United States
Department
of Agriculture

Forest Service

Intermountain
Research Station

Research Paper
INT-RP-481

April 1995

Age-Class Structure of Old Growth Ponderosa Pine/Douglas-Fir Stands and Its Relationship to Fire History

Stephen F. Arno
Joe H. Scott
Michael G. Hartwell

The Authors

Stephen F. Arno is a research forester in the Prescribed Fire and Fire Effects research work unit at the Intermountain Fire Sciences Laboratory in Missoula, MT. He received a B.S. degree in forestry from Washington State University and M.S. and Ph.D. degrees from the University of Montana. He has studied various aspects of forest ecology since 1963, including ecological site classifications, forest succession, fire history, fire effects, and the development of strategies for prescribed fire.

Joe H. Scott is a consultant forester specializing in treatments for stands in the suburban wildland interface. He helped develop and implement this study as a forestry technician for the Prescribed Fire and Fire Effects research work unit at the Intermountain Fire Sciences Laboratory in Missoula, MT. He received a B.S. degree in forest and resource management from the University of California at Berkeley, and is a graduate student in forestry at the University of Montana.

Michael G. Hartwell is a forestry technician for the Prescribed Fire and Fire Effects research work unit at the Intermountain Fire Sciences Laboratory in Missoula, MT. He received a B.S. degree in natural resource sciences from Washington State University and is a graduate student at the University of Montana studying present and past forest structures at the landscape scale.

Research Summary

Trees on nine 100 by 100 m plots in old growth ponderosa pine/Douglas-fir stands in western Montana were aged and mapped. Fire history since the early 1600's was determined for each plot from fire scar cross-sections. Six of seven sample plots on the Bitterroot and Lolo National Forests had a nearly all-aged structure among the overstory ponderosa pine; trees commonly ranged up to 500 years of age. These plots were on steep slopes, and prior to 1900 had experienced nonlethal underburns at mean intervals of 13 to 50 years.

Plots on the Flathead National Forest were on gentle topography in a moist glacial valley. They had even-aged structures supporting primarily ponderosa pine and western larch. Pre-1900 fire history was characterized by patchy stand-replacing events (fire and perhaps bark beetle epidemics) at intervals of 150 to 400 or more years with intervening underburns at mean intervals of 20 to 30 years.

All stands had developed an understory of Douglas-fir in recent decades. Only the two plots that experienced natural fires in this century (1919 and 1953) had a major proportion of vigorous, young ponderosa pine. Our data suggest that understory fires were influential in maintaining ponderosa pine dominance in a variety of stand age structures. We conclude that, in many stands, the effects of fire exclusion during this century preclude use of fire alone to recreate historic structures.

About the cover: Old growth seral ponderosa pine stand on a Douglas-fir habitat type (dry site) at Lick Creek, Bitterroot National Forest, southwest of Hamilton, MT. Scene is in 1909 immediately before partial cutting. Gruell and others found an average fire interval of 7 years between 1600 and 1900, and the last fire was about 1895. U.S. Forest Service photo by W. J. Lubken.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

Age-Class Structure of Old Growth Ponderosa Pine/ Douglas-Fir Stands and Its Relationship to Fire History

Stephen F. Arno
Joe H. Scott
Michael G. Hartwell

Introduction

A century ago the ponderosa pine (*Pinus ponderosa*) type covered about 40 million acres in the Western United States (Van Hooser and Keegan 1988). This species continues to dominate (in denser, younger stands) the driest regions, where it represents the potential climax type (Pfister and others 1977; Wellner 1989). In the less-droughty half of its distribution, however, ponderosa pine formed a seral, fire-maintained cover type, and is often being replaced successionally by other species (Arno 1988). Prior to 1900 in both the climax and seral pine types frequent surface fires, termed underburns, kept most stands in an open park-like condition dominated by large old trees (Cooper 1960; Leiberg 1899; Wickman 1992). In the areas where ponderosa pine is seral, underburns prevented more shade-tolerant competitors—interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), grand fir (*Abies grandis*), and white fir (*A. concolor*)—from developing an understory and eventually replacing the shade-intolerant, but fire-resistant pine (Arno 1988; Weaver 1967).

Underburns have been excluded for 60 to 90 years in most of the seral ponderosa pine forests. As a result, accumulations of surface fuels and conifer thickets have developed that allow stand-replacing wildfires to become common (Arno and Brown 1991; Barrett 1988; Mutch and others 1993). Past selective cutting has removed much of the pine and encouraged development of dense fir thickets. The loss of the seral old growth ponderosa pine type is of great concern for wildlife habitat and maintenance of biodiversity on National Forest lands (Everett 1994). Present-day stands are experiencing extensive mortality from insect and disease epidemics (Wickman 1992). These threats, coupled with a growing appreciation of the importance of natural ecological processes, have spurred interest in strategies to perpetuate seral ponderosa pine forests (Fiedler and others 1992; Mutch and others 1993). Developing such strategies will require knowledge of how ponderosa pine and its companion species regenerated in association with past fires.

Detailed fire history can be determined from analysis of fire scars on trees (Arno and Sneck 1977; McBride 1983), but accurate age-class data from old growth stands have been difficult to obtain. We recently adapted a power increment borer to efficiently sample large trees (Scott and Arno 1992) and determine age structures in old growth stands. Our objectives in this study were to investigate the influence of past fires on stand age structure on both dry and moist site-types and identify changes in stand structure that are associated with fire exclusion.

Study Sites and Fire History

Old growth ponderosa pine was abundant in the accessible lower-elevation valleys and mountain slopes in western Montana and has been logged heavily for more than 100 years. Because of this, it was not possible to locate large unlogged stands and select sample areas using criteria that would ensure representativeness. Less than 1 percent of the old growth seral ponderosa pine type has no history of logging. Much of this remnant unlogged area is confined to precipitous, broken terrain that is difficult to sample. Nevertheless, it seemed that useful information and interpretations on the relationship of fire history to stand structure could be derived from these remnant stands. Therefore, we consulted National Forest silviculturists and inspected stand maps to identify unlogged stands on relatively uniform topography. Eventually we were able to locate and sample remnant stands on both dry and moist sites that were large enough to contain a 100-m square (~2.5 acre) sample plot.

Fire histories were determined for each plot from analysis of partial cross sections from the two to four trees in and immediately adjacent to the plot that had the most complete and least damaged sequences of multiple fire scars (Arno and Sneck 1977). A master fire chronology starting in the early 1600's (except plot F-2) was developed for each plot by correlating dates obtained from individual trees.

The six dry site stands occurred at relatively high elevations on moderately steep (45 to 55 percent) south-facing slopes on the Bitterroot and Lolo National Forests (fig. 1). These represent the *Pinus ponderosa* phase of the *Pseudotsuga menziesii/Calamagrostis rubescens* habitat type (h.t.) (Pfister and others 1977), a common dry site-type for seral ponderosa pine.

The three Bitterroot National Forest plots are located within about 0.3 mile of each other on a broad slope directly north of Fales Flat Campground, southwest of Darby, MT, (fig. 1). This site lies at 5,400 to 5,900 ft elevation and is near the climatic (cold) limits of the ponderosa pine type, where pine/Douglas-fir gives way above to pure Douglas-fir. We located the plots within the large patches where ponderosa pine was a major component of the overstory. Analysis of multiple fire scar sequences (Arno and Sneck 1977)

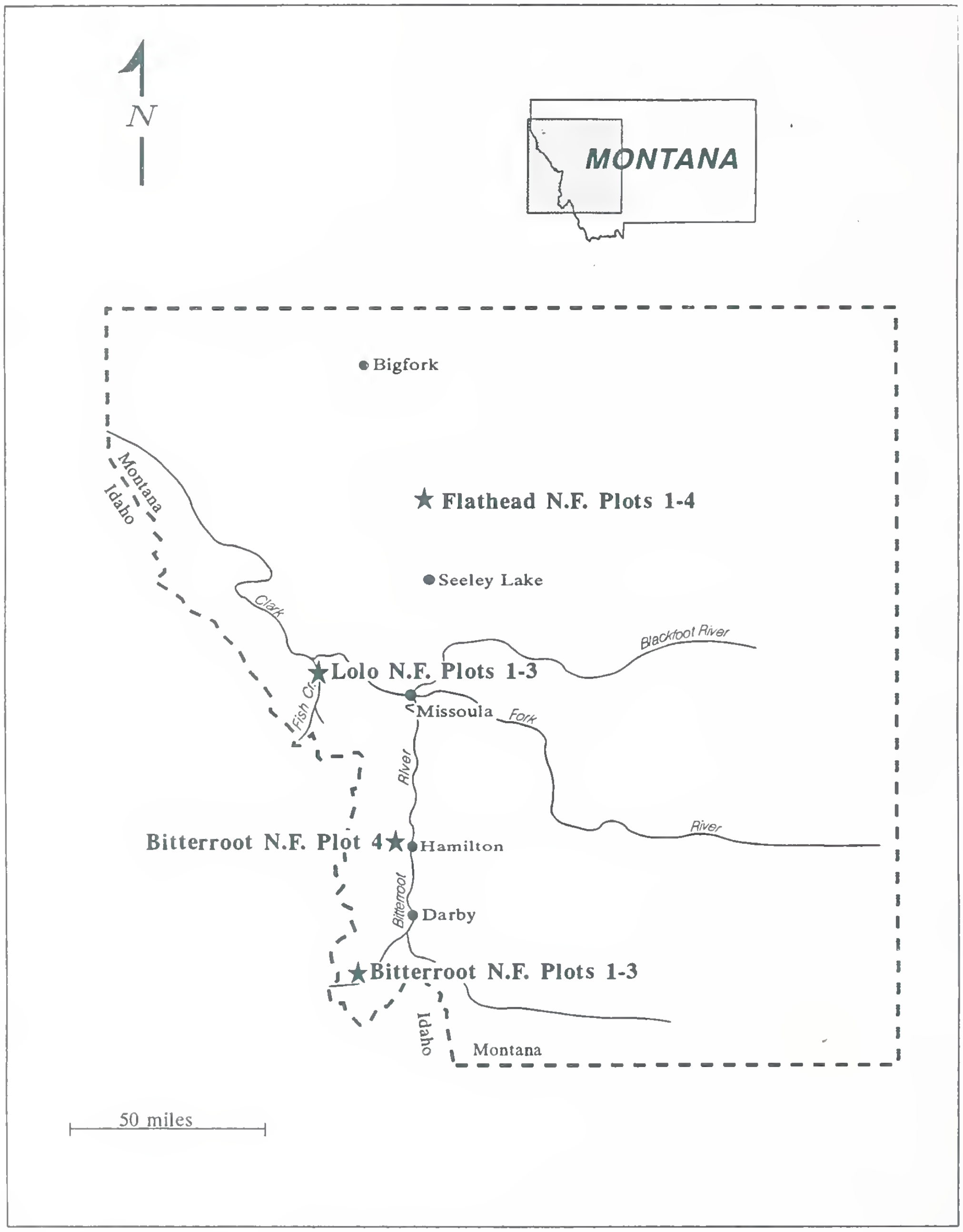


Figure 1—General location of the old growth ponderosa pine/fir study plots.

revealed that fires had occurred in each of these Bitterroot plots at average intervals of about 50 years over a 300-year period ending with the 1889 fire (fig. 2). Fire history literature and ecological process modeling of seral ponderosa pine (Keane and others 1990) suggested that a 50-year average fire interval is near the maximum that would allow perpetuation of pine as a major stand component, when in competition with Douglas-fir.

The three Lolo National Forest plots are located at about 5,000 ft elevation on south-facing slopes, within the broad forest zone dominated by seral ponderosa pine (fig. 1). We established one plot (L-3) at the head of Whitehorse Gulch in the Fish Creek drainage west of Missoula and two other plots on a comparable south slope above Sawmill Creek, 8 miles to the east. One of the Sawmill plots (L-1) had burned in a 1953 lightning-caused underburn, still identifiable by charred bark extending several feet up on many of the trees. The other plot (L-2) did not burn because it was just across the fire control line. Plot L-1 was unusual in having had surface fires nearly

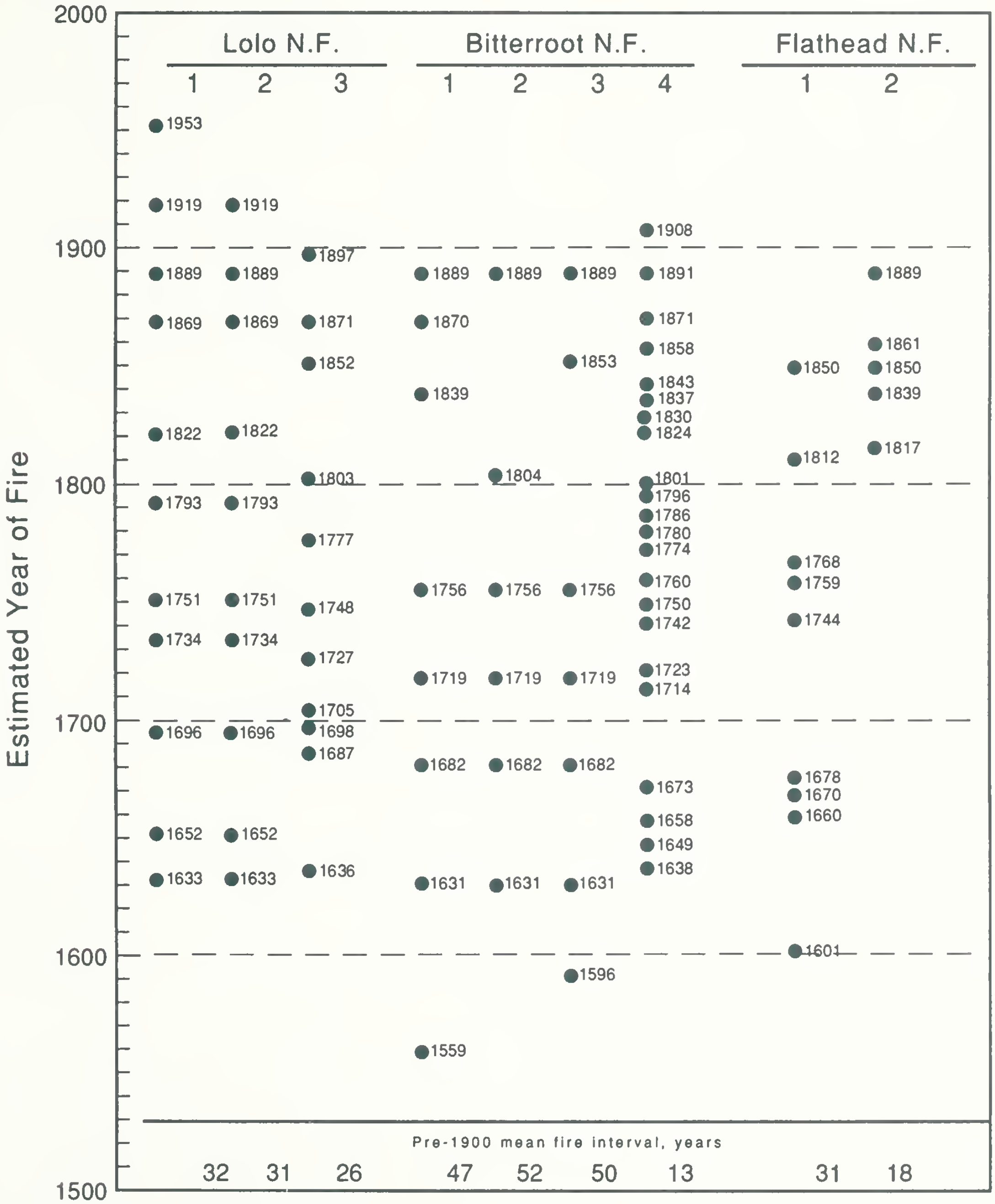


Figure 2—Fire history from each detailed plot based on fire scar cross-sections.

to the present (latest fires in 1889, 1919, and 1953). Plot L-2 had experienced the same fire history through 1919. In contrast, the Whitehorse site (L-3) had its last fire in 1897. Average pre-1900 fire intervals were 26 years at Whitehorse and 31 years at Sawmill (fig. 2).

Abies grandis/Linnaea borealis is the common moist habitat type that supports old growth ponderosa pine stands on the Bitterroot and Lolo National Forests. However, most stands are unsuitable for age-class reconstruction because of past logging, heavy insect and disease mortality, small size, or irregular shape. After considerable searching we located and sampled one stand (B-4) at the 5,000-ft level on an east-facing slope near Canyon Creek. This site lies immediately west of Hamilton (elevation 3,570 ft) in the Bitterroot Valley. Fire scar analysis indicated that pre-1900 fire intervals were relatively short, averaging only 13 years (fig. 2); this is probably due in part to a long history of Indian burning in the Bitterroot Valley (Barrett and Arno 1982).

Our other moist-site plots were located in the Swan Valley of northwestern Montana, on the Flathead National Forest. They are small remnants of a formerly extensive old growth ponderosa pine forest situated in a broad glaciated valley on gently undulating topography (<8 percent slopes), about 3,600 ft elevation. These stands occur in the *Pseudotsuga menziesii/Vaccinium caespitosum* h.t. This and the *Abies grandis/Linnaea borealis* h.t. represent the most productive sites that were dominated historically by seral communities of ponderosa pine (Pfister and others 1977). Western larch (*Larix occidentalis*) and lodgepole pine (*Pinus contorta* var. *latifolia*) were often seral associates of ponderosa pine. We placed detailed plots in the two largest intact stands and "supplementary plots" with less-intensive age and fire history data in two smaller stands. Each plot was 1 to 3 miles from its nearest neighbor. Fire scar analysis revealed average pre-1900 fire intervals of 25 to 31 years (fig. 2; Freedman and Habeck 1985). Plot F-2 had an 18-year average for its very brief period of record, 1817-1889.

Methods of Stand Reconstruction

We placed a 100-m (328-ft) square plot within each small sample stand in a location where topography was relatively uniform. This plot size seemed adequate to encompass age-group patterns found in other studies of stand structure (Bonnicksen and Stone 1981; Cooper 1960; Stephenson and others 1991; West 1969; White 1985). On each plot we recorded species and diameter at breast height (d.b.h.) for all trees that originated before 1900, referred to here as "overstory" trees. Relatively large understory trees that might possibly have originated before 1900 were also increment bored to ensure that all living pre-1900 trees were identified and sampled. The position of each overstory tree was recorded in Cartesian coordinates using 100-m (328-ft) tapes placed along the contour (X-axis) and down the fall line of the slope (Y-axis). On the relatively flat Flathead National Forest plots, the X- and Y-axes were oriented along compass bearings. Additional tapes were placed at 25-m intervals to divide the plot into 16 "cells." Tree positions were determined by sighting at right angles from the nearest tapes (representing the X and Y axes) to each tree using a double right-angle prism or a mirror-sighting hand compass.

The uneven microtopography in plot B-4 discouraged tree mapping with tapes, as described earlier. Instead, we mapped trees in B-4 with a survey laser instrument (Laser Technology, Inc. Criterion 400). Beginning at the lower left corner of the plot, we made a closed-loop traverse through eight sighting points within the plot. The distance and azimuth to each tree were recorded from one of these eight points, allowing computation of the Cartesian position of the tree within the plot.

We chose 1900 as a basis for characterizing historical stand conditions because studies in ponderosa pine/fir forests generally indicate a disruption in the historical pattern of frequent fires shortly after that time (Arno 1988). Results of such comparative analyses can be influenced by the year chosen to represent historic or presettlement conditions. The bias associated with using a single year to typify historic conditions is offset somewhat by sampling several stands with different disturbance histories, as we did. Also, records of fire history in ponderosa pine forests of western Montana show a consistent pattern of frequent fire from 1900 back to about 1500; beyond that threshold few living trees are available to sample (Arno 1976; Barrett and Arno 1982). Stand structure comparisons might be made for several different dates prior to 1900, but the quality of projected stand information declines for earlier dates because of decay and effects of past fires in consuming dead trees.

To recreate an approximation of the circa-1900 stand, diameters of living overstory trees were reduced by their post-1900 radial growth (x 2 = diameter), measured on increment borings. Also, overstory trees that apparently had died since 1900 were recorded by species, diameter, and position (X and Y coordinates). Standing dead trees were assumed to have died after 1900. Fallen trees whose boles were largely disintegrated were assumed to have died before 1900. We verified the approximate accuracy of some of these judgments by examining increment cores showing growth release dates on trees immediately adjacent to the dead trees. We also inspected the condition of trees in a similar stand that had been felled and left on the ground in the 1880's.

All "understory" trees (less than 90 years of age and greater than 4.5 ft tall) in each cell were inventoried by species in 2-inch diameter classes. A subsample of these understory trees by species and diameter class was aged using increment borings and cross sections at the ground line to determine what age classes were present. Isolated understory trees were mapped by X-Y coordinates. Groups of small understory trees were mapped by recording the coordinates of several points on the perimeter of the group.

Ages of overstory trees were determined from increment cores taken 12 inches above the ground line using a power borer and bits up to 28 inches long (Scott and Arno 1992). We bored trees repeatedly, if necessary, to obtain a core that intersected or passed very close to the pith. All overstory ponderosa pine were bored, and in all plots most (74 to 95 percent) were sound enough to obtain a good quality core. Many of the Douglas-fir and western larch had advanced heart rot and could not be aged; however, we were able to age a large sample of both species in all size classes. Plot B-4 contained four stumps of large ponderosa pine removed in early 1900's logging. Three were from trees >30 inches in diameter, a size-class represented by only five living trees in the plot. Since these were some of the oldest trees in the plot, we substituted for the >30-inch logged trees by collecting ages from the three nearest >30-inch pines outside the plot boundary. These three tree ages were added to the tabular stand age-class data, but not to plot tree-age maps.

Cores were mounted into grooved boards in the field using water-soluble glue, and each core was labeled on the board (Arno and Sneck 1977). The boring height above ground line and the direction of the core, in degrees clockwise from the uphill side, were recorded. Generally, only the best core from each tree was kept for analysis.

In the laboratory, we used an orbital sander to prepare the increment cores for measurement, first with fine (150 grit) and then with very fine (400 grit) paper. Annual rings were counted under a 7-30-power binocular microscope. Total tree age was estimated by adding two correction factors to the raw count. The first correction was the estimated number of years the tree took to reach boring height, based on regeneration data collected in past studies (Arno and others 1985; Fiedler 1984). The second correction was the estimated number of rings missed on an off-center core, computed as the product of the estimated distance from the innermost ring on the core to the pith and the growth rate near the innermost ring. For example, 0.8 inch x 5 rings per inch = 4 years (Ghent 1955). Boring large trees at 12 inches instead of the customary height of 4.5 ft, using long borers, and making repeated attempts to intersect the pith, rather than extrapolating from short or very off-center cores, improve estimates of total age. Obtaining exact total ages requires destructive sampling—felling each tree and sectioning the stump at ground line. To assess accuracy of ages determined from direct growth ring counts, increment core ring-width measurements were dendrochronologically cross-dated for the six plots measured during the first year of the study (Fiedler and Steele 1992). Cross-dating was conducted on 443 increment cores using procedures developed by Holmes (1983, 1992), which compare individual tree-ring series to a master tree-ring chronology (the mean series obtained by averaging all available increments for each year).

Historic Age Structure and Disturbances

Age Determination Accuracy

Results of the cross-dating procedure (Fiedler and Steele 1992) indicate that 67 percent of the innermost tree ring data determined from direct growth-ring counts would be within 2 years of the actual age and the majority of the remaining ring data would be within 3 to 10 years of the actual age. Considering the small errors associated with determining total age to the pith at ground line, we felt these estimates of total tree age were sufficiently accurate for characterizing stand age structure by 20-year intervals (table 1).

Dry Sites

Five of the six dry-site plots exhibited a nearly all-aged structure (table 1a; figs. 3a,b). The remaining plot (L-3) was dominated by a single broad age class with only a small representation of other ages. The data for plots L-1 and L-2 represent the nearly all-aged structure of ponderosa pine and Douglas-fir prior to 1900. Nevertheless, nearly adjacent plots (L-1 and 2; B-1, 2, and 3) with virtually identical fire histories varied substantially from each other in terms of which groups of ages were present or most abundant (table 1a). This suggests that despite similar climate (and probably seed crops) in adjacent stands on similar sites, spatial variation in tree establishment, fire-caused mortality, and other factors perpetuated a structural mosaic.

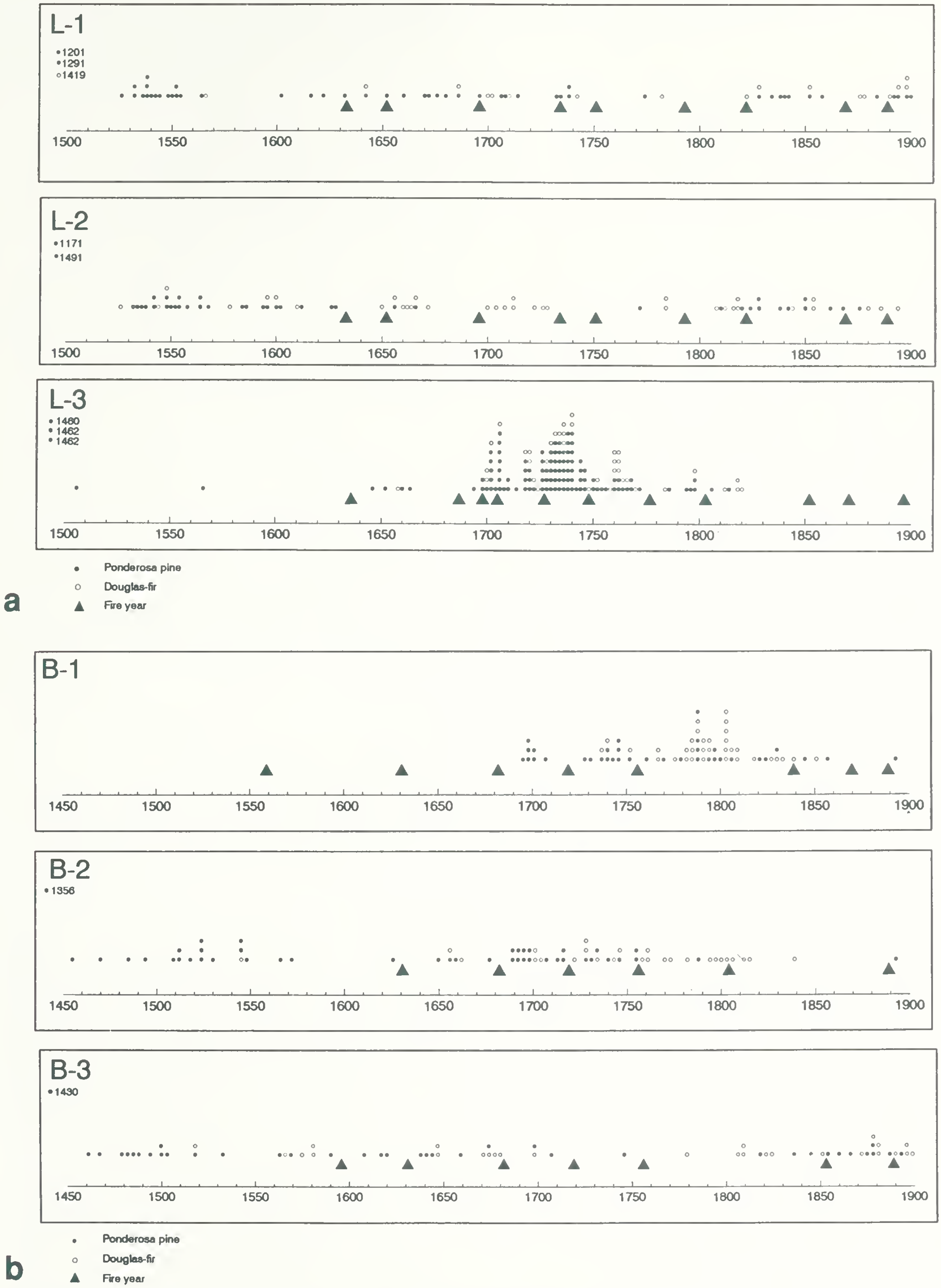
In the nearly all-aged stands, despite fires at the rate of two to four per century, ponderosa pine trees that eventually ascended into the overstory became established in 60 to 90 percent of the 20-year periods between 1500 and 1900 (table 1a). Unknown additional age classes presumably were killed by fires. The abundance of regeneration that developed into overstory trees, termed "successful establishment," varied through the decades, with an occasional major pulse, such as between about 1525 and 1550, in B-2, L-1, and L-2 (figs. 3a,b). Generally, however, pulses

Table 1a—Number of overstory trees by species that became established in each 20-year period for each dry site plot. Data are all trees from which total ages were obtained (see Methods). Four individual trees established before 1400 are listed by date. P = ponderosa pine; F = Douglas-fir.

Midpoint of	L-1		L-2		L-3		B-1		B-2		B-3	
20-year period	P	F	P	F	P	F	P	F	P	F	P	F
1890	5	4		2			1		1		2	5
1870		2	3	1							4	3
1850	3	1	3	3			2	1			3	1
1830	4	2	4				2	4		1	1	1
1810			2	5	2	4	2	12		4	1	4
1790		1		2	5	2	8	18	1	4		
1770	1		1		5	6	3	3		4		1
1750		1			15	6	5	1	4	3	1	
1730	4			3	45	11	5	2	3	4		
1710	3	2		4	24	5	3		4	1	1	
1690	2	2		1	4	2	4		8	2	1	2
1670	4		1	4	1				1	1	1	3
1650	3	1	1	3	3	1			3	1	3	2
1630	2		2						1		1	
1610	2		2	1							3	
1590			5	2							1	1
1570	1	1	3	1	1				2		2	3
1550	7		9	2					3	1		
1530	8		4	1					4		1	
1510					1				4		3	1
1490			1						2		5	
1470					2				1		3	
1450					1				1			
1430											1	
1410		1										
Establishment date of older regen.	1291								1356			
	1201											
			1171									

Table 1b—Number of overstory trees by species that became established in each 20-year period for each moist site plot. P = ponderosa pine; F = Douglas-fir; LP = lodgepole pine; WL = western larch; GF = grand fir.

Midpoint of	F-1				F-2				B-4			
20-year period	P	F	LP	WL	P	F	LP	WL	P	F	LP	GF
1890		3	9				1	1	1	7	2	
1870		1	1		4	1	16	1	1	2		
1850				1	6	1	20	4	10	5		1
1830				1	22	4	5	18	10	6	1	
1810					21	1		6	3	2		
1790									1			
1770	2	1		2	1							
1750	1											
1730												
1710		1							1			
1690		3		1					1			
1670	2								3			
1650	3								3			
1630	14								7			
1610	59								8			
1590	2			1					5			
1570									1			
1550									2			
1530					1							
1510	1								1			
1490									1			
1470					1							
1450									2			
1430									1			
1410												
Establishment date of older regen.												



Figures 3a-b—Approximate regeneration dates for individual overstory trees by species and approximate years of fire events for each dry site plot. (Lolo = L-1, L-2, L-3, Bitterroot = B-1, B-2, B-3). Complete fire histories prior to 1630 could not be determined.

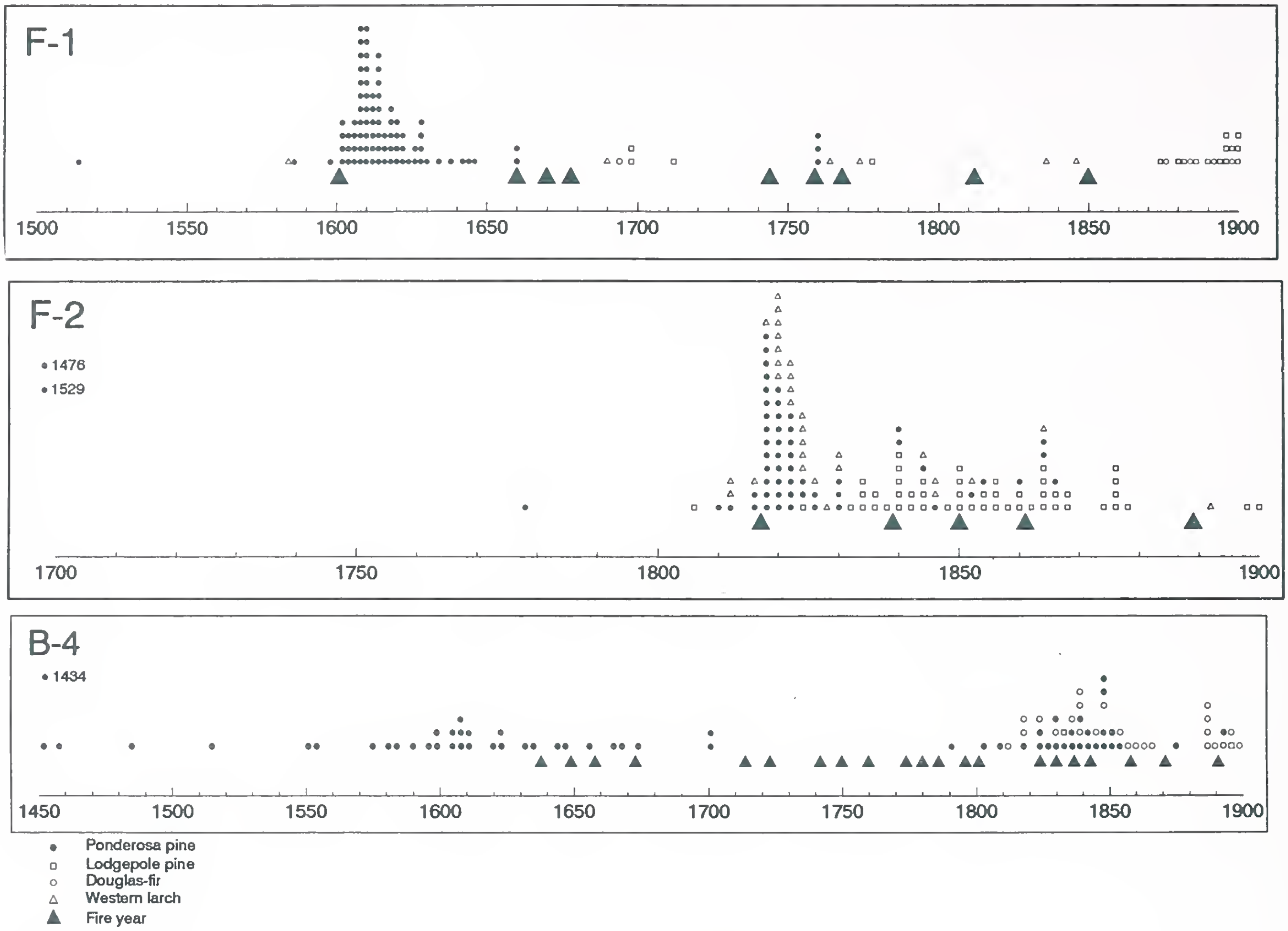


Figure 3c—Approximate regeneration dates for individual overstory trees by species and approximate years of fire events for each moist site plot. (Flathead = F-1, F-2, Bitterroot = B-4). Fire history (black triangles) could not be determined prior to 1600 on F-1, 1817 on F-2, and before 1630 on B-4. On B-4, trees with establishment dates of 1514, 1550, and 1581 were substitutions for large cut stumps inside plot, as described in methods.

of successful establishment came at different times in different plots. Each plot, except the youngest stand (B-1), also had one long period of 50 to 100 years without successful pine establishment. These, too, occurred at different times in different plots, suggesting the causes were not regional phenomena. Presumably the periods without new pine establishment occurred when the site was already too heavily stocked to allow recruitment of a shade-intolerant species or when most of the pine regeneration was killed by fires, perhaps partly because of suppression by the overstory (Cooper 1960).

The overstory Douglas-fir in the dry-site stands with many-aged structures also became established during extended periods, not necessarily coinciding with periods of pine establishment. In plot B-1 most of the Douglas-fir regenerated during the exceptionally long fire interval between about 1756 and 1839. Because of extensive heart rot, many of the apparently old Douglas-fir could not be aged. Thus, the continuity of Douglas-fir establishment throughout the 1500-1900 period may be underestimated in some plots (table 1a). Experimental (Kalabokidis and Wakimoto 1992) and observational evidence (Arno 1988) indicates that seedlings and saplings of pine are more fire-resistant than those of Douglas-fir. Such differential fire resistance might be a factor in the greater continuity of ponderosa pine regeneration between 1500 and 1900 as compared to Douglas-fir. In all plots most of the oldest trees were ponderosa pine. The greater average age of ponderosa pine compared to Douglas-fir may be linked to pine's ability to seal fire wounds with pitch; the less-pitchy Douglas-fir usually develops extensive rot as a result of multiple fire scars.

Much of the present overstory on the two adjacent plots, L-1 and L-2, regenerated in a wave between about 1525 and 1550, which suggests that a fire or other event opened the overstory (fig. 3a). Coincidentally, two approximately 800-year-old pines on this site grew slowly (mean annual radial increments of about 0.02 inch) for >100 years prior to about 1525, followed by accelerated growth (two to three times as fast) for several decades. This kind of growth pattern is often associated with fire-caused thinning (Arno and Sneck 1977). Fire scar records did not extend back before 1630 in these plots.

Plot L-3 had a distinctively different age structure; most of the stand became established during a 70-year period (1700 to 1770) despite intervening surface fires (fig. 3a). This major age group established after surface fires in about 1687 and 1698 and its rapid early growth suggests that these fires (and perhaps associated bark beetle attacks) may have created openings by killing many of the overstory trees. Still, plot L-3 had 15 live trees and about eight dead trees (post-1900 mortality) as well as several older dead trees (1800's mortality) that were established before the late-1600's fires. Thus, an open "shelterwood" overstory of at least 12 trees per acre survived the ~1698 fire, and the 1700-1770 age class developed beneath it. Some of these pines became suppressed and today are only about 12 inches in diameter and 40 ft tall at >250 years of age, less than half the diameter or height of the dominant trees in this age group.

Moist Sites

The moist-site plot on the Bitterroot National Forest had an age class pattern similar to those on the dry sites. In contrast, the Flathead National Forest plots exhibited a distinctively even-aged ponderosa pine structure, despite relatively short fire intervals.

The Bitterroot National Forest moist site (B-4) had a continuous representation of pine trees dating from the mid-1400's until 1680 (fig. 3c). Thereafter, only three trees (all pines) date from the next 120-year period. After 1800, however, both pines and Douglas-fir became successfully established. Today, with fire exclusion after about 1908, there is heavy mortality and damage in Douglas-fir due to root rot, western spruce budworm, dwarf mistletoe, and perhaps other insects and diseases. The oldest Douglas-fir in the plot was only 180 years, and very few large (>200-year-old) Douglas-fir are seen in the surrounding stand. This contrasts with the dry-site plots, all of which had old Douglas-fir, and also with the one Flathead National Forest plot (F-1) that supported >200-year-old trees, including several Douglas-fir.

The high frequency of fires (13-year mean interval) in plot B-4 presumably favored maintenance of nearly pure ponderosa pine among >200-year-old trees. But why is there such a plurality of Douglas-fir establishment during the mid and late 1800's (fig. 3c)? Perhaps Douglas-fir tended to succumb to root or bole rot on this site type in a frequent underburn scenario, just as the species is doing today with fire exclusion. Frequent underburning evidently did not predispose a seral pine-dominated stand to pathogen mortality, since pines commonly achieved ages in excess of 400 years.

The Flathead National Forest moist-site plots had ponderosa pine establishment confined largely to one or two distinct episodes immediately after a major fire (fig. 3c). The dates of fire/pine establishment episodes were similar among some of the four Flathead plots and different among others (fig. 4). Because of these episodes, pre-1900 ponderosa pine stand structure tended to be even-aged. For example, plot F-1 is primarily ponderosa pine that became established after a stand-replacement fire in about 1601 (fig. 3c), with a few additional pines established after an underburn in about 1759. The 1601 fire was dated from a fire scar followed immediately by growth release on one surviving tree and a pronounced growth release at that time on two other pre-1600 trees in the stand. The post-1601 stand maintained an open structure apparently without development of a Douglas-fir understory until the early 1900's, presumably as a result of the eight surface fires between 1660 and 1850. Numerous lodgepole pine became established in the late 1800's, not clearly post-dating any given fire.

Plot F-2 is a dense, nearly even-aged ponderosa pine/western larch stand post-dating a replacement fire in about 1817; it also includes additional age classes

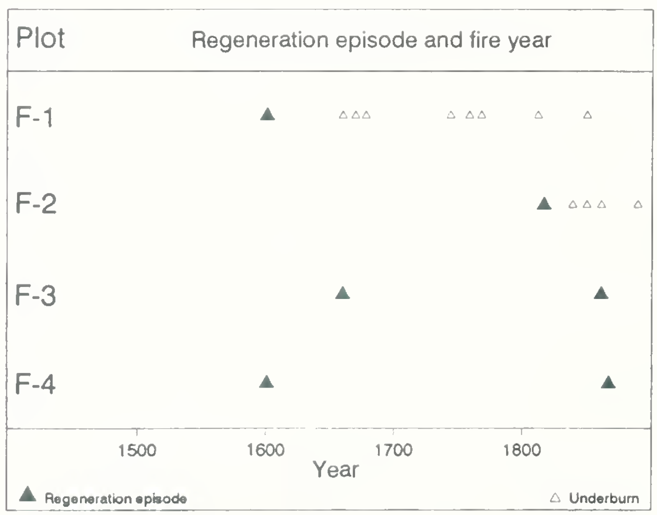


Figure 4—Approximate dates of stand-replacement fire/ponderosa pine regeneration episodes in the vicinity of the Flathead plots. Episodes on F-3 and F-4 are based on pine age classes, since site-specific fire history was not obtained, although Freedman and Habeck (1985) provide data from the general vicinities.

of lodgepole pine and some ponderosa pine and larch regenerated following underburns in about 1839, 1850, and 1861 (fig. 3c). Many of the smaller overstory lodgepole pine and larch trees have multiple scars from fires that occurred after their establishment. Scattered individuals and small groups of >400-year-old ponderosa pine and larch survived the 1817 fire and are found throughout this stand.

Supplementary plot F-3 was also in a young even-aged seral ponderosa pine stand that established following a replacement fire (about 1861), additional scattered survivors had become established around 1660 (fig. 4). Supplementary plot F-4 was located in a mosaic of two even-aged classes: ponderosa pine dating from about 1600; and lodgepole pine/ponderosa pine/larch dating from the late 1800's. All four Flathead plots had evidence of fires at average intervals of 20 to 30 years prior to 1900; the majority were nonlethal surface fires. However, replacement burning also occurred at intervals between 150 and 400+ years (fig. 4), often in a patchy or mosaic pattern on the landscape.

The higher productivity of the moist site-types (Pfister and others 1977) is reflected in greater understory fuels. For example, the Flathead National Forest stands have duff mounds 16 to 24 inches thick at the base of large pines, while dry-site stands have much smaller accumulations (2 to 6 inches). Duff mounds on the Bitterroot moist site (B-4) were of intermediate depth. It is unlikely that stand-replacement fire would have occurred in the relatively open pre-1900 stands on the moist sites (Ayres 1901) unless preceded by a buildup of fuels (Anderson and Brown 1988). Unusually long fire intervals could have facilitated replacement burning, but the fire history does not suggest that the pre-1900 replacement fires were linked to this. Another possibility is that bark beetle epidemics caused extensive mortality and a buildup of fuel from the dead trees that supported replacement burning. Low vigor or stressed old growth pine are especially vulnerable to the western pine beetle (*Dendroctonus brevicomis*) (Johnson 1972). Mountain pine beetle (*D. ponderosae*) epidemics have been common during this century in the extensive lodgepole pine forests that surround our Flathead National Forest plots, and these outbreaks can spread to ponderosa pine (Gibson 1993).

Spatial Relationships in Old Growth

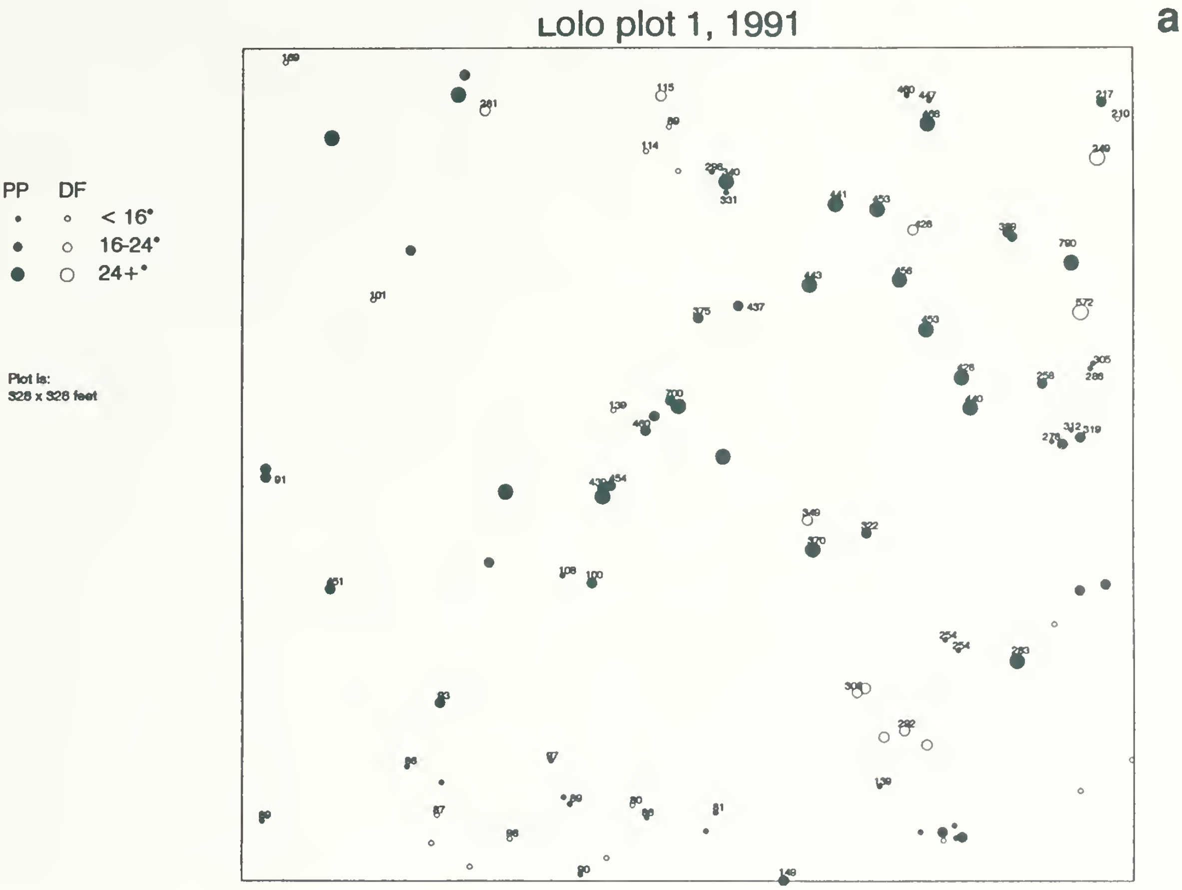
Photographs of pre-1900 ponderosa pine stands in the Northern Rockies (Ayres 1901; Leiberg 1899; Wickman 1992) show a uniform-appearing overstory and scarcely any understory. These stands had a continuous fuelbed of highly combustible pine-needle litter and dry grass, which allowed fires to spread freely over large areas. Nevertheless, adjacent stands (L-1, 2, and B-1, 2, 3) had noticeable differences in tree composition and age structure. Plots L-1 and L-2 were only 200 ft apart on the same smooth slope, and they had the same fire history between 1633 and 1919. Note, however, their differences in circa-1900 and modern stand structure (tables 1a, 2; figs. 5a,b). For example, in L-1 only about 25 percent of the overstory trees were Douglas-fir, compared with over 60 percent in L-2 in 1900, prior to an episode of heavy mortality.

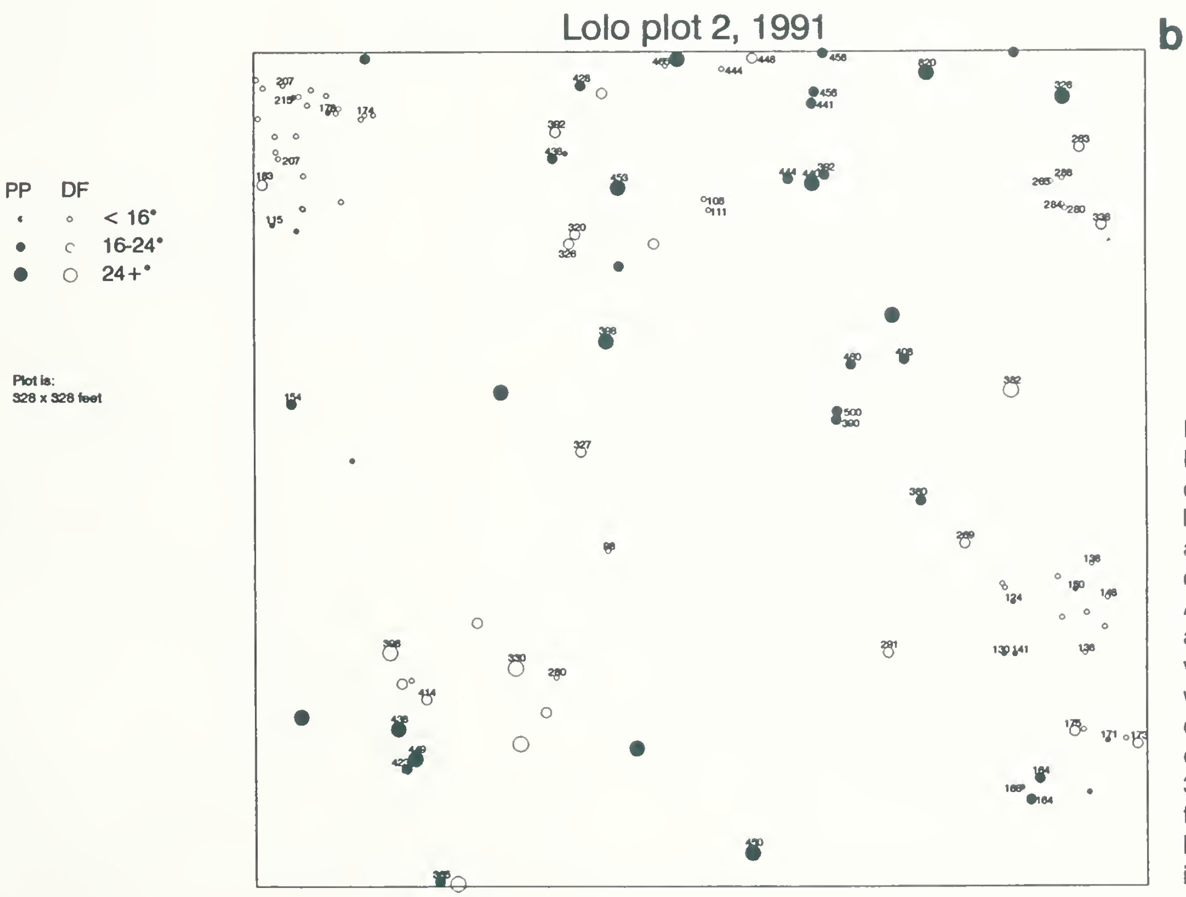
In pre-1900 stands on most of the dry sites and on some moist sites (B-4) the effects of individual fires on mortality, regeneration, and establishment resulted in a fine-grained, subtle mosaic of overstory trees of various ages. This fine mosaic is identifiable in our tree-age plot maps (figs. 5a-i), but is difficult to distinguish on the ground. For instance, note the six 290-year-old pines grouped in the lower left portion of plot B-1 (fig. 5d), the 300-year-old pines and firs in the upper center of B-3 (fig. 5f), and the three 530-year-old pines in the upper right of L-3 (fig. 5c).

In addition to the fine mosaic, occasionally on dry sites we could readily observe a coarser mosaic (units of ½ to 3 acres) apparently related to patches of overstory mortality caused by fire and other factors. For example, note the patch of about 90-year-old trees in the lower left of plot L-1 (fig. 5a) that arose where the 1889 fire had caused mortality. In contrast, on the Flathead moist sites the dominant spatial pattern was a coarse mosaic of even-aged pine stands linked to the patchy stand-replacement fires.

Understory Development

On both dry and moist sites, the major changes in stand structure between 1900 and the 1990's were an increase in basal area and in number of trees per acre as well as the development of an understory of shade-tolerant trees (tables 2 and 3). Douglas-fir represented the majority of the understory trees in all plots (figs. 6a-e, 7). Seven of the nine plots, all those without extensive overstory mortality, had post-1900 increases in basal area of 23 to 144 percent, with a mean of 76 percent. (We were unable to account for small trees that may have died since 1900, but small trees have little effect on stand basal area.) Increased basal area levels in these drought-susceptible forests probably contribute to mortality from insect or disease epidemics, which are becoming widespread in seral ponderosa pine forests (Mutch and others 1993; Wickman 1992). Two of the dry-site plots sustained a large amount of mortality in recent decades (table 2), due in part to root disease (species unidentified); their basal areas have remained similar (L-2) or declined substantially (B-3) since 1900. The Bitterroot National Forest moist site (B-4) has





Figures 5a-i—Mapped position of overstory trees by species and diameter size class on detailed plots. Approximate ages are shown for individual trees from which good quality cores were extracted. The plot size is 328 by 328 ft for figures 5a through h. The plot size for i is 2.36 acres.

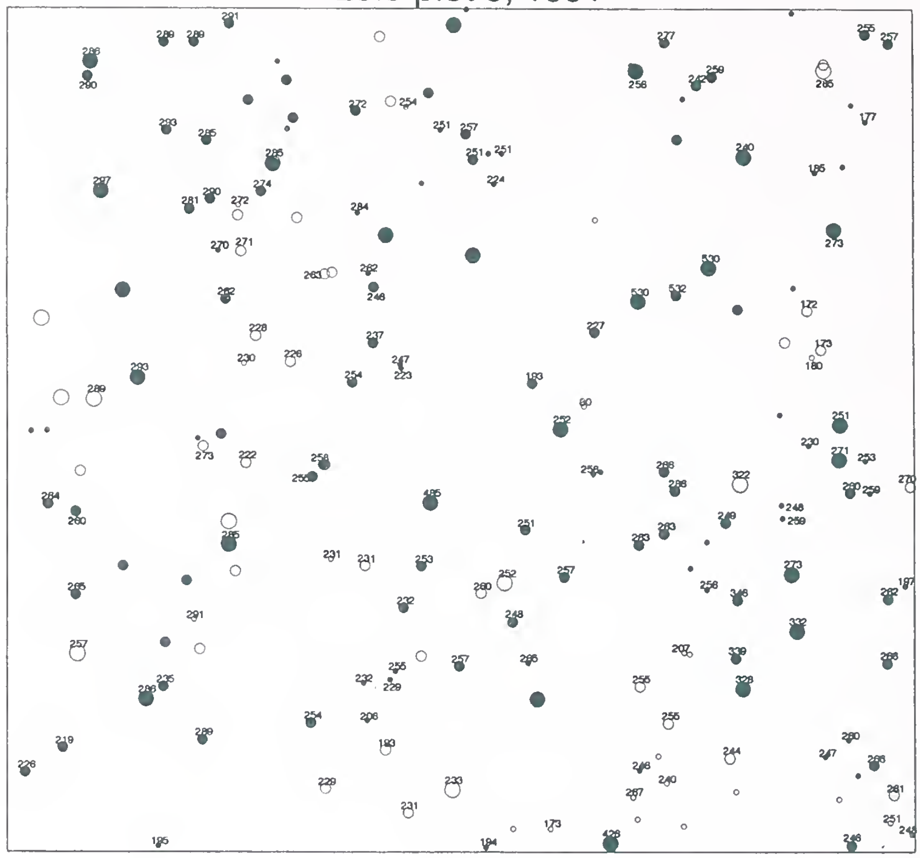
PP DF

- < 16"
- 16-24"
- 24+"

Plot is:
328 x 328 feet

c

Lolo plot 3, 1991



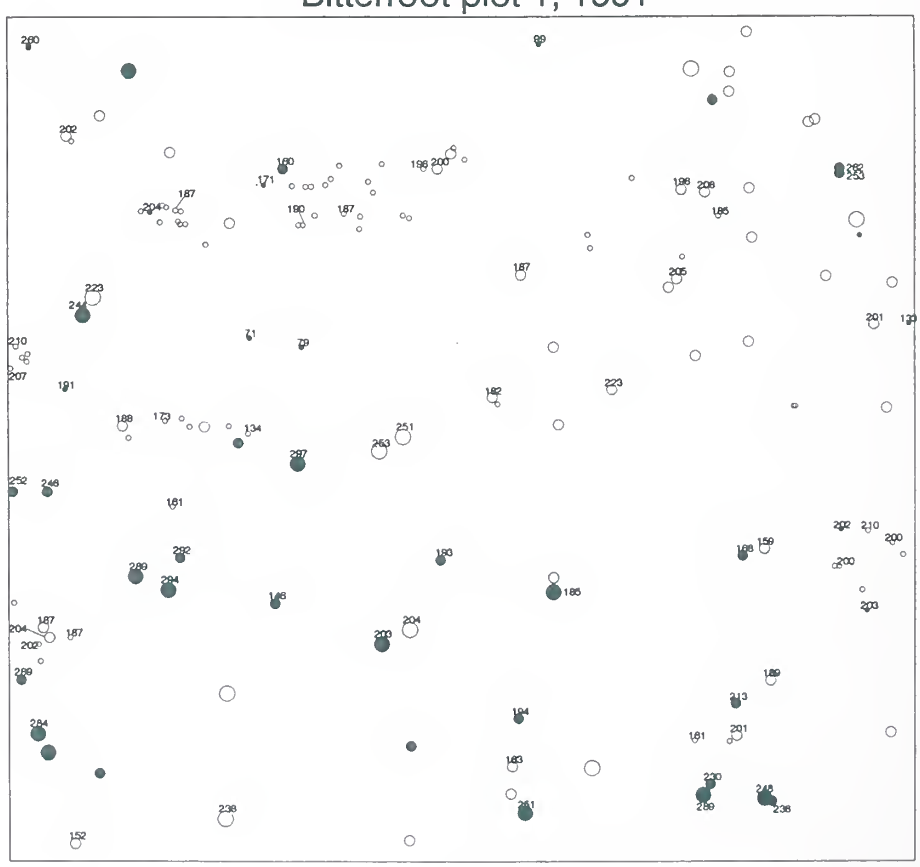
PP DF

- < 16"
- 16-24"
- 24+"

Plot is:
328 x 328 feet

d

Bitterroot plot 1, 1991



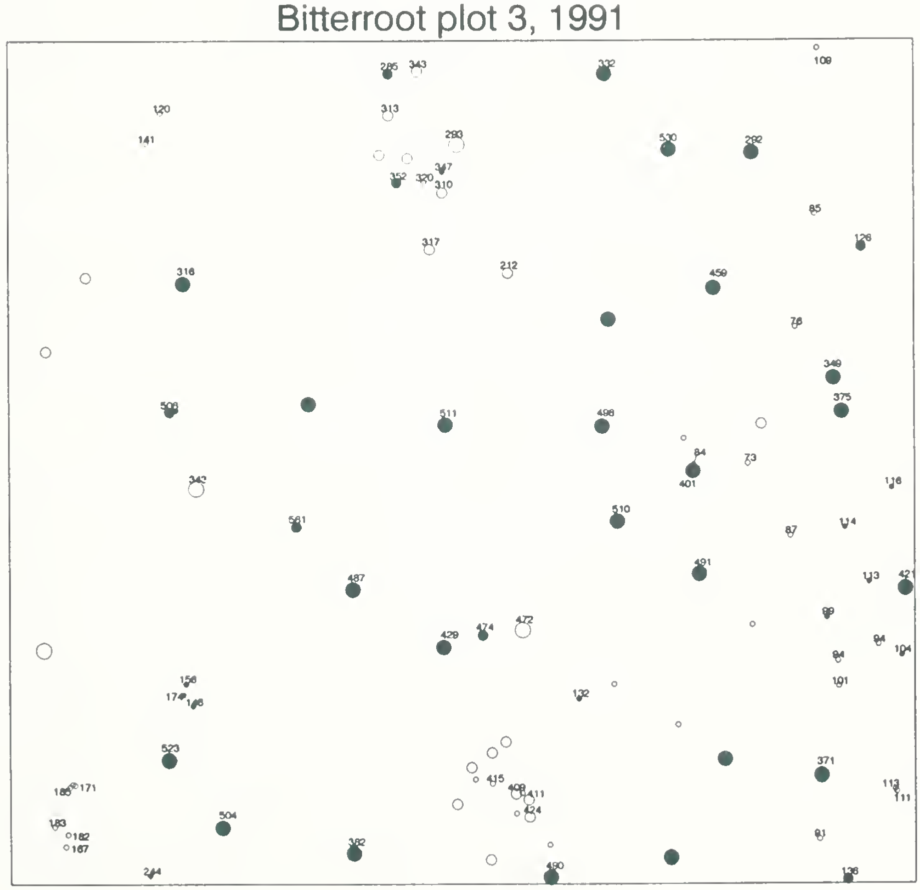
Bitterroot plot 2, 1991

PP	DF	
•	○	< 16"
●	○	16-24"
●	○	24+"

Plot is:
328 x 328 feet

e

Bitterroot plot 3, 1991

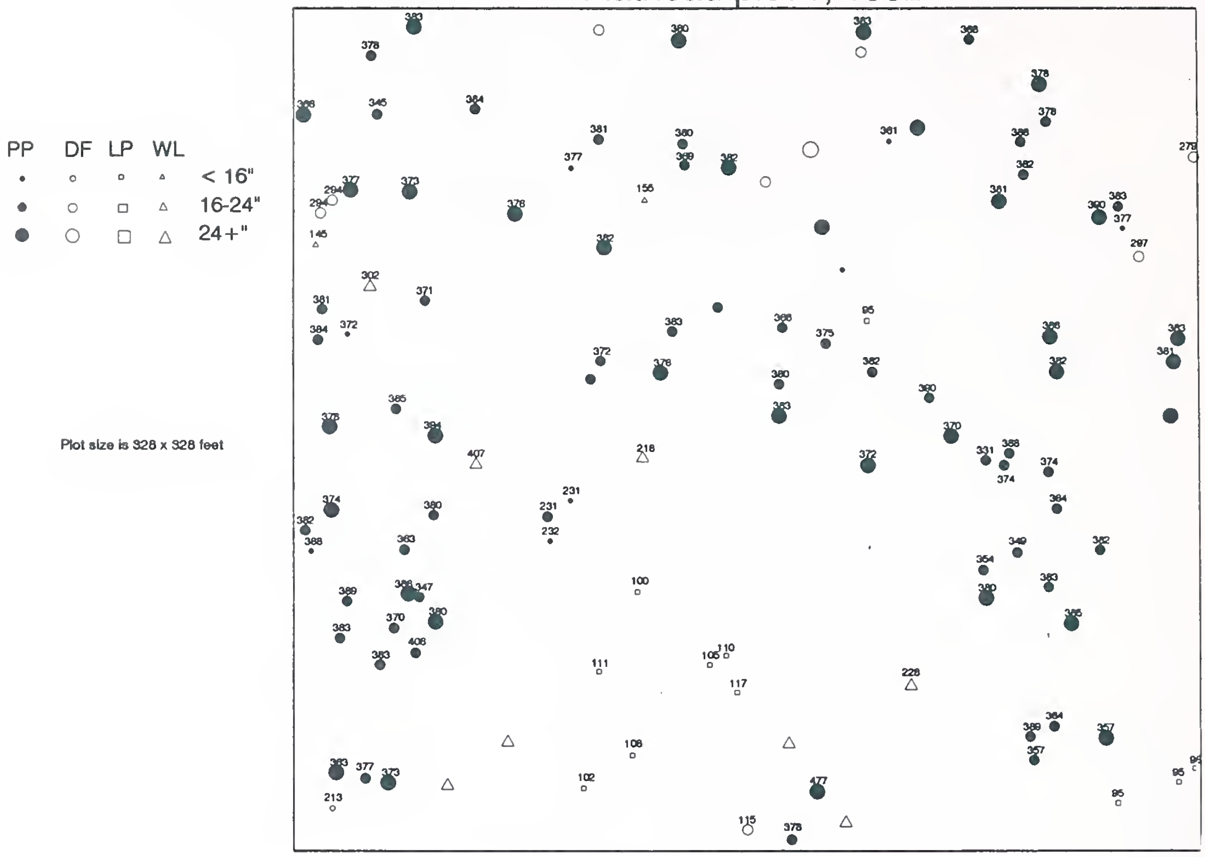


PP	DF	
•	○	< 16"
●	○	16-24"
●	○	24+"

Plot is:
328 x 328 feet

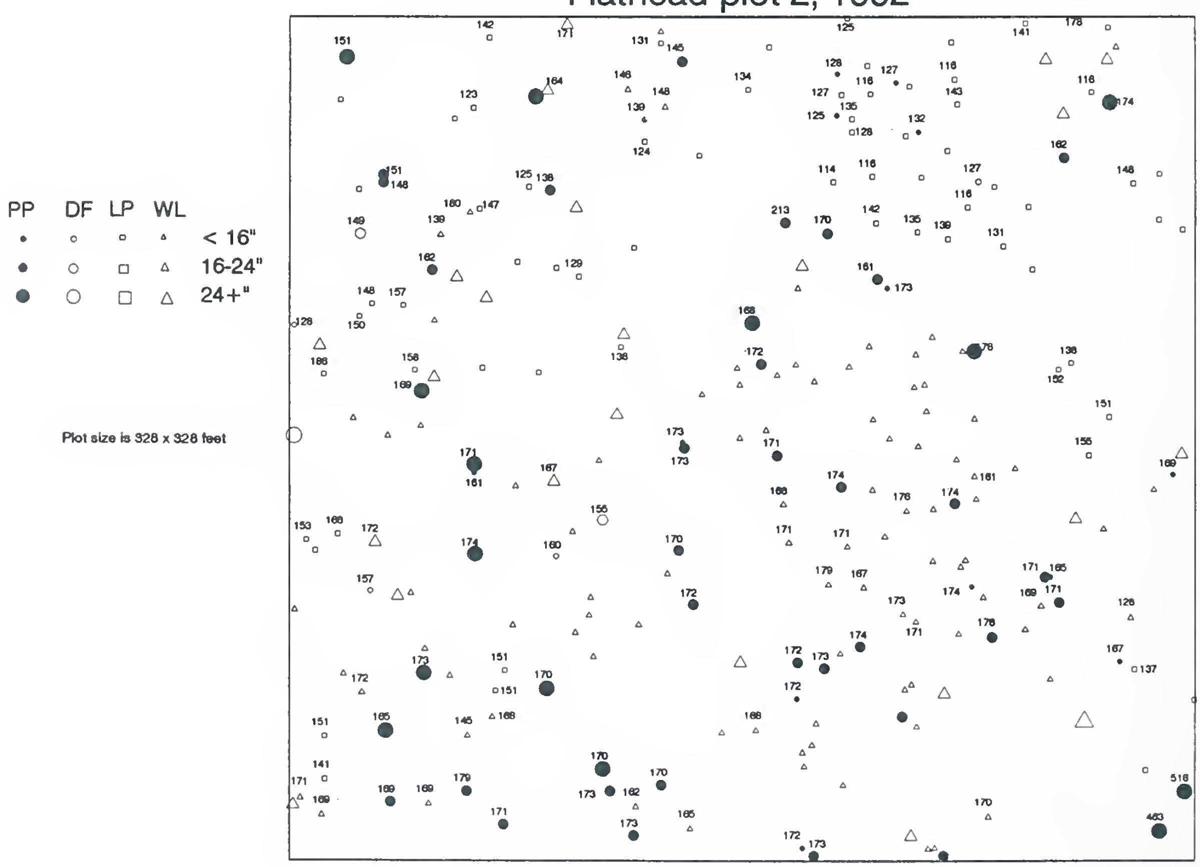
f

Flathead plot 1, 1992



g

Flathead plot 2, 1992



h

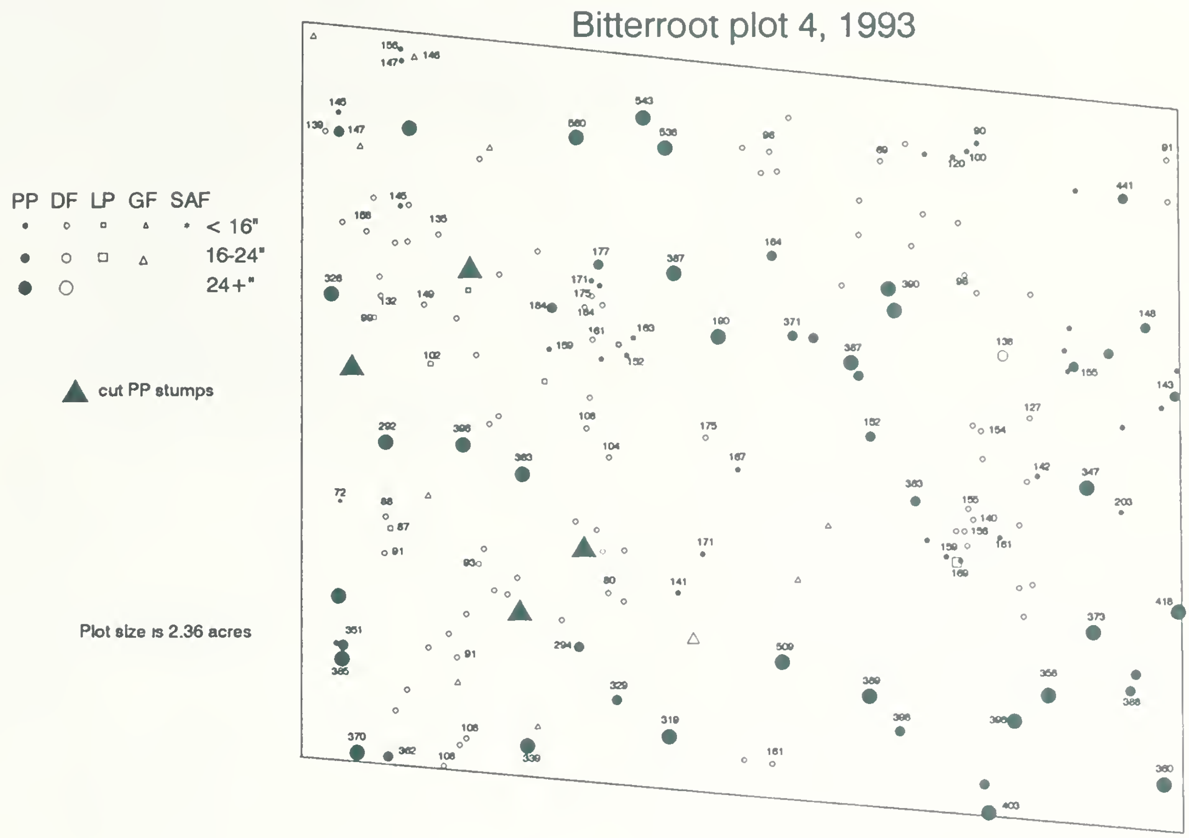
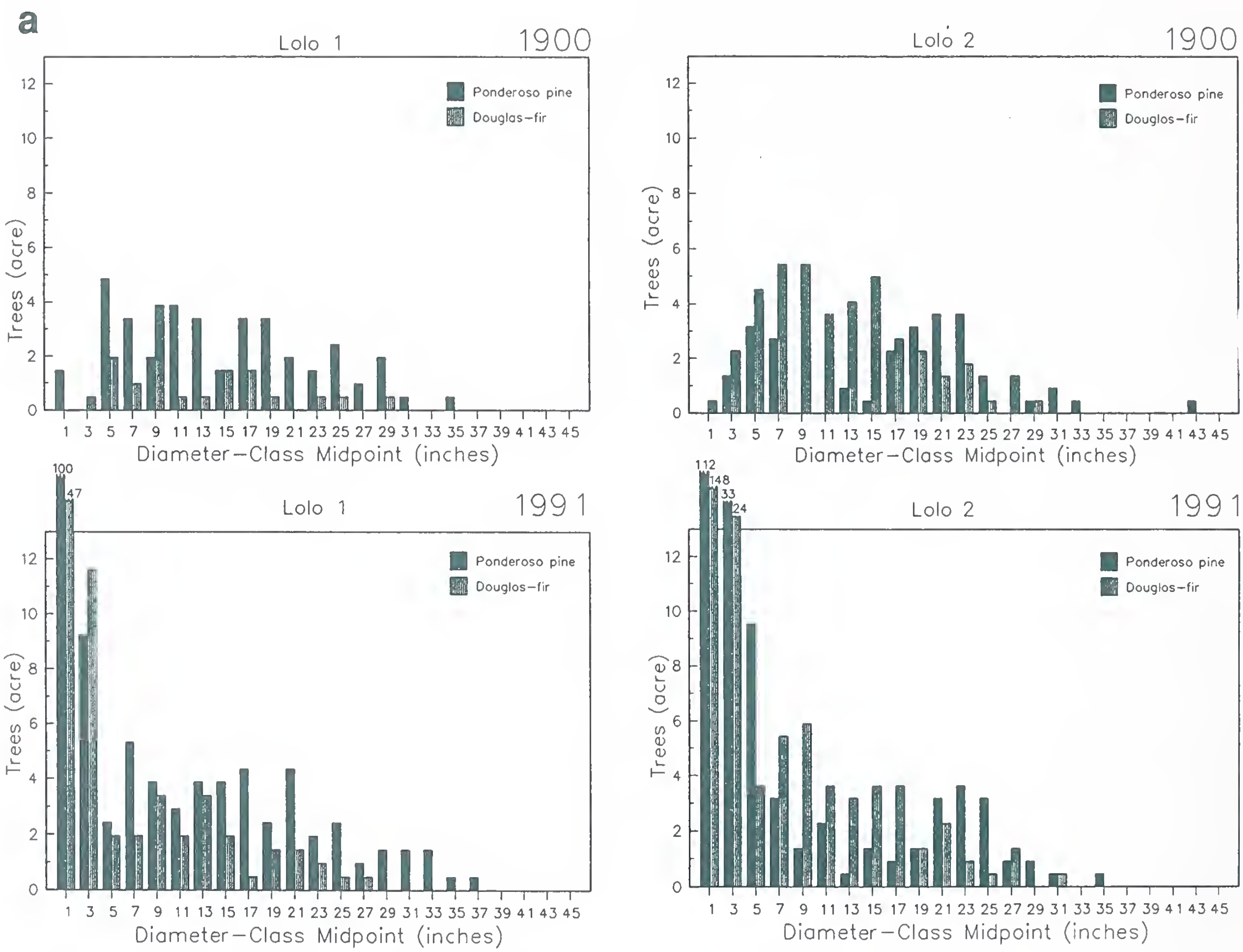


Table 2—Summary of overstory trees (established before 1900) size, density, and composition for each plot, and comparison of current basal area with estimated basal area in 1900. SAF = subalpine fir.

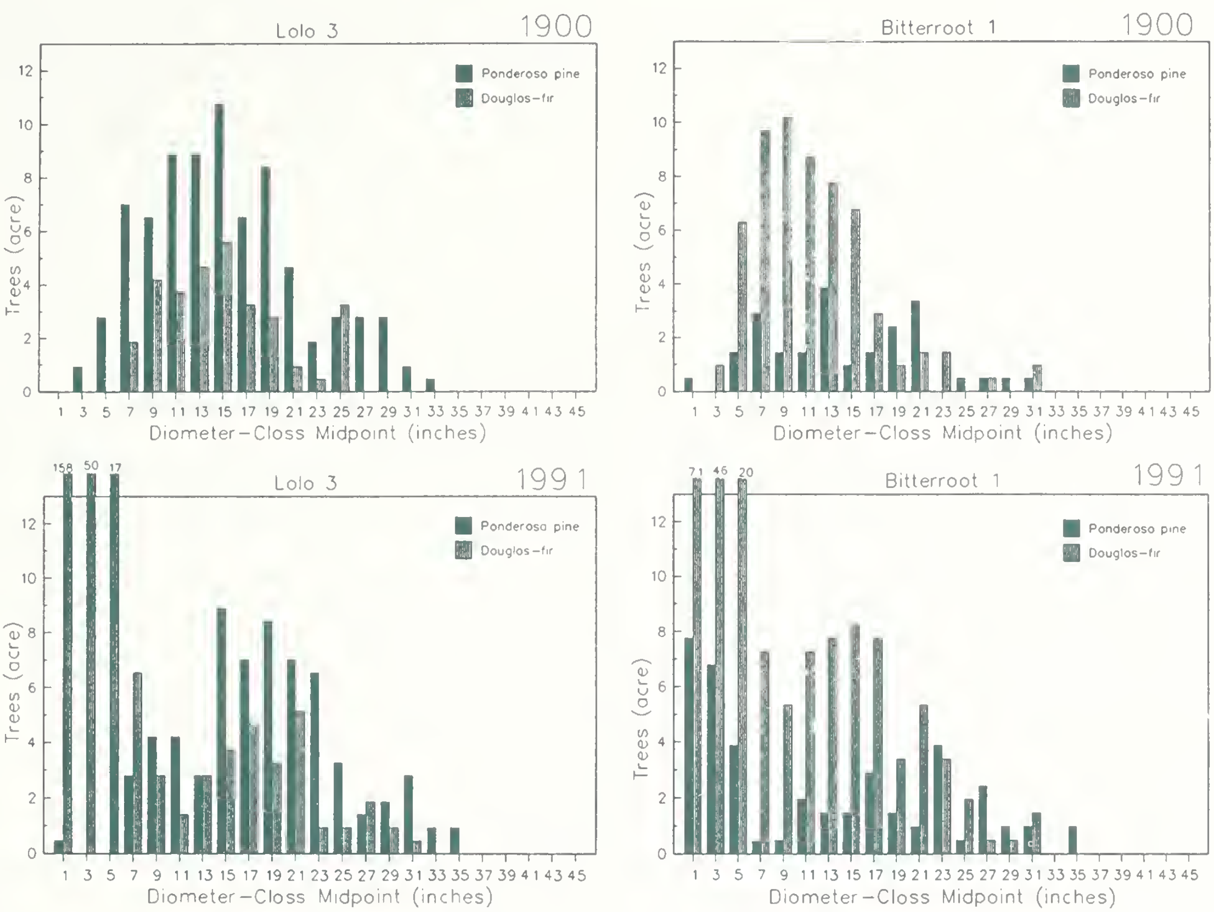
		Dry site type						Moist site type		
		Lolo			Bitterroot			Bitterroot	Flathead	
		1	2	3	1	2	3	4	1	2
Number of overstory trees per acre 1991-93	PP	32	21	60	20	23	19	31	36	24
	DF	12	30	26	52	29	21	12	5	3
	LP							1	4	26
	WL								4	47
	GF							1		
	All	44	51	86	72	52	40	45	49	100
Estimated number of overstory trees per acre that died after 1900	PP	2	4	12	1	1	11	9	3	1
	DF		10	3	3	2	5	6	1	
	LP								6	11
	WL								2	6
	SAF							1		
	All	3	14	15	4	3	16	16	11	17
Average d.b.h. of overstory trees (inches) 1991-93	PP	19	20	19	20	24	24	22	23	20
	DF	16	14	19	16	16	17	13	19	17
	LP							11	9	10
	WL								18	13
	GF							16		
	All	19	17	19	17	20	20	19	21	14
Total basal area (ft^2/acre) 1991-93	PP	78	57	126	52	87	70	90	109	61
	DF	22	43	61	87	87	57	36	30	13
	LP							1	9	17
	WL								9	48
	GF							6		
	SAF							2		
	All	100	100	187	139	174	126	135	158	139
Total estimated basal area (ft^2/acre)1900	PP	52	52	113	30	52	113	81	78	22
	DF	13	43	39	48	26	30	8	9	0
	LP								4	9
	WL								9	26
	SAF							1		
	All	65	96	152	78	78	143	90	100	57

Table 3—Understory trees (>4.5 feet tall, established after 1900) density and species composition for all detailed plots.

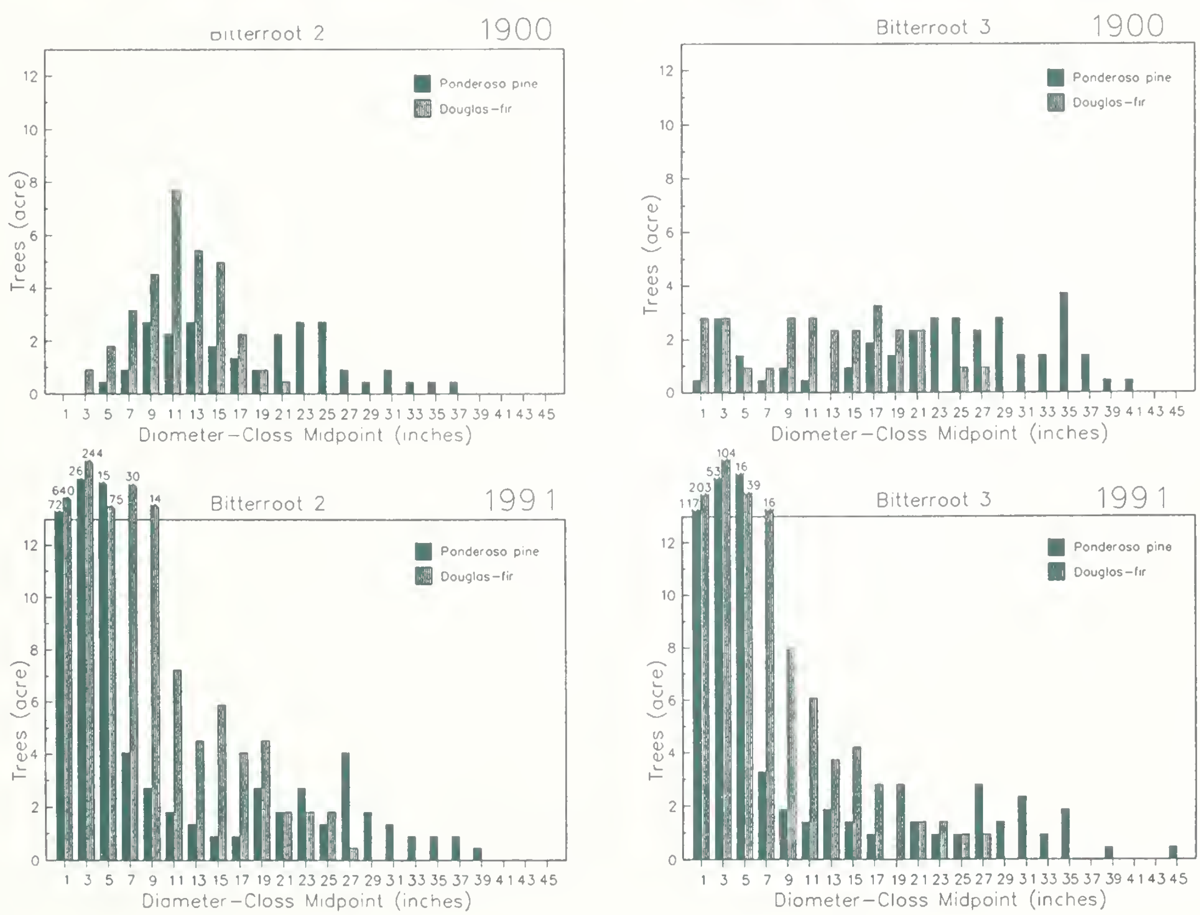
Plot	Trees/acre	Percent composition by species						Most recent
		PP	DF	LP	WL	GF	SAF	fire year
L-1	175	35	65					1953
L-2	340	47	53					1919
L-3	232		100					1897
B-1	164	11	89					1889
B-2	1099	10	90					1889
B-3	524	34	66					1889
F-1	525	12	82	6				1850
F-2	361	3	88	6	3			1889
B-4	265	3	58	1		23	15	1908



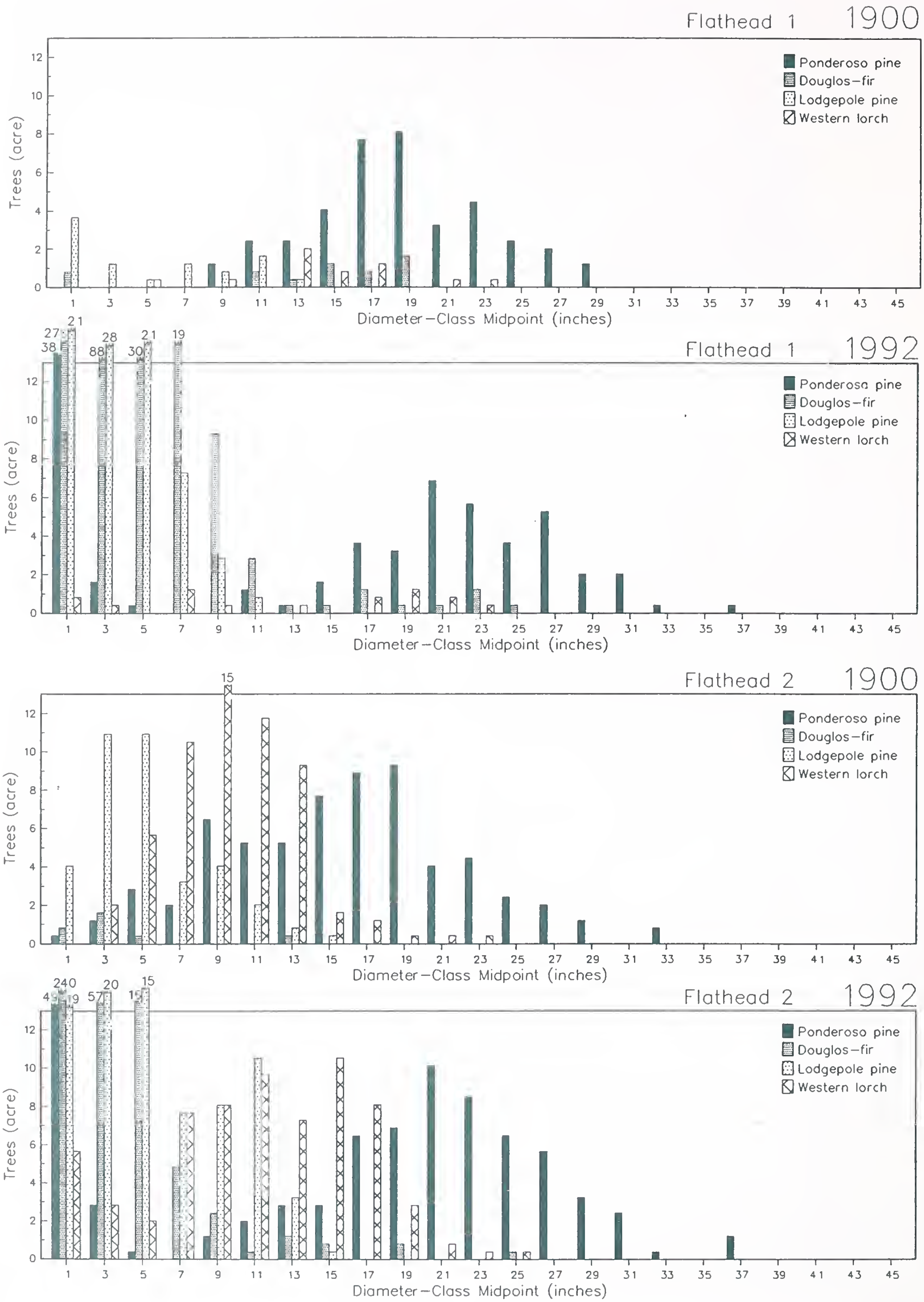
Figures 6a-e—Comparison of stand structures in each plot as estimated for the year 1900 and as measured in 1991-1993. The 1900 estimate does not include small trees that may have been present, but died afterwards as a result of various agents.


Lolo 3
1900
Ponderoso pine
Douglas-fir
Trees (acre)
Diameter-Class Midpoint (inches)
Bitterroot 1
1900
Lolo 3
1991
158
50
17
Bitterroot 1
1991
71
46
20

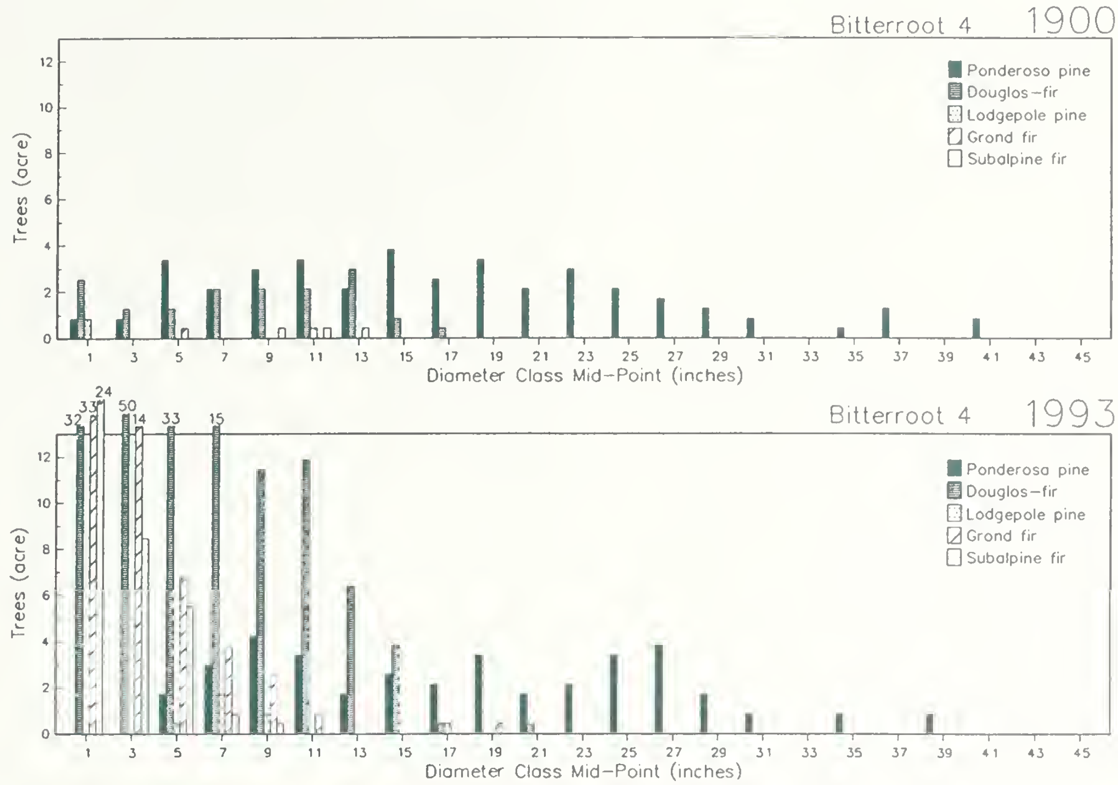
b


Bitterroot 2
1900
Ponderoso pine
Douglas-fir
Trees (acre)
Diameter-Class Midpoint (inches)
Bitterroot 3
1900
Bitterroot 2
1991
640
72
26
244
15
75
30
14
Bitterroot 3
1991
117
203
53
104
16
39
16

c


Flathead 1 1900
Ponderoso pine
Douglos–fir
Lodgepole pine
Western lorch
Trees (acre)
Diameter–Class Midpoint (inches)
Flathead 1 1992
38
27
21
88
28
30
21
19
Flathead 2 1900
15
Flathead 2 1992
240
20
57
15
19

d



e

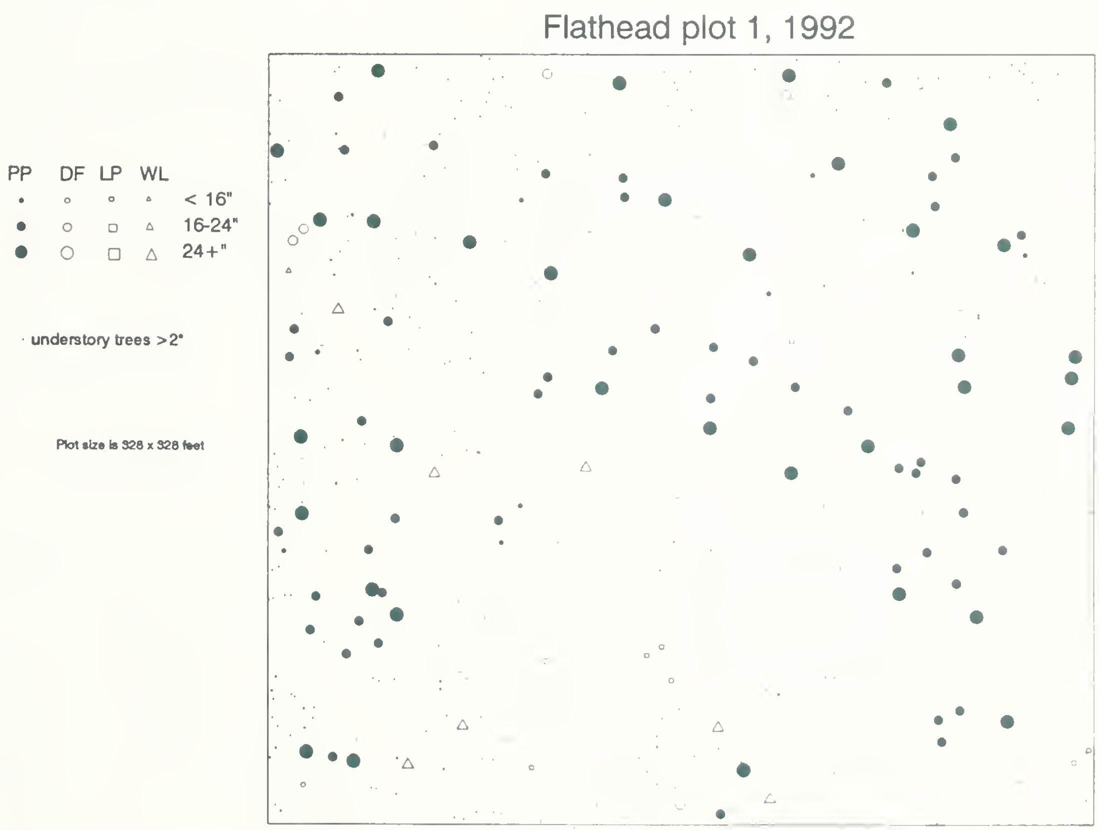


Figure 7—Mapped position of both understory (>2 inches d.b.h.) and overstory trees in plot F-1. Understory composition is mostly Douglas-fir (see table 3). The plot size is 2.47 acres. Understory trees are greater than 2 inches.

also experienced high levels of overstory mortality of all species in recent decades.

Understory composition apparently was linked to disturbance history. Only the three plots that had a major disturbance since 1919 contained a sizeable component (>30 percent) of ponderosa pine in the understory (table 3). Plots L-1 and L-2 underburned in 1919, and L-1 underburned again in 1953. The L-2 and B-3 plots were opened up as a result of major overstory mortality from unidentified pathogens. The six plots that did not have a fire or major pathogen-induced overstory mortality since 1900 contained only minor amounts (<12 percent) of understory ponderosa pine and these trees were generally slow-growing, deformed saplings (table 4b).

The development of a dense Douglas-fir or grand fir understory is an important compositional and structural change in the formerly open stands of old growth ponderosa pine (Keane and others 1990; Weaver 1943). Most seral ponderosa pine forests that have been used for timber production (Mutch and others 1993; Weaver 1967), as well as those that have been protected as natural areas (Habeck 1988, 1990), have developed fir understories or thickets in the absence of fire. These understories and thickets increase risk of stand-replacing wildfires (Anderson and Brown 1988; Arno and Brown 1989).

The Flathead National Forest moist-site plots had been undisturbed since 1900 and understory larch, like ponderosa pine, was scarce and stunted. Our data indicate that regeneration of larch was also limited by exclusion of surface fires on moist ponderosa pine sites (Arno 1988; Mutch and others 1993). In both dry- and moist-site plots that had not underburned since 1900, the understory Douglas-fir were slow-growing (trees 3 to 8 inches in diameter being 70 to 90 years old), but had well-developed crowns. The plots (L-1, 2) that had underburned in 1919 and 1953 had younger, more rapidly growing understory trees—for example, compare the ages of <7-inch-diameter trees among dry-site stands in table 4.

Discussion and Implications for Management

Our findings indicate that on these rather high-elevation dry sites, fires at mean intervals of 26 to 50 years enabled seral ponderosa pine to develop a nearly all-aged structure (except on L-3) despite

Table 4a-c—Mean ages of understory trees by species and size class. Sample size is shown in parentheses.

Diameter-class	Dry site type						Moist site type		
midpoint	B-1	B-2	B-3	L-1	L-2	L-3	F-1	F-2	B-4
(a) Douglas-fir understory									
1	70 (7)	68 (5)	64 (3)	27 (3)	31 (2)	52 (6)	41 (3)	29 (2)	52 (3)
3	72 (4)	71 (1)	50 (2)	22 (1)	58 (6)	78 (3)	79 (4)	41 (7)	74 (2)
5	86 (1)	75 (2)	71 (2)	44 (2)	49 (4)	84 (2)	66 (1)	50 (2)	69 (4)
7	88 (2)	86 (1)	77 (4)		51 (2)	86 (1)	79 (7)	57 (1)	76 (3)
9		86 (3)	70 (4)	93 (1)		80 (1)	78 (16)	64 (6)	88 (1)
11		78 (3)	96 (4)	91 (2)	98 (1)		87 (4)	75 (1)	90 (5)
(b) Ponderosa pine understory									
1		43 (1)	67 (3)	36 (5)	38 (5)		44 (1)	28 (2)	
3	71 (2)		65 (5)	36 (4)	44 (11)		81 (2)	37 (1)	
5	92 (1)	73 (1)	77 (3)		41 (6)				
7			96 (2)	69 (3)					
9		87 (3)	101 (2)	87 (1)					90 (1)
11	85 (2)	80 (1)		86 (3)					
(c) Lodgepole pine understory									
1									
3							82 (2)	85 (3)	
5							82 (8)	75 (3)	
7							92 (7)	92 (2)	99 (1)
9							86 (3)		87 (1)
11							95 (1)		

competition from the more shade-tolerant Douglas-fir. This age-class structure was associated with low-to-moderate intensity surface fires that occasionally killed groups of overstory trees. The nearly all-aged structure of pre-1900 stands is similar to that of pure ponderosa pine forests in Arizona (Cooper 1960; Covington and Moore 1994; White 1985) and eastern Oregon (Weidman 1921). The Arizona pine forests had shorter pre-1900 fire intervals (2 to 10 years) than our dry-site pine/fir stands (Swetnam 1990). However, several dry-site ponderosa pine/fir forests at lower elevations in the northern Rockies and inland Pacific Northwest also had average fire intervals of 7 to 10 years (Arno 1988; Kilgore 1987).

On the Bitterroot National Forest moist site (B-4), fires at a mean interval of 13 years helped maintain a nearly pure ponderosa pine overstory despite competition from both Douglas-fir and grand fir (fig. 8). The pine were multiaged and long-lived. Douglas-fir survived fires but did not attain great longevity, perhaps as a result of decay hastened by fire injury. Only a few grand fir predate the most recent fire (ca. 1908) and these have fire scars accompanied by severe heart rot.

In contrast, on the Flathead National Forest moist sites, seral ponderosa pine stands became established in even-aged classes after patchy and infrequent stand-replacing disturbances—evidently fire and bark beetle epidemics. Low-intensity surface fires at the rate of three to four per century then maintained the stands in ponderosa pine-larch dominance with open understories.

Other pre-1900 fire patterns probably existed in seral ponderosa pine stands. Some patterns were probably intermediate to those we have described. Some probably were beyond the range of the fire effects described here. A high degree of variation and complexity in pre-1900 mixed severity fire patterns has now been documented in diverse western and northern coniferous forests including western larch and lodgepole pine (Arno and others 1993; Barrett and others 1991), coastal Douglas-fir (*P. m.* var.

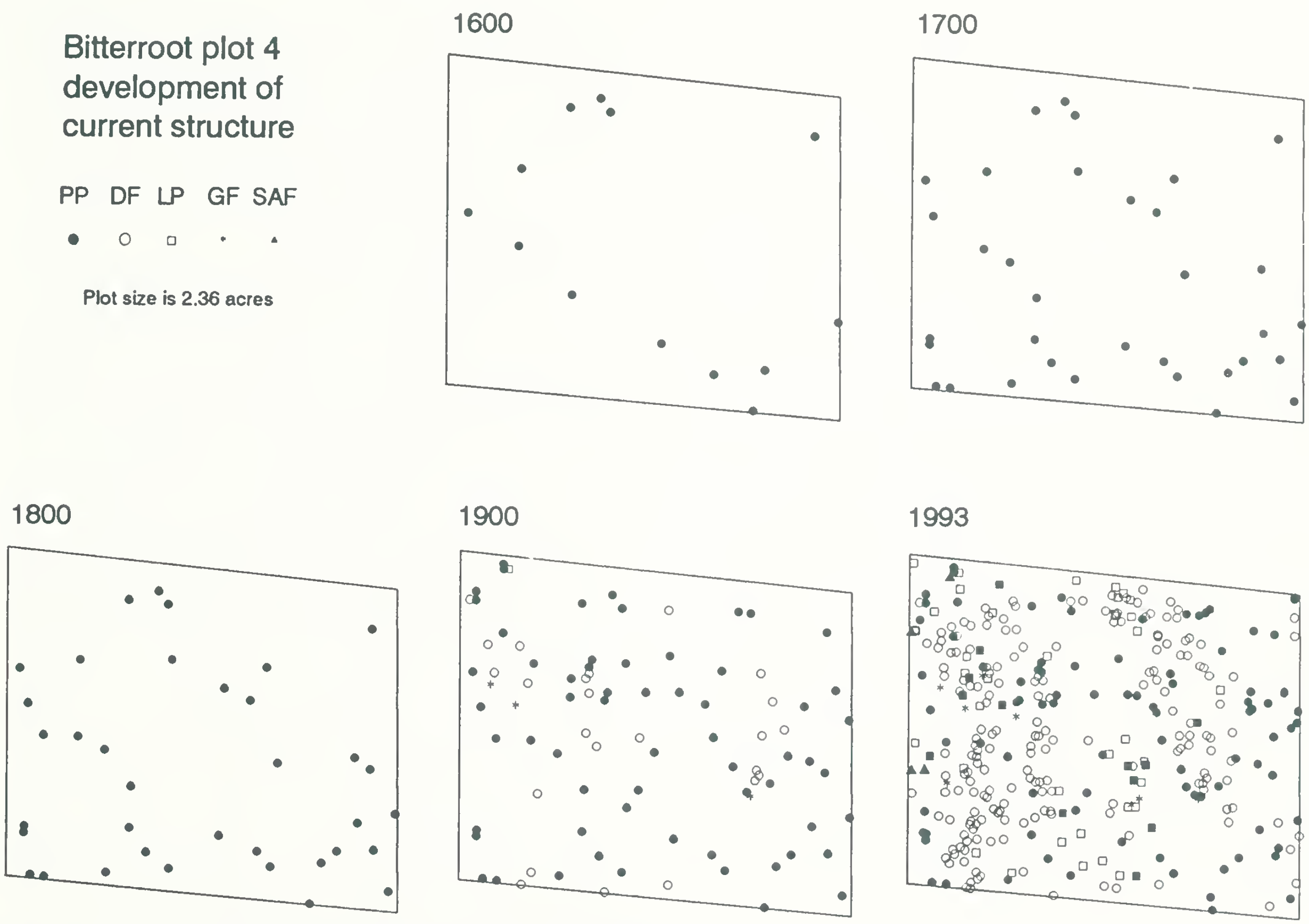


Figure 8—Chronological development of current stand structure on plot B-4. Only trees that were alive in 1993 (and >4 inches d.b.h.) are shown. Ponderosa pine (PP); Douglas-fir (DF); lodgepole pine (LP); grand fir (GF); and subalpine fir (SAF).

menziesii) (Morrison and Swanson 1990), giant sequoia (*Sequoiadendron giganteum*)-mixed conifer (Stephenson and others 1991), red fir (*Abies magnifica*) (Taylor 1993), and red pine-white pine (*Pinus resinosa-P. strobus*) (Heinselman 1981).

On both dry and moist sites, an understory of Douglas-fir developed after fires were suppressed. Similar understories may have developed occasionally in some stands during the longest pre-1900 fire intervals, which ranged from 41 to 97 years in our stands and were about twice as long as the mean fire intervals. Today, however, a large proportion of the seral ponderosa pine type has been without fire for periods exceeding former maximum intervals (Agee 1993; Arno 1988; Swetnam 1993), and succession has also been advanced by removal of overstory pine and larch trees.

Recent management direction for National Forest lands in the Western United States has focused on designing treatments that are consistent with natural processes (Overbay 1992; Risbrudt 1992). This management approach also seeks to maintain a range of forest composition and structure somewhat similar to that of presettlement forests. Reintroducing fire alone will not restore most old growth stands because of unprecedented accumulations of duff and ladder fuels. The dense understories, including many trees whose crowns extend into the overstory canopy, cannot now be killed by fire without damaging the old growth trees (Harrington 1991). Growth and vigor of the old trees also have declined noticeably in many stands while mortality has increased. A comparison of growth from the most recent 50 years (1942-1991) and an historic period (1851-1900), on overstory trees in our six dry site plots indicates significantly greater growth in the two plots that had fires since 1900 (Fiedler and others 1994). Slower growth and declining vigor in the four plots without fire are presumably related to increased understory and stand basal area density, and reduced nutrient availability.

In the past, frequent underburns helped maintain both uneven-aged and even-aged seral ponderosa pine forests. Effects of these disturbance regimes suggest that, to restore a semblance of self-perpetuating pine, it will be necessary to reduce the understory mechanically and thereafter control understory development using prescribed fire. Periodic burning can remove most Douglas-fir up to 4 inches in diameter and grand fir of somewhat larger size (Kilgore and Curtis 1987). If the stand is opened significantly (for example, reducing basal area to about 40 to 60 square feet per acre), natural or planted pine and larch could become established (Fiedler and others 1988). If annosus root disease (*Heterobasidion annosum*) is suspected, a pathologist should be consulted before planning silvicultural treatment (Hawksworth and Shaw 1988). Subsequent treatments through the use of selective thinning and carefully applied prescribed burning, at intervals of perhaps 20 to 25 years could favor these seral trees over competing fir regeneration.

Because of prolonged fire exclusion, reintroduction of fire must be done carefully, perhaps with successive low-intensity burns, to prevent damage to old growth trees (Harrington 1991; Harrington and Sackett 1992). When reintroducing fire after a long period of exclusion, some risk to old growth trees is unavoidable. In some old growth stands, tree health is so poor that major mortality will probably occur regardless of treatment. Nevertheless, treatments that create openings and establish regeneration of seral species will be beneficial in the long term. Conversely, if prescribed fire and fuels management are not initiated, loss of ponderosa pine from the stand is virtually assured due to successional replacement; this is often accompanied by insect or disease epidemics and severe wildfire (Arno and others 1985; Keane and others 1990).

A different sort of management challenge is implied by knowledge that occasional stand-replacement events were responsible for an even-aged ponderosa pine stand structure in the Swan Valley study sites on the Flathead National Forest. There is a need to discover what natural conditions predisposed these stands to these disturbances and allowed ponderosa pine to reestablish itself as the major species. The result of modern stand-replacing fires in both dry and moist sites tends to be greater regeneration of Douglas-fir (Arno and others 1985; Keane and others 1990). Unlike the pre-1900 replacement fires on the Swan Valley sites, however, modern wildfires are occurring after long periods of logging and successional replacement of ponderosa pine across the landscape. This has reduced the amount of pine seed source and increased seed source for late-successional species. Conversely, prior to 1900 underburns at 20 to 30 year mean intervals would have helped maintain pine dominance by removing much of the small Douglas-fir. Thus, when a stand-replacing fire eventually occurred, pine was the primary tree surviving at the periphery of heavily burned patches of forest, and was able to reseed much of the area.

Today it may be undesirable to have stand-replacing fires in the small natural areas that remain in this ecological type. Fuels management with silviculture and prescribed fire could be used to maintain pine and larch while preventing replacement fires. Some of the large even-aged ponderosa pine plantations on clearcuts in the Swan Valley could be converted gradually, with the application of prescribed fire at 20 to 30 year intervals, to old growth similar to the even-aged pre-1900 stands on these sites.

References

Agee, J. K. 1990. The historical role of fire in Pacific Northwest forests. In: Walstad, J. D.; Radosevich, S.; Sandberg, D., eds. Natural and prescribed fire in Pacific Northwest forests, Corvallis, OR: Oregon State University Press: 25-38.

Anderson, H. E.; Brown, J. K. 1988. Fuel characteristics and fire behavior considerations in the wildlands. In: Fischer, William C.; Arno, Stephen F., comps. Protecting people and homes from wildfire in the Interior West: Proceedings of the symposium and workshop; 1987 October 6-8; Missoula, MT. Gen. Tech. Rep. INT-251. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 124-130.

Arno, S. F. 1976. The historical role of fire on the Bitterroot National Forest. Res. Pap. INT-187. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 29 p.

Arno, S. F. 1988. Fire ecology and its management implications in ponderosa pine forests. In: Baumgartner, D. M.; Lotan, J. E., comps. Proceedings—ponderosa pine: the species and its management. Pullman, WA: Washington State University, Cooperative Extension Service: 133-140.

Arno, S. F.; Brown, J. K. 1989. Managing fire in our forests—time for a new initiative. Journal of Forestry. 87(12): 44-46.

Arno, S. F.; Brown, J. K. 1991. Overcoming the paradox in managing wildland fire. Western Wildlands. 17(1): 40-46.

Arno, S. F.; Reinhardt, E. D.; Scott, J. H. 1993. Forest structure and landscape patterns in the subalpine lodgepole pine type: a procedure for quantifying past and present conditions. Gen. Tech. Rep. INT-294. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 17 p.

Arno, S. F.; Simmerman, D. G.; Keane, R. E. 1985. Forest succession on four habitat types in western Montana. Gen. Tech. Rep. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 74 p.

Arno, S. F.; Sneck, K. M. 1977. A method for determining fire history in coniferous forests of the Mountain West. Gen. Tech. Rep. INT-42. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 28 p.

Ayres, H. B. 1901. Lewis and Clark Forest Reserve, Montana. U.S. Department of the Interior, U.S. Geological Survey, 21st Annual Rep. Part V: 27-80.

Barrett, S. W. 1988. Fire suppression's effects on forest succession within a central Idaho wilderness. Western Journal of Applied Forestry. 3(3): 76-80.

Barrett, S. W.; Arno, S. F. 1982. Indian fires as an ecological influence in the Northern Rockies. Journal of Forestry. 80: 647-651.

Barrett, S. W.; Arno, S. F.; Key, C. H. 1991. Fire regimes of western larch-lodgepole pine forests in Glacier National Park, Montana. Canadian Journal of Forest Research. 21: 1711-1720.

Bonnicksen, T. M.; Stone, E. C. 1981. The giant sequoia-mixed conifer forest community characterized through pattern analysis as a mosaic of aggregations. Forest Ecology and Management. 3: 307-328.

Cooper, C. F. 1960. Changes in vegetation, structure, and growth of southwestern pine forests since white settlement. Ecological Monographs. 30(2): 129-164.

Covington, W. W.; Moore, M. M. 1994. Southwestern ponderosa forest structure: changes since Euro-American settlement. Journal of Forestry. 92(1): 39-47.

Everett, R. L., comp. 1994. Restoration of stressed sites and processes. Gen. Tech. Rep. PNW-330. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 123 p.

Fiedler, C. E. 1984. Unpublished regeneration data on file at: School of Forestry, University of Montana, Missoula, MT.

Fiedler, C. E.; Arno, S. F.; Carlson, C. E.; Harrington, M. G. 1992. Management prescriptions for restoring biodiversity in Inland Northwest ponderosa pine-fir forests. Northwest Environment Journal. 8(1): 211-213.

Fiedler, C. E.; Becker, R. R.; Haglund, S. A. 1988. Preliminary guidelines for uneven-aged silvicultural prescriptions in ponderosa pine. In: Baumgartner, D. M.; Lotan, J. E., comps. Proceedings, ponderosa pine—the species and its management. Pullman, WA: Washington State University, Cooperative Extension Service: 235-241.

Fiedler, C. E.; Steele, B. M. 1992. Relationship of tree growth and recruitment to fire in old-growth pine/fir forests—results of cross-dating. Unpublished report of Research Joint Venture Agreement INT-92683 on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Intermountain Fire Sciences Laboratory, Missoula, MT. 23 p.

Fiedler, C. E.; Steele, B. M.; Arno, S. F. 1994. Growth trends in old-growth pine/Douglas-fir forests as influenced by fire exclusion. Review draft.

Freedman, J. D.; Habeck, J. R. 1985. Fire, logging, and whitetailed deer interrelationships in the Swan Valley, northwestern Montana. In: Lotan, J. E.; Brown, J. K., comps. Fire effects on wildlife habitat. Gen. Tech. Rep. INT-186. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 23-35.

Ghent, A. W. 1955. A guide for the re-alignment of off-center increment borings. Forest Chronicles. 31: 353-355.

Gibson, K. E. 1993. [Personal communication]. Entomologist, Northern Region, U.S. Department of Agriculture, Forest Service, Missoula, MT.

Habeck, J. R. 1988. Old-growth forests in the northern Rocky Mountains. Natural Areas Journal. 8: 202-211.

Habeck, J. R. 1990. Old-growth ponderosa pine-western larch forests in western Montana: ecology and management. Northwest Environment Journal. 6(2): 271-292.

Harrington, M. G. 1991. Fire management in interior Douglas-fir forests. In: Baumgartner, D. M.; Lotan, J. E., comps. Proceedings, interior Douglas-fir—the species and its management. Pullman, WA: Washington State University, Cooperative Extension Service: 209-214.

Harrington, M. G.; Sackett, S. S. 1992. Past and present fire influences on southwestern ponderosa pine old-growth. In: Kaufmann, M. R.; Moir, W. H.; Bassett, R. L., tech. coords. Old-growth forests in the Southwest and Rocky Mountain regions: proceedings of a workshop. Gen. Tech. Rep. RM-213. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 44-50.

Hawksworth, F. G.; Shaw, C. G., III. 1988. Damage and control of major diseases of ponderosa pine. In: Baumgartner, D. M.; Lotan, J. E., comps. Proceedings, ponderosa pine—the species and its management. Pullman, WA: Washington State University, Cooperative Extension Service: 99-108.

Heinselman, M. L. 1981. Fire intensity and frequency as factors in the distribution and structure of northern ecosystems. In: Mooney, H. A.; [and others], tech coords. Proceedings—Fire regimes and ecosystem properties. Gen. Tech. Rep. WO-26. Washington, DC: U.S. Department of Agriculture, Forest Service: 7-57.

Holmes, R. L. 1983. Computer-assisted quality control in tree-ring dating and measurement. Tree-Ring Bulletin. 43: 69-78.

Holmes, R. L. 1992. Dendrochronology Program Library. Tucson, AZ: University of Arizona, Laboratory of Tree-Ring Research. 35 p.

Johnson, P. C. 1972. Bark beetle risk in mature ponderosa pine forests in western Montana. Res. Pap. INT-119. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 32 p.

Kalabokidis, K. D.; Wakimoto, R. H. 1992. Prescribed burning in uneven-aged stand management of ponderosa pine/Douglas-fir forests. Journal of Environmental Management. 34: 221-235.

Keane, R. E.; Arno, S. F.; Brown, J. K. 1990. Simulating cumulative fire effects in ponderosa pine/ Douglas-fir forests. Ecology. 71: 189-203.

Kilgore, B. M. 1987. The role of fire in wilderness: a state-of-knowledge review. In: Lucas, R. C., comp. Proceedings—national wilderness research conference: issues, state-of-knowledge, future directions. Gen. Tech. Rep. INT-220. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 70-103.

Kilgore, B. M.; Curtis, G. A. 1987. Guide to understory burning in ponderosa pine-larch-fir forests in the Intermountain West. Gen. Tech. Rep. INT-233. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 39 p.

Leiberg, J. B. 1899. Bitterroot Forest Reserve. U.S. Department of the Interior, U.S. Geological Survey, 19th Annual Rep. Part V: 253-282.

McBride, J. R. 1983. Analysis of tree rings and fire scars to establish fire history. Tree-Ring Bulletin. 43: 51-67.

Morrison, P. H; Swanson, F. J. 1990. Fire history and pattern in a Cascade Range landscape. Gen. Tech. Rep. PNW-254. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 77 p.

Mutch, R. W.; [and others]. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. Gen. Tech. Rep. PNW-310. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 14 p.

Overbay, J. C. 1992. Ecosystem management. In: taking an ecological approach to management. WO-WSA-3. Washington, DC: U.S. Department of Agriculture, Forest Service, Watershed and Air Management: 3-15.

Pfister, R. D.; Kovalchik, B. L.; Arno, S. F.; Presby, R. C. 1977. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 174 p.

Risbrudt, C. 1992. Sustaining ecological systems in the Northern Region. In: Taking an ecological approach to management. WO-WSA-3. Washington, DC: U.S. Department of Agriculture, Forest Service: 27-39.

Scott, J. H.; Arno, S. F. 1992. Using a power increment borer to determine the age structure of old-growth conifer stands. Western Journal of Applied Forestry. 7(4): 100-102.

Stephenson, N. L.; Parsons, D. J.; Swetnam, T. W. 1991. Restoring natural fire to the sequoia-mixed conifer forest: should intense fire play a role? Proceedings, Tall Timbers Fire Ecology Conference. 17: 321-337.

Swetnam, T. W. 1990. Fire history and climate in the southwestern United States. In: Proceedings, symposium on the effects of fire management of Southwestern natural resources; 1988 November 15-17; Tucson, AZ. Gen. Tech. Rep. RM-191. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 6-17.

Swetnam, T. W. 1993. Fire history and climate change in giant sequoia groves. Science. 262: 885-889.

Taylor, A. H. 1993. Fire history and structure of red fir (*Abies magnifica*) forests, Swain Mountain Experimental Forest, Cascade Range, northeastern California. Canadian Journal of Forest Research. 23: 1672-1678.

Van Hooser, D. D.; Keegan, C. E., III. 1988. Distribution and volumes of ponderosa pine forests. In: Baumgartner, D. M.; Lotan, J. E., eds. Proceedings—ponderosa pine—the species and its management. Pullman, WA: Washington State University, Cooperative Extension Service: 1-6.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific slope. Journal of Forestry. 41: 7-14.

Weaver, H. 1967. Fire and its relationship to ponderosa pine. Proceedings, Tall Timbers Fire Ecology Conference No. 7. 7: 127-149.

Weidman, R. H. 1921. Forest succession as a basis of the silviculture of western yellow pine. Journal of Forestry. 19: 877-885.

Wellner, C. A. 1989. Classification of habitat types in the western United States. In: Ferguson, D. E.; Morgan, P.; Johnson, F. D., comps. Proceedings—Land classifications based on vegetation: applications for resource management; 1987 November 17-19; Moscow, ID. Gen. Tech. Rep. INT-257. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 7-21.

West, N. E. 1969. Tree patterns in central Oregon ponderosa pine forests. American Middland Naturalist. 81(2): 584-590.

White, A. S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology. 66: 589-594.

Wickman, B. E. 1992. Forest health in the Blue Mountains: the influence of insects and disease. Gen. Tech. Rep. PNW-295. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 15 p.

*U.S. GOVERNMENT PRINTING OFFICE 1995-0-673-034/01018

Arno, Stephen F.; Scott, Joe H.; Hartwell, Michael G. 1995. Age-class structure of old growth ponderosa pine/Douglas-fir stands and its relationship to fire history. Res. Pap. INT-RP-481. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 25 p.

Describes age structure of nine old growth ponderosa pine/Douglas-fir stands in western Montana. Interprets the influence of past fires and 20th century fire exclusion on stand structure. Gives implications for management to restore and maintain these forests for multiple resource values.

Keywords: forest health, forest succession, fire-dependent forest, all-aged stands

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)