	17	0.1	50						
Prunus emarginata									0.1	25				

Table 8 . Cover (a) and constancy (b) of selected species of shrubs and herbs in 6 communities. Species are in same order as in ordinated partial table. Numbers are percent. Plus sign means < 0.05%.

	Chimpahila		*Ceanothus/ Carex*		*Carex*		*Chimaphila-Carex*		*A. magnifica* var. *shastensis-P. ponderosa*		*A. magnifica* var. *shastensis/ Chimaphila*	
	a	b	a	b	a	b	a	b	a	b	a	b
Arctostaphylos patula	+	33			+	10						
Symphoricarpos mollis					0.1	30						
Staphanomeria lactucina					+	20						
Fragaria virginiana	0.1	100			0.1	50	+	40				
Chimaphila menziesii	+	100	+	100	0.1	80	0.2	100	+	75	+	100
Carex pensylvanica + *C. brainerdii*	0.1	67	37.4	100	9.6	100	1.9	100	10.6	100	0.5	80
Epilobium angustifolium	+	33			+	20			+	25	+	20
Stipa occidentalis var. *occidentalis*	+	67	+	50	+	30			0.1	25	0.1	40
Ceanothus velutinus	4.5	67	7.9	100	2.4	90			+	25		
Kelloggia galioides			0.1	50	0.1	80	+	20				
Apocynum androsaemifolium	0.6	67	0.3	50	0.5	80	+	20				
Salix scouleriana	1.5	100	0.8	50	0.8	60	+	20			+	20
Chimaphila umbellata	1.2	100	0.7	100	7.0	100	2.1	100	6.4	100	3.6	80
Arctostaphylos nevadensis	8.9	100	1.9	50	4.7	90	0.4	40	11.2	75	1.2	100
Pyrola secunda					0.5	100	0.3	100	0.1	50	0.1	60
Goodyera oblongifolia					+	60	+	40	+	75	+	20
Castanopsis sempervirens	1.5	33					+	20			+	20
Pyrola dentata	+	100	0.2	50	0.1	100	0.1	40	0.1	50	+	20

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Table 8 . (Continued)

	Chimaphila		*Ceanothus*/*Carex*		*Carex*		*Chimaphila*-*Carex*		*A. magnifica* var. *shastensis*-*P. ponderosa*		*A. magnifica* var. *shastensis*/*Chimaphila*	
	a	b	a	b	a	b	a	b	a	b	a	b
Pyrola picta	+	33			+	30	+	40			+	40
Brachythecium leibergii + *Pohlia nutans*	0.2	100	0.1	50	0.1	70	1.1	100	0.2	100	0.2	100
Polytrichum juniperinum	+	33	+	50	0.1	70	+	60	+	50	0.2	80
Roellia roellii					[a]	[a]	+	40			+	20
Listera caurina							+	20			+	20
Vaccinum scoparium					+	10						
Rubus ursinus	+	33										
Hypopitys monotropa											+	20
Allotropa virgata											+	20
Ribes viscossium			+	50								

[a] I did not recognize *Roellia roellii* as a separate species of moss at the time I was sampling this community.

Table 9 . Cover (a) and constancy (b) of selected species of shrubs and herbs in 3 communities. Species are in same order as in ordinated partial table. Numbers are percent. + = 0.05%.

	Mesic species		Castinopsis		Alnus/Elymus	
	a	b	a	b	a	b
Arctostaphylos patula			+	25		
Lonicera conjugalis	0.3	40			0.2	50
Lupinus albicaulus			+	50		
Symphoricarpos mollis	2.1	100	6.0	100	0.2	100
Festuca sp.			+	25 (?)		
Hieracium albiflorum + H. cynoglossoides	0.1	60	+	100	0.2	50
Melica aristata			0.1	50		
Amelanchier alnifolia	0.3	60	2.6	100	1.3	100
Phacelia heterophylla			+	50	+	50 (?)
Bromus spp.	1.3	100	0.5	75	16.1	100
Collomia			+	25		
Cynoglossum occidentale			+	25		
Stepharomeria lactucina			0.1	25		
Fragaria virginiana	0.3	80	+	25	4.1	100
Chimaphila menziesii	0.1	100	0.2	100		
Carex pensylvanica + C. brainardii	0.5	60	1.6	50		
Epilobium angustifolium	+	40			0.3	100
Ceanothus velutinus			+	50		
Kelloggia galiodes	0.2	40	+	50		
Apocynum androsaemifolium	0.1	40	0.3	25		
Salix spp.	+	60			1.3	100
Chimaphila umbellata	3.9	100	2.1	100	+	50
Pyrola secunda	0.5	100	0.2	50	0.2	50
Goodyera oblongifolia	0.1	80				
Smilacina spp.	0.8	100	0.1	100	4.7	100
Adenocaulon bicolor	0.3	100	+	100	10.7	100
Ozmorhiza chilensis	0.6	80	0.1	75	1.6	100
Galium triflorum	0.9	80	0.1	75	8.7	100
Ribes lacustre	0.2	60	+	75	5.3	100
Clintonia uniflora	1.0	60	0.1	50	2.2	100
Rosa gymnocarpa	0.1	40	1.1	100	0.3	50

(Continued on next page)

Table 9 . (Continued)

	Mesic species		Castinopsis		Alnus/Elymus	
	a	b	a	b	a	b
Castinopsis sempervirens	+	20	6.3	100		
Rubus parviflorus	+	40	0.8	100		
Pteridium aquilinum			2.7	75	+	50
Elymus glaucus	+	40	0.1	25	32.3	100
Alnus incana	+	20			21.7	100
Lupinus latifolius	+	20			11.8	100
Stachys rigida					+	50
Agrostis scabra					+	50
Spiraea douglasii					17.1	100
Solidago canadensis	+	40			3.8	100
Aster modestus					2.8	100
Pyrola dentata	+	20				
Pyrola picta	+	60	0.1	100		
Brachythecium leibergii + Pohlia nutans	0.3	80	0.6	100		
Polytrichum juniperinum					+	50
Roellia roellii			+	25		
Pachistima myrsinites			0.1	25		
Ribes viscosissimum	1.6	60	0.3	75		
Anaphalis margaritacea	+	40	+	25	2.1	50
Viola glabella	+	40			1.5	100
Pyrola asarifolia	+	20	+	25	1.3	100
Listera caurina	+	40				
Vaccinum scoparium	+	20				
Aquilegia formosa	+	20				
Carex disperma	+	20				
Mitella caulescens			+	25		
Vaccinum membranaceum			1.9	25		
Carex microptera					9.5	100
Senecio triangularis					1.3	50
Geum macrophyllum					2.1	50
Veronica spp.					2.5	50
Aulacomnium androgynum + Pohlia nutans					0.6	100

(Continued on next page)

Table 9 . (Continued)

	Mesic species		Castinopsis		Alnus/Elymus	
	a	b	a	b	a	b
Epilobium glandulosum					0.9	100
Calamogrostis canadensis					0.8	100
Mimimus spp.					0.2	50
Poleminium occidentale					0.6	50
Glyceria elata					3.2	50
Equisetum arvense					2.4	100
Juncus ensifolius					0.2	100
Prunella vulgaris					0.1	100
Aster occidentalis					0.5	50
Taraxacum officinale					0.2	100
Sorbus sitchensis					0.1	50

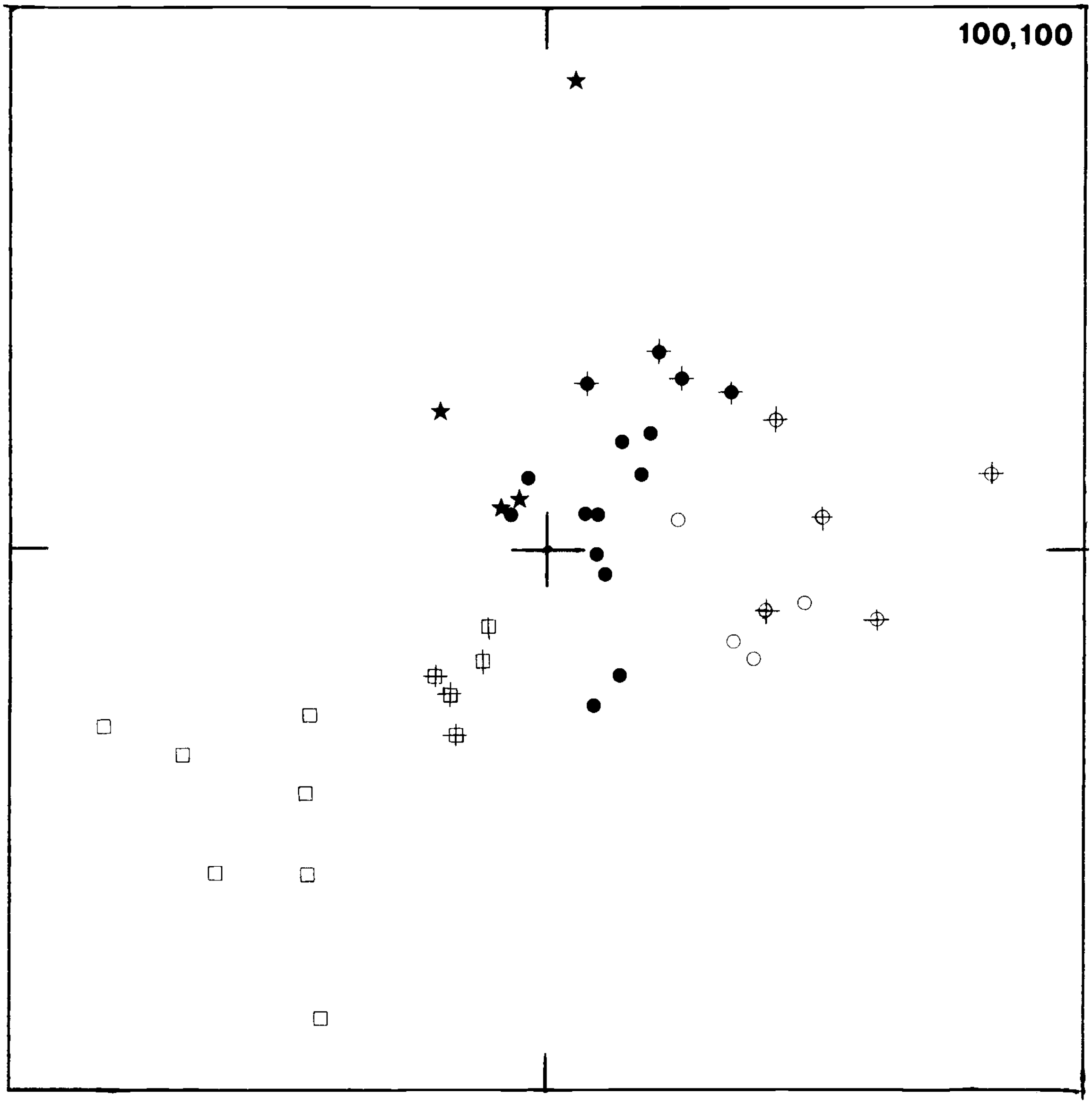


Fig. 6. Ordination of vegetation data from eight plant communities based on tree numbers and understory cover.

□ = *Ceanothus* community
⊞ = *Chimaphila* community
◫ = *Ceanothus-Carex* community
★ = *Melica* community
● = *Carex* community
◉ = *Chimaphila-Pyrola* community
○ = *Abies magnifica* var. *shastensis-Pinus ponderosa* community
⊕ = *Abies magnifica* var. *shastensis*/*Chimaphila* community

Fig. 7. Location of plant communities.

A. *Calocedrus decurrens*/*Arctostaphylos patula* habitat type

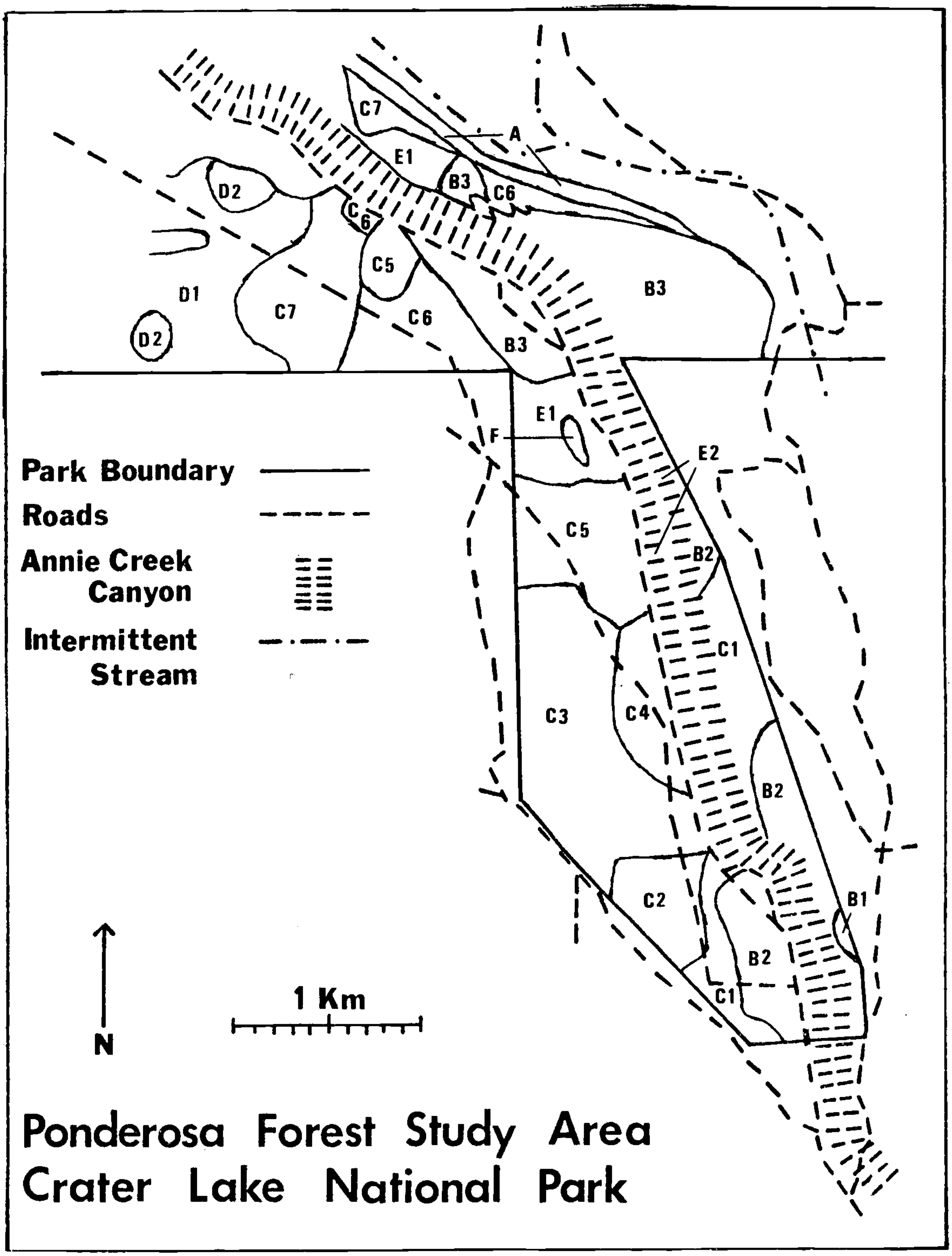
B. *Abies concolor*/*Symphoricarpos mollis* habitat type
  - B1. *Senecio* community
  - B2. *Populus* community
  - B3. *Melica* community

C. *Abies concolor*/*Chimaphila umbellata* habit type
  - C1. Logged *Pinus ponderosa* community
  - C2. Logged *Pinus contorta* community
  - C3. *Ceanothus* community
  - C4. *Chimaphila* community
  - C5. *Ceanothus*/*Carex* community
  - C6. *Carex* community
  - C7. *Chimaphila*-*Pyrola* community

D. *Abies magnifica* var. *shastensis*/*Chimaphila umbellata* habitat type
  - D1. *Abies magnifica* var. *shastensis*/*Chimaphila* community
  - D2. *Abies magnifica* var. *shastensis*-*Pinus ponderosa* community

E. *Abies concolor*/mesic species habitat type
  - E1. Mesic species community
  - E2. *Castinopsis* community

F. *Alnus incana*/*Elymus glaucus* habitat type


A
C7
E1
B3
C6
D2
C6
C5
D1
C7
C6
B3
D2
B3
E1
F
E2
C5
B2
C1
C3
C4
B2
C2
B1
B2
C1
Park Boundary
Roads
Annie Creek Canyon
Intermittent Stream
N
1 Km
Ponderosa Forest Study Area
Crater Lake National Park

Calacedrus decurrens/Arctostaphylos patula Habitat Type (2 plots)

This is one of the drier habitat types in the study area. It occupies about 20 ha on the northeast edge of the study area. It is on a southwest facing ridge with a 60% slope. The soil is stony and appears shallow with no pumice. The topsoil has about 87% sand, 11% silt and 2% clay. The vegetation is dominated by Calocedrus decurrens, Pinus ponderosa, Arctostaphylos patula, and Carex pensylvanica. Some plants that are more abundant here than in other communities include Grimmia sp., Ceanothus prostratus, and Senecio integerrimus. The dominance of Calocedrus and A. patula distinguish this community from any other in the study area. It may be similar in some respects to the west slope of Green Ridge (Swedberg 1961). On such steep slopes, the vegetation may be near climax because a closed canopy may be prevented by the wide spacing of microsites suitable for development of large trees, and possibly disturbance caused by mass soil movement. These two factors would permit shade intolerant species to remain as part of the climax vegetation.

Abies concolor/Symphoricarpos mollis Habitat Type

Parts of this habitat type may be drier than the Calocedrus/ Arctostaphylos habitat type. It contains traces of plants such as

Eriophyllum lantanum, *Purshia tridentata*, *Castilleja applegatei*, and *Collomia grandiflora* that might indicate greater soil water stress than *C. decurrens* or *A. patula* (Griffin 1967). It is questionable whether *A. concolor* would be the climax tree in the *Populus* and *Senecio* communities, due to the abundance of small *Pinus ponderosa*. However, these are also the most recently disturbed communities, and disturbance often favors plants from drier communities (Franklin and Dyrness 1973). Also, *Carex pensylvanica* may slow down succession by competing with trees.

The dominance of *Symphoricarpos mollis* beneath *Abies* canopy in this type is somewhat surprising; *S. mollis* also occurs in one of the more mesic habitat types, and not in the intermediate communities. I found no reference in the literature to a *S. mollis* habitat type elsewhere in central Oregon, but *S. mollis* occurs in relatively dry habitats in western Oregon (Franklin and Dyrness 1973). This is closer to the place on the moisture gradient where one might expect a *Symphoricarpos albus* (Daubenmire and Daubenmire 1968) or *S. oreophilus* (Sherman 1969) habitat type. Applegate (1939) reported some *S. albus* in the study area. However, *Symphoricarpos* in the study area has the trailing habit and pubsecent leaves of *S. mollis*. The few plants I found that lacked hairs gave no other indication of being a different taxon. It is possible, though, that at higher elevations *S. albus* becomes more prostrate (Hall 1973).

This habitat type is on alluvial soil. The three communities in it are named after characteristic species.

Populus community (2 plots)

This community covers about 2 ha (Fig. 7). It is dominated by *Pinus ponderosa*, with a strong component of *Populus tremuloides*. *Ribes cereum* and *Happlopapus bloomeri* are important shrubs and *Carex pensylvanica* is the dominant herb, with lesser amounts of *Sitanion hystrix* and *Stipa occidentalis* var. *occidentalis*. The species composition of this community is very close to that of the *Senecio* community, and they differ mainly in the dominants. This community has much more *P. tremuloides* and *Ribes cereum* and less *Ceanothus velutinus* than the *Senecio* community. The *P. ponderosa*/*Purshia tridentata*/*Carex pensylvanica* community, which is recognized on alluvial soils in the Winema National Forest (USDA Forest Service 1972) is similar, except *Purshia tridentata* is not a dominant in my area.

Senecio community (6 plots)

This community covers about 55 ha (Fig. 7). It is dominated by *P. ponderosa*, but near the edge of Annie Creek canyon *A. concolor* is dominant. The shrub and herb dominants are *Ceanothus velutinus* and *Carex pensylvanica*. There are many characteristic species for this community (and the *Populus* community), including *Senecio integerrimus*, *Poa nervosa*, and *Lupinus albicaulis*. These are the only communities in which *Hieracium cynoglossoides* flowers. In the study area *Stipa occidentalis* var. *californica* is confined to alluvial soils, even though it also may occur on the Pumice Desert north of Crater Lake (Horn 1968). These characteristic species, the more open aspect and the small amount of *Pinus contorta*, *Chimaphila umbellata*, and *Salix scouleriana*, readily distinguish this vegetation type from any other in the study area. It appears to be somewhat similar to *P. ponderosa*/*Ceanothus velutinus*, *Abies concolor*/*Ceanothus* (Dyrness 1960, Volland 1963), and *P. ponderosa*/*Purshia tridentata* - *Ceanothus velutinus*/*Carex pensylvanica* communities (U.S.D.A. Forest Service 1972).

Melica community (4 plots)

This community covers about 105 ha (Fig. 7). The tree layer is dominated by *A. concolor*, with large *P. ponderosa*. There are few small *P. ponderosa*. *Carex pensylvanica* is the principal herb, and *Ceanothus velutinus*, *Arctostaphylos nevadensis*, and *Symphoricarpos mollis* are the only other species that have more than 1% average cover. Characteristic species are *S. mollis*, *Melica aristata*, and *Hieracium albiflorum* (*H. albiflorum* and *S. mollis* are also characteristic of the *Abies concolor*/mesic species habitat type).

Chimaphila umbellata is fairly common and there are some *Pinus contorta*, indicating that this is an intergrade between habitat types (Daubenmire and Daubenmire 1968). *Symphoricarpos mollis* occurs in an *A. concolor*/*Chimaphila umbellata* community in the Klamath Mountains (Sawyer and Thornburgh, personal communication). This community is similar to the *Carex* community which adjoins it but is distinguished by the characteristic species and alluvial soil. I know of no descriptions in the literature of a similar community. This community appears to be relatively close to climax, in that the canopy is principally *A. concolor*.

Abies concolor/*Chimaphila umbellata* Habitat Type

This habitat type seems to be divisible into two phases, based on the presence of *Pyrola secunda*, which occurs only in the upper portion. There is very little in the logged area and it does not occur in the *Ceanothus*, *Ceanothus*/*Carex* or *Chimaphila* communities in the panhandle, but is common in the *Carex* and *Chimaphila*-*Pyrola* communities.

Franklin and Dyrness (1973) mention that *Chimaphila umbellata* is a relatively common herb in the dense *A. concolor* stands around Lake of the Woods, 45 km south of the study area. Sawyer and Thornburgh (personal communication) recognize an *A. concolor*/*C. umbellata* community in the Klamath Mountains of California on granitic parent material, which is considered a fairly dry *A. concolor* forest. In mature *A. concolor* forests in the Klamath Mountains, *Pinus ponderosa*, *P. lambertiana*, *Calocedrus* and *Pseudotsuga* reproduction can be found.

The *Ceanothus* and *Ceanothus*/*Carex* communities resemble the *A. concolor*/*Ceanothus velutinus* habitat type of Dyrness (1960) and Volland (1963). They thought that no more crown closure would occur, and that *Ceanothus* would maintain itself vegetatively. However, in the present study area, it appears that some *Ceanothus* bushes are still being shaded out, and that canopy closure is still increasing.

This habitat type occurs on pumice soil. Most communities are named after the dominant shrubs or herbs.

Loggged *Pinus ponderosa* community (4 plots)

This community covers about 25 ha on Lapine soil east of Annie Creek, and about 15 ha on Steiger soil west of Annie Creek. The area west of Annie Creek appears to be transitional between the *Senecio* community and the logged *Pinus contorta* community. *P. ponderosa* is the most important tree species, but *Pinus contorta* and *Abies concolor* are also important. The shrub dominant is *Ceanothus velutinus*, with lesser amounts of *Ribes cereum*, and the herb dominant is *Carex pensylvanica*, with *Stipa occidentalis* var. *occidentalis* of secondary importance. The area east of Annie Creek resembles the Chimaphila community, but I included it in the logged Pinus ponderosa community because of its logging history, and some spots, such as plot E-7 are like the logged Pinus ponderosa community west of Annie Creek.

Logged Pinus contorta community (3 plots)

This community covers about 25 ha in the southern part of the panhandle. The tree layer has much more Pinus contorta than the logged Pinus ponderosa community. However, the understory is dominated by Ceanothus velutinus and Carex pensylvanica, as in the logged Pinus ponderosa. The soil in this community and the adjacent part of the Ceanothus community seems to be rockier than any other pumice soil. This community is distinguished from the unlogged Ceanothus community by evidence of logging. The greater abundance of herbs in this community does not provide as sharp a delineation and the change in herb coverage is usually south of the division indicated by logging.

Ceanothus community (7 plots)

This community covers about 95 ha in the middle of the panhandle. It is a mixture of P. ponderosa, A. concolor, P. contorta, and large P. lambertiana. The shrub dominants are C. velutinus and Arctostaphylos nevadensis. (However, A. nevadensis is not dominant near the lower edge of the community.) It is the most heterogeneous community. Near its southern and eastern edges, there is more P. contorta than elsewhere in the community. The western part of the community is more open, with more C. velutinus and A. nevadensis than elsewhere. In the northern part of the community, A. magnifica var. shastensis becomes an important component. It is similar to the Abies concolor/Ceanothus velutinus habitat type (Dyrness 1960, Volland 1963), and the mixed conifer/C. velutinus community (U.S.D.A. Forest Service 1972).

Chimaphila community (3 plots)

This community is scattered throughout the panhandle in spots up to 5 ha in size, and in one large spot of 25 ha in the center of the panhandle. One of the three plots used to characterize this community (plot 5-1) is in one of the smaller spots in the Ceanothus/Carex community, and another (plot 4-1) is on the edge of the mapping unit. Most of the mapping unit has lower shrub and herb cover than the means in the data indicate. The main characteristics of this community are the depauperate understory and the dense, smaller size classes of A. concolor.

Ceanothus/*Carex* community (2 plots)

This community covers about 55 ha in both the panhandle and the main part of the Park. The shrub and herb dominants are *Ceanothus velutinus* and *Carex pensylvanica*. It is similar to the *Ceanothus* community, except that it seems transitional between the *Ceanothus* community and the *Carex*. It has less *P. lambertiana*, more *Abies magnifica* var. *shastensis*, and a greater proportion of the area is covered by dense thickets of *A. concolor*, similar to the *Chimaphila* community. This community is similar to a Mixed Conifer/*Ceanothus velutinus* community except it has much *Carex pensylvanica*, and similar to a Mixed Conifer/*Ceanothus*-*Castinopsis* community except *Castinopsis* is not important (U.S.D.A. Forest Service 1972). This may be because of the low slope in the present study area.

Carex community (10 plots)

This community covers about 65 ha and is on both sides of Annie Creek. It is dominated by *Abies concolor*, except in the large size classes, where *P. ponderosa* is important. The species with the greatest cover are *Carex pensylvanica* and *Chimaphila umbellata* followed by *Arctostaphylos nevadensis* and *Ceanothus velutinus*. However, it also contains such species as *Kelloggia galioides*, *Apocynum* androsaemifolium, and Salix scouleriana. It has somewhat more species than the depauperate Chimaphila-Pyrola community. It is also similar the Melica community, except it lacks the characteristic species.

Chimaphila-Pyrola community (5 plots)

This community covers about 50 ha and is on both sides of Annie Creek (Fig. 7). The part east of Annie Creek is on aerially deposited pumice on a steep slope. The tree layer is dominated by A. concolor or A. magnifica var. shastensis but there are also important amounts of Pinus contorta and large P. ponderosa. The only understory species with more than 1% mean cover are Carex pensylvanica, Chimaphila umbellata and Brachythecium leibergii + Pohlia nutans. (The + means the sum of the cover for these two species is greater than 1%.) It is similar to the Chimaphila community, except there are more large Abies, and there is more Carex pensylvanica and Pyrola secunda. This appears to be the most mature community in the A. concolor/Chimaphila habitat type. This is an example of the closed Abies forests of central Oregon that commonly occur above the Pinus ponderosa forests (Sherman 1969, Swedberg 1961, West 1964), except it lacks Pseudotsuga.

Abies magnifica var. shastensis/ Chimaphila umbellata Habitat Type

There is some question whether this is really an A. magnifica var. shastensis habitat type because of the presence of small A. concolor. Franklin and Dyrness (1973, p. 152) think that "Abies concolor probably replaces Abies magnifica shastensis on most sites where mixed stands of the two species occur." But they also note that A. concolor can be a climax associate of A. magnifica var. shastensis. Sawyer and Thornburgh (personal communication) report that in the Klamath Mountains of California, there are stands in which A. concolor appears to be replaced by A. magnifica var. shastensis. In the present study there is a transition zone 200-300 m wide on each side of the boundary between the A. concolor and the A. magnifica var. shastensis habitat types in which small trees of the two species occur in about equal numbers.

In the A. magnifica forests of the Sierra Nevada a shade tolerant understory union, composed of species that are in the present study area (including C. umbellata and Pyrola spp.) occurs with a shade intolerant union composed of species that do not occur in the present study area (Oosting and Billings 1943). There are A. magnifica var. shastensis/C. umbellata communities in the High Cascades occupying modal sites, which have a depauperate understory including Carex pensylvanica (Franklin and Dyrness 1973). In the

Klamath Mountains there is an *A. magnifica*/*C. umbellata* forest type in the Shasta Fir Zone which has a different understory composition from the *A. magnifica* var. *shastensis*/*C. umbellata* in the present study area (Sawyer and Thornburgh, personal communication).

Abies magnifica var. *shastensis*/ *Chimphila umbellata* community

(5 plots)

This community occupies about 60 ha. It is dominated by the two *Abies*, but *Pinus contorta* is important in some places. Very few, large *P. ponderosa* can be found in it. *Chimaphila umbellata* and *Arctostaphylos nevadensis* are the only species that average more than 1% cover. *Pinus monticola* and *Tsuga mertensiana* are more important here than elsewhere in the study area. It is similar to the *Chimaphila*-*Pyrola* community, differing from it mainly in the greater amount of *A. magnifica* var. *shastensis*. It is similar to a Mixed Conifer/Manzanita community (U.S.D.A. Forest Service 1972).

Abies magnifica var. *shastensis*-*Pinus ponderosa* community

(4 plots)

This community covers about 10 ha. The trees are a mixture of *Abies* spp., *Pinus contorta*, and large *P. ponderosa*. *Abies* species are the main reproduction. Important shrubs and herbs are *Arctostaphylos nevadensis*, *Carex pensylvanica* and *Chimaphila* umbellata. It is similar to the A. magnifica var. shastensis/C. umbellata community, but it has more P. ponderosa and more shrub and herb cover. It is also similar to a Mixed Conifer/Manzanita community (U.S.D.S. Forest Service 1972).

Abies concolor/Mesic Species Habitat Type

Many species that indicate moist conditions such as Smilacina spp., Adenocaulon bicolor, Osmorhiza chilensis, Galium triflorum, Ribes lacustre, Clintonia uniflora, Rosa gymnocarpa, and Ribes viscosissimum, grow in this habitat type. It is similar to the Abies grandis/Pachistima myrsinites habitat in the northern Rocky Mountains (Daubenmire and Daubenmire 1968), the A. grandis/Linnaea-forb community in the Blue Mountains (Hall 1973), and the area near a spring on Swedberg's (1961) transect in the Cascades. Rosa gymnocarpa shows a fairly high fidelity to the mesic communities in the present study, even though it can occur in drier habitats elsewhere (Sherman 1969, Volland 1963, West 1964).

Mesic species community (4 plots)

This community occupies about 35 ha in the northern part of the panhandle and northeast of Annie Creek. It is dominated by A. concolor, but other species are important in places. There is a small stand of Picea engelmannii (plot M-1) near the western boundary of the panhandle, and another just north of the study area. There is another small area in which a crown fire probably occurred about 90 years ago in which the canopy is *Pinus contorta* (plot 6-1).

Castinopsis community (4 plots)

This community is located on the sides of Annie Creek canyon. I investigated the vegetation and flora of the canyon only in the panhandle. The vegetation appears to change north of the panhandle, where the columnar scoria appears.

The tree layer is dominated by *A. concolor* and large *Pseudotsuga*. The shrub and herb layers are dominated by *Castinopsis sempervirens*, *Amelanchier alnifolia*, *Symporicarpos mollis*, and *Chimaphila umbellata*. The soil, slope and microclimate are different from the Mesic Species community and these factors may be reflected in the lesser importance of *Bromus* and *Smilacina* and the greater importance of *Pseudotsuga*, *Castinopsis*, and *Rubus parviflorus*. There often appears to be a gradient from the top to the bottom of the canyon, with the top being drier.

Alnus incana/*Elymus glaucus*
Habitat Type (2 plots)

This habitat type occupies about 3 ha near the north end of the panhandle. It has a relatively sparse tree layer, composed of *Populus* *trichocarpa*, *Populus tremuloides*, *Abies concolor* and *Pinus contorta*. The relatively rich shrub and herb layers, with *Alnus incana*, *Spiraea douglasii*, *Elymus glaucus*, *Bromus* spp., *Lupinus latifolius*, and *Adenocaulon bicolor*, give the area a meadow-like aspect. This community is easily distinguished from any other in the study area, except the meadows that occupy the bottom of Annie Creek canyon, which I did not sample. Many of these creek-side meadows resemble this habitat type floristically. However, even within the small mapping unit, there is much variation, including meadows dominated by *Scirpus microcarpus* or *Equisetum arvense*.

General Discussion of the Vegetation

The communities in the present study area can be separated along moisture, successional, and elevational gradients (Fig. 8). Each of these gradients is composed of correlated gradients of factors that directly influence the plant, such as soil water potential, air temperature, amount of light, and length of snow free season. Of course, the three complex gradients are not completely independent. There are other gradients that influence the vegetation (e.g., soil fertility or stoniness), and in some cases may be the most important (e.g., the difference in the Mesic Species and *Castinopsis* communities). But much of the variation between communities seems to be explainable by these three gradients. The communities

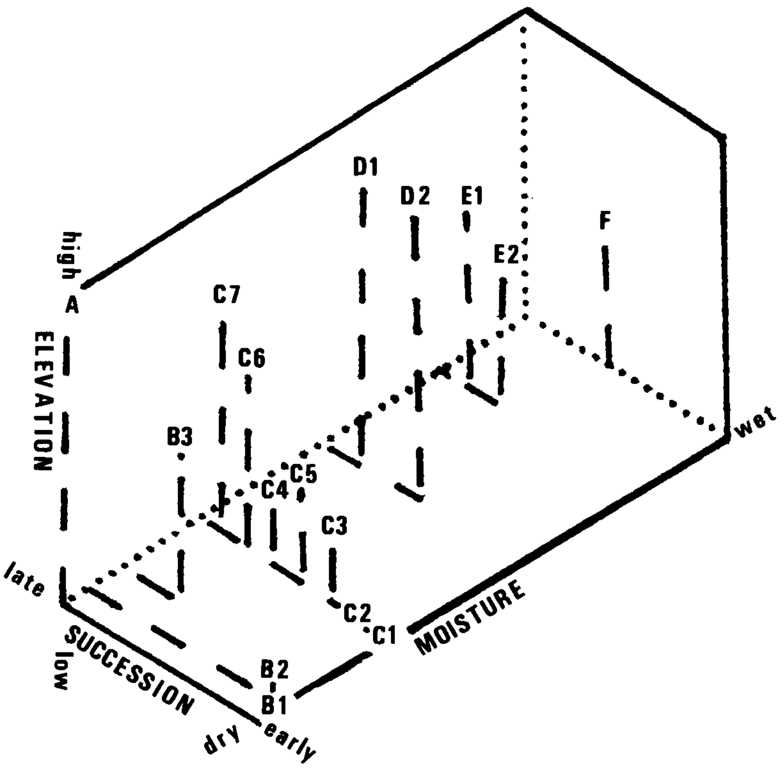


Figure 8. Hypothetical relative position of communities on gradients of moisture, succession, and elevation. The relative position on the gradients was inferred from the environment and the species present. The positions are only relative, so the large gap on the moisture gradient between the Abies concolor/Chimaphila habitat type and the A. magnifica var. shastensis habitat type does not mean that the hypothesized difference in moisture is great.

A. Calocedrus decurrens/Arctostaphylos patula habitat type

B. Abies concolor/Symphoricarpos mollis habitat type
  B1. Senecio community
  B2. Populus community
  B3. Melica community

C. Abies concolor/Chimaphila umbellata habitat type
  C1. Logged Pinus ponderosa community
  C2. Logged Pinus contorta community
  C3. Ceanothus community
  C4. Chimaphila community
  C5. Ceanothus-Carex community
  C6. Carex community
  C7. Chimaphila-Pyrola community

D. Abies magnifica var. shastensis/Chimaphila umbellata habitat type
  D1. Abies magnifica var. shastensis/Chimaphila community
  D2. Abies magnifica var. shastensis-Pinus ponderosa community

E. Abies concolor/mesic species habitat type
  E1. Mesic species community
  E2. Castinopsis community

F. Alnus incana/Elymus glaucus habitat type were arranged along the moisture gradient by knowing about the environment (soil, water table, and elevation), and the moisture requirements of the species in other areas. I inferred the relative position on the successional gradient from the known logging and fire history, and the relative abundance and sizes of *Pinus* and *Abies*.

The placement of some of the communities along the moisture gradient is supported by Scholander-type pressure chamber measurements (Table 10). This shows little change in soil moisture with elevation within the *A. concolor*/*Chimaphila* habitat type on Steiger soil and more moisture stress in the *A. concolor*/*Symphoricarpos* habitat type. The difference between the *Melica* and the *Senecio* communities may be due to climate, pumice content of the soil or vegetation differences.

Most of the mapping units (Fig. 7) show more variation than the vegetation samples of community would lead one to expect. Most of this extra variation results from transitions between adjacent communities. However, this is not always the case. For instance, the data indicate that significant amounts of large *Abies magnifica* var. *shastensis* occur only in its habitat type, but there are areas in the *Ceanothus*, *Carex*, and *Chimaphila*-*Pyrola* communities with large *A. magnifica* var. *shastensis*.

There are several pairs of communities that are quite similar, including the *Populus* and *Senecio* communities, the Logged *P.*

Table 10. Predawn xylem pressure potential in 1-2 m tall *Abies concolor* (n = 5 to 10).

Community	Soil parent material	Mean xylem pressure potential ± 2 standard errors		Sampling location and elevation (m)
		28 Aug 1974	18 Sept 1974	
Transition between *Abies concolor* and *A. magnifica* var. *shastensis* habitat types	pumice	- 5.4 ± 0.6	- 6.5 ± 1.8	ca 200 m north of plot 9-6 1540
Carex community	pumice	- 4.8 ± 0.3	- 6.9 ± 0.6	ca 20 m west of plot 7-11 1460
Logged *P. ponderosa* community	pumice	- 5.4 ± 1.3	- 7.0 ± 0.5	ca 200 m south of panhandle 1340
Melica community	alluvial	- 9.4 ± 1.7	-17.2 ± 2.5	ca 50 m south of plot 7-14 1460
Senecio community	alluvial	-13.3 ± 1.2	-18.8 ± 1.0	ca 200 m south of panhandle 1340

ponderosa and the Logged P. contorta communities, the Ceanothus and the Ceanothus/Carex communities, and the Carex and the Chimaphila-Pyrola communities. The value of separating these communities can be questioned. However, they are recognizable units in the field so some factor(s) caused the differences. The cause may merely be a somewhat different history but it may also be some unrecognized factor in the environment. Because of this I felt it was safer to treat them as separate communities. However, for some purposes it may be reasonable to consider them as a single unit.

Fire History

The study area was divided into three parts, each of which had different fire histories (Table 11; Appendix D): (1) the panhandle south of the Mesic Species community, (2) the northwest part, and (3) the northeast part. These three areas are separated by the natural fire breaks of Annie Creek canyon and the Mesic Species community. Fires rarely burned on both sides of Annie Creek during one year; it was apparently an effective fire break. The Mesic Species community at the north end of the panhandle stopped some fires burning from lower elevations (e.g., 1892, 1841, 1812) and it may have stopped a fire from higher elevations (1791). The only year that a relatively large fire burned in the northwest part that a large fire

Table 11 . Fire incidence at different spots, 1748-1902. Each spot includes sears on two trees, usually within 100 m of each other. x = sear formed; (x) = possible sear formed--usually a growth rate decrease and some hint of sear present; map = sears at nearby spots indicate may have burned this one also; interval = usually long interval without a fire; GR = decrease in growth rate that coincided with a fire year; · = date before the first sear on one tree at the spot; | = date before the first sear on both trees at the spot.

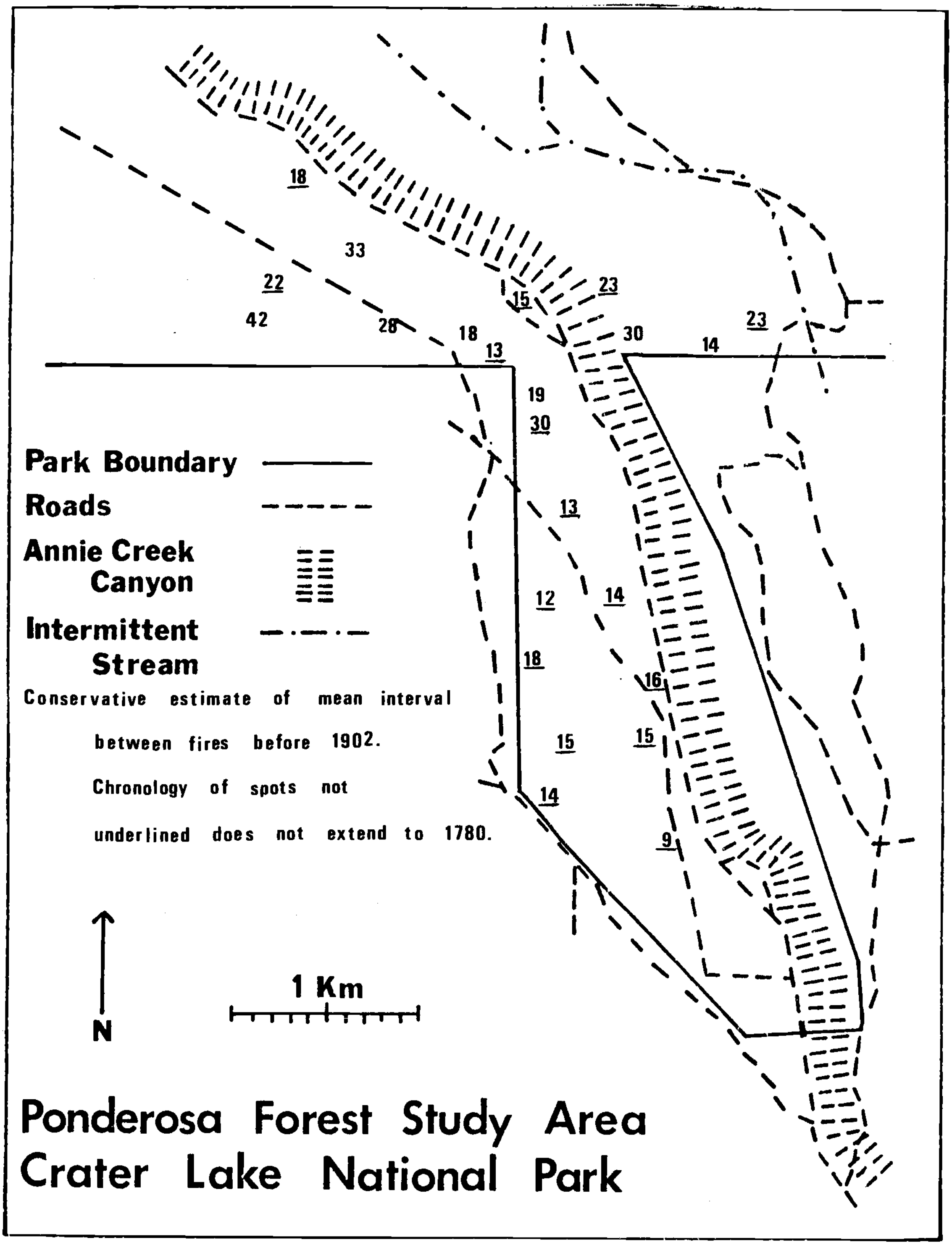
	Panhandle									Northwest part										Northeast part					
Spot:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1902		x	x			map	x	x	x	x	x	x	x		x									.	1902
1897								x						x										.	1897
1892	x	map	x	x	x	x	x	x	x															.	1892
																								.	
1889																				x	x	x	map	x	1889
1883	x	x	x								x													x	1883
1879				x	x	x	x	x	x	x		x	x						x					.	1879
1877																				x	x	x	x	x	1877
1870	x		x						x												.			.	1870
1864	x	x	x	map	x	x	x	x	x	x	x	x	x	x	x			map	x		.			.	1864
1859																				x	GR	interval	x	x	1859
1855									x												.			.	1855
1849		x																			.			x	1849
1846	x			x	GR	GR	x	(x)	x	map	x	x	x	x	x	x	x	x	x		.			.	1846
1841	x	x	x	x	x	x	x	x	x		.			x	.						.			.	1841
1831											.				.					interval	x	x	x	x	1831
1829	x										.				.						.			.	1829
1826					GR	GR		x	x		.	x			.		x				.			.	1826
1818	x	map	x	map	x	map	x	map	x	x	x	x	x	x	x	x	x	x	x		.			.	1818
1815											|				.	.					x			(x)	1815
1812	x	x	x	x	x	x	x	x	x		|				.	.					.	x			1812
1804	(x)										|	x	x		.	.		x			.			(x)	1804
1800	x										|				.	.		.	x		.			.	1800
1798											|				.	.		.		x	x	x	x	.	1798
1797	x	x	map	x	x	x	x		interval		|				.	.		.			.	.		.	1797
1791							x	x			|	x	x	x	x	.		.	x		.	.		.	1791
1788											|		.	x	.	.		.			x	map	x	x	1788
1786											|		.		.	.		(x)			.	.		|	1786
1782-84	x		x		x	x	x		x	x	|	x	x	x	x	x	x	.			x	.		|	1782-84
1779				interval							|			x		|								|	1779
1776	GR	x			x			x		.	|		.		.	|		.			.	.		|	1776
1775					.					.	|		.	x	.	|		.	x	(x)	x	.		|	1775
1773					.			x		.	|		.		.	|		.	.		.	.		|	1773
1771					.					.	|		.		.	|		.	.		x	.		|	1771
1770					.					.	|	x	x		.	|	x	.	.		.	.		|	1770
1769	x	x	x	x	x	x			GR	.	|		.		.	|		.	.		.	.		|	1769
1762			.		.					.	|		.		(x)	|		.	.		.	.		|	1762
1759	x		x		x	map	x	x	x	.	|	x	x	x	|	|	x	.	.	x	x	x	x	|	1759
1755	x		.	x	|				.	|	.	.		|	|		.	.					|	1755
1751			.		|				.	|	.	.		|	|		.	.	x	x	x	x	|	1751
1748			.		|	x	x	x	x	x	|	x	.		|	|	x	x	x		.			|	1748

did not also burn in the panhandle was 1791. Other fires burned through or around the Mesic Species community (e.g., 1902, 1879, 1846, 1818). Unfortunately, there is no way to tell from what direction these fires burned.

Table 11 does not show the 10 sear that were formed after 1902. Three sears were probably the result of the logging (e.g., 1914 at spot 1) and four may have been small fires that were extinguished (all before 1930). The three possible fires after 1930 did not have sears and are not shown on the Fire Atlas for the Park, and so may not have been actual fires. The three trees illustrate the possibility of a fire being indicated when none actually occurred. If these are not sears, they may have been caused by strain caused by the growth of the tree over the scar.

The mean interval between fires can be calculated using just the dates of fires that certainly seared the trees and fires that probably seared them (Figs. 9, 10, 11, and 12). However, this may overestimate the mean interval because every fire does not sear both trees at a spot. In the panhandle about 20% of the fires that burned in a spot did not sear the tree with the greatest number of sears. In the northeastern part, 10% of the fires did not sear the tree with the highest number of sears, but in the northeast part, almost all the fires seared the most susceptible tree. This suggests that fires could have burned through a spot and not seared either tree,

Fig. 9. Mean interval (in years) between fires, calculated using only evidence provided by sears. Both clear sears and obscure, questionable sears (usually a hint of a sear on the face of the scar, accompanied by a growth rate decrease) were used.



Conservative estimate of mean interval between fires before 1902. Chronology of spots not underlined does not extend to 1780.

Ponderosa Forest Study Area
Crater Lake National Park

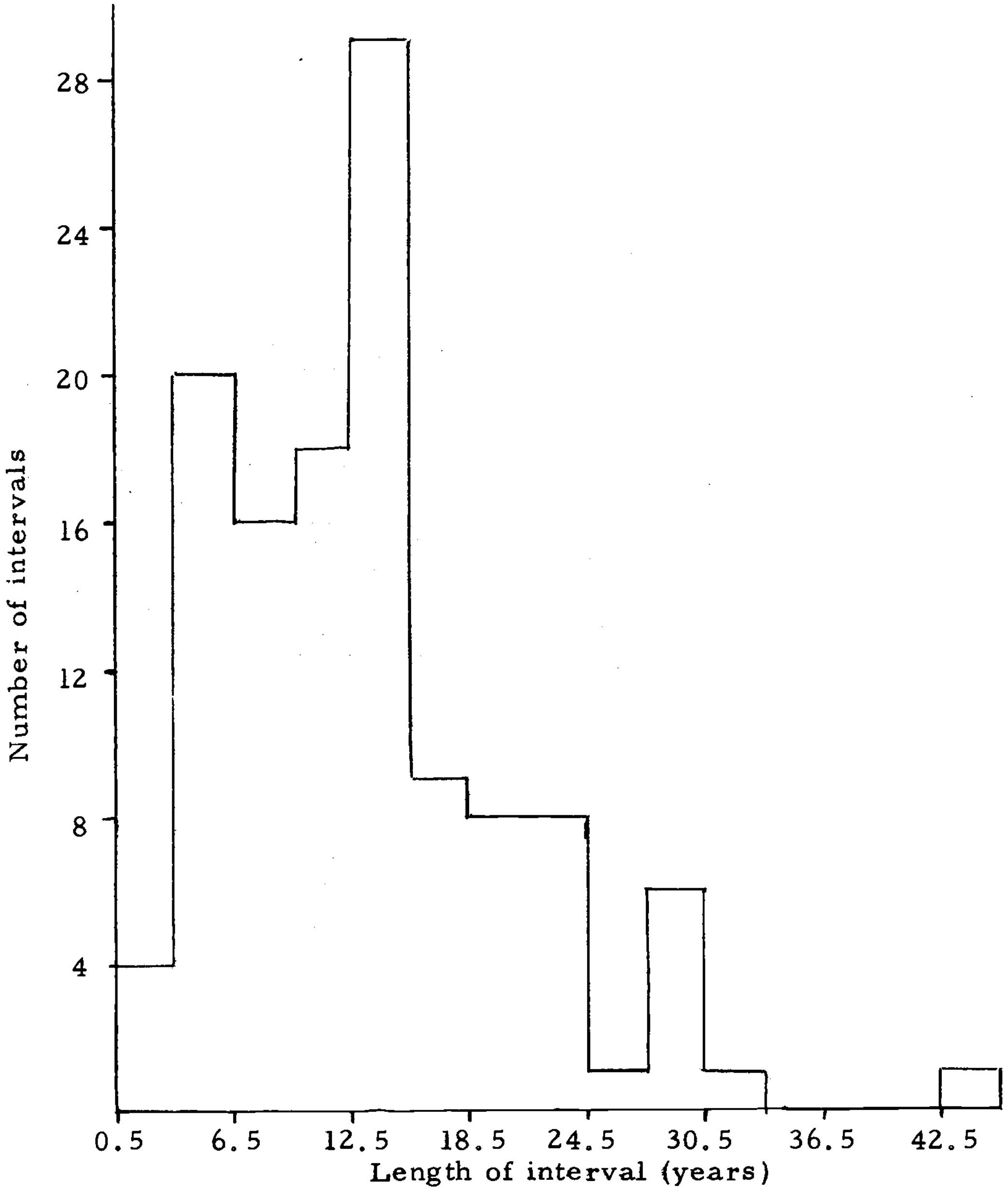


Figure 10. Frequency distribution of intervals between sears and possible sears at single spots in the panhandle. (The intervals used to calculate the means in Fig. 9 .)

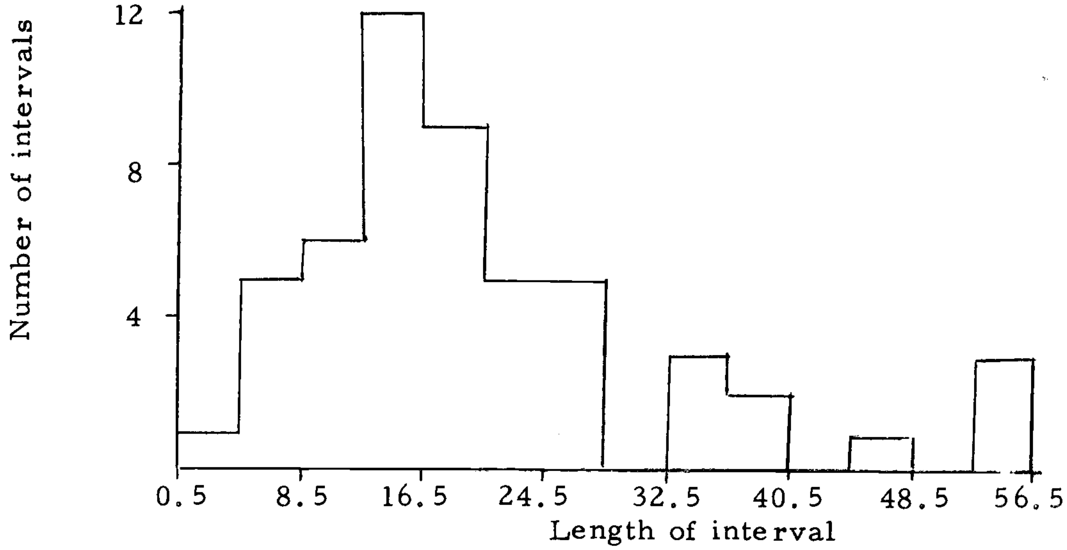


Fig. 11. Frequency distribution of intervals between sears and possible sears at single spots in the northwest part. (The intervals used to calculate the means in Fig. 9.)

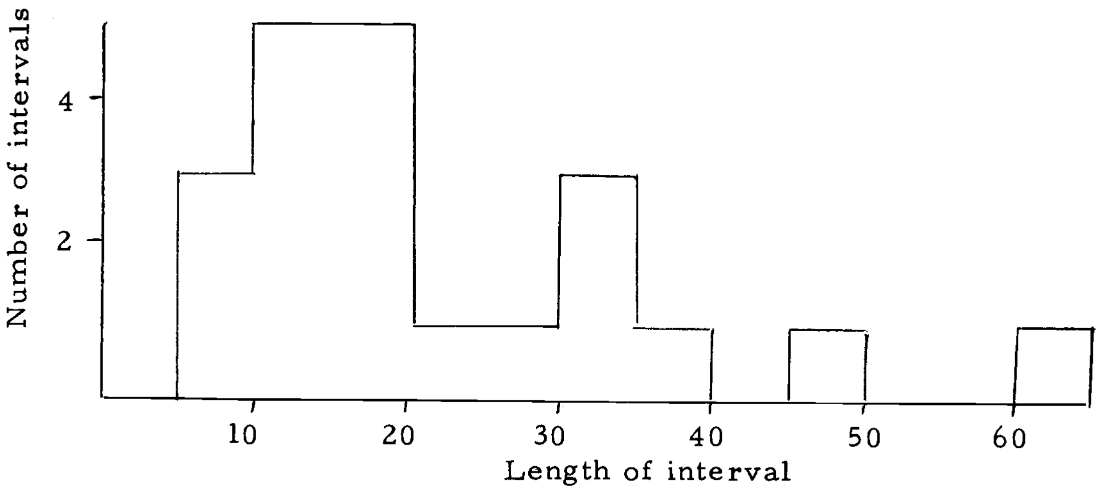


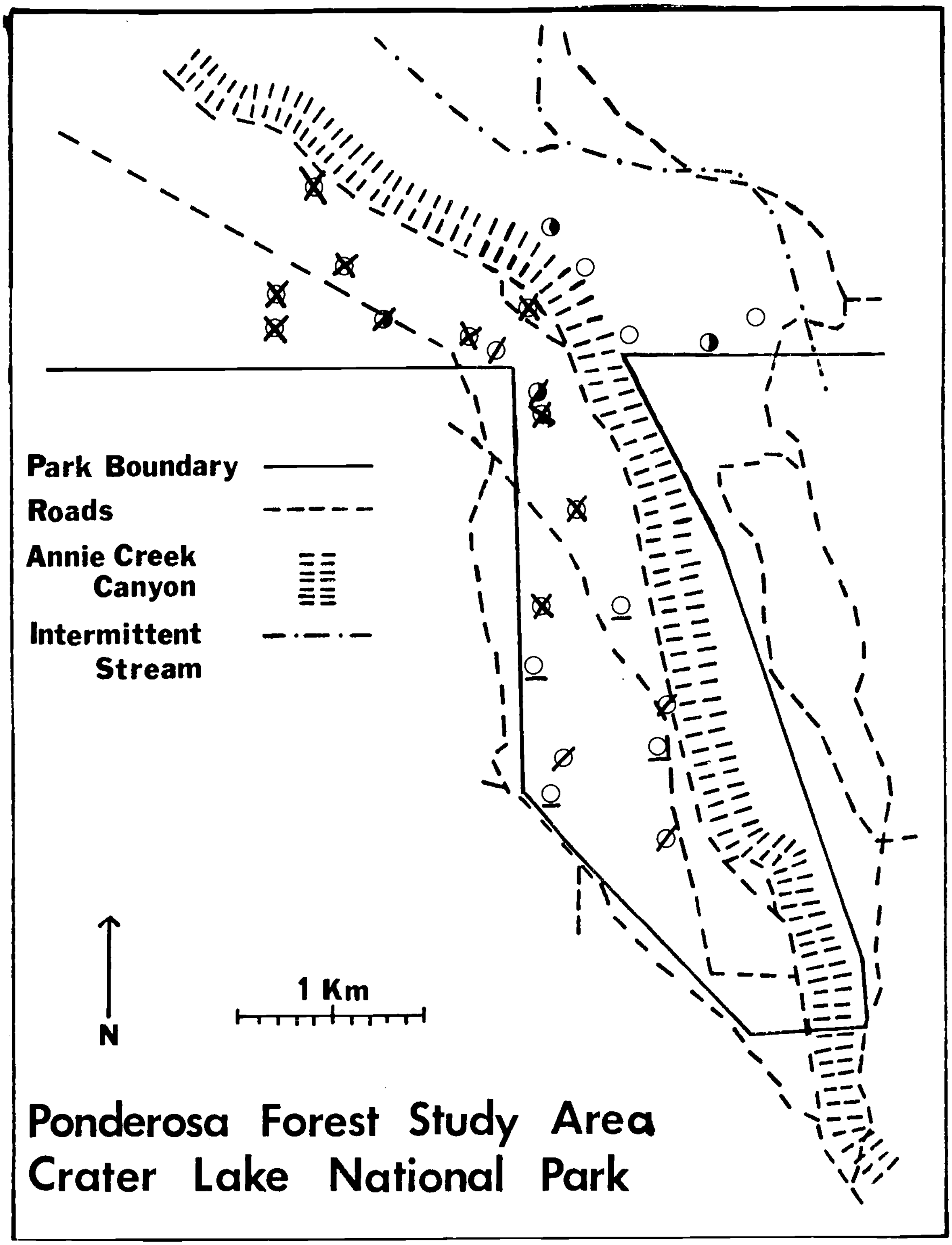
Figure 12. Frequency distribution of intervals between sears and possible sears at single spots in the northeast part. (The intervals used to calculate the means in Fig. 9.).

especially in the panhandle. In order to compensate for this possibility, the mean interval was calculated using additional indications that a fire may have burned through the spot. These additional indications are: (1) sears at nearby spots which indicate that a fire may have occurred (Fig. 13), (2) unusually long interval without a fire, and (3) growth rate decreases that coincided with fires (Fig. 14). The difference in mean interval obtained by including these indications is usually small when compared with the variance in intervals (Figs. 10, 11, and 12).

Because of the small size and irregular shape of the study area, little can be said about the size of the fires that occurred. The large fires burned outside the study area, so their area is not known. However, the 1864, 1846, and 1818 fires burned the entire 400 ha west of Annie Creek. Many of the small fires (one or two spots seared) may also have burned outside the study area. However, from 1800 to 1902 there were about 15 fires in the area that seared three or more adjacent spots, and 12 to 16 or more fires that seared only one or two spots that were well separated from any other spots seared the same year. So small fires may have been as common as large fires. This is somewhat surprising because between 1930 and 1974, only two lightning fires were set in the study area (Fire Atlas, Crater Lake National Park). However, in the two years of this study, at least two large _P. ponderosa_ were killed by lightning, so lightning

Fig. 13. Map showing an instance in which a fire (1818) may have burned through a spot without searing either sample tree.

○ = location of a sample spot
Ø or ⊗ = one or both trees at a spot seared
O̲ = spot where fire probably burned without searing either sample tree
◑ = 1818 is before the first sear of one of the trees sampled at the spot



Ponderosa Forest Study Area
Crater Lake National Park

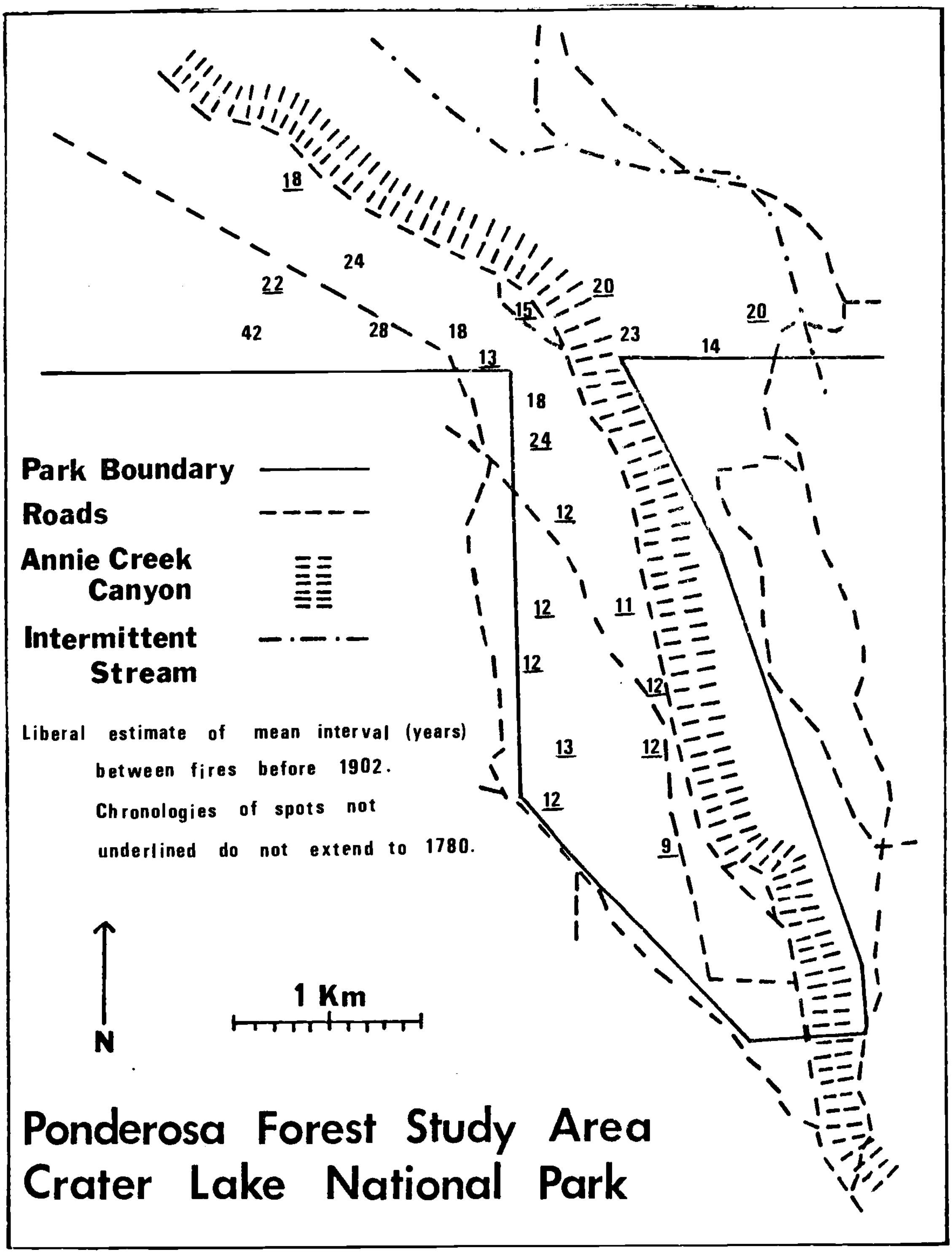


Fig. 14. Mean intervals between fires, calculated using the indications of fires on the sample wedge, and considering nearby spots and unusually long intervals between fires.

strikes probably are fairly common, and it is possible that the flammability of the vegetation has decreased, especially early in the summer, due to increased Abies litter.

Comparison of the dates of fires (both large fires and all fires) with Keen's (1937) dendrochronological record of weather for south central Oregon indicates that there is little correlation between the years that fires occurred and those in which P. ponderosa growth was less than normal (probably the drier years). In the panhandle there is almost zero correlation. This conclusion is not changed by allowing for the possibility that the fire date may be wrong by a year or two. In the northwest part there may have been a tendency for fires to occur during wetter years, and in the northeast part there may have been a tendency for fires to occur during drier years, but neither of these trends is statistically significant at the 95% level. This does not mean that weather did not influence what years fires burned, but only that different components of weather influenced tree growth and fire incidence. However, the lack of correlation with Keen's data, and the fact that fires occurred consistently in different years on the two sides of Annie Creek, indicate that precipitation does not control fire occurrence as much as might be supposed.

Most of the scars were made after the latewood of the annual growth ring formed. Because of lack of knowledge of the phenology of

P. ponderosa in the area, I do not know what this means in terms of the seasons.

There is some evidence that the severity of a fire can be decreased if it occurs soon after another moderately severe fire. In 1812 and 1841 fires burned in the panhandle but stopped at the Mesic Species community. In 1818 and 1846 fires burned in both the panhandle and the northwest part, but the fires were much more spotty in the panhandle. Possibly this effect lasts as long as 10 years, because the 1892 and 1902 fires may be a similar case.

In the second half of the 1700's the pattern of the fires in the panhandle seems different from the pattern elsewhere. In most of the area, over most of the time, large fires (that seared seven or more spots) are generally most important in that they account for most of the sears. However, from 1797 to 1769, and from 1759 to 1729 somewhat smaller fires that seared fewer than seven spots are the most important in the panhandle. The appearance of this could, in part, be due to the greater likelihood that a sear formed that long ago would be destroyed by later fires.

The fire frequency and the vegetation are correlated to some extent. Ceanothus velutinus is dominant only where the mean interval between fires was 15 years or less, and it is almost absent where the interval was greater than 20 years. The Chimaphila community occupies an area in which the last fire occurred in 1892, whereas most of the rest of the panhandle was burned in 1902. At least parts of the Chimaphila-Pyrola community have not been burned since 1846. The data presented here support Soeriaatmadja's (1965) conclusion that at higher elevations the interval between fires is greater, perhaps due to moister conditions or different vegetation and fuels. Others have noted that fire history can cause important differences in vegetation (Dyrness 1960, West 1964).

There is some indication that in the northwest part the frequency of fire may have decreased before fire suppression started in the early 1900's (Table 12). This is especially true at spots 16, 17, and perhaps 18, which did not burn for 56 years before fire suppression became effective. It is possible that Abies species were increasing in importance at this time, and if this was the case, this change in interval may have been related to increasing amounts of Abies litter.

Age-Density Relationships

The relation between size and age was needed to find the relation between age and density. However, examination of the data showed that the variance of age increased with size. Since this violates one of the assumptions of least squares regression, logarithmic and square root transformations of the data were made. The square root transformation of age seemed to give a nearly constant variance, and the relation appeared to be linear. To find the relation between

Table 12. Number of fires at the fire scar sampling spots. Omitted spots do not have an adequate record to 1748.

	No. of scars + possible scars		No. of scars + possible scars + map indications + interval indications + growth rate decreases	
	1902-1825	1825-1748	1902-1825	1825-1748
1	8	9	8	10
2	5	5	6	6
3	6	5	6	6
4	4	4	5	6
5	4	7	6	7
6	4	5	7	7
7	6	7	6	7
8	8	6	8	7
9	9	5	9	7
10	3	3	4	3
12	6	7	6	7
13	4	6	4	6
14	4	7	4	7
17	2	5	2	5
18	1	4	2	4
19	3	5	3	5
20	3	4	4	4
21	3	8	4	8
22	3	4	4	5
23	3	4	4	4

age and size I did a linear least squares regression of the square root of age against size (Figs. 15 and 16, Table 13). By combining this relation between age and size and the relations between size and density (Table 6), relations were found between age and density (Figs. 17 to 21).

The curves of age vs. density can be used in two ways. First, the position of the line at any given age should tell approximate density of trees that are still alive that are that age or older. Second, the slope of the line represents the number of trees that are still alive that germinated each year during the time period.

In the *Ceanothus* community, at the time of the last fire, *Pinus contorta* was apparently the most abundant species, followed by *Abies* concolor and *Pinus ponderosa* (Fig. 17). However, 70 to 90% of the *P. contorta* and *A. concolor* had germinated in the 10 years since the previous fire in 1892, whereas only about 50% of the *P. ponderosa* had germinated in this period. The density of *A. concolor* more than 50 years old, and *P. contorta* more than 60 years old was very low in 1902; the canopy was probably almost exclusively *P. ponderosa*. The rate of increase of the tree populations was greatest about the time that the last fire burned through the area. Before the 1892 fire *P. contorta* was the second most important species.

The *Chimaphila* community followed about the same pattern, except *A. concolor* and *P. contorta* did not start increasing until after

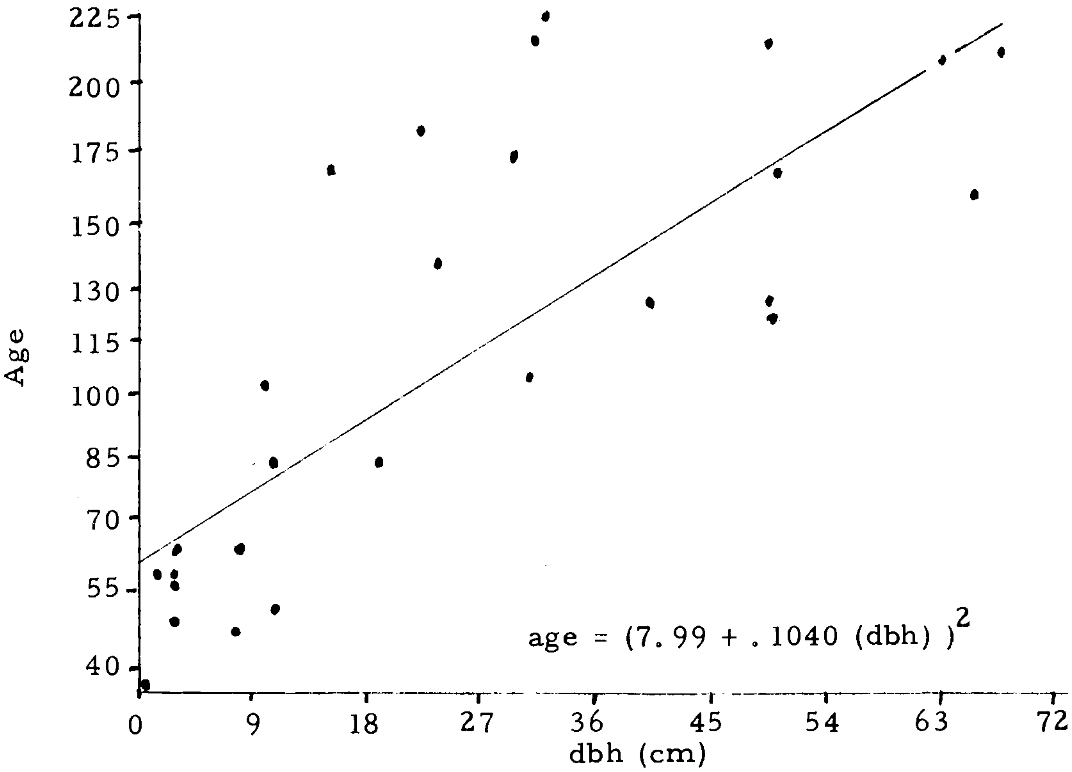


Fig. 15. Data and regression relating size and age for Pinus ponderosa found on transect 3. The age scale is linear for the square root. This is the poorest fit of any of the regressions.

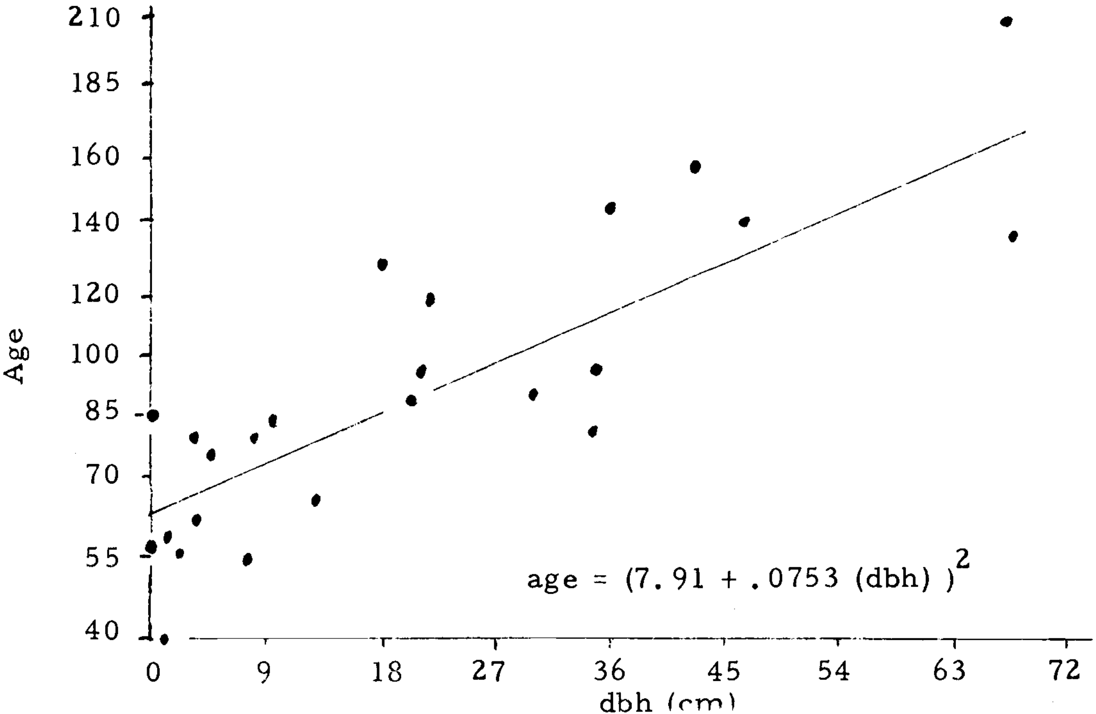


Fig. 16. Data and regression relating size and age for Abies concolor on transect 6. The age scale is linear for the square root. This shows somewhat better than average fit.

Table 13. Coefficients of equations used to relate tree age to size. The empirically derived equation is age = $(b_0 + b_1(\text{dbh}))^2$.

Location	Species	b_o	b_1	Median dbh in data (cm)	Greatest dbh in data (cm)	No. of data points	r^2
Melica community, east of Annie Creek	*Abies concolor*	8.34	.0886	23.2	54.8	29	.63
Ceanothus and *Chimaphila* communities on transect 3 and part of 4	*Abies concolor*	7.72	.0642	16.3	66.5	47	.57
	Pinus contorta	6.91	.1130	11.9	50.7	36	.81
	Pinus ponderosa	7.99	.1040	22.0	68.1	27	.60
Abies magnifica var. *shastensis* habitat type on parts of transects 8 and 9	*Abies concolor*	8.74	.1008	17.8	58.9	19	.79
	Pinus contorta	8.59	.1136	20.3	42.0	22	.61
	Abies magnifica var. *shastensis*	9.22	.0785	21.4	72.8	29	.72
Mesic Species community on part of transect 6	*Abies concolor*	7.91	.0753	19.2	76.6	24	.67

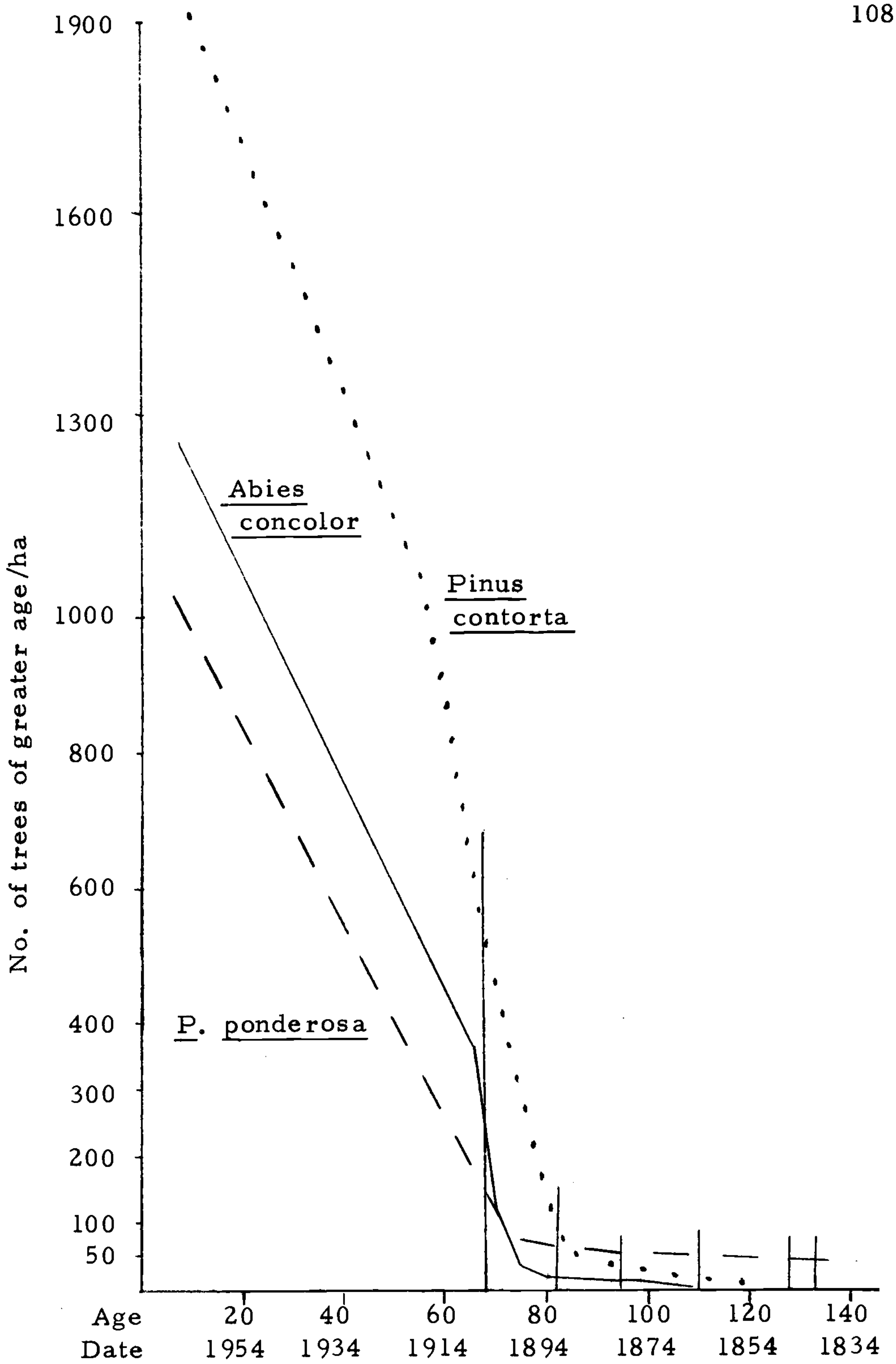


Fig. 17. Age-density relations of three major tree species in the Ceanothus community. The vertical lines indicate dates of fires.

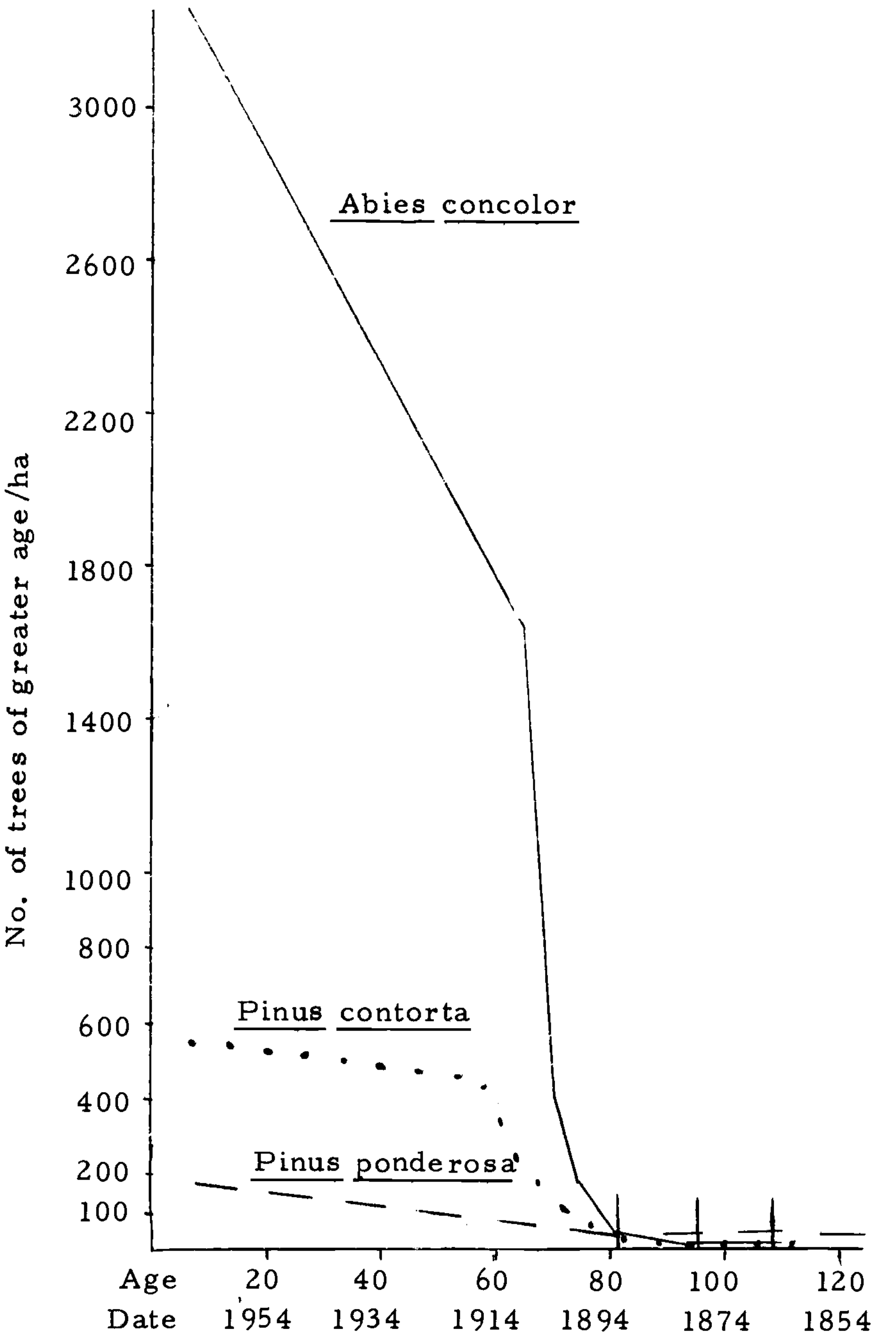


Fig. 18. Age-density relations of three major tree species in the Chimaphila community. The vertical lines indicate date of fires.

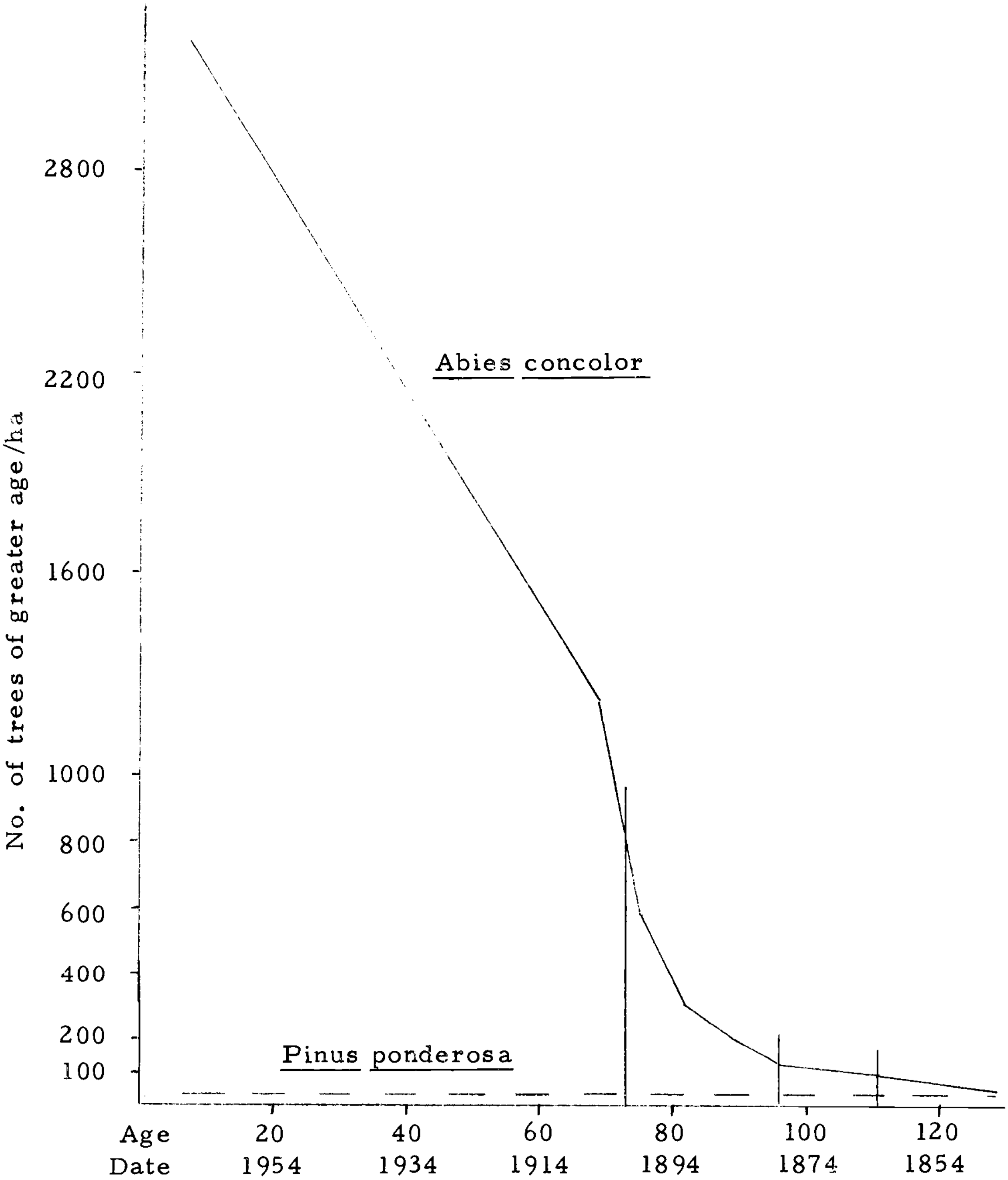


Fig. 19. Age-density relations of two major tree species in the Mesic Species community. Vertical lines show dates of fires.

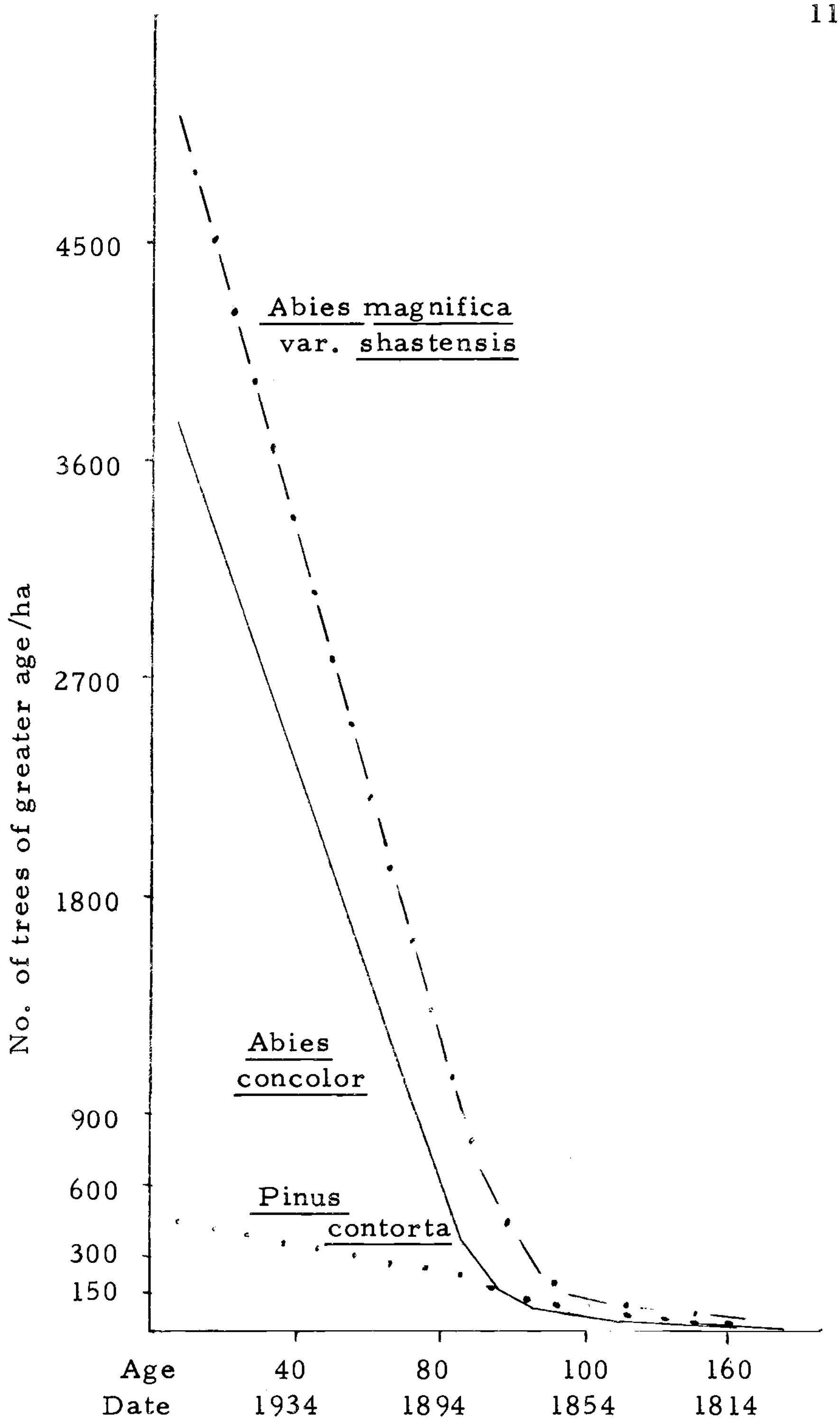


Fig. 20. Age-density relations of three major tree species in the *A. magnifica* var. *shastensis*/*Chimaphila* community.

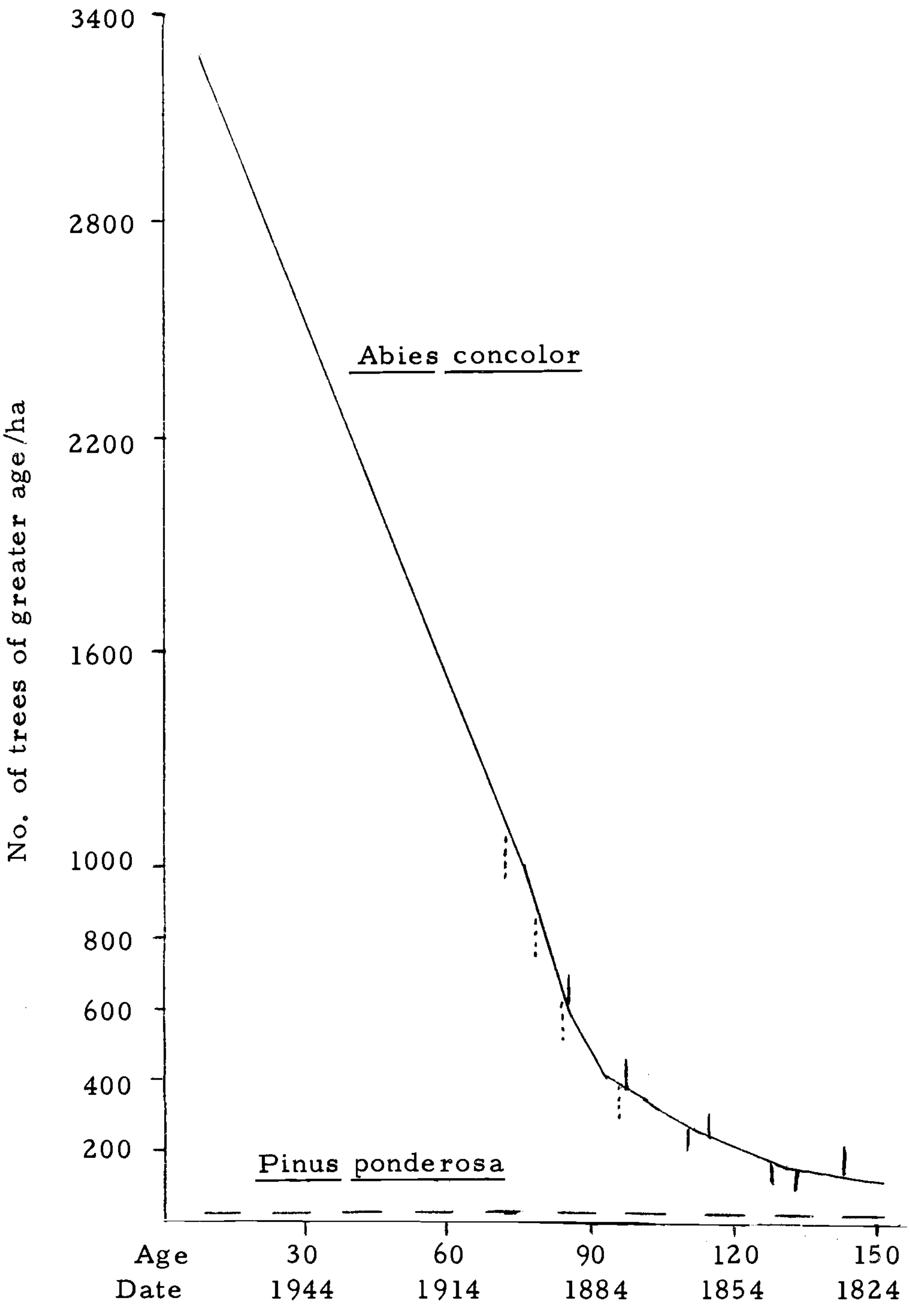


Fig. 21. Age-density relations of two major tree species in the *Melica* community. Vertical lines below the *A. concolor* line show dates of fires in the *Melica* community west of Annie Creek, and lines above the *A. concolor* line show dates of fires east of Annie Creek. The dotted vertical lines show dates of fires that probably did not burn the whole area.

the last fire (Fig. 18). *A. concolor* was second in importance in the primeval community. *P. contorta* has not increased as much as in the *Ceanothus* community, perhaps due to competition by the large amount of *A. concolor* that germinated soon after the last fire. Between 1820 and 1890 *P. ponderosa* was not reproducing, as indicated by the slope of the line. This result may partially be due to sampling error, since there are only three vegetation plots in this community.

The *A. concolor* in the Mesic Species community follows the same pattern as in the *Ceanothus* and *Chimaphila* communities, except that it was the most important species at least as far back as 1850 (Fig. 19).

In the *A. magnifica* var. *shastensis*/*Chimaphila* community, *A. magnifica* var. *shastensis* has apparently been the most important species at least since 1820. However, before about 1880 *P. contorta* was the second most important species whereas *A. concolor* is now. *P. contorta* has not increased in importance as the *Abies* has since about 1875 (Fig. 20).

In the *Melica* community fire seems to have had a smaller influence on the *A. concolor* than in the *Ceanothus* and *Chimaphila* communities, because it has been the most important species in the community through several fires. It was probably the most important as far back as 1830. However, this curve may mean less than the others because the vegetation data were taken west of Annie Creek, and the age-size data were taken east of the creek (Fig. 21).

CONCLUSIONS

The two main soil parent materials in the study area support different habitat types. Alluvial material from Annie Creek supports the relatively dry *Abies concolor*/*Symphoricarpos mollis* habitat type, which includes the *Populus*, *Senecio*, and *Melica* communities. The *Populus* and *Senecio* may be the driest and are the most recently disturbed communities in the study area, and *A. concolor* may not be the climax dominant. These two communities are on a soil with an A_1 horizon 35 cm thick, in contrast to the soil on the rest of the area, where the maximum thickness of the A_1 is 25 cm. The *Melica* community is at somewhat higher elevation, is less disturbed, and occurs on soil with somewhat more pumice in it. The second type of parent material is the pumice of the Steiger and Lapine soil series. These soils support *Abies concolor*/*Chimaphila umbellata* and *A. magnifica* var. *shastensis*/*C. umbellata* habitat types and a Mesic Species community. The Mesic Species community occurs in an area with a water table near the surface in the spring, and this provides enough moisture to support a mesophytic flora, and to stop some fires. The soil structure in this community is stronger than elsewhere in the study area. The *A. concolor*/*Chimaphila* habitat type can be subdivided on the basis of the presence of *Pyrola secunda*, and the division thus made also corresponds to changes in the importance of *Ceanothus velutinus*, and to a lesser extent, in the relative importance of *Pinus ponderosa* and *A. concolor* in the primeval vegetation. These two subdivisions are located on different sides of the Mesic Species community fire break, and some of the differences in them are probably due to different frequencies of fires before 1902 as well as the climatic changes associated with elevation. The change is probably not due to soil moisture stress. The change to the *A. magnifica* var. *shastensis*/*Chimaphila* habitat type is very gradual, and probably results from climatic differences at higher elevations. The *Calocedrus decurrens*/*Arctostaphylos patula* and *Alnus incana*/*Elymus glaucus* habitat types and the *Castinopsis* communities occur only in special topographic or edaphic situations.

Fires occurred at sampling spots at intervals from 3 to more than 50 years, with the mean interval at a spot ranging from 9 to 42 years. The intervals between fires lengthened with increased elevation. Precipitation may have had little influence on what years fires burned, but the length of time since the last major fire may have had some control over fire occurrence.

It appears that substantial changes have taken place in the vegetation of the study area since fire suppression became effective. Without disturbance, the entire *A. concolor*/*Chimaphila* habitat type will probably become more or less like the *Chimaphila*-*Pyrola* community. *A. concolor* and, in places, *Pinus contorta* have increased in importance, and the smaller *Pinus ponderosa* reproduction, where present, appears to be in ill health. The canopy is probably still closing, decreasing the importance of *Ceanothus velutinus* and *Arctostaphylos patula*. Extrapolation of these trends indicates that, without disturbance, in perhaps 50 or 100 years, *Abies* species would be the only trees with a significant amount of reproduction. The shrubs would nearly be eliminated. *Arctostaphylos patula* is already reduced almost to insignificance, even though it was once important (Fig. 2). Other plants that have probably decreased in importance since the 1930's include *Poa juncifolia* (*P. ampla*), *Eriogonum spergulinum*, *Eriogonum umbellatum*, *Habenaria unalascensis*, and *Aquilegia formosa*. Applegate (1939) reported that all of these were common in the *P. ponderosa* forests of Crater Lake National Park, and Wynd (1941) considered all of them except the *Poa* to be among the more noticeable species in the Transition Zone. I did not find any specimens of the *Poa* or *Eriogonum spergulinum* (Appendix E), and the *Habenaria*, *Aquilegia*, and *Eriogonum umbellatum* are far from common. Applegate (1939) also reported that *Ceanothus prostratus* formed large, dense mats over considerable areas in the *P. ponderosa* forests. Now it is found only in the *Calocedrus/Arctostaphylos* habitat type and on part of the edge of Annie Creek canyon. These changes may or may not be the result of succession, but they have apparently occurred.

If fire is reintroduced, the trends of succession will probably be reversed to some extent in part of the area. *P. ponderosa* reproduction will probably increase and become vigorous in some areas, and at least the smaller *Abies* and *P. contorta* will be killed. *Ceanothus velutinus* and *Arctostaphylos patula* will probably increase in cover within a few years after each fire. Oosting and Billings (1943) regarded the occurrence of *Arctostaphylos nevadensis* as a good indicator of past fires in the *Abies magnifica* forests of California. *Ribes cereum* increases after fires in the same zone (Kilgore 1971, Oosting and Billings 1943). *Salix scouleriana* and *Ribes viscossimum* resprout after fire, whereas *Ribes lacustre* does not (Lyon 1971). Certain herbs, such as *Chimaphila* spp., *Pyrola secunda*, *Goodyera oblongifolia*, *Clintonia uniflora*, *Adenocaulon bicolor*, *Rosa gymnocarpa*, and *Linnaea borealis* are easily killed by fire and may become less important after it (Dyrness 1973, Hartesvedt and Harvey 1968, Kilgore 1971, Krefting and Ahlgren 1974, McLean 1969). Other herbs, such as *Epilobium angustifolium*, *Eriophyllum lanatum*, *Cryptantha affinis*, *Gayophytum nuttallii*, *Phacelia heterophylla*, *Gilia aggregata*, *Stipa occidentalis* var. *occidentalis*, *Sitanion hystrix*, *Anaphalis margaritacea*, *Solidago canadensis*, *Pteridium aquilinum*, and *Rubus parviflorus*, may increase after fires (Dyrness 1973, Hartesveldt and Harvey 1968, Hitchcock *et al.* 1969, Kilgore 1971, Krefting and Ahlgren 1974, McLean 1969, Oosting and Billings 1943, Sweeny 1956).

Hieracium albiflorum and Apocynum androsaemifolium are not consistent in their reaction to fire (Dyrness 1974, Krefting and Ahlgren 1974, McLean 1969).

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APPENDIX A

SOIL DESCRIPTIONS

A typical Lapine pedon

A_1	0 to 10 cm; grayish brown (10YR 5/2) loamy sand, very dark grayish brown (10YR 3/2) moist; weak, medium or coarse granular structure; very friable; roots common; gravel 15%, clear wavy boundary.
AC	10 to 50 cm; brown (10YR 5/3) gravelly loamy sand, dark brown (10YR 3/3) moist; single grain; very friable; roots common; gravel 50%; gradual wavy boundary.
C_1	50 to 100 cm; yellowish brown (10YR 5/4) moist gravel; roots rare; clear wavy boundary.
C_2	100 to 125 cm; yellow (2.5Y 7/6) moist gravelly sand; single grain; loose; roots rate; gravel 90%; abrupt wavy boundary.
IIC_3	125 cm to 140 cm plus; light yellowish brown (10YR 6/4) cobbly sandy loam, dark brown (10YR 3/3) moist; moderate fine subangular blocky structure; friable; roots occasional.

The description is based on one pedon (plot E-7).

A typical Steiger pedon

A_1	0 to 15 cm; brown (10YR 5/3) loamy sand, dark brown (10YR 4/3) moist; weak medium or coarse granular structure; very friable; roots abundant; clear wavy boundary.
AC	15 to 60 cm; brown (7.5YR 5/4) sand, dark reddish brown (5YR 3/3) moist; single grain; loose; roots common; gradual wavy boundary.
C	60 to 110 cm plus; light reddish brown (5YR 6/3) sand, dark reddish brown (5YR 3/3) moist; single grain; loose; roots rare.

Range in Characteristics

The gravel and cobble content can range from 10 to 70%. The A_1 can range from 10 to 25 cm in thickness. The color of the A_1 can range from 10YR 6/2 to 10YR 3/1 dry and 10YR 4/4 to 10YR 2.5/1 moist. The structure of the A_1 often tends to be weak, medium subangular blocky, and in parts of the *A. concolor*/mesic species habitat type, can be moderate, medium subangular blocky. In some pedons the AC is lacking but it can be up to 50 cm thick. The moist hue of the AC can range to 10YR, the value of the moist soil can be as low as 2, and the dry soil can be as light as 6/2. In some pedons, there are places in the AC with weak, coarse granular structure. There is a wide variety of colors in the C, with hues ranging to 10YR, chomas ranging 1-4, moist values of 3-4 and dry values of 5-6. Often there is a tendency for the C horizon to be massive, rather than single grained. The description is based on six pedons at plots 1-2, 3-2, 5-1, 6-1, 7-1, and 8-3.

A typical pedon in the *Senecio* community

A_1	0 to 35 cm; dark brown (10YR 3/3) sand, very dark brown (10YR 2/2) moist; weak fine subangular blocky; very friable; roots common; gravel 20%; diffuse wavy boundary.
C	35 to 120 cm plus; grayish brown (10YR 5/2) sand, very dark grayish brown (10YR 3/2) moist; single grain; loose; roots occasional; gravel 20%.

Range in Characteristics

The A_1 can range from 15 to 40 cm thick. Chroma can range down to 1 and value can range to 4. In places the structure is granular. In some pedons there is a horizon with slightly higher chroma, about 20 cm thick, in the upper part of the C. The chroma in the C can range from 4 to 6, and the value can range up to 3. The description is based on three pedons at plots E-3, E-5 and E-6.

Soil in *Melica* community

A_1	4-7 cm thick; dark grayish brown (10YR 4/2) loamy sand; very dark grayish brown (10YR 3/2) moist; weak medium or coarse granular structure; very friable; roots abundant; clear wavy boundary.
AC	5 cm deep, 10-15 cm thick; brown (10YR 5/3) loamy sand, dark brown (10YR 3/3) moist; weak coarse granular structure; very friable; roots abundant; gradual wavy boundary.
C_1	20 cm deep, 75-100 cm thick; yellowish brown (10YR 5/4) sand, dark yellowish brown (10YR 3/4) moist; single grain; loose; roots common; gradual irregular boundary.
C_2	110 cm deep, 30-45 cm thick; grayish brown (10YR 5/2) sand, very dark grayish brown (10YR 3/2) moist; single grain; loose; roots occasional; abrupt wavy boundary.
C_3	145 cm deep, 10-20 cm thick; brown (10YR 5/3) loamy sand, dark brown (10YR 3/3) moist, single grain; loose; roots abundant; abrupt wavy boundary.
C_4	160 cm deep; grayish brown (10YR 5/2) sand, very dark grayish brown (10YR 3/2) moist; single grain; loose; roots occasionally; gravel 30%.

Range in Characteristics

The description is based on one pedon, plot 7-14. Presumably, there are pedons lacking this stratification.

APPENDIX B

TREE AND UNDERSTORY DATA BY PLOTS

Tree data are given as the number of trees per plot by dbh class and understory is given as % cover. The species are in the order resulting from the table sorting. + = present in the central 5 x 25 m plot; - = present in the 15 x 25 m plot, but not in the central 5 x 25 m plot.

[a] Even though this number is *Carex pensylvanica* + *Carex brainerdii*, the coverage of *C. brainerdii* is comparatively very low, so the coverage, except in the *Ceanothus* and *Chimaphila* communities, is essentially that of *Carex pensylvanica*.

Calocedrus/*Arctostaphylos* Habitat Type

dbh	No. trees in plot	
	E-9	E-10
Calocedrus decurrens		
0-5	53	17
5-10	17	
10-15	2	
15-20	1	
45-55		1
55-65		1
Pinus lambertiana		
0-5	1	2
5-10		
10-15		1
Pseudotsuga menziesii		
45-55		1
55-65		1
Pinus ponderosa		
0-5	5	24
5-10	4	1
10-15	2	1
65-75	1	
75-85		1
Abies concolor		
0-5	16	4
5-10	1	1
10-15	1	1

Species	% Cover	
	E-9	E-10
Grimmia	0.05	0.30
Ceanothus prostratus	2.50	0.05
Arctostaphylos patula	36.30	6.50
Senecio integerrimus	1.05	0.05
Poa nervosa	-	
Hieracium sp.	-	
Carex pensylvanica[1]	10.75	8.90
Ceanothus velutinus	2.95	
Polytrichum juniperinum	+	+
Arctostaphylos nevadensis	2.50	
Castinopsis sempervirens	-	
Corylus cornuta	+	
Polystichum munitum var. *imbricans*	+	+

Populus community

dbh	No. trees in plot		Species	% Cover	
	E-2	E-3		E-2	E-3
Populus tremuloides					
0-5	121	117	*Senecio integerrimus*	+	
5-10	2	9	(?) *Agoseris* sp.	-	-
10-15	2	10	*Eriogonum umbellatum*	+	0.05
15-20	2	5	*Antennaria rosea*	1.05	-
20-25		1	*Stipa occidentalis* var. *californica*	0.10	0.30
			Purshia tridentata	4.70	0.35
Pinus ponderosa			*Lonicera conjugalis*	3.00	0.80
0-5	16	13	*Poa nervosa*	0.40	+
5-10	4	5	*Lupinus albicaulis*	3.50	0.50
10-15	4	4	*Bromus* sp.	3.40	3.10
15-20	7	7	*Phacelia heterophylla*	0.30	+
20-25	2	5	*Hieracium* spp.	4.50	4.60
25-35	6	3	*Symphoricarpos mollis*	0.30	1.45
35-45	2		*Cynoglossum occidentale*		+
			Haplopappus bloomeri	5.40	5.05
Abies concolor			*Ribes cereum*	12.15	+
0-5	15	5	*Sitanion hystrix*	8.75	7.90
5-10		2	*Fragaria virginiana*	2.95	1.20
10-15		4	*Carex pensylvanica**	32.30	19.80
			Chimaphila menziesii		+
			Epilobium angustifolium		0.05
			Stipa occidentalis var. *occidentalis*	7.45	8.15
			Ceanothus velutinus		2.35
			Kellogia galioides	1.25	0.55
			Osmorhiza chilensis	0.05	-
			Elymus glaucus	+	0.75
			Festuca occidentalis	+	
			Collomia tinctoria	0.05	
			Gilia aggregata		-

Senecio community

	dbh	No. trees in plot					
		E-4	E-5	E-6	0-2	E-8	E-1
Populus tremuloides	0-5	13		4			
Pseudotsuga menziesii	0-5			1		1	1
Pinus ponderosa	0-5	9	4	10	4	1	
	5-10	6	5	6			1
	10-15	12	2	2			
	15-20	13					
	20-25	3	1	2			
	25-35	5	1	2			
	35-45		3	1			
	45-55		3				1
	55-65		2	2		1	
	65-75			3			
Abies concolor	0-5	43	83	11	1	48	68
	5-10	8	47	19		9	26
	10-15	4	16	9		7	8
	15-20		4	5		4	3
	20-25			1		3	2
	25-35		2			3	5
	35-45						6
	45-55						2
	55-65						1

	% Cover					
	E-4	E-5	E-6	0-2	E-8	E-1
Arctostaphylos patula	+					
Senecio integerrimus		+	+	0.05		
Eriogonum umbellatum	-					
Antennaria rosea				0.15		
Stipa occidentalis var. *californica*		0.05	-			
Purshia tridentata	+	+	-	+		
Lonicera conjugalis	0.30	-	0.05			
Poa nervosa	0.30	+	2.55	0.30		
Lupinus albicaulis	+	+	0.35			-
Bromus sp.	0.30			10.95	0.60	0.05
Phacelia heterophylla				+	-	
Hieracium spp.	0.95	0.15	1.00	0.05	0.10	+
Symphoricarpos mollis	0.30	2.85	16.70		2.05	0.15
Melica aristata	-		4.30		-	0.05
Cynoglossum occidentale	+	-	0.05	-	+	
Stephanomeria lactucina	0.05	+	0.40	+	0.30	0.05
Haplopappus bloomeri	3.50	0.05	0.05	0.70	0.05	-
Ribes cereum	0.05	0.30	+	7.60	-	
Sitanion hystrix	2.90	0.60	1.05	1.85		0.05
Fragaria virginiana	1.50	0.90	2.30	0.65	0.40	-
*Carex pensylvanica**	40.25	22.15	66.20	77.50	49.70	9.60

(Continued on next page)

Senecio community (Continued)

	% Cover					
	E-4	E-5	E-6	0-2	E-8	E-1
Chimaphila menziesii		+	+		0.20	
Epilobium angustifolium	0.40				0.10	0.05
Stipa occidentalis var. occidentalis	1.80	0.95		18.95	-	
Ceanothus velutinus	33.95	10.40	3.25		43.30	2.00
Kellogia galioides	0.35	0.30	4.00		+	+
Apocynum androsaemifolium					0.35	0.40
Pyrola dentata					-	
Pyrola picta					+	+
Brachythecium leibergii + Pohlia nutans						0.05
Polytrichum juniperinum						
Chimaphila umbellata					+	
Smilcania sp.	-				+	+
Osmorhiza chilensis			+			
Rosa gymnocarpa	-					
Castanopsis sempervirens					-	
Pteridium aquilinum					-	
Elymus glaucus			1.20			
Pterospora andromedea	-				-	+
Festuca occidentalis		-				
Collomia tinctoria	-			0.45		
Gilia aggregata			-			
Amelanchier alnifolia		1.50	20.85		+	
Arnica cordifolia		-				
Pachistima myrsinites			-			
Melica subulata			-			
Gayophytum nuttallii				6.15		
Phlox caespitosa				0.50		
Arablis holboellii				0.05		
Aster canescens				-		
Lomantium triternatum				+		
Castilleja applegatei					-	
Pyrola aphylla						-

Melica community

dbh	No. trees in plot 7-14	7-13	8-8	7-12
Abies magnifica var. *shastensis*				
0-5			1	
Pinus ponderosa				
75-85		1		
85-95				
95+			1	
Abies concolor				
0-5	45	30	53	215
5-10	6	14	15	25
10-15	5	7		10
15-20	6	7		2
20-25	6	3		2
25-35	12	3		3
35-45	2	1	1	3
45-55	2		3	1
55-65	1	2	1	2
65-75	1			
75-85	1			

Species	% Cover 7-14	7-13	8-8	7-12
Arctostaphylos nevadensis				7.55
Pyrola secunda		+		0.05
Smilacina sp.	+		-	
Adenocaulon bicolor	+	-		
Osmorhiza chilensis		+		
Galium triflorum	+			
Ribes viscosissimum		-		-
Elymus glaucus		+	2.35	
Pterospora andromedea	-		-	
Corallorhiza spp.	0.10	-		+
Amelanchier alnifolia	0.75			
Melica subulata	+	0.30		
Listera caurina		+		
Phacelia heterophylla		+		
Hieracium spp.	+	-	+	
Symphoricarpos mollis	0.70	1.50	2.05	1.35
Melica aristata	-		2.00	
Stephanomeria lactucina				+
Sitanion hystrix			0.05	+
Fragaria virginiana	0.05	0.05	0.60	0.55
*Carex pensylvanica**	1.10	31.06	57.05	19.60
Chimaphila menziesii	0.25	0.10	0.05	0.45
Epilobium angustifolium		0.45	-	+
Stipa occidentalis var. *occidentalis*			0.05	0.10
Ceanothus velutinus			0.30	9.30
Kellogia galioides	0.35	0.05	0.10	0.20
Apocynum androsaemifolium	0.15	0.40		2.35
Pyrola dentata	+			0.05
Pyrola picta				+
Brachythecium leibegii + *Pohlia nutans*	1.15			0.05
Polytrichum juniperinum				0.05
Chimaphila umbellata		+	0.75	1.05

Logged *Pinus ponderosa* community

dbh	No. trees in plot			
	0-1	1-5	1-4	E-7
Populus tremuloides				
0-5	20			
5-10	14			
10-15	4			
Pinus lambertiana				
0-5			1	
Pinus contorta				
0-5	6	2	3	
5-10	1	1	1	
10-15	1			
15-20			1	
20-25	4			
25-35	2		2	
35-45			1	
Pinus ponderosa				
0-5	9	19		4
5-10	7	3	2	2
10-15		1	5	3
15-20	3	1	6	1
20-25	1	1	4	
25-35	1	9	6	
35-45		4	2	1
45-55				
55-65				
65-75	1			
75-85	1			

Species	% Cover			
	0-1	1-5	1-4	E-7
Arctostaphylos patula				-
Purshia tridentata	0.30			
Bromus sp.	-			-
Phacelia heterophylla				0.05
Hieracium spp.	-			
Symphoricarpos mollis			+	
Cynoglossum occidentale	-	+		
Staphanomeria lactucina	-	1.10		-
Haplopappus bloomeri	1.90	+		
Ribes cereum	0.75	18.05	12.30	-
Sitanion hystrix	1.35	3.60	1.25	1.95
Fragaria virginiana	2.90	3.95	0.75	0.70
*Carex pensylvanica**	15.55	30.50	7.55	24.45
Chimaphila menziesii				-
Epilobium angustifolium	1.85	0.70	0.50	1.25
Stipa occidentalis var. *occidentalis*	8.35	13.00	7.30	0.40
Ceanothus velutinus	11.75	26.95	34.70	40.70
Kellogia galioides	+	0.10	0.40	
Apocynum androsaemifolium	+	0.05	0.05	0.30
Salix scouleriana			7.10	7.85
Pyrola dentata		0.05	+	-
Pyrola picta		-	-	
Brachythecium leibergii + *Pohlia nutans*	0.05			0.15
Polytrichum juniperinum	0.30	+		1.30
Chimaphila umbellata	0.60	+	0.05	+
Pyrola secunda			0.05	
Pterospora andromedea	-		-	
Collomia tinctoria				0.15

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Logged Pinus ponderosa community (Continued)

dbh	No. trees in plot			
	0-1	1-5	1-4	E-7
Abies concolor				
0-5	17	29	17	98
5-10		1		49
10-15				15
15-20				7
20-25				7
25-35				7
35-45				3
45-55		1		1

Species	% Cover			
	0-1	1-5	1-4	E-7
Amelanchier alnifolia				-
Gavophytum diffusum	-			-
Phlox caespitosa	0.40			
Arablis holboellii				+
Aster canescens			-	
Prunus emarginata				0.35
Two unidentified annuals				+

Logged *Pinus contorta* community

dbh	No. trees in plot 1-3	1-1	1-2
Pinus lambertiana			
0-5	2		1
5-10			
10-15			1
55-65		1	
Pinus contorta			
0-5	16	12	6
5-10	6	3	1
10-15	8	4	7
15-20	4	8	10
20-25	1	4	4
25-35	5	3	5
35-45		2	
Pinus ponderosa			
0-5	7	2	10
5-10		2	4
10-15		4	
15-20	1		1
20-25		1	3
25-35	1	1	
35-45			
45-55		1	
55-65	2	1	
65-75	1		

Species	% Cover 1-3	1-1	1-2
Arctostaphylos patula	0.30	-	
Hieracium spp.			-
Haplopappus bloomeri	0.30		
Ribes cereum	-		
Sitanion hystrix		0.05	-
Fragaria virginiana	0.15	0.55	0.50
*Carex pensylvania**	10.65	18.55	8.50
Chimaphila menziesii	+	0.05	+
Epilobium angustifolium	+	1.20	0.50
Stipa occidentalis var. *occidentalis*	0.30	3.45	1.25
Ceanothus velutinus	33.05	15.50	8.10
Kellogia galioides	0.45	0.60	0.75
Apocynum androsaemifolium	-	0.10	0.05
Salix scouleriana	1.25	0.75	12.70
Pyrola dentata	+	+	
Pyrola picta		-	
Brachythecium leibergii + *Pohlia nutans*		0.05	+

(Continued on next page)

Logged P. contorta community (Continued)

dbh	No. trees in plot		
	1-3	1-1	1-2
Abies concolor			
0-5	9	10	12
5-10	3	4	17
10-15	2	2	8
15-20			2
20-25			
25-35		1	2
35-45			2

Species	% Cover		
	1-3	1-1	1-2
Polytrichum juniperinum	1.25		
Chimaphila umbellata	1.10	0.05	+
Pyrola secunda	-	+	
Pterospora andromedea	-	+	+
Gayophytum nuttallii	+		
Phlox caespitosa	+		

Ceanothus community

dbh	No. trees in plot						
	2-2	2-1	2-3	3-2	3-3	3-1	3-4
Calocedrus decurrens							
0-5	1			3	1	2	
Pinus lambertiana							
0-5	82	24	1	4	12	4	13
5-10	4	1	2		7		
10-15		1			2		
25-35		1					
95+	1						
Pinus contorta							
0-5	31	67	8	19	42	55	25
5-10	30	30	17	1	22	18	18
10-15	7	21	8		8	8	5
15-20	3	3	5		4	4	4
20-25		1	2		1		2
25-35	1		2		4		1
35-45							1
Pseudotsuga menziesii							
0-5					1		
5-10			1				
Pinus ponderosa							
0-5	109	24	9	4	5	7	4
5-10		1			3		
10-15							1
20-25					1		
25-35				1	2		
45-55			1				
55-65							1
65-75			1				
75-85	1			1			1
85-95	1		1	1			
95+		1		1			
Abies concolor							
0-5	4	28	31	43	39	93	24
5-10	1	10	10	4	17	11	12
10-15	1		9	1	6	2	3
15-20					4		
20-25							1
25-35					1		
35-45					2		
85-95						1	

(Continued on next page)

Ceanothus community (Continued)

Species	% Cover						
	2-2	2-1	2-3	3-2	3-3	3-1	3-4
Arctostaphylos patula			-	0.30	-		
Fragaria virginiana		+				+	
*Carex pensylvanica**			-		+		
Chimaphila menziesii		0.05	+				+
Epilobium angusifolium	2.70	1.30	+	0.80	1.30	0.05	0.45
Stipa occidentalis var. *occidentalis*	1.05	2.95	0.05	0.95	+		1.80
Ceanothus velutinus	22.50	13.75	21.30	8.60	18.85	30.20	17.20
Kellogia galioides	0.05	0.10	+	+	0.60		+
Apocynum androsaemifolium	2.30	5.75	0.30	2.90	2.55	0.35	4.20
Salix scouleriana	0.30	-	-	2.60	8.85	7.40	-
Pyrola dentata		+	-			+	+
Pyrola picta	-			0.05	0.05		+
Brachythecium leibergii + *Pohlia nutans*	0.05	0.05	+		0.05		
Polytrichum juniperinum		+					
Chimaphila umbellata	0.40	1.65	0.05	-	3.05	2.45	0.30
Arctostaphylos nevadensis	-	-		41.10	-	21.20	9.90
Castanopsis sempervirens			0.05			4.05	-
Elymus glaucus							-
Pterospora andromedea			+				+
Pyrola aphylla					0.05		

Chimaphila community

dbh	No. trees in plot 3-5	4-1	5-1
Pinus lambertiana			
0-5	1	8	1
5-10	1	1	
10-15		1	
Pinus contorta			
0-5	8	1	3
5-10	19	5	3
10-15	11	3	3
15-20	2	2	
20-25		2	
25-35			
35-45			1
Pseudotsuga menziesii			
0-5		7	
Tsuga mertensiana			
0-5		1	
Pinus ponderosa			
0-5	3	4	5
5-10		1	1
45-55		1	
65-75	1		
95+	1		2

Species	% Cover 3-5	4-1	5-1
Arctostaphylos patula		-	
Fragaria virginiana	0.05	0.10	+
Carex pensylvanica*	+		0.10
Chimaphila menziesii	+	+	0.05
Epilobium angustifolium	0.05		
Stipa occidentalis var. occidentalis	+		-
Ceanothus velutinus		1.95	7.05
Apocynum androsaemifolium	1.10	0.80	
Salix scouleriana	0.60	+	3.90
Pyrola dentata	-	-	+
Pyrola picta	+		
Brachythecium leibergii + Pohlia nutans	0.10	0.25	0.10
Polytrichum juniperinum			0.05
Chimaphila umbellata	1.05	2.25	0.40
Arctostaphylos nevadensis	0.55	18.15	7.95
Castanopsis sempervirens		4.45	
Pterospora andromedea	+		
Rubus urinus		0.05	

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Chimaphila community (Continued)

dbh	No. trees in plot			Species	% Cover		
	3-5	4-1	5-1		3-5	4-1	5-1
Abies concolor							
0-5	63	94	129				
5-10	39	40	61				
10-15	15	3	12				
15-20	3	3	8				
20-25	1		1				
25-35			3				
45-55			1				
95+		1					

Ceanothus-Carex community

dbh	No. trees in plot 5-2	5-3
Pinus lambertiana		
0-5	1	
Pinus contorta		
0-5		2
5-10	9	2
10-15	2	1
Abies magnifica var. *shastensis*		
0-5	16	2
5-10	16	
10-15	3	
Pinus ponderosa		
0-5	19	55
5-10	2	8
10-15	1	
95+		2
Abies concolor		
0-5	51	28
5-10	66	21
10-15	4	12
15-20	1	7
20-25		1
25-35		1

Species	% Cover 5-2	5-3
*Carex pensylvanica**	22.95	51.95
Chimaphila menziesii	0.05	+
Stipa occidentalis var. *occidentalis*		-
Ceanothus velutinus	22.85	15.75
Kellogia galioides	0.15	
Apocynum androsaemifolium		0.60
Salix scouleriana	1.50	
Pyrola dentata	0.45	-
Brachythecium leibergii + *Pohlia nutans*	0,15	
Polytrichum juniperinum	0.05	
Chimaphila umbellata	1.30	-
Arctostaphylos nevadensis		3.80
Ribes viscosissimum	+	

Carex community (Continued)

Species	% Cover									
	7-11	7-10	7-9	7-8	8-7	8-6	9-1	7-7	7-6	8-5
Ceanothus velutinus	3.05	-	-	15.75	-	-	-	3.30		1.65
Kellogia galioides	0.10	+	0.25	-	0.30	+		-	+	
Apocynum androsaemifolium	0.75	1.05	1.20	0.05	0.15	1.20	0.85		0.15	
Salix scouleriana		6.80	-	-	0.05	0.30		1.25		
Pyrola dentata	+	+	+	0.05	0.10	0.10	0.10	0.05	+	0.05
Pyrola picta	-				-		+			
Brachythecium leibergii + Pohlia nutans		0.20	0.05	0.15	0.05	0.20	0.35			0.05
Polytrichum juniperinum	0.05	+	0.40	+		0.05	0.30			0.35
Chimaphila umbellata	0.70	7.25	13.90	6.30	4.45	0.40	-	19.35	14.35	3.75
Arctostaphylos nevadensis	2.35	1.05		0.05	3.30	0.80	35.75	1.10	0.30	2.45
Pyrola secunda	0.05	0.55	0.40	1.90	1.20	+	-	0.05	1.15	0.25
Goodyera oblongifolia	+	+		+	+			+	+	
Pterospora andromedea					0.05	+	+	+	-	
Corallorhiza spp.	+	+	0.30	-	-			+		
Pyrola aphylla							+			
Vaccinium scoparium			-							

Carex community

dbh	No. trees in plot									
	7-11	7-10	7-9	7-8	8-7	8-6	9-1	7-7	7-6	8-5
Pinus contorta										
0-5		14		1	2	6	19	2		
5-10		3				2	5			
10-15		1	1				4			
15-20		1	1				5			1
25-35			2							
Abies magnifica var. shastensis										
0-5	2	37	12	14	5	5	17	14	2	6
5-10		4				1	1			3
10-15				2					1	
25-35	1									1
35-45									2	
Pinus monticola										
0-5		3			1	1		2	1	
Pinus ponderosa										
0-5		2				3	2			
65-75			1							
75-85	1		1				2			
85-95							2	1	1	
95+							1	3	1	
Abies concolor										
0-5	117	407	224	39	423	254	161	196	134	50
5-10	29	36	43	19	16	59	25	28	20	21
10-15	5	10	12	7	5	17	6	2	4	11
15-20	4	7	5	5	2	7	1	1	4	6
20-25	1	3	1	2	1	1	2		1	3
25-35	3	3	2	1	2	1		3	2	3
35-45	3		1	1	1				3	1
45-55	3			3	1	1		1	1	2
55-65										2
65-75						1		1		1
75-85					1	1				
85-95	1									

Species	% Cover									
	7-11	7-10	7-9	7-8	8-7	8-6	9-1	7-7	7-6	8-5
Arctostaphylos patula						-				
Symphoricarpos mollis	0.05	0.50	+							
Staphanomeria lactucina	0.10							0.30		
Fragaria virginiana	+	0.35	0.35		-	+				
Carex pensylvanica*	2.25	14.85	22.35	5.15	0.50	19.25	0.40	20.80	7.50	3.20
Chimaphila menziesii	0.15	0.25	0.05	0.20	0.35	0.20	+			0.10
Epilobium angusifolium						+	+			
Stipa occidentalis var. occidentalis					-	+	0.30			

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Chimaphila-Pyrola community

dbh	No. trees in plot				
	8-4	7-3	8-3	7-5	7-4
Pinus contorta					
0-5	2		1	1	
25-35		1			5
35-45				3	2
45-55				4	
Abies magnifica var. shastensis					
0-5	26	19	3	6	28
5-10	1	1		2	
15-20		1			
25-35		1			
Pinus monticola					
0-5				4	2
10-15				1	
Tsuga mertensiana					
0-5	1			1	

dbh	No. trees in plot				
	8-4	7-3	8-3	7-5	7-4
Pseudotsuga menziesii					
10-15	1				
Pinus ponderosa					
95+	1				
Abies concolor					
0-5	223	69	23	93	90
5-10	20	12	7	24	17
10-15	3	8	9	12	11
15-20	1	8	2	7	8
20-25	3	3	2	2	6
25-35	3	7	5	2	5
35-45	2	4	2	2	2
45-55	2		1	1	
55-65	1				
95+	1				

	% Cover				
	8-4	7-3	8-3	7-5	7-4
Fragaria virginiana	-				+
Carex pensylvanica*	1.20	0.20	2.35	0.30	5.60
Chimaphila menziesii	0.05	+	0.30	0.35	0.35
Kellogia galioides	-				
Apocynum androsaemifolium	+				
Salix scouleriana	0.05				
Pyrola dentata		0.05	0.50		
Pyrola picta	-	+			
Brachythecium leibergii + Pohlia nutans	0.25	1.05	3.75	0.15	0.25
Polytrichum juniperinum	0.15		0.05		-
Chimaphila umbellata	4.30	1.15	0.30	4.20	0.70
Arctostaphylos nevadensis			1.80		+
Pyrola secunda	0.20	1.10	0.10	+	+
Goodyera oblongifolia	+		-		
Castanopsis sempervirens					-
Pterospora andromedea	+				
Listera caurina		-			
Pyrola aphylla				0.15	
Roellia roellii	0.40		+		

Abies magnifica var. *shastensis*-*Pinus ponderosa* community

dbh	No. trees in plot 9-5	9-4	9-2	7-1
Pinus contorta				
0-5		16	28	7
5-10	1	3	4	2
10-15			4	
15-20		1	3	1
20-25	1			1
25-35		2		
35-45	1			
Abies magnifica var. *shastensis*				
0-5	99	93	195	63
5-10	13	3	1	6
10-15	4		1	4
15-20	2		1	1
20-25				1
25-35		1		
35-45				1
45-55				
55-65		1		
65-75		3		
75-85		1		
85-95			1	
95-100			1	1
Pinus monticola				
0-5	2	3	4	13
5-10	1			1
Tsuga mertensiana				
0-5		1		1
Pinus ponderosa				
75-85	1			
85-95		2		
95+			2	1
Abies concolor				
0-5	113	65	149	40
5-10	17	3	5	1
10-15	7	1	1	
15-20	3			
20-25	1			
25-35	2		1	
35-45				1
45-55				
55-65				
65-75	1			
75-85				
85-95				
95+	1			

(Continued on next page)

A. magnifica var. *shastensis*-*P. ponderosa* community (Continued)

Species	% Cover			
	9-5	9-4	9-2	7-1
*Carex pensylvanica**	11.95	13.50	12.35	4.55
Chimaphila menziesii	0.05		+	+
Epilobium angustifolium	+			
Stipa occidentalis var. *occidentalis*			0.30	
Ceanothus velutinus		-		
Pyrola dentata		0.15		0.05
Brachythecium leibergii + *Pohlia nutans*	+	0.35	+	0.30
Polytrichum juniperinum		+		0.10
Chimaphila umbellata	10.55	15.45	+	0.10
Arctostaphylos nevadensis		28.75	6.90	9.30
Pyrola secunda	0.15	0.10		
Goodyera oblongifolia		0.05		
Pterospora andromedea				+
Corallorhiza spp.	+			

Abies magnifica var. shastensis/Chimaphila community

dbh	No. trees in plot 8-2	8-1	9-3	7-2	9-1
Pinus contorta					
0-5	10	12	4	2	16
5-10	3		3		1
10-15	4		5		
15-20	1		1		
20-25	4	1	2	1	1
25-35	2	2		2	4
35-45				3	
45-55	1				
Abies magnifica var. shastensis					
0-5	124	144	205	75	270
5-10	3	11	14	11	10
10-15	1	6	10	8	4
15-20		3	1	5	4
20-25	2	1	2	3	
25-35	1	2		1	2
35-45		3	1	2	
45-55			1	1	1
55-65	1			1	
65-75			1		
75-85		1	1		
85-95			1		

dbh	No. trees in plot 8-2	8-1	9-3	7-2	9-1
Pinus monticola					
0-5	5	17	7	4	10
5-10		1			
10-15		1			
15-20	1				
25-35					1
Tsuga mertensiana					
0-5	1	2	1	10	
15-20		1			
Pinus ponderosa					
95+	1				
Abies concolor					
0-5	217	146	170	78	20
5-10	13	6	9	7	1
10-15	1	4	6	2	1
15-20	2		1	4	
20-25	1	1	1	1	
25-35	1	4			
45-55	1				
55-65				1	

Species	% Cover 8-2	8-1	9-3	7-2	9-1
Carex pensylvanica*		0.90	0.95	0.75	0.15
Chimaphila menziesii	0.05	+	0.10	+	+
Epilobium angustifolium				-	
Stipa occidentalis var. occidentalis			0.60		+
Salix scouleriana			-		
Pyrola dentata			+		
Pyrola picta		+	+		
Brachythecium leibergii + Pohlia nutans	0.05	0.45	0.15	0.35	0.20
Polytrichum juniperinum	+	0.30	0.05		0.40
Chimaphila umbellata	10.50	0.30	3.90	3.45	
Arctostaphylos nevadensis	1.70	1.70	0.10	0.10	2.50
Pyrola secunda	-		0.40	+	
Goodyera oblongifolia			-		
Pterospora andromedea	-	+			
Listera caurina			-		
Roellia roellii		+			
Corallorhiza spp.			-		
Castanopsis sempervirens		+			

Mesic Species community

dbh	No. trees in plot M-3	M-2	M-1	6-1	6-3
Populus tremuloides					
0-5					24
Pinus contorta					
15-20				5	
20-25				5	2
25-35				9	4
Abies magnifica var. shastensis					
0-5				1	
5-10				1	
Pinus monticola					
5-10			1		
Picea engelmannii					
0-5			1		
5-10			1		
10-15			1		
20-25			2		
25-35			2		
35-45			1		
55-65			1		
65-75			1		
85-95			2		

dbh	No. trees in plot M-3	M-2	M-1	6-1	6-3
Pinus ponderosa					
35-45				1	
75-85	1				
85-95		1			
95+	1		2		1
Abies concolor					
0-5	63	66	4	202	36
5-10	18	38	9	27	23
10-15	4	14	5	13	10
15-20	2	9	3	6	4
20-25	3	7		2	
25-35	5	1	1		2
35-45	2		1		5
45-55	4				1
55-65	2		1		1
65-75			1		
75-85			1		

Species	% Cover M-3	M-2	6-1	6-3	M-1
Lonicera conjugialis			0.30	1.35	
Bromus spp.	-	0.75	1.70	2.30	1.95
Hieracium spp.	-		0.15	0.10	
Symphoricarpos mollis	1.95	1.05	2.95	3.45	0.90
Fragaria virginiana	-	0.25	0.40	0.60	
Carex pensylvanica*		0.90	+	1.80	
Chimaphila menziesii	0.05	0.15	0.15	-	+
Epilobium angustifolium			+	-	
Kellogia galioides	-		0.90		
Apocynum androsaemifolium	0.45	0.05			
Salix scouleriana	+	+	-		
Pyrola dentata		+			
Pyrola picta	+	0.05			+
Brachythecium leibergii + Pohlia nutans		0.30	+	0.90	0.05
Chimaphila umbellata	9.55	8.10	1.10	0.75	-
Pyrola secunda	+	1.45	0.10	0.15	0.60
Goodyera oblongifolia	0.30	-		0.05	+
Smilacina spp.	+	0.10	0.35	1.15	2.15

(Continued on next page)

Mesic Species community (Continued)

Species	% Cover				
	M-3	M-2	6-1	6-3	M-1
Adenocaulon bicolor	-	0.80	+	0.45	-
Osmorhiza chilensis		+	0.95	1.35	0.60
Galium triflorum		3.80	0.35	0.35	-
Ribes lacustre	+			0.75	0.10
Clintonia uniflora	0.35			1.30	3.20
Rosa gymnocarpa				-	0.45
Ribes viscosissimum	0.85	7.30	+		
Castanopsis sempervirens					-
Rubus parviflorus		-		+	
Elymus glaucus			-	+	
Alnus incana			+		
Solidago canadensis			0.10	-	
Lupinus latifolius			0.05		
Pterospora andromedea	0.05				-
Corallorhiza spp.		+			-
Amelanchier alnifolia			-	1.60	0.05
Listeria caurina	+	+			
Vaccinum scoparium		-			
Anaphalis margaritacea			+	-	
Viola glabella				0.05	-
Pyrola assarifolia				-	
Aquilegia formosa					+
Carex disperma					-

Castinopsis community

dbh	No. trees in plot			
	C3	C4	C1	C2
Pinus lambertiana + *Pinus monticola*				
0-5	2		1	2
5-10				
10-15		1		
Tsuga mertensiana				
10-15				1
Pseudotsuga menziesii				
0-5	4	5	4	3
35-45	1			
45-55				1
55-65			1	2
65-75				1
75-85		1		1
85-95			1	1
95+			2	1
Pinus ponderosa				
0-5		1		
5-10				
10-15			1	
25-35	1			
65-75		1		
Abies concolor				
0-5	60	28	73	56
5-10		11	19	6
10-15	1	1	8	1
15-20		1		1
20-25		1	3	
25-35			2	

Species	% Cover			
	C3	C4	C1	C2
Arctostaphylos patula		-		
Bromus sp.	0.35	-		1.50
Phacelia heterophylla		0.10	+	
Hieracium spp.	+	0.10	-	-
Symphoricarpos mollis	10.75	2.45	8.20	2.45
Melica aristata	-	0.30		
Cynoglossum occidentale	+			
Stephanomeria lactucina	0.30			
Fragaria virginiana	+			
*Carex pensylvanica**	2.15	4.40		
Chimaphila menziesii	0.10	0.10	0.10	0.45
Ceanothus velutinus		-	+	
Kellogia galioides	0.05	+		
Apocynum androsaemifolium		1.00		
Pyrola picta	0.05	0.05	0.05	0.05
Brachythecium leibergii + *Pohlia nutans*	+	0.05	0.60	1.80
Chimaphila umbellata	2.70	2.75	0.35	2.70
Pyrola secunda	+			0.70
Smilacina spp.	0.05	0.05	0.40	0.05
Adenocaulon bicolor	+	0.05	0.05	-
Osmorhiza chilensis	0.35		-	0.15
Galium triflorum	0.05		0.15	0.35
Ribes lacustre	+		-	-
Clintonia uniflora			0.05	0.35
Rosa gymnocarpa	+	+	2.50	2.00
Ribes viscosissimum	0.60	0.75		-
Castanopsis sempervirens	21.45	3.65	+	+
Rubus parviflorus	0.95	-	0.95	1.10
Pteridium aquilinum	1.55	2.55	6.55	
Elymus glaucus			0.35	

(Continued on next page)

Castanopsis community (Continued)

dbh	No. trees in plot				Species	% Cover			
	C3	C4	C1	C2		C3	C4	C1	C2
Abies concolor (continued)					*Lupinus latifolius*	-		0.05	
35-45					*Collomia tinctoria*		+		
45-55	1				*Amelanchier alnifolia*	+	1.25	5.40	3.50
55-65	4		1		*Pachistima myrsinites*			0.25	
65-75	2		1		*Anaphalis margaritacea*	-			
75-85			1		*Pyrola assarifolia*				-
85-95	1	1	1		*Vaccinum membranacium*				7.55
95+		1							

Alnus/Elymus habitat type

dbh	No. trees in plot	
	M-4	6-2
Populus tremuloides		
0-5	50	32
25-35		1
35-45	1	
45-55	1	
Pinus contorta		
20-25		1
25-35		2
35-45	1	1
Populus trichocarpa		
45-55		1
65-75	1	

dbh	No. trees in plot	
	M-4	6-2
Pinus ponderosa		
0-5	3	
Abies concolor		
0-5	16	5
5-10	6	3
10-15	9	2
15-20	3	4
20-25		1
25-35	1	

Species	% Cover	
	6-2	M-4
Osmorhiza chilensis	0.60	2.65
Galium triflorum	13.00	4.30
Ribes lacustre	6.10	4.40
Clintonia uniflora	0.40	3.95
Rosa gymnocarpa		0.60
Pteridium aquilinum	+	
Elymus glaucus	39.90	24.70
Alnus incana	22.95	20.35
Spiraea douglasii	22.90	6.30
Soldago canadensis	3.45	4.10
Aster modestus	5.35	0.30
Lupinus latifolius	10.80	12.80
Amelanchier alnifolia	0.35	2.25
Anaphalis margaritacea	4.15	
Viola glabella	1.25	1.75
Pyrola assarifolia	0.10	2.50
Carex microptera	18.45	0.60
Senecio triangularis	2.60	
Geum macrophyllum	4.10	
Veronica spp.	4.90	
Epilobium glandulosum	1.70	0.05
Calamogrostis canadensis	1.65	+
Mimulus guttatus	0.35	
Poleminum occidentale	1.25	
Glycera elata	6.40	
Equisetum arvense	1.35	3.40
Juncus ensifolius	0.10	0.30
Prunella vulgaris	0.10	0.05
Aster occidentalis	0.90	
Taraxacum officinale	0.30	-
Agrostis scabra	+	
Stachys rigida	+	

Species	% Cover	
	6-2	M-4
Sorbus sitchensis		0.30
Aulacomnium androgynum + Pohlia nutans	0.80	0.35
Lonicera conjugialis		0.35
Bromus spp.	9.20	23.00
Hieracium spp.	0.40	
Symphoricarpos mollis	0.05	0.30
Fragaria virginiana	5.40	2.75
Epilobium angustifolium	0.50	0.05
Salix spp.	2.15	0.35
Polytrichum juniperinum		+
Chimaphila umbellata		-
Pyrola secunda		0.45
Smilacina spp.	2.50	6.90
Adenocaulon bicolor	0.75	20.60

APPENDIX C

SPECIFIC CRITERIA USED IN THE FIELD TO DISTINGUISH COMMUNITIES IN FOUR *ABIES* HABITAT TYPES

A. Ratio of *A. concolor* reproduction to *A. magnifica* var. *shastensis* reproduction greater than 1.

1. More than a single individual of mesic species (*Smilacina* spp., *Adenocaulon bicolor*, *Osmorhiza chilensis*, *Galium triflorum*, *Ribes lacustre*, *Clintonia uniflora*, *Rosa gymnocarpa*, *Rubus parviflorus*, *Pteridium aquilinum*, *Elymus glaucus*, and *Bromus vulgaris*) visible in 100 m^2.

---*ABIES CONCOLOR*/MESIC SPECIES HABITAT TYPE

a. On steep slope, *Castinopsis sempervirens* common, *Pseudotsuga* important in overstory

---Mesic Species community

b. On gentle slope, *Castinopsis* rare, *Pseudotsuga* absent to occasional

---*Castinopsis* community

2. Less than two individuals of mesic species, present within 100 m^2.

a. *Symphoricarpos mollis* abundant; *Chimaphila umbellata* may be present, but usually not dominant. At least two of the following present: *Melica aristata*, *Hieracium* spp., *Senecio integerrimus*, *Lupinus albicaulis*, *Castilleja applegatei*, *Gilia aggregata*, *Poa nervosa*, *Bromus carinatus*, *Amelanchier alnifolia*, *Stipa occidentalis californica*, or *Festuca idahoensis* within 100 m^2. *Pinus contorta* usually absent. On alluvial soil.

---*ABIES CONCOLOR*/*SYMPHORICARPOS MOLLIS* HABITAT TYPE

(1) *Chimaphila umbellata* sometimes abundant, *Melica aristata* and *Hieracium albiflorum* principal characteristic species, forest nearly mature (unlogged).

---*Melica* community

(2) *Chimaphila umbellata* rare. Other species are principal characteristic species. Forest immature (logged).

- (a) *Populus tremuloides* unusual and much *Ceanothus velutinus* present
  ---*Senecio* community
- (b) Much *P. tremuloides* and *Ribes cereum* present, little *Ceanothus velutinus*
  ---*Populus* community

b. *Symphoricarpos mollis* unusual, never abundant. *Chimaphila umbellata* usually present, 0 to 1 of species listed in a. present. On pumice soil.
---*ABIES CONCOLOR*/*CHIMAPHILA UMBELLATA* HABITAT TYPE

(1) Area has been logged (no very large pine present, relatively few trees in 0-5 cm dbh class, stumps present).

- (a) *Pinus ponderosa* is the dominant tree
  ---logged *Pinus ponderosa* community
- (b) *Pinus contorta* is the dominant tree
  ---logged *Pinus contorta* community

(2) Area has not been logged.

(a) *Ceanothus velutinus* is a dominant in the understory.

- (1) *Carex pensylvanica* is not abundant
  ---*Ceanothus* community
- (2) *Carex pensylvanica* is abundant under the *Ceanothus velutinus*.
  ---*Ceanothus*/*Carex* community

(b) *Ceanothus velutinus* is not a dominant in the understory.

- (1) *Pyrola secunda* not present. *Abies magnifica shastensis* not usually present, very little *Carex pensylvanica* present.
  ---*Chimaphila* community

(2) *Pyrola secunda* usually present, *Abies magnifica shastensis* present, amount of *Carex pensylvanica* varies.

-1- Only species present in understory are *Chimaphila* spp., *Pyrola* spp., *Carex pensylvanica*, and *Arctostaphylos nevadensis*, and these species have very low coverage.
---*Chimaphila*-*Pyrola* community

-2- Species other than those above present or they have higher coverage.
---*Carex* community

B. Ratio of Abies concolor reproduction of *A. magnifica shastensis* reproduction less than 1.

---*ABIES MAGNIFICA SHASTENSIS*/*CHIMAPHILA UMBELLATA* HABITAT TYPE

1. Either no *Pinus ponderosa* present or understory lacks *Carex pensylvanica* and *Arctostaphylos nevadensis*.
---*Abies magnifica* var. *shastensis*/*Chimaphila umbellata* community

2. *Pinus ponderosa* and *Carex pensylvanica* or *Arctostaphylos nevadensis* present.
---*A. magnifica* var. *shastensis*-*P. ponderosa* community

APPENDIX D

FIRE SEAR DATA

These tables show the probable actual dates of sear formation, an estimate of the accuracy of the count to the sear, and the number of years by which the actual count appears to be wrong. Sears are indicated by a letter between b and i, or z, followed by a number. If the letter and number are enclosed in parentheses, the sear was very indistinct, and may not have actually been a sear.

The reliability of the count was judged by the distinctness of the rings, how well a sear could be associated with a given ring, and any other indication of factors that might make the count wrong. The letter b indicates that the count appeared to be wrong by ± 2 years or less, d indicates ± 6 years or less, and so on. The letter z indicates that the cambium may have been killed further back around the tree than the fire scar sample went, so there may have been several rings missing between that sear and the next one. If the letter alone is in parentheses, it indicates how accurate the count from the sear with the z is, rather than how accurate the count from the present location of the cambium is.

Adding the number in the table to the probable actual date of the fire gives the date that I counted on the fire scar sample. For instance, the sea that formed in 1879 on tree 7A was counted on the sample as 1878 ± 4 years.

Growth rate decreases are recorded as GR and the number of years the count appears to be wrong by. These are not all growth rate decreases. They are only those that coincided with years that fires burned.

The designation of the trees shows where they are located in Fig. 4.

Appendix D. Panhandle.

	1945	1940	1932	1920	1914	1902	1897	1892	1883	1879	1870	1864	1855	1849	1846	1841	1829	1826	1818	1812	1804	1800
3A						b0		b0	b0		b0	b0				b0				b0		
9A								b0		b0		b0			b0	b0			b0			
3B						b0		b+1				b0				b+1			c+1	c+1		
6B								b-2		b-2		b-2				b-2						
4B								b+15		b+15						b+15				b+15		
8A							b0	b0				b0			(c+1)					c0		
7B						b0				b0						c+1						
8B		(b0)		c0	c0	b0		b0		b+1		c+1				c+2		d+2		c+3		
4A										b+3					c+1					d+2		
2B						b+1			b+2			c+2		d+2		(d+2)				d+2		
7A						b-1		b-1		c-1		c-1			c-1	d-2			d0	d-1		
6A								b0		d+2		c0			GR+1	c0		GR0		c0		
7C								b+1		c0		c+2			(c+2)	c+1			c+1			
5A								c+3		d+4		d+3				d+3			d+3	d+3		
5B								z+3		z+6		(b)+6			GR+7	(b)+6		GR+9		(d)+9		
2A									d+6			d+6				d+5				e+5		
9B	(b0)		(b0)			c0		c0		c+2	c+2	c+3	c+3		(d+3)	d+3		d+3	d+3	d+3		
1B				b0					b+2			b+2			c+3	c+2	c+2		GR+2	c+2		c+2
1A				GR0	(c0)	(c+2)		c0	c-2		c0	c0			(c+2)				d+3	d+1	(d+1)	

	1797	1791	1784	1782	1776	1773	1769	1759	1755	1748	1745	1738	1729	1718	1708	1705	1701	1693	1686	1671	Uncorrected dates
3A			b0				b0														
9A				c0				c0		c0			c0				c-1		d0	d0	d1659, e1623, d1601
3B			d+1				e0	f-2			f-1										
6B	c-2		c-2				c-2			c-1			c-1	c0		d-1		c-1			
9B	b+14						b+14		c+14			c+13	c+15			c+15		c+15		c+15	c 1669
8A						d0				d0			d0					d0		e0	e1646, e1639, f1625, f1584, f1557
7B			c0										d+1				c+1	(d+1)		c+1	c1659, c1640, z1584
8B		c+3			c+3			c+3		GR+3		GR+3							c+3		
4A	d+3								e+4				f+3	f+2	f+1						g1658, g1632, 61612, g1606
2B	e+1				z+2		(b)+2		(c)+1		(c)+1		(c)+3	z+1				(c)+1	(b)+1		
7A	d-1	d-1		d-2				d-1			d0	(d+1)	d-1	(d-1)							
6A	GR+1		z0				(b)0			z0											
7C		c+2						d0		d0			d0								
5A	d+3				d+4		d+3	d+3													
5B	(d)+9		(d)+9																		
2A	e+6						e+6		e+5		e+5	f+3	f+1								
9B				d+4			GR+3			d+3							e+3	f+3		f+4	f1662, GR1649
1B							d+2	d+1			d+1	d+1				(f0)					
1A	d+1			e+1	GR0		e+1		f+1			g0									

Appendix D. Northeast Part.

	1927	1889	1883	1877	1859	1831	1815	1812	1804	1798	1788	1783	1775	1771	1759	1751	1737	1729	1720	**Uncorrected dates**
24A		d+4	e+4	f+5	h+5	h+4	(h+4)		(h+5)		z+5	—	—	—	—	—	—	—	—	
23B				b0	b-1	c-1				c-1						c0	—	—	—	
23A				b0	b0	c0					c0				c+1	GR+1	(d+1)	(e+1)		**c1714, d1694**
22B		b0		b0		b0		b0		b0					c0	c0	c0	c0	c0	**c1705, c1686, z1660**
22A		c+3		c+2		c+2		c+3		c+2	—	—	—	—	—	—	—	—	—	
21B	b0			c+2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
21A		b0		c+1	GR-1	(e-1)	c0			c0	c0	c0	c0	c0	c0	c0	(d-1)	—	—	
20B		c+4		c+4	c+5					c+4			(b+5)			d+4			d+6	**(e1690)**
20A		c+2		c+2						c+2					c+2		d+2	—	—	**GR1687**

Appendix D. Northwest Part.

	1929	1924	1902	1897	1884	1879	1864	1846	1841	1826	1818	1804	1800
10B			f+7			h+7					i+9		
10A			b+1			b+1	b+1				b+2		
11B			b-1				b0	b0	—	—	—	—	—
11A			b0		b0			b0			c0	—	—
14A							GR+2		c0		c+2		
14B	b0	.		b0			b+1	b0	b+1		b+1		
12A			b+1			c+1	c+1	d+3		d+2		d+3	
12B			b+1			b+1	b+1	b0			b0	b0	
13A			b+1			b+1	b+1	b+1			b+1	b+1	
13B						d+3		d+3			d+3	GR+3	
15A			b+1				c+1	d+2			d+2		
15B			b0				b0	b0	—	—	—	—	—
18A								c+9			c+9		
18B								z+4			(b)+5	((b)+4)	—
19A							b+2	b+2			c+2		
19B		b0				d+2	GR0	c0			e0		f0
17A								c+4			c+4		
17B								b+1		b+1	b+1		
16A								d+4			d+5		
16B								c+1			c+1	—	—

	1791	1788	1786	1783	1779	1775	1770	1762	1759	1748	Uncorrected dates
10B										i+10	
10A				b+2	—	—	—	—	—	—	
11B	—	—	—	—	—	—	—	—	—	—	
11A	—	—	—	—	—	—	—	—	—	—	
14A	c+2					c+2			d0		d1745, d1729
14B	c+1	c+1			c+1	z+1			(b)+1		z1749
12A	d+3			e+3			e+3		e+3	e+3	(e1741), e1729, e1703, e1689, f1664
12B	b0						c0		c0	—	
13A	b+1	—	—	—	—	—	—	—	—	—	
13B	d+3			d+3			d+3		e+3		d1749
15A	d+2			z+2				(b)+2	—	—	
15B	—	—	—	—	—	—	—	—	—	—	
18A			(c+9)							c+9	c1702, c1665
18B	—	—	—	—	—	—	—	—	—	—	
19A						c+3	—	—	—	—	
19B	h0					h0				h0	h1717
17A				c+4					c+4	d+4	
17B				b+1			b+1		b+1	—	
16A				d+4	—	—	—	—	—	—	
16B	—	—	—	—	—	—	—	—	—	—	

APPENDIX E

SPECIES OF PLANTS IN PONDEROSA STUDY AREA, CRATER LAKE NATIONAL PARK

Marchantiaceae
- *Marchantia polymorpha* L.

Mnionopsida
- *Amblystegium serpens* (Hedw.) B. S. G.
- *Aulacomnium androgynum* (Hedw.) Schwaegr.
- *Brachythecium* (?) *frigidum* (C. Mull.) Fleisch.
- *Brachythecium leibergii* Srout
- *Grimmia* sp.
- *Mnium regicum*
- *Pohlia nutans* (Hedw.) Lindb.
- *Polytrichum juniperinum* Hedw.
- *Roellia roellii*

Equisetaceae
- *Equisetum arvense* L.
- *Equisetum hyemale* L.

Polypodiaceae
- *Athyrium filix-femina* (L.) Roth
- *Polystichum munitum* (Kaulf.) Presl var. *imbricans* (D.C. Eat.) Maxon
- *Polystichum munitum* (Kaulf.) Presl var. *munitum*
- *Pteridium aquilinum* (L.) Kuhn

Pinaceae
- *Abies grandis* (Dougl.) Lindl. x *concolor* (Gord. & Glend.) Lindl.
- *Abies lasiocarpa* (Hook.) Nutt.
- *Abies magnifica* Murr. var. *shastensis* Lemm.
- *Picea engelmannii* Parry
- *Pinus contorta* Dougl. var. *latifolia* Engelm.
- *Pinus lambertiana* Dougl.
- *Pinus monticola* Dougl.
- *Pinus ponderosa* Dougl.
- *Pseudotsuga menziesii* (Mirbel) Franco
- *Tsuga mertensiana* (Bong.) Carr.

Cupressaceae
Calocedrus decurrens (Torr.) Florin.

Juncaceae
Juncus effusus L.
Juncus ensifolius Wikst.
Juncus mertensianus Bong.
Juncus orthophyllus Cov.
Luzula divaricata Wats.

Cyperaceae
Carex aquatilis Wahl.
Carex brainerdii Mack
Carex canescens Bailey
Carex disperma Dewey
Carex laeviculmis Meinsh.
Carex lenticularis Michx.
Carex microptera Mackenzie
Carex pensylvanica Lam.
Carex subfusca W. Boott
Scirpus microcarpus Presl.

Graminae
Agrostis exarta Trin. ssp. *minor* (Hook) C. L. Hitchc.
Agrostis scabra Wild.
Agrostis thurberiana Hitchc.
Bromus carinatus Hook. & Arn.
Bromus orcuttianus Vasey
Bromus vulgaris (Hook.) Shear var. *vulgaris*
Calamogrostis canadensis (Michx.) Beauv.
Cinna latifolia (Treviv.) Griseb.
Elymus glaucus Buckl.
Festuca idahoensis Elmer. var. *idahoensis*
Glyceria elata (Nash) M. E. Jones
Melica aristata Thurb.
Melica subulata (Griseb.) Scribn.
Muhlenbergia sp.
Phleum alpinum L.
Poa nervosa (Hook.) Vasey var. *wheeleri* (Vasey) C. L. Hitchc.
Poa pratensis L.
Sitanion hystrix (Nutt.) J. G. Smith
Stipa occidentalis Thurb. var. *occidentalis*
Stipa occidentalis Thurb. var. *californica* (Merr. & Davy)
C. L. Hitchc.

Liliaceae
Clintonia uniflora (Schult.) Kunth.
Frittilaria atropupurea Nutt.
Smilacina racemosa (L.) Desf.
Smilacina stellata (L.) Desf.
Veratrum sp.

Orchidaceae
Corallorhiza maculata Raf.
Corallorhiza mertensiana Bong.
Goodyera oblongifolia Raf.
Habenaria dilatata (Pursh.) Hook. var. *leucostachys* (Lindl.) Ames
Habernaria unalascensis (Spreng.) Wats.
Listera caurina Piper.

Salicaceae
Populus angustifolia James
Populus tremuloides Michx.
Populus trichocarpa T. & G.
Salix lasiandra Benth.
Salix scouleriana Barratt
Salix sitchensis Sanson (?)

Betulaceae
Alnus incana (L.) Moench
Corylus cornuta Marsh. var. *californica* (DC) Sharp

Fagaceae
Castanopsis sempervirens (Kell.) Dudl.

Loranthaceae
Arceuthobium americanum Nutt.

Polygonaceae
Eriogonum umbellatum Torr.
Rumex acetosella L.
Polygonum bistortoide Pursh

Portulacaceae
Montia sibirica (L.) How.
Spraguea umbellata Torr.

Caryophyllaceae
Sagina occidentalis Watts.

Stellaria crispa Cham. & Schlecht.
Stellaria obtusa Engelm.

Ranunculaceae
Aconitum columbianum Nutt.
Anemone sp.
Aquilegia formosa Fisch.
Delphinium depauperatum Nutt.
Ranunculus gormanii Greene
Thalictrum sparsiflorum Turcz.

Fumaricaeae
Dicentra formosa (Andr.) Walpers

Cruciferae
Arabis holboellii Hornem.
Descurainia richardsonii (Sweet) Schulz

Saxifragaceae
Lithophragma tenella Nutt.
Mitella caulescens Nutt.

Grossulariaceae
Ribes binominatum Hel.
Ribes cereum Dougl.
Ribes lacustre (Pers.) Poir.
Ribes viscosissimum Pursh.

Rosaceae
Amelanchier alnifolia Nutt.
Fragaria virginiana Ducheshe var. *platypetala* (Rydb.) Hall
Geum macrophyllum Willd. var. *macrophyllum*
Holodiscus discolor (Pursh) Maxim.
Prunus emarginata (Dougl.) Walpers var. *emarginata*
Purshia tridentata (Pursh) DC.
Rosa gymnocarpa Nutt.
Rubus leucodermis Dougl.
Rubus parviflorus Nutt.
Rubus ursinus Cham. & Schlecht.
Sorbus sitchensis Roemer var. *sitchensis*
Spiraea douglasii Hook.

Leguminosae
Lupinus albicaulis Dougl.
Lupinus latifolius Agardh.

Lupinus lepidus Dougl. var. *lobbii* (Gray) C. L. Hitch.
Trifolium sp.
Vicia americana Muhl. var. *truncata* (Nutt.) Brew.

Celastraceae
Pachistima myrsinites (Pursh) Raf.

Aceraceae
Acer glabrum Torr. var. *douglasii* (Hook) Dippel

Rhamnaceae
Ceanothus prostratus Benth.
Ceanothus velutinus Dougl.

Hypericaceae
Hypericum anagalloides C. & J.

Violaceae
Viola glabella Nutt.
Viola nuttallii Pursh var. *bakeri* (Greene) Hitchc.

Onagraceae
Circaea alpina L.
Epilobium angustifolium L.
Epilobium glaberrimum Barbey var. *glaberrimum*
Epilobium glandulosum Lehm.
Gayophytum nuttallii T. & G.

Umbelliferae
Heracleum lantum Michx.
Lomatium triternatum (Pursh) Coult. & Rose
Osmorhiza chilensis H. & A.

Ericaceae
Allotropa virgata T. & G.
Arctostaphylos nevadensis Gray
Arctostaphylos patula Greene
Chimaphila menziesii (R. Br.) Spreng.
Chimaphila umbellata (L.) Bart.
Hypopitys monotropa Crantz
Pterospora andromedea Nutt.
Pyrola aphylla Smith
Pyrola asarifolia Michx.
Pyrola dentata Smith
Pyrola minor L.
Pyrola picta Smith

Pyrola secunda L. var. *secunda*
Vaccinium membranaceum Dougl.
Vaccinium scoparium Leiberg

Apocynaceae
Apocynum androsaemifolium L.

Polemoniaceae
Collomia grandiflora Dougl.
Collomia linearis Nutt.
Collomia tinctoria Kell.
Gilia aggregata (Pursh) Spreng. var. *aggregata*
Phlox caespitosa Nutt.
Polemonium occidentale Greene

Hydrophyllaceae
Phacelia heterophylla Pursh.

Boraginaceae
Cryptantha affinis (Gray) Greene
Cynoglossum occidentale Gray
Hackelia jessicae (McGregor) Brand

Labiatae
Prunella vulgaris L.
Stachys rigida Nutt.

Scrophylariaceae
Castilleja applegatei Fern.
Castilleja minata Dougl.
Mimulus guttatus DC.
Mimulus lewisii Pursh
Mimulus moschatus Dougl.
Scrophularia lanceolata Pursh
Veronica americana Schwein.
Veronica serpyllifolia L.

Rubiaceae
Galium triflorum Michx.
Kelloggia galioides Torr.

Caprifoliaceae
Linneae borealis L. ssp. *longiflora* (Torr.)
Lonicera conjugialis Kell.
Sambucus racemosa L.
Symphoricarpos mollis Nutt.

Compositae

- *Achillea millefolium* L. subsp. *lanulosa* (Nutt.) Piper
- *Adenocaulon bicolor* Hook.
- *Agoseris aurantiaca* (Hook.) Greene
- (?) *Agoseris* sp.
- *Anaphalis margaritacea* (L.) B. & H.
- *Antennaria rosea* Greene
- *Arnica cordifolia* Hook var. *cordifolia*
- *Aster canescens* Pursh.
- *Aster modestus* Lindl.
- *Aster occidentalis* (Nutt.) T. & G. var. *occidentalis*
- *Cirsium vulgare* (Savi) Airy-Shaw
- *Erigeron* (?) *corymbosis* Nutt.
- *Eriophyllum lanatum* (Pursh) Forbes var. *achillaeoides* (DC.) Jeps.
- *Graphalium palustre* Nutt.
- *Haplopappus bloomeri* Gray
- *Hieracium albiflorum* Hook.
- *Hieracium cynoglossoides* Arv.-Tour.
- *Madia minima* (Gray) Keck
- *Microseris nutans* (Geyer) Schultz-Bip.
- *Senecio integerrimus* Nutt.
- *Senecio triangularis* Hook.
- *Solidago canadensis* L. var. *salebrosa* (Piper) Jones
- *Stephanomeria lactucina* Gray
- *Taraxacum officinale* Weber