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Old Growth Ponderosa Pine and Western Larch Stand Structures: Influences of Pre-1900 Fires and Fire Exclusion

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Research Summary

Historically, as a result of frequent fires, seral ponderosa pine and western larch trees dominated old growth stands in the Northern Rocky Mountains. We present detailed data on age structure and fire history of two remnant old growth stands on the Lolo National Forest in western Montana. These stands occupy contrasting sites; one is codominated by ponderosa pine and larch while the other is larch without ponderosa pine. Also, we compare age structures of eleven stands that represent a broad range of sites historically characterized by frequent fire regimes. These stands are located in western Montana, on the Bitterroot, Flathead, and Lolo National Forests. Three of the stands on moderately moist site types were distinctly even-age. These reflected a variable fire regime of frequent nonlethal fires and infrequent stand replacement fires. Seven of the stands, including the driest sites and two moist sites with comparatively frequent fires, had highly uneven-age structures. The remaining stand, on a moderately dry site, had an intermediate age structure: uneven-age but with one very abundant age class. We interpret causal factors possibly linked to these variations in age structure, including aboriginal burning.

Ten of the 11 stands have now experienced an unusually long interval without fire (75 to 105 years). Related changes in stand structure between 1900 and the 1990's include large increases in basal area per acre (+50 to +150 percent) and in Stand Density Index per acre (+60 to +200 percent) except for two stands that have experienced large amounts of overstory mortality. We discuss implications for management to perpetuate old growth ponderosa pine and larch.

Acknowledgments

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Table of Conversions

Parameter	Multiply this unit	By this factor	To obtain this unit
Basal area	Square feet per acre (ft^2/acre)	0.2296	Square meters per hectare (m^2/ha)
	Square meters per hectare (m^2/ha)	4.3354	Square feet per acre (ft^2/acre)
Length	Feet (ft)	0.3048	Meters (m)
	Meters (m)	3.2808	Feet (ft)
	Inches (inches)	2.54	Centimeters (cm)
	Centimeters (cm)	0.3937	Inches (inches)
	Miles	1.6093	Kilometers (km)
	Kilometers (km)	0.6214	Miles
Area	Acres	0.4047	Hectares (ha)
	Hectares	2.4711	Acres

About the cover: View of Girard Grove from across the Clearwater River at the outlet of Seeley Lake, MT. Study plot Lolo-5 (L-5) is located in this highly uneven-age larch stand containing trees greater that 500 years old. This stand is a result of frequent fires prior to 1860.

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Introduction

Ponderosa pine (*Pinus ponderosa*) and western larch (*Larix occidentalis*) are long-lived fire-resistant trees of the Northern Rocky Mountains and inland Northwest. The pine is often seral and at a competitive disadvantage to interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and grand fir (*Abies grandis*) in the absence of fire or other major disturbance. Larch is always considered seral to the above firs and other shade-tolerant conifers (Daubenmire and Daubenmire 1968; Pfister and others 1977).

Historically, seral stands of large old ponderosa pine and western larch dominated millions of acres. Losensky (1995) estimated that the historic ponderosa pine type covered about 25 million acres between central Montana and the Cascade Range in Washington and Oregon. Many of the pine and pine-larch stands were maintained in an open parklike condition, having sparse understories, by frequent low-intensity surface fires at average intervals of between 5 and 30 years (Arno 1988). Old growth larch stands on sites too cold or moist for ponderosa pine generally had a history of either (1) mixed severity fires at intervals of 30 to 75 years, or (2) stand-replacement burning at mean intervals of 120 to 350 years (Arno and Fischer 1995).

Old growth stands of seral ponderosa pine and larch are essentially "fire dependent" (Habeck 1988). Remnant stands found today are highly valued as recreational and natural areas. Paradoxically, since the early 1900's most stands have been under management that attempts to exclude fire. In contrast, recent management direction in many National Forests and other public lands often seeks to maintain or restore old growth pine and larch with the aid of prescribed fire. To accomplish this new management direction, better information is needed regarding how to restore and perpetuate seral old growth that was associated with frequent burning. Knowledge of how remaining old growth stands developed in conjunction with frequent fires of the past should be helpful. Consequently, we sought to obtain detailed age structure and fire history information for a range of pine and larch old growth stands in western Montana that were historically associated with frequent burning.

A previous study (Arno and others 1995) reported age structure information for nine ponderosa pine stands on the Bitterroot, Lolo, and Flathead National Forests, but only one of these was codominated by western larch. Here we present data from two additional old growth stands on Lolo National Forest representing habitats that contrast with the previous larch stand. One of the additional stands is a mixture of pine and larch on a steep upland slope and the other is larch dominated in a frost-prone valley bottom evidently at the cold limits of ponderosa pine. We also synthesize and compare age-class data, basal areas (BA), and Stand Density Indexes (SDI) for the entire range of old growth stands that we have sampled to represent the historical frequent fire types in western Montana.

Study Sites and Fire History

Our eleven sample stands include eight locations (fig. 1). One location was sampled with three plots and another with two plots to compare spatial variation (Arno and others 1995). Collectively, these eight locations represent a range of contrasting conditions among western Montana pine and larch forests having had a history of frequent fire (table 1). Certainly, additional situations existed in natural stands. For instance, we were unable to locate any relatively low-elevation dry-site ponderosa pine old growth that had experienced no logging and could therefore represent short fire intervals (5 to 15 years) on a dry site. We did, however, sample one short-fire-interval ponderosa pine stand on a moist site (plot B-4) as well as a larch stand on a very moist site (plot L-5) that had relatively short fire intervals (table 1). Because these forest types have been logged, often repeatedly, for more than 100 years it was not possible to locate large unlogged stands and select sample areas using criteria that would ensure representativeness (Arno and others 1995). Our samples represent all of the remnant stands on both dry and moist sites that we were able to locate with a moderate amount of search and inquiry. Additional

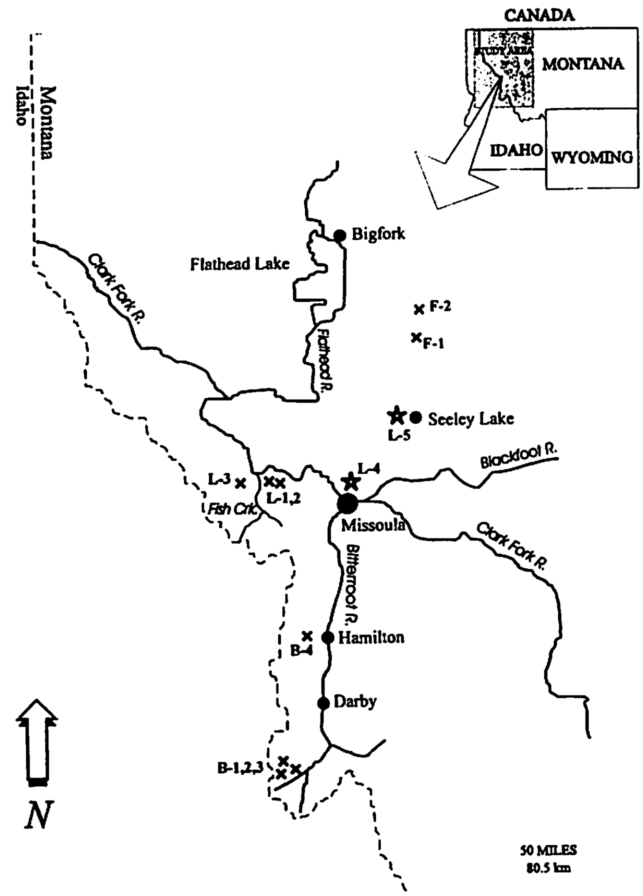


Figure 1—General location of the 11 old growth study sites in western Montana. The stars indicate the two new study sites Lolo-4 (L-4) and Lolo-5 (L-5) while an "X" indicates one of the nine previously reported sites identified by the symbols "B" (Bitterroot National Forest), "F" (Flathead National Forest), or "L" (Lolo National Forest).

criteria were that stands needed to be large enough to easily contain our 2½ acre sample plot and that they had experienced no logging, so that the original stand structure could be measured and aged. Unquestionably there are additional stands that could be sampled in western Montana, especially on dry high-elevation ridges in roadless areas, but this is the situation we have already sampled most heavily (plots B-1, 2, 3, and L-1, 2, 3 in table 1). Other situations have nearly all experienced some logging, heavy mortality, and successional replacement by Douglas-fir or grand fir.

Fire histories were determined for each plot from analysis of partial cross sections (wedge cuts) 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 late 1500's or early 1600's (except plot F-2, table 1) was developed for each plot by correlating dates obtained from individual trees.

Our new sample stand L-5 represented an unusual challenge for obtaining fire history since ponderosa pine is rare and multiple fire scars on larch cannot normally be sampled using a partial cross-section (wedge). One of the larch trees in the vicinity of L-5 has multiple fire scars (fig. 2). Wedge sampling multiple scarred larch is inadvisable due to extensive rot and ring shake (separation along the growth rings) that causes the wedge-cut tree to break off in windstorms. Thus, dating multiple fire scars on larch requires felling the trees and taking full cross sections. Stand L-5 is in a recreation area where land managers wanted to avoid felling old growth trees. We were able to obtain a reasonably good and complete fire history by (1) felling a single old larch with the maximum number (five) of undecayed fire scars observed; (2) wedge sampling fire scar sequences on one live and one

Table 1—Summary of fire history and site characteristics of the 11 old growth stands representing eight different sites in western Montana, arranged according to increasing site moisture conditions. Samples Lolo-4 and Lolo-5 have not been previously reported.

Sample area, plot number	Habitat type[a]	Aspect, slope inclination	Site moisture	Old growth composition[b] PP	WL	Historic mean and (minimum, maximum) fire intervals in years (about 1600-1900)	Stand replacement fires detected
Bitterroot 1, 2, 3	PSME/CARU	SW, >40%	Very dry	X		49 (19, 97)	No
Lolo 1, 2	PSME/CARU	SW, >40%	Very dry	X		32 (17, 47)	No
Lolo 3	PSME/CARU and VAGL	SW, >40%	Moderately dry	X		26 (7, 51)	No
Lolo 4	PSME/VAGL	WNW, >40%	Moderate	X	X	27 (17, 35)	Yes
Flathead 1	PSME/VACA	Flat	Moderate	X		31 (8, 66)	Yes
Flathead 2	PSME/VACA	Flat	Moderate	X	X	25-30[c]	Yes
Bitterroot 4	ABGR/LIBO	E, gentle	Moderately moist	X		13 (5, 41)	No
Lolo 5	ABLA/CLUN	Flat	Moist		X	24 (9, 42)	No

[a]Based on Pfister and others (1977). Key to abbreviations: ABGR = *Abies grandis*, grand fir; ABLA = *Abies lasiocarpa*, subalpine fir; CARU = *Calamagrostis rubescens*, pinegrass; CLUN = *Clintonia uniflora*, queencup beadlily; LIBO = *Linnaea borealis*, twinflower; PSME = *Pseudotsuga menziesii*, Douglas-fir; VACA = *Vaccinium caespitosum*, dwarf huckleberry; VAGL = *Vaccinium globulare*, blue huckleberry.

[b]PP = Ponderosa pine; WL = Western larch. On Flathead-1 WL is present but scarce; Bitterroot-4 is 10 miles south of geographic range limits of WL, site would probably support WL based on success of planted and natural WL regeneration in the general vicinity.

[c]Based on Freedman and Habeck (1985). Our fire scar history on Flathead-2 extended back only to 1817, having a pre-1900 mean interval of 18 years with a minimum of 11 and a maximum of 28.

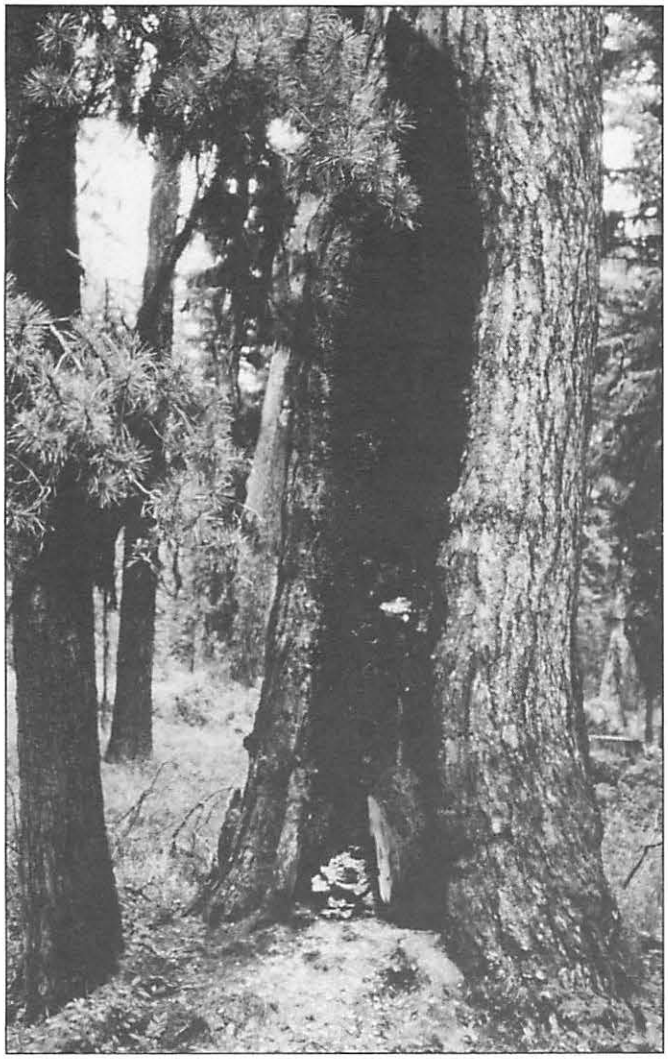


Figure 2—Western larch at Lolo-5 (L-5) with multiple fire scars.

dead ponderosa pine, a rare species in this stand; and (3) wedge sampling old fire scars from broken larch snags. These fire history samples indicate that nine fires occurred in the stand from about 1671 through 1859, with a mean fire interval of 24 years (fig. 3). Age class cohorts of larch trees (discussed later) also suggest the occurrence of fires in the 1630's, the late 1500's, and the early 1500's. The common occurrence of more than 500-year-old trees in this stand indicates that none of the post-1500 fires were stand replacement burns.

The other new sample stand, L-4, represented a different kind of challenge for determining fire history. Several fire scarred ponderosa pine and larch were available for dating the seven fires occurring from about 1777 through 1919. Most of the old trees became established in a single cohort during the late 1600's, and there were no living trees with fire scars old enough to record a fire that might have set the stage for that regeneration event. However, a search of the adjacent logged stand, immediately downslope, revealed a well preserved stump of a huge ponderosa pine that had been harvested in about 1919. This pitch-permeated stump dated back to the early 1300's and had a continuous fire scar record from about 1594 including all of the fires recorded on the live trees, except 1919 (fig. 3). The trees in plot L-4 and the stump in the adjacent stand recorded 12 fires from about 1594 through 1889, with a mean fire interval of 27 years. As discussed later, the apparent stand-replacing fire that gave rise to the even-age old growth occurred in about 1663.

Methods of Stand Reconstruction

Methods were similar to those used in the previous study of nine old growth stands (Arno and others 1995). We placed a 100 m (328 ft) square plot within each small sample stand in a location where topography was relatively uniform. Our plot covered 1 ha (2.47 acres) on a flat site, but we did not enlarge it on sloping topography and thus acreage was smaller on sloping sites. Actual acreage was used in basal area calculations for each plot. This plot size seemed adequate to encompass age-group patterns found in other studies of stand structure of coniferous forest in the inland western United States (Bonnicksen and Stone 1981; Cooper 1960; Stephenson and others 1991; West 1969; White 1985). We used this plot as a basis for inventorying the current stand structure and tree ages, and for reconstructing stand structure circa 1900. To do this we (1) recorded species and diameter at breast height (d.b.h.) of each tree more than 4 inches in diameter, (2) mapped each tree's position, (3) number tagged all trees more than 8 inches in diameter and took increment borings to determine total tree age, (4) inventoried all dead trees estimated to have been alive in 1900, and (5) tallied saplings less than 4 inches in diameter by species on a representative 25 m square subplot.

We chose 1900 as a basis for characterizing historical stand conditions because studies in mixed ponderosa pine and fir forests generally indicate a disruption in the historical pattern of frequent fires shortly after that time. Records of fire history in ponderosa pine forests of western Montana show a consistent pattern of frequent fire from 1900 back to about 1500 (Arno 1976; Barrett and Arno 1982); beyond that threshold few living trees are available to sample (Arno and others 1995).

The position of all trees more than 4 inches diameter was recorded using a survey laser instrument (Criterion 400, Laser Technology, Inc.). Beginning in one corner, we made a closed-loop traverse through several sighting points within the plot. The azimuth and horizontal distance to each tree were then recorded from one of the traverse points, allowing computation of the Cartesian position of each tree within the plot.

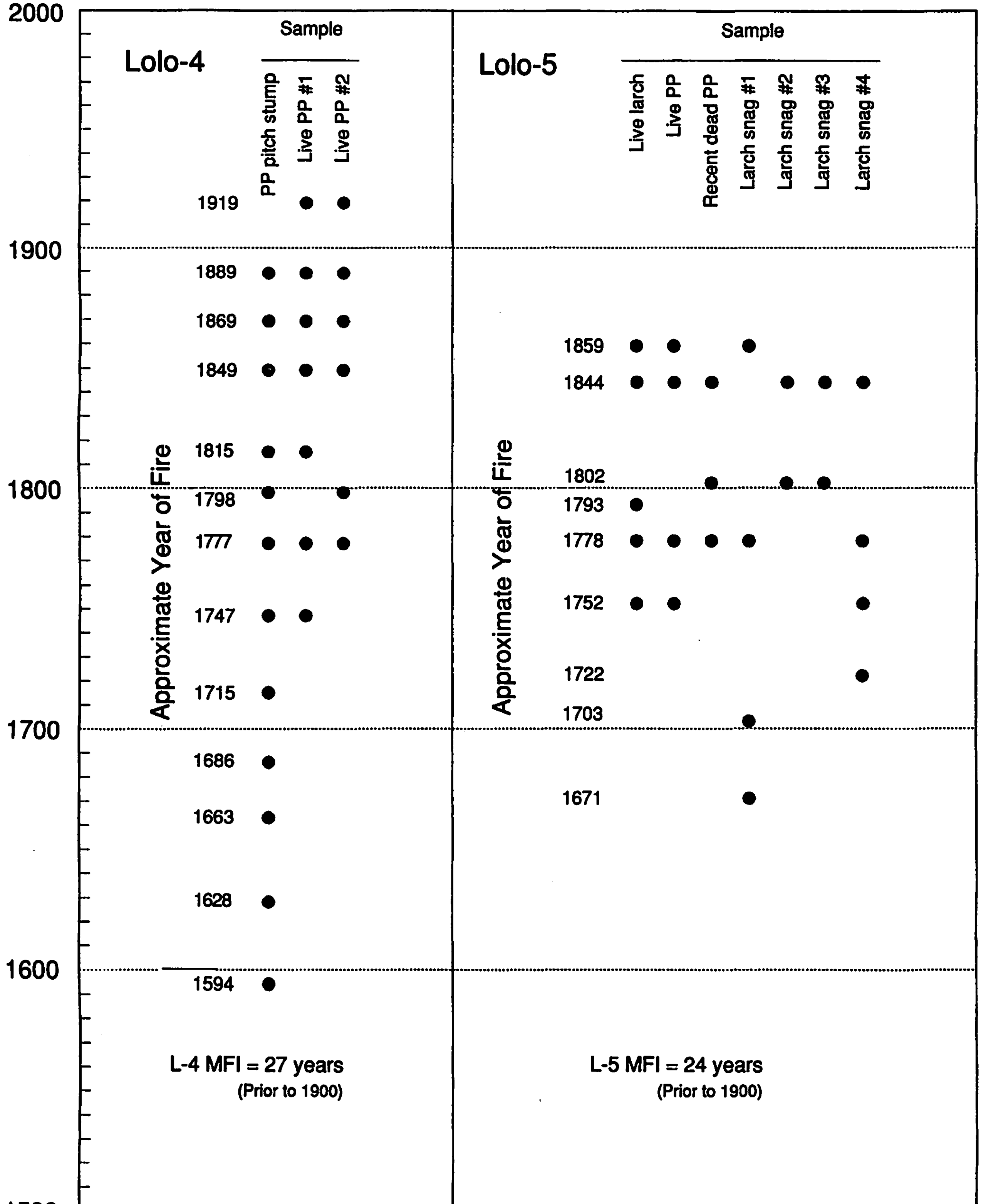


Figure 3—Comparison of Lolo-4 (L-4) and Lolo-5 (L-5) fire histories. PP = ponderosa pine, MFI = Mean Fire Interval.

Increment boring showed that most trees less than 8 inches diameter at breast height (d.b.h.) originated after 1900; therefore we sampled them less intensively. Ages of trees that became established before 1900 were determined from increment borings taken approximately 12 inches above the ground line, or occasionally higher when necessary because of basal rot. We used a power borer and bits up to 32 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. Cores were mounted onto grooved boards in the field (Arno and Sneck 1977).

Use of a power borer increased sampling efficiency. It allowed time for repeated boring attempts in large old growth trees where rot and off-center pith location necessitate several borings to obtain a useful sample (Scott and Arno 1992). Also, our experience has been that power boring results in less breakage of the expensive borer bits, probably because the bit is driven in and extracted under consistent power in contrast to the stop-and-go action of hand boring. To further reduce friction and breakage—especially important in larch, which has very dense wood—we applied beeswax to the borer bit prior to each drive. (Wax is conveniently applied to the warm or hot bit immediately after it is removed from a tree.)

Many of the core samples from old growth larch trees were highly fragmented due to ring shake and rot and required careful handling to ensure properly sequenced placement on core boards in the field. Plastic drinking straws commonly used for holding cores would not have worked in this case.

We prepared the increment cores for measurement using an orbital sander with medium (80 grit) and fine (up to 400 grit) paper. Annual rings were counted under a 7 x 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 age data collected in past studies (Arno and others 1985; Fiedler 1984). The second correction was the estimated number of rings missed on a core that did not intersect the pith. This is computed as the product of the estimated distance to the pith from the innermost ring visible on the core and the average growth rate near the innermost ring. For example, 0.4 inches to the pith x 8 rings per inch = correction of about 3 years. Distance from the innermost ring to the pith is determined using a clear template with nested circles (Ghent 1955).

To improve estimates of total age we bored the trees as low as possible, used long borer bits, and made repeated attempts to intersect the pith. Fiedler and Steele (1992) cross-dated increment borings from six of our previously sampled old growth stands and found 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 (Arno and others 1995). 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. Cross-dating of each core (Stokes and Smiley 1968) would have been difficult in the numerous rotten and highly fragmented larch cores. Obtaining exact total ages would require destructive sampling—that is, felling each tree and sectioning the stump at ground line.

To reduce diameters of present overstory trees to estimate their circa 1900 d.b.h.'s, we could have subtracted two times the post-1900 radial growth as measured on increment cores. However, our cores were generally taken lower on the tree, where diameter is larger than d.b.h. Also, individual radii reflected in cores are often wider or narrower than the mean reflected in a d.b.h. measurement. To overcome these problems we took the ratio of pre-1900 growth to the total radial growth of the tree on each increment core. For example, the increment core from an overstory tree has a total radial growth of 14 inches and the post-1900 radial growth is 4.2 inches. The ratio of pre-1900 growth to total growth in this case is 70 percent [(1 – (4.2/14)) x 100]. We multiplied 0.70 by the tree's measured d.b.h., 31 inches in this example, to arrive at a circa 1900 diameter of 21.7 inches. Using this method we were able to calculate an estimated basal area and a general stand structure for 1900.

Post-1900 dead trees were added to the circa 1900 stand based on their diameters at the time of death. Trees that apparently died since 1900 were recorded by species and diameter. Standing dead trees were assumed to have died after 1900. Fallen trees whose boles were largely disintegrated were assumed to have died before 1900. Similar states of decay of trees felled and left on the ground in the late 1800's have been examined previously in these forest types (Arno and others 1995; Habeck 1994).

Both basal area and Stand Density Index (Reineke 1933) are measures of stand density, and therefore of site use. However, Stand Density Index provides a more sensitive measure of site use or growing space occupancy than does basal area (Long and Dean 1986). The Stand Density Index adjusts for tree size, and thereby provides a superior estimate of density in uneven-age stands or stands with numerous larger trees (Fiedler and Cully 1995; O'Hara and Valappil 1995). For example, the Stand Density Index associated with a square foot of basal area in 24 inch d.b.h. trees is only half that of a square foot of basal area in 4 inch trees (1.29 versus 2.64) (Fiedler and Cully 1995), reflective of the much lower ratio of sapwood to total basal area in larger, older trees. The Stand Density Index may also provide a better estimate of density in old growth stands being considered for restoration treatments. The Stand Density Index for all 11 of our old growth stands was calculated for both current conditions and circa 1900 conditions. For greater accuracy, we calculated the Stand Density Index of our stands based on actual tree diameters

Table 2—Summary of basal areas/acre and Stand Density Index/acre (SDI/acre) for all 11 old growth stands comparing historic and modern levels.

Plot	Year	BA	SDI
		Ft²/acre	
B-1	1991	137	198
	1900	77	116
B-2	1991	176	292
	1900	80	114
B-3	1991	131	202
	1900	143	179
B-4	1993	135	206
	1900	90	121
F-1	1990	155	237
	1900	97	137
F-2	1990	138	220
	1900	59	102
L-1	1991	109	153
	1900	72	100
L-2	1991	98	147
	1900	95	132
L-3	1991	197	278
	1900	159	229
L-4	1994	173	298
	1900	87	132
L-5	1995	226	321
	1900	85	106

Note—Basal area (BA) was calculated on actual tree diameters instead of by d.b.h. classes; therefore, figures for the nine previously sampled stands are slightly different than those published earlier in Arno and others 1995.

instead of by d.b.h. classes or average stand diameter (table 2). We also calculated basal areas from actual tree diameters, hence the figures presented for the nine previously sampled stands (table 2) are slightly different than those published earlier (Arno and others 1995).

Results

Age-Class Structures

Stand Lolo-4 (L-4) has a distinctly even-age structure among the pre-1900 trees (fig. 4a). Most of the pre-1900 ponderosa pine and larch regenerated within 35 years after an apparent stand replacement fire in about 1663. Curiously, seven larch (obviously small at the time) in the upper right portion of the sample plot (fig. 5a) survived this fire, whereas none of the pine predated 1663. The large ponderosa pine (pitch stump from about 1919 logging) that we sampled about 100 yards below the plot survived and was scarred by the 1663 fire (fig. 3). All our data on age-class structure (fig. 4, 5) represents trees still surviving. Many more trees probably regenerated but were killed, especially as saplings, by fires and other agents.

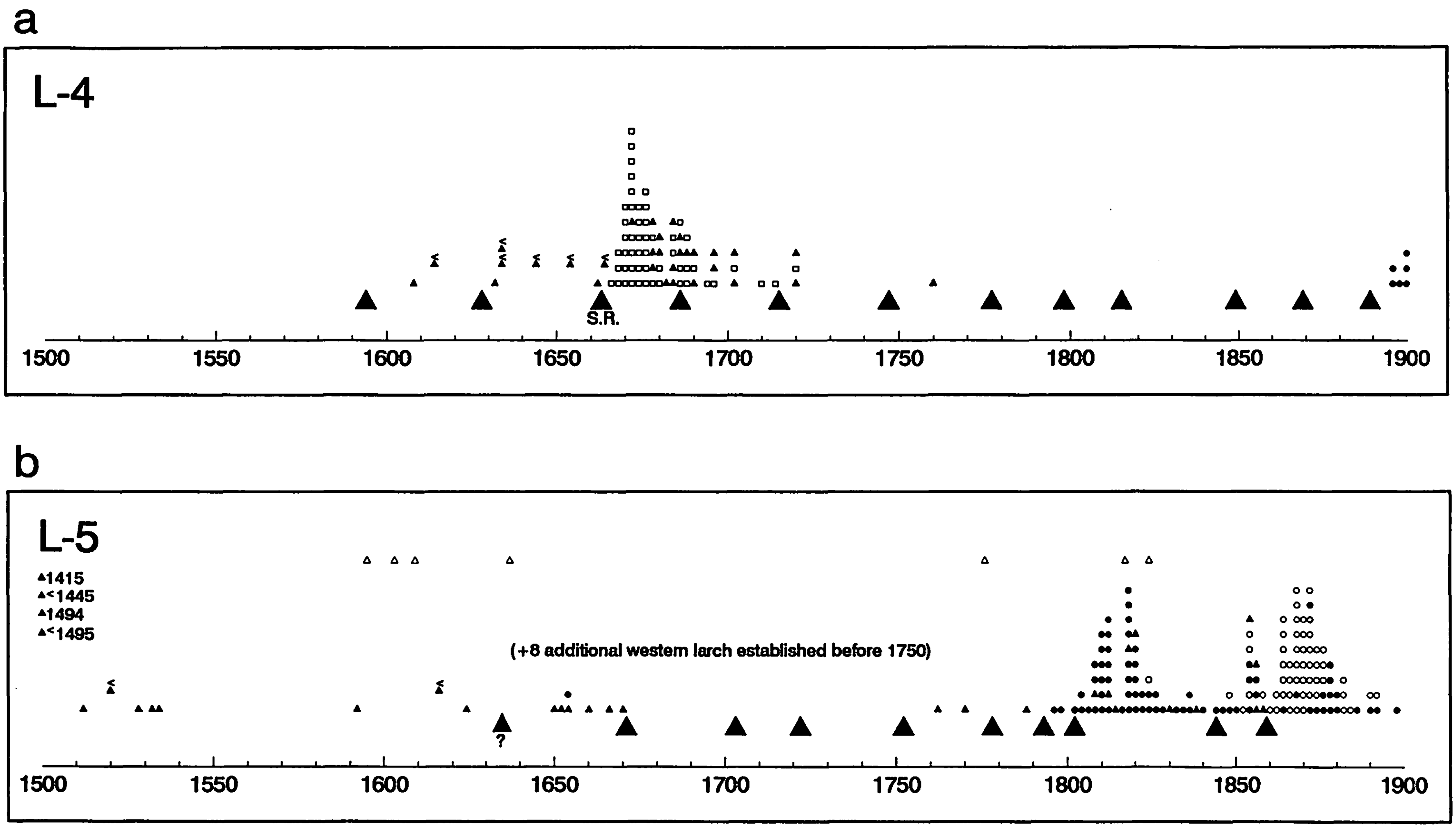
Stand Lolo-5 (L-5) has a highly uneven-age structure among the pre-1900 trees (fig. 4b). Larch became established in every century starting with the early 1400's. There are apparent age classes of larch originating in the early 1500's, early 1600's, and mid-1600's. In the early 1800's an abundance of Douglas-fir became established and survived, perhaps as a result of a comparatively long (42 year) fire interval. New larch establishment became scarce after 1800, possibly because of larch's inability to compete with Douglas-fir (Pfister and others 1977). Many young Douglas-fir survived the fires in about 1844 and 1859, and this final fire gave rise to an abundance of lodgepole pine regeneration (fig. 5b). The relatively short-lived lodgepole pine has produced small trees, averaging 9 to 13 inches in d.b.h. and 80 ft tall, which are now stagnated in growth and are succumbing to bark beetle attacks.

We arrayed L-4, L-5, and our nine earlier sample stands in a progression from most even-age to most uneven-age based on the establishment dates of the overstory ponderosa pine and larch—the long-lived, fire-dependent, and fire-resistant species (fig. 6). In this array only L-4, F-2, and F-1 are distinctively even-age, as a result of stand replacement fires in circa 1663, 1817, and 1601, respectively. These are three of the four stands that have larch as a component, although larch was a minor component in F-1.

Seven stands have a highly uneven-age structure. Stand L-5 is the only stand having larch, and it is dominated by larch. Stand L-3 is intermediate in being dominated by a single age class, arising in the early 1700's, but also having numerous older trees originating during previous centuries (Arno and others 1995).

Post-1900 Structural Changes

Both stands L-4 and L-5, like the nine previously reported stands, have undergone dramatic changes in structure and composition during this century. Stand L-4 was historically dominated by ponderosa pine and larch, with a small component of Douglas-fir (fig. 7a), which evidently did not live as long as the pine and larch. After the last fire in 1919, Douglas-fir saplings became established in great abundance along with lesser numbers of larch and a few ponderosa pine (fig. 7b). By 1994 the stand had developed a Douglas-fir understory thicket (fig. 8) with more than 650 trees per acre, mostly 1 to 5 inches in d.b.h. (fig. 7b). The larch and ponderosa pine regeneration has grown poorly in competition with Douglas-fir during this long fire-free period. The current fire interval is three times the pre-1900 mean fire interval and two times the maximum fire interval detected prior to 1900. Stand basal area (square feet per acre) has nearly doubled since 1900. The most dramatic element



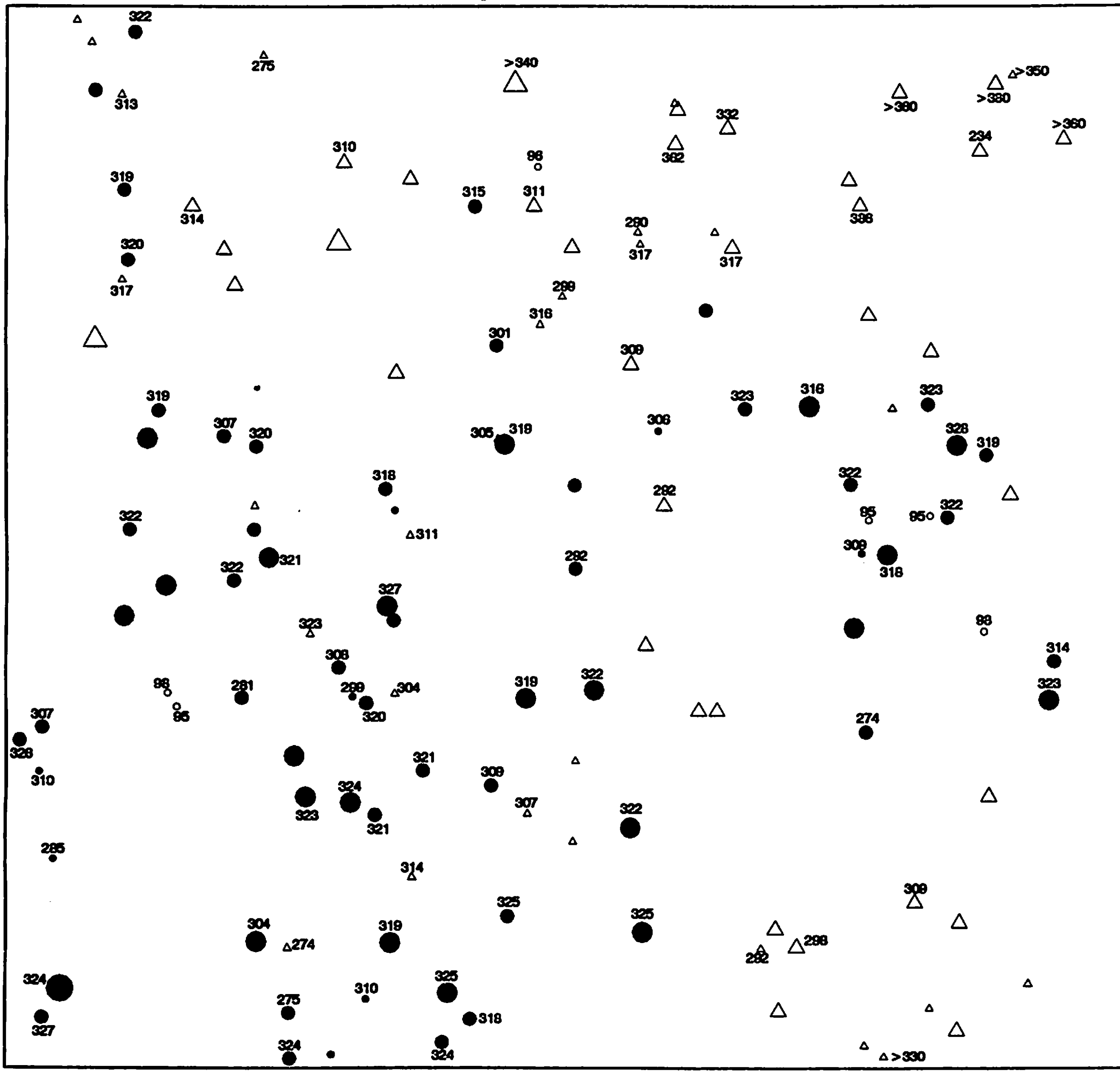
□ Ponderosa pine
○ Lodgepole pine
● Douglas-fir
▲ Western larch
△ Western larch found just outside boundary of study plot
▲ Fire year

S.R. designates a stand replacement fire
? designates an uncertain fire year
< designates that the tree predates its placement; precise date unknown due to rot near the pith

Figure 4a,b—Approximate regeneration dates for individual overstory trees by species plotted against number of trees, (each symbol represents one tree's establishment date) and approximate years of fire events for Lolo-4 (L-4) and Lolo-5 (L-5).

a

Lolo plot 4, 1994



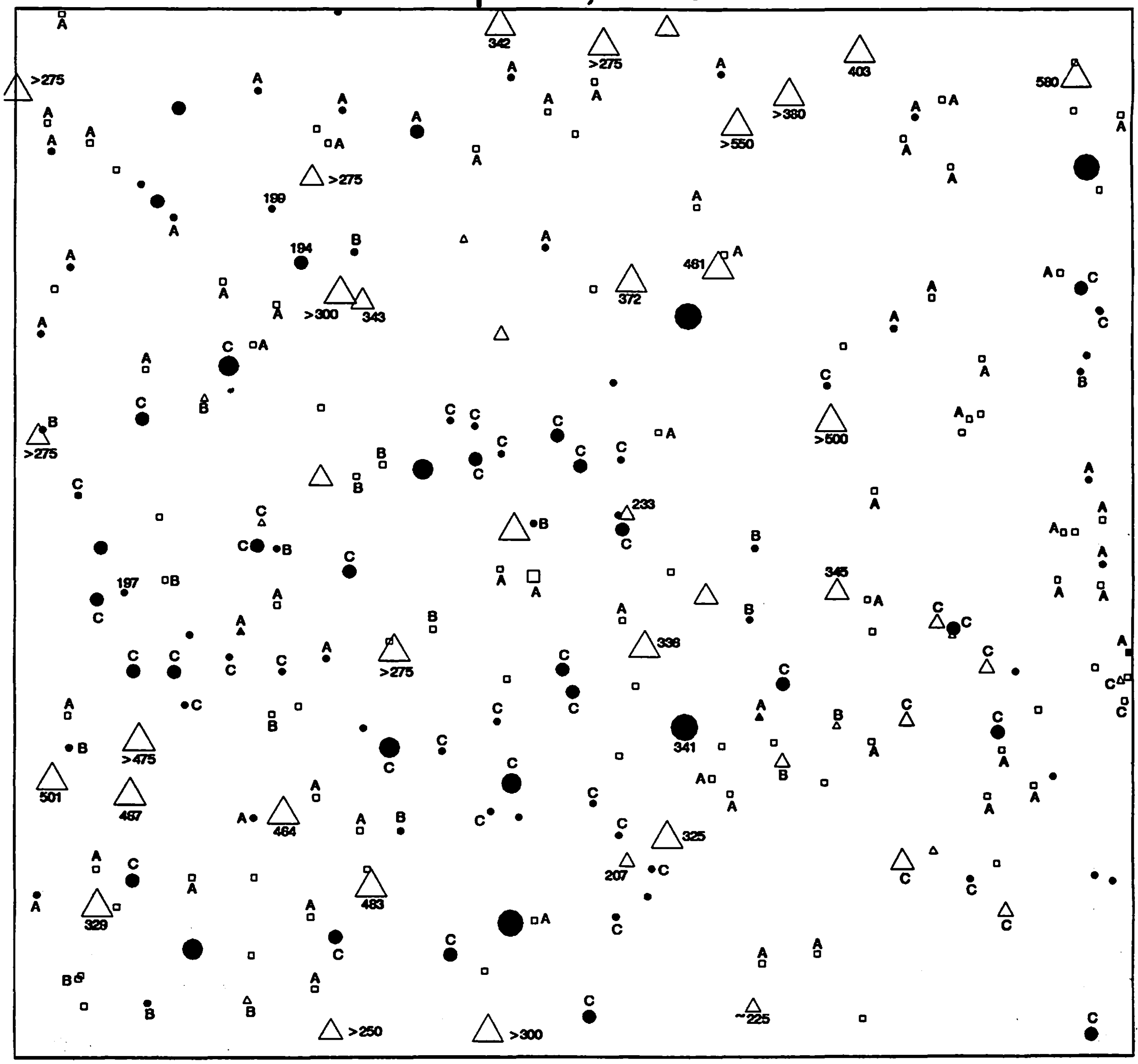
PP	WL	DF	
•	▵	∘	< 16.1"
●	△		16.1-24"
⬤	△		24.1-32"
⬤			32.1+"

Plot size is 328 x 328 ft
(2.22 acres)

Figure 5a,b—Mapped position of overstory trees (established before 1900) by species and diameter size class on Lolo-4 (L-4) and Lolo-5 (L-5). Approximate ages are shown for individual trees from which good quality cores were extracted. A > symbol preceding an age indicates the minimum age for that tree; a ~ symbol indicates the approximate age; PP = ponderosa pine; WL = western larch; DF = Douglas-fir; LP = lodgepole pine; ES = Engelmann spruce; SAF = subalpine fir.

b

Lolo plot 5, 1995



Post Fire Regeneration Classes

A = 1859 fire (95-136 years old)
B = 1844 fire (137-151 years old)
C = 1802 fire (152-193 years old)
Numbers indicate ages of trees that are greater than 193 years old

Plot size is 328 x 328 ft
(2.22 acres)

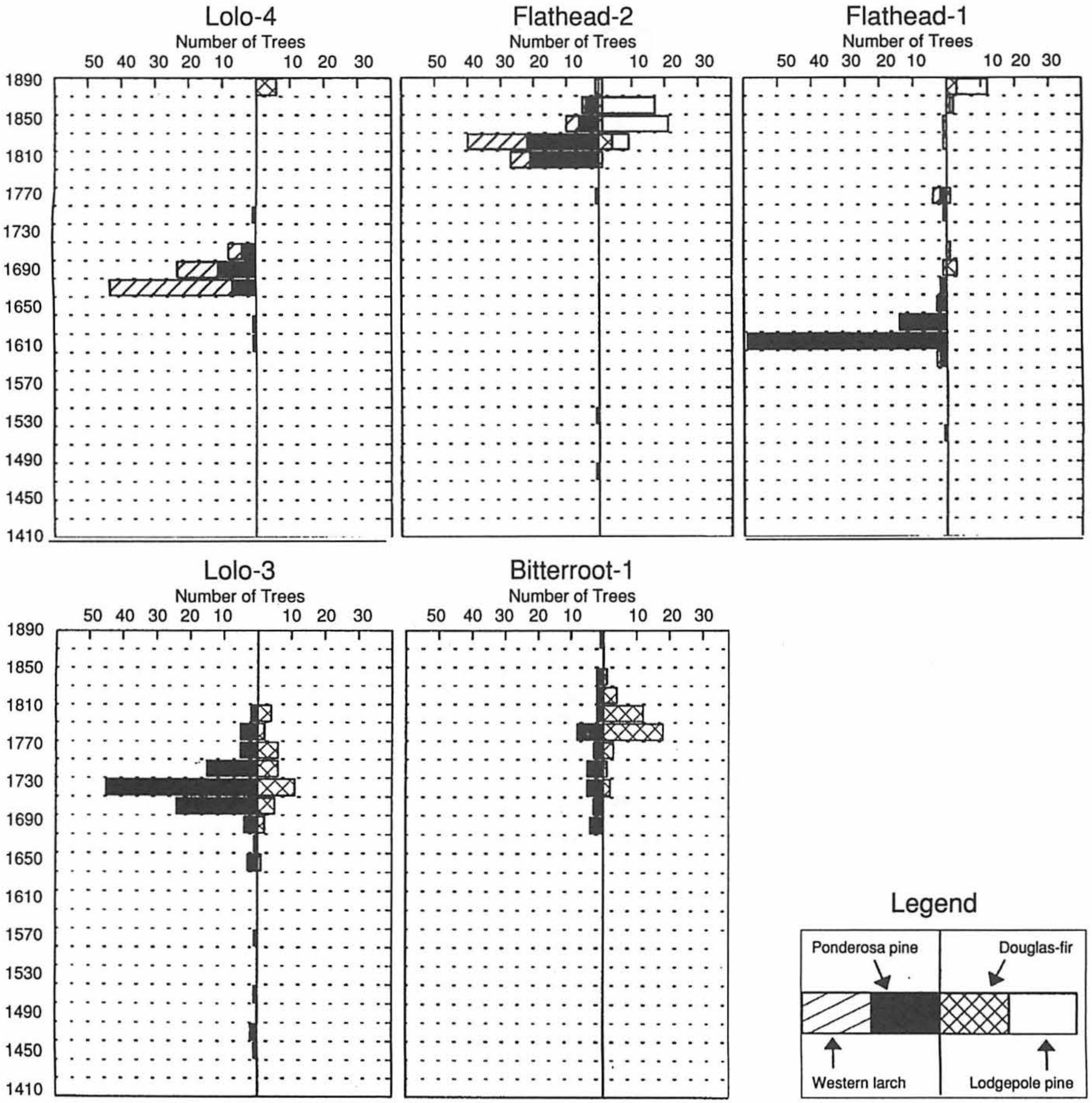
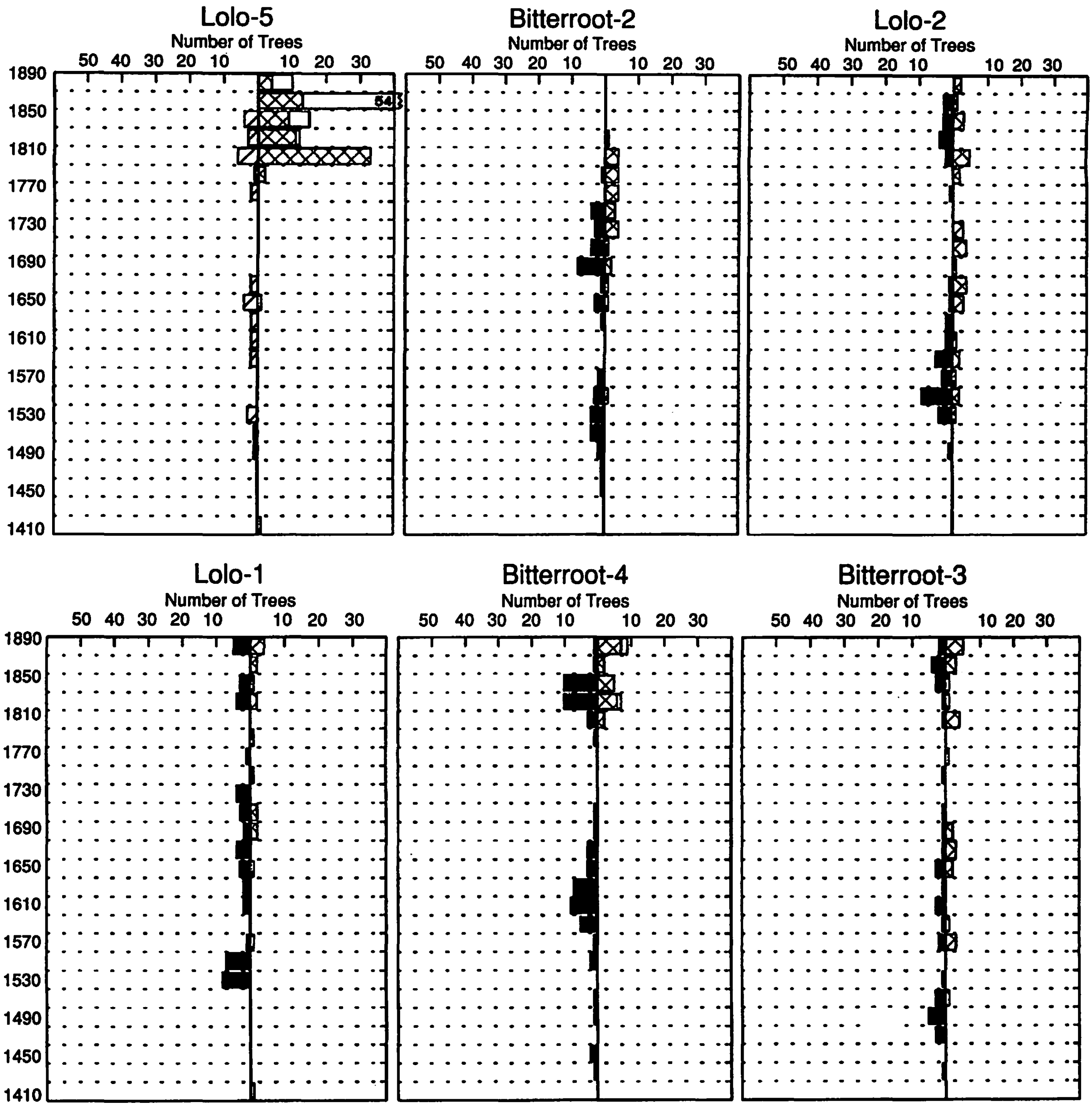


Figure 6a,b—Age class distributions based on tree establishment dates in 11 old growth ponderosa pine (PP) and larch (L) stands in western Montana. Years at left are midpoints of 20-year intervals. Stands are arranged from most even-age PP and L, shown on the left side of each graph, to most uneven-age PP and L. Data on right side of each graph represent other tree species. Data were taken from a 1 hectare plot in each stand as described in the text.

(con.)

Figure 6 (Con.)


Lolo-5
Number of Trees
50 40 30 20 10 10 20 30
543
Bitterroot-2
Number of Trees
50 40 30 20 10 10 20 30
Lolo-2
Number of Trees
50 40 30 20 10 10 20 30
1890
1850
1810
1770
1730
1690
1650
1610
1570
1530
1490
1450
1410
Lolo-1
Number of Trees
50 40 30 20 10 10 20 30
Bitterroot-4
Number of Trees
50 40 30 20 10 10 20 30
Bitterroot-3
Number of Trees
50 40 30 20 10 10 20 30

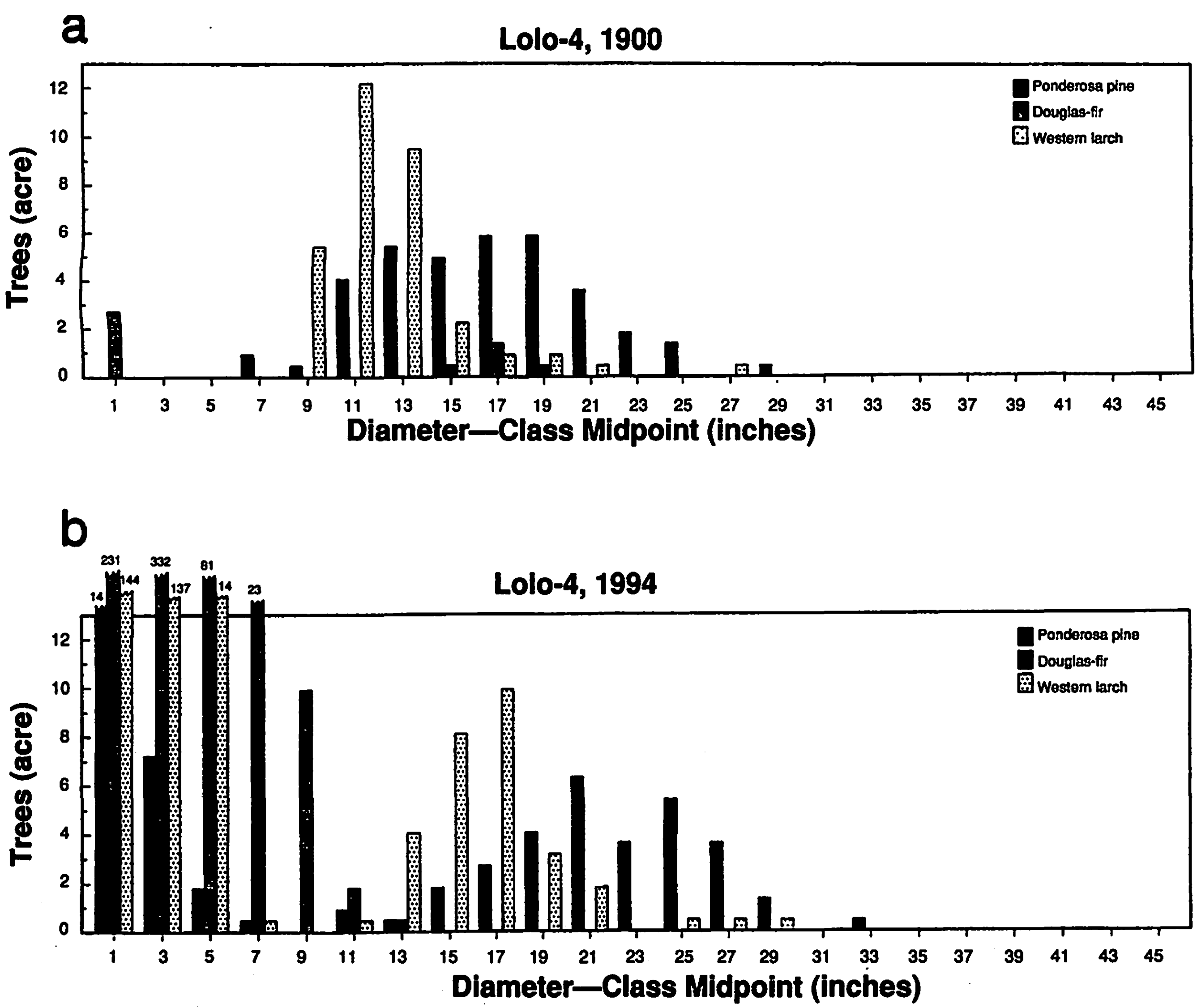


Figure 7a,b—Comparison of stand structures for Lolo-4 (L-4) as estimated for the year 1900 and as measured in 1994. The 1900 estimates do not include small trees that may have been present, but have since died as a result of various agents.

of this change is the 10 fold increase in basal area of Douglas-fir (fig. 9; table 3). Stand Density Index per acre has increased by a factor of 2.3 (table 2), largely as a result of the understory development. A comparison of density, structure, and species composition between 1900 and the 1990's (fig. 10a,b) illustrates the successional advancement of Douglas-fir in the understory. Meanwhile, the number of overstory pine and larch has declined by 10 percent during this century.

Changes in L-5 have been noticeable since the early 1800's, when a prominent age class of Douglas-fir became established, followed after 1859 by an age class of lodgepole pine (fig. 4b). Since 1900, an additional 250 Douglas-fir per acre have become established, forming a patchy understory layer (fig. 11a,b; 12). Larch regeneration is almost nonexistent, with the youngest larch being more than 130 years old (fig. 4b). Stand basal area has increased 2.7 times since 1900, with Douglas-fir increasing by 73 square feet per acre (fig. 13). The Stand Density Index has increased three-fold in L-5 (table 2). Figures 14a,b illustrate structural changes during this century. The total number of trees on the plot increased 4.5 times since 1900, including dramatic increases in the numbers of Douglas-fir and lodgepole pine in the overstory.

In the comparison of post-1900 changes in Stand Density Index for all 11 sample stands, the increase in Stand Density Index has been slightly to moderately higher than the increase in basal area (table 2). The one stand (B-3) that showed a decrease in basal area during

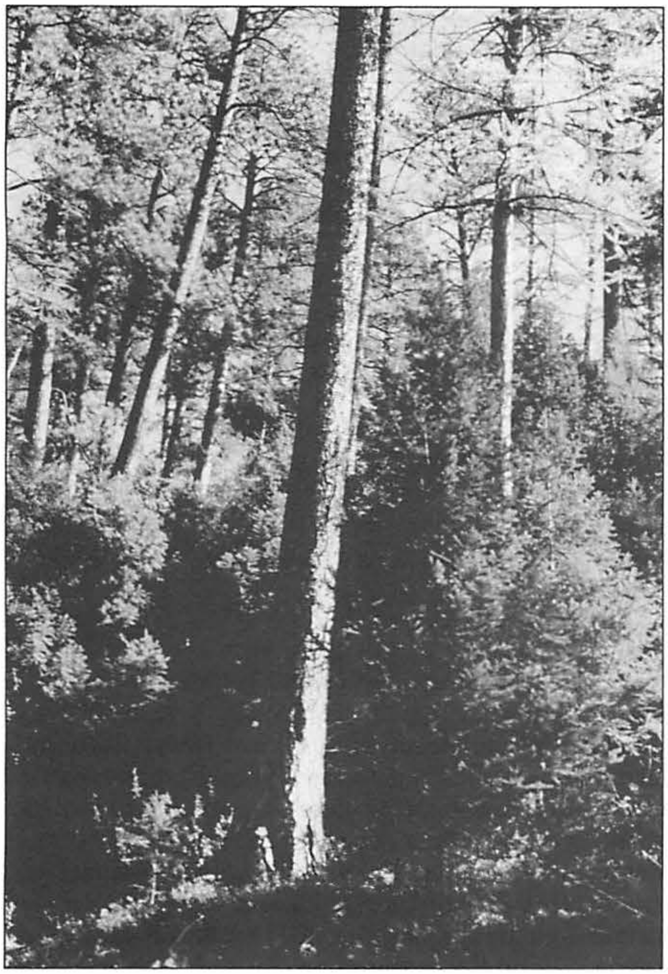


Figure 8—Photograph of Lolo-4 (L-4) in 1994 showing Douglas-fir understory thicket with predominantly larch and ponderosa pine overstory.

this century, due to major mortality of large overstory trees, still increased in Stand Density Index, due to continued ingress of Douglas-fir in the understory.

Discussion

The 11 stands on eight different sites sampled in western Montana represent a considerable range of site conditions and corresponding contrasts in topography from well-watered valley bottoms to droughty south-facing slopes on high ridges. All historically experienced frequent low-intensity fires, a condition that favored retention of the long-lived, fire-dependent, and fire-resistant species—ponderosa pine and western larch. Three of the sites also had occasional stand-replacing fires, and all of these stands had larch. Western larch sites are more moist and productive than many of the ponderosa pine sites without larch. Mixed severity fire regimes are generally associated with more moist sites, perhaps because drier sites (having nonlethal fire regimes) are receptive to burning for a longer time each year. The drier sites experience fires and their fuel reduction effects more often (Agee 1993). The natural distribution of western larch extends more to cooler and wetter sites than does ponderosa pine, and in these sites larch is a fire-dependent associate of mixed-severity and stand-replacement fire regimes (Arno and Fischer 1995). Historically, some dry ponderosa pine sites must have experienced occasional stand replacement fires, but this appears to have been relatively uncommon in western Montana.

Our new sample stands, L-4 and L-5, provide interesting examples and contrasts regarding influences of site conditions and other factors in determining the pre-1900 fire regime. Stand L-4 had a regime of frequent low-intensity fires and an occasional stand replacement fire. This is understandable, given the moderately moist and productive habitat type and the stand's location high on a steep, west-facing slope. Prevailing westerly winds would enhance the slope

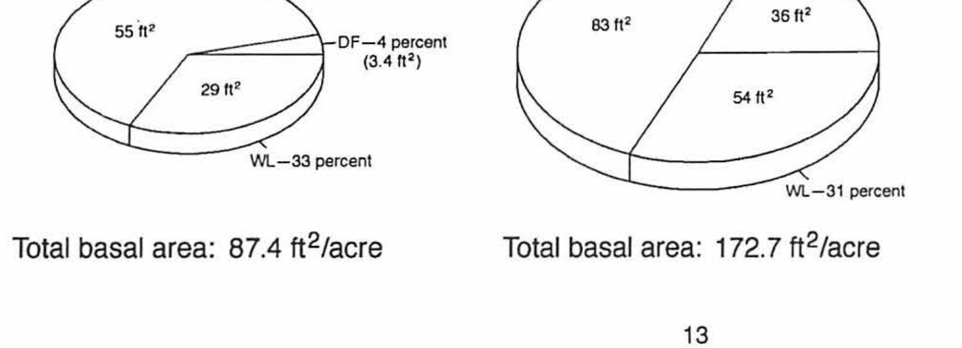


Figure 9—Comparison of basal areas for Lolo-4 (L-4) for 1900 and 1994 by square feet and percent composition. Tree abbreviations are as follows: PP = ponderosa pine; DF = Douglas-fir; WL = western larch.

Table 3—Summary of overstory tree density, composition, and size; and comparison of current total basal areas with estimated basal area in 1900 for Lolo-4 (L-4) and Lolo-5 (L-5). ("+" signifies a value less than 1).

	Number of overstory trees[a] 1994-1995		Estimated number of overstory trees that died after 1900		Median d.b.h.[b] of overstory trees 1994-1995		Total basal area 1994-1995		Total estimated basal area in 1900	
	Lolo-4	Lolo-5	Lolo-4	Lolo-5	Lolo-4	Lolo-5	Lolo-4	Lolo-5	Lolo-4	Lolo-5
	Acres				*Inches*		*Ft²/acre*			
PP[c]	28		4		21.8		83		55	
DF	2	38	2		10.2	14.6	36	86	3.4	12.6
LP		36		4		11.4		29		1.2
WL	26	19	3	+	16.5	31.3	54	109	29	70.7
SAF		+				8.2		1		+
ES		+				12.1		1		+
All	56	93+	9	4+	16.2	15.5	172.7	226.4	87.4	84.5+

[a]Overstory trees are those that were established before 1900.
[b]Diameter at breast height.
[c]PP = ponderosa pine, DF = Douglas-fir, LP = lodgepole pine, WL = western larch, SAF = subalpine fir, ES = Engelmann spruce.

effect allowing fire to spread with greater intensity upslope. Stand B-4 was even more moist as determined by habitat type (table 1), but did not experience a stand-replacing fire in the last few centuries. This difference in fire regimer topography and easterly aspect at B-4 and to the short fire intervals, half as long as at L-4, which would minimize fuel accumulation.

Stand L-5 occurs on the wettest of the eight sample sites, based on habitat type (table 1), and surprisingly shows no history of stand-replacing fire. It is on a flat site, but drier flat sites at F-1 and F-2 had occasional replacement fires. Stand L-5 (at Girard Grove along Seeley Lake) had a history of low to moderate intensity underburns at comparatively high frequencies—mean fire interval of 24 years from about 1859 back to about 1671 based on fire scars (fig. 3), and apparently back to the early 1500's based on larch age-class cohorts (fig. 4b). In contrast, most forests away from the lake show evidence of historic replacement fires. The abundance of 500- to 600-year-old larch with multiple fire scars at Girard Grove and in much of the forest surrounding Seeley Lake, based on examination of the stumps of early 1900's logging, suggests an absence of stand-replacing fires in many of these forests for at least 600 years. Koch (1945) examined ages of logged larch trees in stands bordering Seeley Lake and reported that the oldest had become established soon after the year 1000 and in the early 1200's. The oldest of these was one of a few trees that had attained a diameter of 7 ft (Koch 1945). One such giant larch at Girard Grove is 84 inches d.b.h. and is listed as the co-champion largest known western larch (American Forests 1996). Considering this tree's size and gnarled appearance, it is probably well over 600 years, but is too large and probably too rotten for age determination.

Today, the undergrowth at Girard Grove (L-5) and surrounding stands is not very flammable and tends to burn poorly except under summer drought conditions, when severe wildfires occur (Margaret Doherty, personal communication). The virtual absence of ponderosa pine on this site further reduces sources of fuel for surface fires such as long pine needles. Paradoxically, at stands F-1 and F-2 in the same glacial trench or valley train about 25 miles north on a warmer and drier habitat type with abundant ponderosa pine, pre-1900 fire intervals were about the same or slightly longer (Arno and others 1995; Freedman and Habeck 1985).

Another anomaly in the relationship of fire frequencies to site moisture arises at site B-4 (table 1). This site had very frequent fires and is immediately adjacent to the Bitterroot Valley where an earlier study suggests that Indian burning played a major role in increasing fire frequencies on the landscape (Barrett and Arno 1982). Similarly, the historical fire regime at stand L-5 may have had an important component of Indian burning for hundreds of years. The U.S. Geological Survey inspection, of what was then the Lewis and Clark Forest Reserve, made in the late 1890's (Ayres 1901) states:

> There is no doubt that some of the fires, especially on the higher ranges, are due to lightning, but most of those in the valley seem to have been set by Indian and other hunting parties or by prospectors. The trails most frequented by Indians, as the Jocko and Pend Oreille, are noticeably burned, especially about the camping places.

European-American travel in the valley was evidently rare prior to the late 1800's. Girard Grove, the site of stand L-5, is at the outlet of Seeley Lake and is

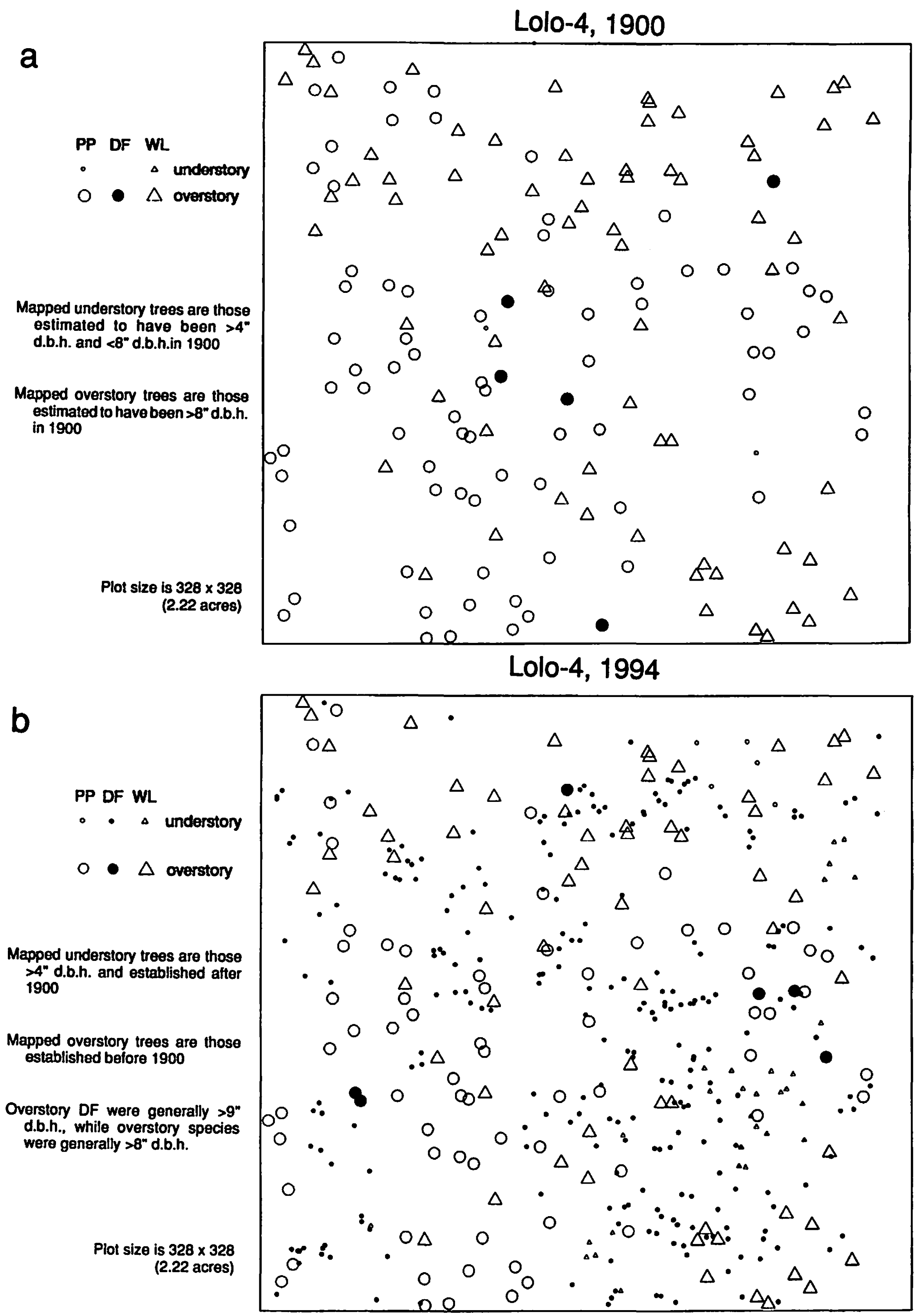
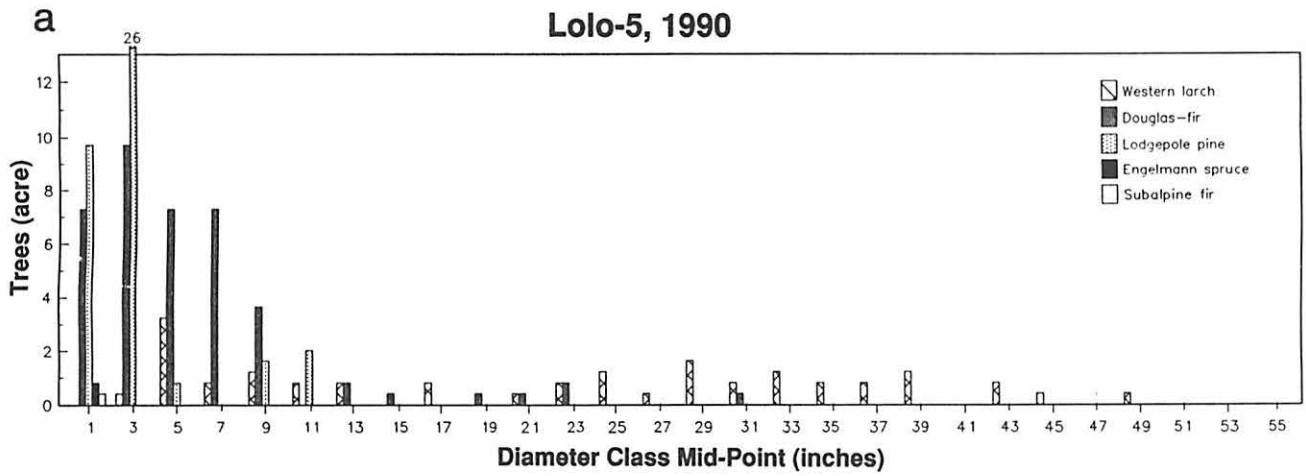


Figure 10a,b—Mapped position of both understory and overstory trees on Lolo-4 (L-4) in 1900 and 1994. Tree abbreviations are as follows: PP = ponderosa pine; DF = Douglas-fir; WL = western larch.

a



b

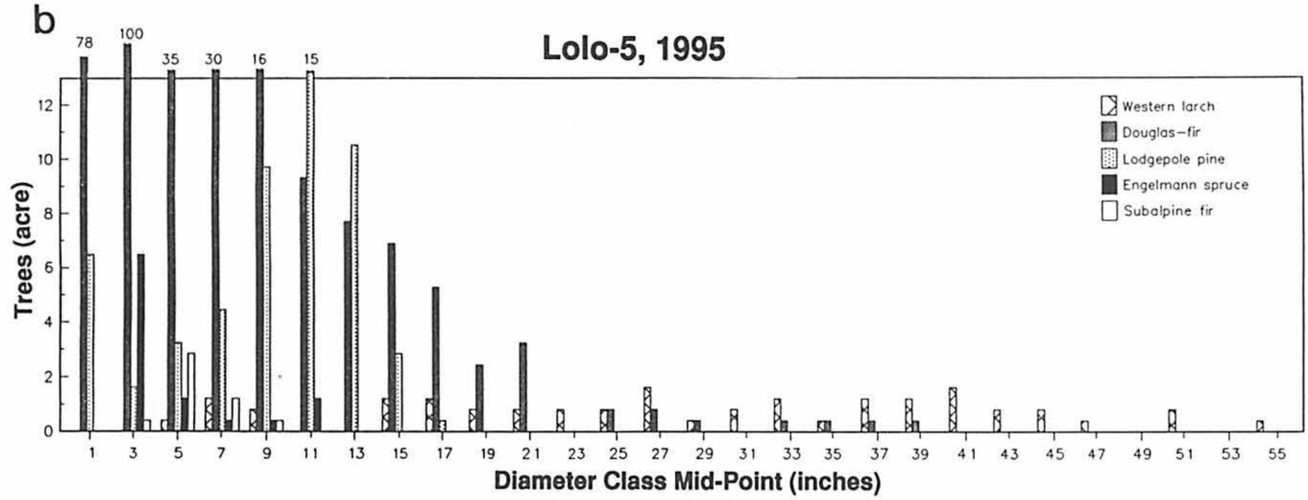


Figure 11a,b—Comparison of stand structures for Lolo-5 (L-5) as estimated for the year 1900 and as measured in 1995. The 1900 estimates do not include small trees that may have been present, but have since died as a result of various agents.

Figure 12—Photograph of Lolo-5 (L-5) in 1995 showing large old larch and Douglas-fir understory.

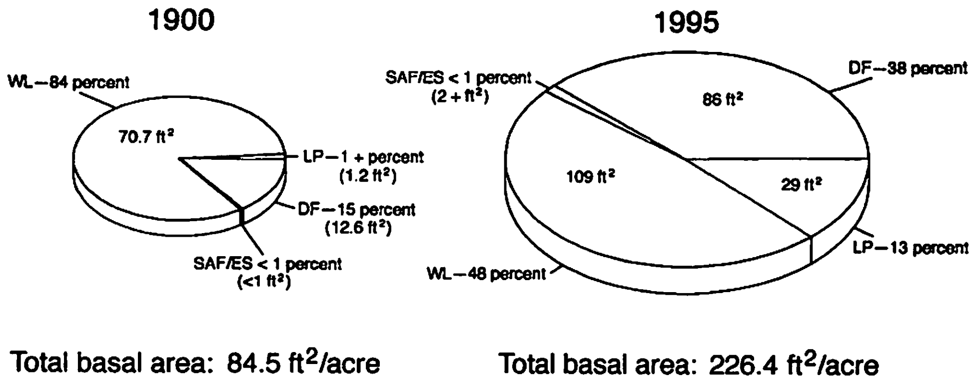


Figure 13—Comparison of basal areas for Lolo-5 (L-5) 1900 and 1995 by square feet and percent composition. Tree abbreviations are as follows: DF = Douglas-fir; LP = lodgepole pine; WL = western larch; ES = Engelmann spruce; and SAF = subalpine fir.

evidently at end of the "Jocko Trail." Girard Grove could be assumed to be a likely camping area for native peoples. Numerous artifacts suggest a sustained level of aboriginal activity in areas immediately surrounding Girard Grove and dating back 3,500 years (Milo McLeod, personal communication).

The much more open growing conditions associated with the historic stand structure at Girard Grove (fig. 14a; table 2), would have presumably favored a grassy undergrowth more conducive to burning than the current undergrowth of huckleberry (*Vaccinium* spp.), kinnikinnick (*Arctostaphylos uva-ursi*), and other shade-tolerant plants.

Implications for Stand Management

The historical interaction of frequent fire with ponderosa pine and larch in our 11 old growth stands helped produce a variety of age-class structures, although most stands probably had a similar physical (open, parklike) appearance. This historical evidence suggests that a range of management alternatives is possible while restoring some semblance of pre-1900 composition, structure, and disturbance history. Such restoration is a general goal of national forest management in western Montana (Losensky 1989) due to a variety of esthetic and ecological values associated with old growth ponderosa pine and larch. The greatest challenge in restoration management will be dealing with radical alterations in stand structure, live and dead fuels, and the shift of seed sources in favor of the shade-tolerant conifers.

It seems probable that silvicultural removal of understory trees, which constitute the "ladder fuels" that allow fires to crown out, will be necessary preceding any reintroduction of fire (Fiedler 1996; Harrington 1996). The current stand structure and condition of overstory trees in stand L-4 exemplifies a need for tree removal. Growth of the ponderosa pine and larch overstory has increased basal area from a moderate 84 square feet per acre in 1900 to 137 square feet in 1994 (fig. 9; table 3). Additionally, the 10-fold increase in basal area of the Douglas-fir understory to 36 square feet per acre produces an evident stress on all trees. Foliage of both ponderosa pine and larch crowns is noticeably thin and sparse. The Douglas-fir understory is heavily infected with dwarf mistletoe (*Arceuthobium douglasii*) and Douglas-fir radial growth is very slow. Some post-1919 understory Douglas-fir and larch already have advanced bole rot, apparently from *Phellinus pini*. Post-1900 radial growth of overstory ponderosa pine and larch averaged only 0.4 inch in the last 20 years. These are symptoms of severe growth stress related to overstocking.

Effective application of fire without prior removal of understory trees would be difficult since any burn sufficiently intense to kill understory trees would probably damage the already stressed overstory. A stand replacement fire today (unlike the one in about 1663) probably would not result in significant natural regeneration of ponderosa pine, due to depletion of seed source in the area as a result of past logging and succession to Douglas-fir. Successional studies on comparable sites suggest that Douglas-fir and possibly larch would become dominant after a stand replacement wildfire (Arno and others 1985; Jacobsen 1986). Given the advanced successional state of the vegetation at this relatively high-elevation site, any strategy to perpetuate ponderosa pine will probably require planting in small openings. Such openings could be created by harvesting or slashing understory trees and burning them in natural openings when there is little likelihood of fire spreading appreciably.

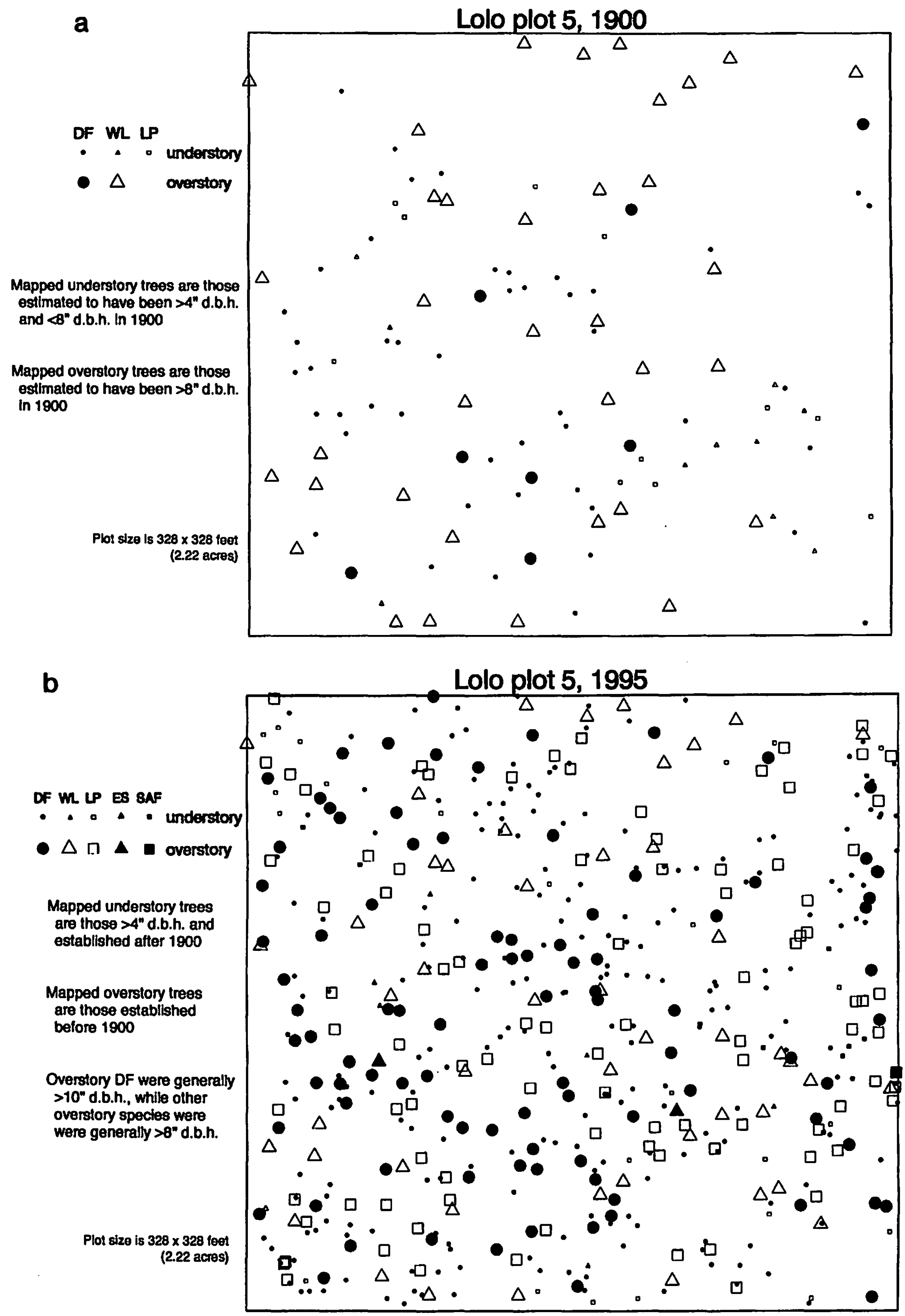


Figure 14a,b—Mapped position of both understory and overstory trees on Lolo-5 (L-5) in 1900 and 1995. Tree abbreviations are as follows: DF = Douglas-fir; LP = lodgepole pine; WL = western larch; ES = Engelmann spruce; and SAF = subalpine fir.

Stand L-5, Girard Grove at Seeley Lake, represents an easier opportunity for restoration management. Condition and growth of the overstory is reasonably good, and the understory of Douglas-fir is less dense than in stand L-4. Flat terrain and easy access contrasts with the steep slope at stand L-4, and would facilitate removal of understory trees as well as application of prescribed fire.

Perhaps the most difficult question in designing restoration management for Girard Grove is establishing a conceptual goal for such management. It appears that the parklike, uneven-age larch stand at Girard Grove—and probably extending along much of the immediate vicinity of Seeley Lake—was a product of aboriginal burning. Regardless of the ignition source, however, the frequent low-intensity fires produced an open stand of very large and long-lived larch represented by many different age classes. This contrasts with patchy larch-lodgepole pine stands with 1 to 3 age classes that are typical of this forest type and habitat type (Antos 1977; Barrett and others 1991; Davis 1980). Due to occasional replacement fires, most larch-lodgepole pine forests did not develop extensive areas dominated by 300 to 600-year-old trees. At Girard Grove the frequent fire regime and its effects are relatively clear. If these effects are considered desirable, they could be simulated through the use of understory removal cutting and prescribed burning.

Conclusions

Recent ecological and anthropological evaluations suggest that aboriginal burning was an important component of many historical fire regimes in western and central North America (Barrett and Arno 1982; Botkin 1990; Boyd 1986; Denevan 1992; Finney and Martin 1992; Gruell 1985; Lewis 1985). Moreover, trying to partition out and remove the effects of aboriginal ignitions to define a conceptual "natural" condition without human influence would no doubt be a highly speculative endeavor.

A common perception in American society is that old growth forests can be perpetuated by leaving them alone—letting nature take its course without human interference. This concept has serious shortcomings in forests that evolved under the influence of fire and where preservation continues the practice of excluding fire. The problem of preservation is further compounded in old growth stands historically associated with a frequent fire regime, because fire exclusion has drastically altered these ecosystems (Agee 1993; Covington and Moore 1994; Habeck 1988; Moir and Dieterich 1988; Swetnam and Dieterich 1985). We hope that this information on the relationship of stand structure to fire history will provide useful background for designing strategies to restore and maintain old growth ponderosa pine and larch.

References

Agee, J. K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

American Forests. 1996. National register of big trees. American Forests. 102(1): 20-51.

Antos, J. A. 1977. Grand fir forests of the Swan Valley, Montana. University of Montana, Missoula. 220 p. Thesis.

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.; Fischer, W. C. 1995. *Larix occidentalis*—fire ecology and fire management. In: Ecology and management of larix forests: a look ahead. Gen. Tech. Rep. INT-GTR-319. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 130-135.

Arno, S. F.; Scott, J. H.; Hartwell, M. 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.

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 Forest and Range Experiment 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. 21st Annual Rep. Part V. U.S. Department of the Interior, U.S. Geological Survey: 27-80.

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.

Botkin, D. B. 1990. Discordant harmonies: a new ecology for the twenty-first century. NY. Oxford University Press. 241 p.

Boyd, T. 1986. Strategies of Indian burning in the Willamette Valley. Canadian Journal of Anthropology. 5: 65-86.

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.

Davis, K. M. 1980. Fire history of a western larch/Douglas-fir forest type in northwestern Montana. Gen. Tech. Rep. RM-81. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 69-74.

Daubenmire, R.; Daubenmire, J. B. 1968. Forest vegetation of eastern Washington and northern Idaho. Tech. Bull. 60. Pullman, WA: Washington State University, Agriculture Experiment Station. 104 p.

Denevan, W. 1992. The pristine myth: the landscape of the Americas in 1492. Association of American Geographers Annals. 82: 369-385.

Doherty, M. M. 1995. [Personal communication]. Fire management officer, Seeley Lake Ranger District, Lolo National Forest, Seeley Lake, MT.
Fiedler, C. E. 1984. Unpublished regeneration data on file at: School of Forestry, University of Montana, Missoula.
Fiedler, C. E. 1996. Silvicultural applications: restoring ecological structure and process in ponderosa pine forests. In: Hardy, C. C.; Arno, S. F., eds. The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 39-40.
Fiedler, C. E.; Cully, J. F., Jr. 1995. A silvicultural approach to develop Mexican spotted owl habitat in Southwest forests. Western Journal of Applied Forestry. 10: 144-148.
Fiedler, C. E.; Steele, B. M. 1992. Relationship of tree growth and recruitment to fire in old growth pine/fir forests-results in cross-dating. Unpubl. Rep. 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.
Finney, M. A.; Martin, R. E. 1992. Short fire intervals recorded by redwoods at Annadel State Park, California. Madrono. 39: 251-262.
Freedman, J. D.; Habeck, J. R. 1985. Fire, logging, and white-tailed 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.
Gruell, G. E. 1985. Fire on the early western landscape: an annotated record of wildland fires 1776-1900. Northwest Science. 59: 97-107.
Habeck, J. R. 1988. Old-growth forests in the Northern Rocky Mountains. Natural Areas Journal. 8: 202-211.
Habeck, J. R. 1994. Using General Land Office records to assess forest succession in ponderosa pine/Douglas-fir forests in western Montana. Northwest Science. 68: 69-78.
Harrington, M. G. 1996. Prescribed fire applications: restoring ecological structure and process in ponderosa pine forests. In: Hardy, C. C.; Arno, S. F., eds. The use of fire in forest restoration. Gen. Tech. Rep. INT-GTR-341. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 41.
Jacobsen, G. L. 1986. Are you getting ponderosa pine and Douglas-fir cone crops at high elevations? In: Shearer, Raymond C., comp. Proceedings—conifer tree seed in the Inland Mountain West symposium. Gen. Tech. Rep. INT-203. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 47-49.
Koch, E. 1945. The Seeley Lake tamaracks. American Forests. 51(1): 21, 48.
Lewis, H. T. 1985. Why Indians burned: specific versus general reasons. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings—symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 75-80.
Long, J. N.; Dean, T. J. 1986. Sapwood area of *Pinus contorta* stands as a function of mean size and density. Oecologia. 68: 410-412.
Losensky, B. J. 1989. Development and implementation of an ecosystem maintenance burning system. In: Baumgartner, D. M.; Brever, D. W.; Zamora, B. A.; Neuenschwander, L. F.; Wakimoto, R. H., eds. and comps. Prescribed fire in the Intermountain Region: forest site preparation and range improvement. Pullman, WA. Washington State University Cooperative Extension Service: 3-6.
Losensky, B. J. 1995. Historical vegetation types of the Interior Columbia River Basin. Contract Rep. RJVA-94951. Missoula, MT: Intermountain Research Station, U.S. Department of Agriculture, Forest Service. [Not paginated].
McLeod, C. M. 1996. [Personal communication]. Archaeologist. U.S. Department of Agriculture, Forest Service, Lolo National Forest, Missoula, MT.
Moir, W. H.; Dieterich, J. H. 1988. Old-growth ponderosa pine from succession in pine-bunchgrass forests in Arizona and New Mexico. Natural Areas Journal. 8(1): 17-24.
O'Hara, K. L.; Valappil, N. I. 1995. Age class division of growing space to regulate stocking in uneven-aged stands. In: O'Hara, K. L., ed. Uneven-aged management: opportunities, constraints and methodologies. Misc. Publ. 56. Missoula, MT: Montana Forest and Conservation Experiment Station, University of Montana: 123-143.
Pfister, R. D.; Kovalchik, Bernard L.; Arno, Stephen F.; Presby, Richard 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.
Reineke, L. H. 1933. Perfecting a stand-density index for even-aged forests. Journal of Agricultural Research. 46: 627-638.
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? In: High intensity fire in wildlands: management challenges and options: proceedings, 17th tall timbers fire ecology conference. 1989 May 18-21; Tallahassee, FL. Tallahassee, FL: Tall Timbers Research Station: 321-337.
Stokes, M. A.; Smiley, T. L. 1968. An introduction to tree-ring dating. University of Chicago Press. 73 p.
Swetnam, T. W.; Dieterich, J. H. 1985. Fire history of ponderosa pine forests in the Gila Wilderness, New Mexico. In: Lotan, James E.; Kilgore, Bruce M.; Fischer, William C.; Mutch, Robert W., tech. coords. Proceedings—symposium and workshop on wilderness fire. Gen. Tech. Rep. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station: 390-397.
USDA Forest Service, Lolo National Forest. 1994. Fire in western Montana ecosystems: a strategy for accomplishing ecosystem management through the effective use of prescribed fire in the Lolo National Forest. Lolo National Forest, Missoula, MT. 145 p.
West, N. E. 1969. Tree patterns in central Oregon ponderosa pine forests. American Midland Naturalist. 81(2): 584-590.
White, A. S. 1985. Presettlement regeneration patterns in a southwestern ponderosa pine stand. Ecology. 66: 589-594.

Arno, Stephen F.; Smith, Helen Y.; Krebs, Michael A. 1997. Old growth ponderosa pine and western larch stand structures: influences of pre-1900 fires and fire exclusion. Res. Pap. INT-RP-495. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 20 p.

Presents detailed age structure for two western larch stands that historically experienced frequent fires. Compares age structures of eleven ponderosa pine and western larch stands representing a broad range of sites that had frequent fires. Interprets causal factors possibly linked to variations in stand age structures.

Keywords: forest health, forest succession, fire-dependent forest, uneven-age management, aboriginal burning

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)