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Title: Fire History in Three Vegetation Types on the East Side of the Oregon Cascades

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Historic fire return intervals in three different vegetation types dominated by ponderosa pine (Pinus ponderosa Laws.) were determined using fire scarred trees. Dendrochronological techniques were used to achieve accuracy in dating fire scars on samples collected from six 40 acre plots established in each site. Mean fire return intervals (MFRI) differed for site and plots within each site; Pringle Butte site showed the shortest MFRI of 4 years with an average of 11 years for individual plots, Cabin Lake site had a 7 year MFRI and a 24 year MFRI for plots, while Lookout Mountain site had a MFRI of 8 years and 16 years for plots. The overall average for plots incorporates all of the data for the site but uses a 40 acre plot mean to determine length of time required for fire to return to the same location, giving a more accurate indication of MFRI in a given stand. The plot mean may be the most useful way of expressing the data. Basal area and understory vegetation were found to be useful for predicting MFRI.

Tree-ring chronologies from the three sites were examined to determine their suitability for climatic interpretation. Statistics show low mean sensitivities, high serial correlations and low variance for all trees and cores, suggesting that chronologies are of limited use for climatic analysis. However, climatic information was found. Growth patterns in sites show similar years for drought and high precipitation. Long-term trends were not evident at Cabin Lake or Lookout Mountain. Pringle Butte provided the chronology most useful for estimating climatic history, with 3 long periods of slow growth, 1900-1980, 1710-1790, and 1590-1640.

Fire History in Three Vegetation Types on the Eastern Side of the Oregon Cascades

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GENERAL INTRODUCTION

Fire has played an important ecological role in the ponderosa pine (*Pinus ponderosa* Laws.) forest, creating openings and exposing mineral seed beds for pine to grow and serving as a thinning agent, by reducing competing vegetation. Modern fire suppression has resulted in development of dense understories, causing abnormal fuel loads and adversely affecting growth rates and vigor of understory plants (Weaver 1959). The narrow policy of fire control is being modified to a policy of fire management. Fire history studies are now providing essential information for use in developing management plans. Fire history is a way of evaluating the role of fire since it provides an understanding of how existing stand structure developed and helps explain changes in age class distribution, fuel accumulation, natural regeneration and nutrient cycling.

The main objective of Chapter I is to determine the historic fire return interval in three different ponderosa pine vegetation types. Dendrochronological techniques were used in crossdating samples from fire scarred trees to provide accuracy in identifying fire years. Calculated mean fire return intervals (MFRI) differed among sites and among plots within sites. The overall average for plots within each site incorporates all of the data for the site but uses plot means to determine the length of time required for fire to return to the same location, thus giving a more accurate indication of MFRI in a given stand and may be the most useful way of expressing the data. Basal area and understory vegetation were examined as possible predictors of mean fire return intervals.

Chapter II examines tree-ring chronologies from the three vegetation types for their usefulness in climatic interpretation, and compares the growth patterns to determine the effects of regional climatic influence.

CHAPTER I. FIRE HISTORY

INTRODUCTION

Fire is a principal force that shapes forest ecosystems by initiating changes in vegetational patterns and composition. Vegetation types may be characterized by either severe surface or crown fires, which have intermediate to long return intervals and often establish a new stand (Heinselman 1981), or frequent small fires which produce a mosaic of many aged groups instead of even-aged stands (Kilgore 1981).

Components of a fire regime include season, intensity and return intervals. Season influences fire intensity. Fires that occur in late summer and early fall generally remove the organic layer of the forest floor, in contrast spring and early summer fires normally leave portions of the forest floor intact (Kilgore 1981). Fire return intervals, intensity and fuel consumption are reflected by vegetation characteristics such as age class, successional stage and vegetation type.

Success of a particular species in a specific fire regime depends on its fire-resistant characteristics. Thick bark, self-pruning of branches, adventitious buds, serotinous cone habit and coppicing are traits found in species that survive and benefit from frequent fires.

Prior to 1919 when fire suppression began in the United States, forest fires caused mostly by lightning, had a major impact on the ecology of the temperate and boreal forests. Fire allowed perpetuation of many species.

The boreal fire regime had short to long frequencies with low to high intensities. Heinselman (1981) describes the boreal fires as surface or crown fires that encompass areas of 40-400 hectares, occurring every 50-100 years. Examples of species adapted to frequent crown fires are jack pine (Pinus banksiana Lamb.), lodgepole pine (Pinus contorta Dougl.) and black spruce [Picea mariana (Mill.) B.S.P.]. Species adapted to frequent low intensity surface fires are red pine (Pinus resinosa Ait.) and white pine (Pinus strobus L.). The boreal floodplain, where fire is rare is occupied almost exclusively by white spruce [Picea glauca (Moench) Voss].

Kilgore (1981) classifies fire regimes in temperate forests similarly to Heinselman. Kilgore combines frequency, intensity and fire type (surface or stand replacement) into six categories. For example, ponderosa pine (Pinus ponderosa Laws.) forest has a low intensity, frequent (1-25 year) surface fire regime; lodgepole pine can be found where moderate (25-50 year) surface fires take place or where stand replacement fires occur; and mountain hemlock [Tsuga mertensiana (Bong.) Carr.] is associated with infrequent crown fires.

Even though fire has been repeatedly described as a dominant factor in plant communities, what is typically portrayed to the public is the catastrophic wildfire, destroying thousands of acres of trees. This perception of fire is gradually being replaced by the recognition that fire is an important natural phenomenon. The narrow policy of fire control is being modified to a policy of fire management. This change in attitude is reflected in the increasing number of fire history studies found in the literature. Three recent bibliographies show that there were eleven fire history studies done between

1900-1920 and 174 were done between 1970-1979 (Alexander 1979, 1980; Mastroguiseppe et al. 1983). Despite the large number of recent studies, the Wilderness Fire Symposium held in Missoula, Montana in 1983 clearly brought out the desire and need for additional fire history research.

Fire history studies can provide essential information used in developing forest management plans. Fire history determines how existing stand structure developed and helps to explain changes in age class distribution and nutrient cycling.

This study concentrates on fire history in the ponderosa pine forests on the east side of the Oregon Cascades. Studies have been made of fire history of ponderosa pine forests in Montana, Colorado, Nevada and in the Southwest. Fire return intervals are as variable as the study areas. Three fire history studies have been done along the east side of the Oregon Cascades. Weaver (1959) sampled ponderosa pine on the Warm Springs Indian Reservation and identified fire return intervals between 11 and 47 years. Soeriaatmadja (1966) expanded on work done by Weaver, identifying fire return intervals from 3 to 36 years. McNeil and Zobel (1980) sampled fire scarred ponderosa pine at Crater Lake National Park and measured return intervals between fires to be from 9 to 42 years. The above studies cover many different elevations and moisture regimes. However, none used dendrochronological cross-dating techniques to increase the accuracy of fire scar dating. The cross dating technique is recommended for ponderosa pine systems where mean fire return intervals are relatively short, instead of methods that correlate dates within a pool of trees (Mandany et al.

1982). The correlation method adjusts fire dates that are within two years of each other to the same date. Consecutive fire years and missing or false rings are less likely to be identified in the correlation. False rings are rare in eastern Oregon trees but missing rings are common (Keen 1937). Fire, insect defoliations, frost or other injuries and abrupt decreases in moisture can cause missing rings (Keen 1937). Cross dating helps identify missing rings and consecutive fire years, thus reducing the error in dating fire scars.

This study used dendrochronological techniques to determine the fire history of ponderosa pine forests in central Oregon. The main objective was to determine the historic fire return intervals in three different vegetation types dominated by ponderosa pine. A second objective was to provide reliable data to guide foresters in managing ponderosa pine forests.

Influence of Early Inhabitants

Aboriginal man has intentionally burned vegetation ever since fire was domesticated about 500,000 years ago (Stewart 1963). Fires were purposely set to aid in hunting, improve pasture for game, increase seed yield of wild grasses and weeds, improve berry harvests and for war (Stewart 1956). Small bands of Paiute and Tenino Indians resided in the Deschutes River Valley. Principally seed gatherers, they exhibited a sophisticated basket technology. There are historical accounts showing the Deschutes Indians regularly practiced burning (Shinn 1978, Stewart 1936). Even though there is no direct evidence that indicates Indian presence at Pringle Butte or Lookout Mountain, it is likely that they occasionally visited these sites while hunting or gathering seeds and berries. The first aboriginal inhabitants in Fort Rock area were there at least 9,000 years ago (Hatton 1982, Vaughn 1981). Aboriginal sandals found in the Fort Rock cave, ten miles south of Cabin Lake, date back to 9,000 B.P. Paiute ancestors hunted the sage plains as well as the forest (Vaughn 1981).

White settlement in the Fort Rock Valley began about 1880, peaking at 1000 people by 1915. This same year drought struck and precipitation has never returned to its original level. By 1941, population at Fort Rock had declined to 100 people. Vaughn (1981) describes the pattern of white man's settlement in the Deschutes Valley. The first men to appear were trappers in 1825. In 1845 immigrant wagons passed through attempting to find shorter routes to the Willamette Valley and by 1880 settlers were establishing residences throughout the Deschutes Valley. There are numerous accounts of burning by Indians. Records do not show settlers in the Deschutes or Fort Rock Valley setting fire but Pyne (1982) discusses white man following the Paiute Indian way of broadcast burning in the northern part of Oregon. It is quite likely that settlers in central Oregon burned too.

Role of Lightning

Lightning has played a major role in the high incidence of fire in the ponderosa forests. Deschutes National Forest records written in the early 1900's recount a large fire in the vicinity of Lookout Mountain which was called the "Edison Ice Cave Fire." It was ignited by lightning and burned more than 7000 acres. The Deschutes Forest, listed 85 lightning fires between 1908 and 1915, and 1325 lightning fires between 1970 and 1983 (J. Holroyd, Fire Dispatch, Redmond, personal communication). Fires start as early as May and as late as October but the majority of fires took place in August. Although lightning is still the most frequent cause of fire, recreational use of the Deschutes National Forest has rapidly increased, resulting in an increase in man caused fires.

STUDY AREA

The study was conducted on three sites located in the Deschutes National Forest. Sites were selected to represent areas of relatively high, intermediate and low precipitation in the ponderosa pine forests of central Oregon. The Pringle Butte and Lookout Mountain sites are located in the Pringle Falls Experimental Forest, southwest of Bend (Figure I-1). The Cabin Lake site, southeast of Lapine, is in the Fort Rock Ranger District (Figure I-2).

Environmental characteristics for the three sites are summarized in Table I-1. Cabin Lake is the driest of the three and frost is common any month of the year. Located on flat topography, soil at Cabin Lake developed primarily from pumice deposited during the eruption of Mt. Mazama. It is composed of 71-91 cm A horizon. Because the soil is well drained, ponderosa pine has been able to extend its range into the *Artemesia*/shrub steppe (Franklin and Dyrness 1973). In the last 70 years precipitation has declined and the steppe is gradually advancing into the ponderosa forest (D. Warner, Fort Rock Ranger District, personal communication). This area can be used as summer cattle range if water is provided.

The site located on Pringle Butte has intermediate moisture falling mostly as snow. Study plots are on southeast facing slopes with occasional frosts occurring during the summer (D. Frewing, Bend Silviculture Laboratory, personal communication). This ponderosa pine/bitterbrush/needlegrass community (Volland 1976) also includes Ross's sedge (Carex rossii Boott.) as a major species.

Lookout Mountain is the wettest site with 90 percent of the annual precipitation falling during October through April. The soil is a 91 cm deep pumice, originating from Mt. Mazama. The plant community is classified as a mixed conifer/snowbrush (Volland 1976) in an area where a white fir/snowbrush community is climax (Barrett 1983).

METHODS

Part I. Dendrochronology

Dendrochronological techniques were used to develop a master chronology for use in cross dating samples from fire scarred trees (Stokes and Smiley 1968). To construct the Master Chronology, increment cores were taken from trees on steep slopes or rocky hillsides, environmental settings in which sensitivity to moisture and therefore variation in ring width should be maximal. A minimum of 10 trees and two cores per tree on opposite sides were sampled at each study site using a 30 inch increment core.

The skeleton plot technique (Stokes and Smiley 1968) was employed as an aid to relate samples chronologically to each other. In this technique narrow ring-width is plotted on graph paper, beginning with the pith and progressing to the cambium. The narrower the ring the longer the line is drawn by using a subjective scale from 1 to 10. The skeleton plot for each core is then matched to skeleton plots of all other cores, using the narrowest rings for comparison. A master chronology is designed from all the skeleton plots, identifying sequences of narrow rings that are common to all specimens. The master chronology is then used to cross date a fire scarred section by correlating the patterns of ring widths on the scarred tree with the master sequence. In this way, missing or false rings can be identified. Cross dating provides the precision necessary to identify fire years correctly or differentiate small changes in fire frequency (Mandany et al. 1982).

Normalized ring widths (indices) were plotted over time to identify periods of decreased growth. This was done using computer programs from the Laboratory of Tree-Ring Research, Tucson, Arizona (Graybill 1979). Ring-widths are normalized to take into account the change in ring width as the tree ages (Fritts 1976). This is done by fitting a polynomial, exponential or linear growth curve to the ring width measurements from each core and dividing each ring width by the value of the same year predicted by the growth curve. Indices from rings formed in each year are averaged over all trees at a site and reflect year-to-year growth variation. Sequences of indices were checked to see whether periods of decreased growth correspond with periods of high fire activity.

Part II. Fire History

At each site six 40-acre plots were located in areas that had uniform vegetation and fire scarred trees. A thorough reconnaissance in each plot located trees or stumps that provided the best fire scar information. Ponderosa pine, the principal conifer species at each site, was the only species sampled. Ponderosa pine provides an excellent record because of its natural resistance to injury by fire, while recording the event with an identifiable scar. Tables I-2 and I-3 show number and age of trees sampled at each site.

At Pringle Butte only trees with external evidence of scarring by fires were sampled. Salvage logging had removed all the fire scarred trees on three of the Pringle Butte plots but the remaining stumps showed numerous scars. Stumps recording at least four fires and cross sections that remained intact when cut were sampled. Stumps with fire scars were not available at Lookout Mountain or Cabin Lake.

At Lookout Mountain few scarred trees recorded more than five fires, so trees with the most scars were selected. Many fire scarred trees had extensive decay that could not be detected until the tree was cut. This made it necessary to reject some of the selected trees and include others with fewer fire scars.

At Cabin Lake only five fire scarred trees were found in each plot. One scarred snag was sampled.

Sampled trees were felled and two sections from each sampled tree or stump were taken to the laboratory for examination. One section was cut from the base of the tree and a second cut directly above the first. Sections cut from the base of the tree usually provided the best fire scar record and were used for fire dating, except when recent fires had eliminated earlier fire scar evidence; in these cases the second section was used for fire scar dating. Occasionally it was necessary to use both sections. The location of sampled trees on each plot was mapped.

At the laboratory, cross sections were sanded with progressively finer grades of abrasive paper (#80 through #400) using a small floor sander, switching to a belt sander and finally by hand. A low power microscope was used to determine age, cross date and to identify fire years on each section. Dates of fire years were plotted on a Composite Fire Interval Chart to correlate fire and year of occurrence in each site. This chart makes it possible to identify fire dates that the various samples have in common and displays periods of years having minimum periods between fires (Dieterich 1980). Fire dates from the composite fire charts were coordinated with mapped trees to estimate sizes of fires in each plot and site. Probable size of burns was mapped by location of trees showing identical fire years. The proportion of total trees scarred and their frequency of scarring was calculated and graphed. The relationship between estimated fire size and number of years since the previous fire was also determined.

Understory vegetation was sampled at each site. Sampling was done in the established plots and in a recently burned area of the same vegetation type at each site, in order to determine how rapidly vegetation recovered following fire. Forty microplots (Daubenmire 1959) were sampled in each burned area, and 30 microplots were sampled in the areas established for sampling fire scarred trees. The prescribed burn area sampled at Pringle Butte was chosen because the period since burning corresponded with the mean fire return interval for the site. The only suitable prescribed burn on Lookout Mountain was done two years prior to sampling. These burns were for shrub abatement studies and produced medium flame lengths and fuel consumption. The Cabin Lake prescribed burn was done eight years prior to sampling.

Statistical Analysis

Mean fire return intervals (MFRI) were calculated for each site, beginning with the century that had more than one fire scarred tree and ending at 1900 (before fire suppression began). The MFRI period for Pringle Butte is from 1400 to 1900 and for Cabin Lake and Lookout Mountain from 1600 to 1900. MFRI for site (MFRIs) is based on the number of years intervening between fires occurring anywhere on the site. MFRI for plots (MFRIp) is the average number of years between fires in each plot, averaged over plots. MFRI for the region (MFRIr) is the mean return interval averaged for all sites. MFRI for region plots (MFRIpr) is the average of all plots in all sites. t-tests were used to compare percent cover of understory and litter and duff of burned and unburned plots.

RESULTS

At least 139 fires occurred between 1362 and 1900 at Pringle Butte; calculated MFRIs is four years. Cabin Lake registered 45 fires between 1460 and 1900 with MFRIs of 7 years, while Lookout Mountain recorded 37 fires from 1416 to 1900 with MFRIs of 8 years (Table 2). The oldest tree examined was at Pringle Butte; it also recorded the earliest fire. The greatest number of fire scars on a single tree was

30. The MFRIp for plots within each site and within the region are greater than the MFRI for each site or the region (Table I-2). The return interval of fire to a site type is shorter than the return interval to a small area within that type. This reflects the mosaic pattern of fire occurrence on these sites. The difference between MFRIp and MFRIs is 7 years for Pringle Butte, 17 years for Cabin Lake and 7 years for Lookout Mountain. The difference between MFRIpr and MFRIr is 11 years.

Composite fire intervals for the three sites are illustrated in Figures I-2 to I-4. Composite fire interval analysis, when correlated with mapped trees and physiographic features, can be used to estimate fire size. Two trees which are some distance apart frequently register fires for the same year; however, this does not necessarily mean that the entire area between the two trees burned. Nevertheless, when two or more trees in close proximity register the same fire year, estimates of fire size can be made (Figures I-5 to I-21). The largest estimated fire at any site was at Pringle Butte (Figure I-8). In no case were trees in all six plots at a site scarred during the same year. Small fires occurred regularly and large fires infrequently.

Figure I-22 displays the history of fire events for each site. Bar length indicates the proportion of sampled trees scarred during a given year, which is an estimate of area burned. Fire was more frequent in the Pringle Butte site than at Cabin Lake or Lookout Mountain (Figure I-22). Forty-eight fires occurred between 1700 and 1800 at Pringle Butte; for the same time period Lookout Mountain had 9 and Cabin Lake had 12 fires. From 1800 to 1900 Pringle Butte had 41 fires, Cabin Lake 26 and Lookout Mountain 23. The advent of fire suppression activity in 1910 resulted in a decrease in fire frequency at Pringle Butte and Lookout Mountain, with Pringle Butte registering 17 fire scars and Lookout Mountain 4 fires between 1910 and 1981. Cabin Lake does not show a decrease, with 16 fires occurring between 1910 and 1981, most of which were small.

Normalized ring widths from the tree ring chronologies show substantial variation in ring growth at all three sites (Figure I-23). Growth was slow during 1850, 1871, 1889, and 1900 at all three sites. These years of poor growth were also reported by Keen (1937). Ring width was compared with fire scar years to see if any correlation could be found. Periods of widespread poor growth probably indicate low precipitation (Keen 1937), and drought years were expected to be associated with increased fire activity, since fuels would be drier and more flammable. No correlation was found between ring width and fire activity, however.

Mean return interval for fires of different size, or alternatively, years with a given level of fire activity (estimated by the proportion of plots having at least two fire scarred trees), was calculated for each site (Figure I-24). Although MFRIs is higher at Lookout Mountain than Cabin Lake or Pringle Butte, the return interval for large fires (or years of high activity) is shorter, illustrating the inverse relationship between frequency and size of fires. Figure I-24 shows the mean return interval for years of varying fire "activity". For any given year, fire "activity" is estimated as the proportion of plots in a particular site on which at least 2 trees were scarred. High fire activity (i.e., a high proportion of plots with scarred trees) may indicate many small fires or a few large ones.

Differences between burned and unburned plots for percent cover of understory vegetation and litter and duff at Cabin Lake and Pringle Butte are not significant (Table I-4), indicating that vegetative regrowth was complete within an 8 year period at Cabin Lake and 4 years at Pringle Butte. At Lookout Mountain, litter and duff and snowbrush cover were lower in the burned area than in fire scar sampling plots (Table I-4), probably because only 2 years had elapsed since burning. Regrowth may also be slow because, unlike the other sites in the burned area, the tree canopy at Lookout Mountain is closed.

Basal area was examined as a possible indicator of historic fire frequency. Basal area data were available from several sources for ponderosa pine forests on the east side of the Oregon Cascades: for Sisters, northwest of Bend, from Sherman (1966) and West (1964); Black Butte, northwest of Bend, from Sherman (1969); Cabin Lake, from Volland (1976); Pringle Butte, from D. Frewing (personal communication); and Lookout Mountain, from Barrett (1983) and Barrett and Newman (1974). Sherman (1966, 1969) also included information on fire history so that MFRIs could be calculated. The relationship between basal area and precipitation can be seen in Figure I-25. The shortest MFRIs and MFRIp are found in the middle of the scale. In these forests, fire occurs more frequently in vegetation of moderate growth and moisture level and with less frequency where moisture and growth are either high or low.

Vegetation type may also be important in predicting MFRI. Four understory species may be indicators of MFRI. Figure I-26 shows the relationship between bitterbrush, snowbrush, Idaho fescue (*Festuca* idahoensis Elmer), Ross's sedge and MFRIs. At Pringle Butte, where MFRIs is short, bitterbrush is more important than snowbrush, whereas at Lookout Mountain, with a relatively long MFRIs, snowbrush is important and bitterbrush is absent. At Cabin Lake bitterbrush is less important than Idaho fescue, and snowbrush and Ross's sedge are absent.

DISCUSSION

Past studies have confirmed fire's role as an important ecological factor in the ponderosa pine forests for at least the past 600 years (Weaver 1951). Fire's role has varied, removing only the understory or developing into a conflagration that kills entire stands. Ponderosa pine is most susceptible to scarring between the ages of 10 and 80 years and scars can still be initiated at advanced ages (Mandany and West 1980), all fires do not scar all trees and trees are more susceptible after having been scarred. Light surface fires may not scar any trees. For these reasons most investigators feel that the MFRI identified for a particular site is probably a conservative value.

Lightning activity and Indian fires are incorporated in the same record. It is not possible to determine how much Indians augmented natural fires in the Deschutes Forest. The low fire frequency prior to 1600 reflects the smaller number of sampled trees that contribute to the fire record (Table I-3). Pringle Butte provides some of the oldest dated trees from central and eastern Oregon and may form the longest record of fire history for any one region (Mazany and Thompson 1983).

The ponderosa pine forest has been described as open and parklike (Weaver 1951, 1961). Frequent light primaeval fires controlled understory growth and left the ground comparatively free of fuel. Fire suppression has resulted in development of dense understories, creating abnormal fuel loads in understory and on soil surface, and adversely affecting growth rates and vigor of understory pines through competition for soil moisture (Weaver 1959). Pressure bomb tests do not show that lodgepole pine trees in the Deschutes Forest are experiencing water stress (Waring and Pitman 1985, D. Zobel personal communication), similar studies have not been done on ponderosa pine but stem growth in ponderosa pine has decreased since the early 1880's at Pringle Butte (see Chapter 2). Waring (personal communication) theorizes that under conditions of low moisture or nutrients, carbon is allocated to roots instead of the stem. Keyes and Grier's work in Douglas-fir (1981) shows that trees on infertile sites allocate more carbon to root growth than trees on fertile sites. Experiments with Scots pine (*Pinus sylvestris* L.) in Sweden (Linder and Axelson 1982) show that moisture stress also results in greater root growth. Low rainfall, competition, slow nutrient turnover or all of these could cause greater allocation to roots in the ponderosa pine in this study, resulting in decreased stem growth. No increase in growth, expected due to nutrient turnover caused by fire, was detected following fire. Fires may be severe enough to cause nitrogen to be volatilized instead of being returned to the soil. Only scarred trees from the Pringle Butte site were found to exhibit five to ten years decreased growth after every major fire. This pattern was assumed to have been caused by fire; however, climatic influences could be involved (see Chapter 2).

Differences in fire pattern among the three vegetation types probably reflect differences in moisture and therefore both fuel levels and flammability (Martin 1982). At Cabin Lake, limited moisture prevents rapid growth of any species and results in a sparse understory and low fuel accumulation. The scant understory may not provide enough fuel for fires to scar trees or for fires of any size or intensity to develop. Vegetation analysis did not indicate significant differences between species composition in burned and unburned plots; however, bitterbrush regeneration appears to have been stimulated by fire. Bitterbrush in the burned plots is young and healthy, while in the unburned plots it has matured and is no longer vigorously growing.

Favorable moisture conditions at Lookout Mountain maintain a vigorous understory, but the higher moisture probably deters fires (Weaver 1959). With a longer time period between fires, fuel will increase, so that when a fire is ignited, size and intensity are greater than they would be on sites where less fuel is available. Logs in the Lookout Mountain plots indicate greater fuel accumulation than at the other sites, where no logs were recorded during vegetation sampling.

As at Cabin Lake, understory regeneration at Pringle Butte appears to have been stimulated by fire. The additional moisture at Pringle Butte probably contributes to understory growth.

Calculated MFRI differed for site and for plots within each site. MFRI shortens as the study area becomes larger and more sample trees are included (Arno 1983). Such data indicate that fire return intervals may be very different when averaged over a large area rather than calculated as mean fire return at any one point on the ground. For example, during the 500 year period from 1400 to 1900 at Pringle Butte, fire burned some part of the area an average of once every four years. However, the return of fire to the same 40 acre plot within the site is every 11 years. Arno (1983) determined that small plots (1-100 acres) are suitable as a data base since they allow adequate sampling intensity for most light surface fires. But one plot of 40 acres may not show the true picture. There is a wide range of MFRIp calculated for the plots at each site (Table I-2). The overall average (MFRIp) for the six plots incorporates all data for the site but uses a 40 acre plot mean to determine the length of time required for fire to return to the same location, thus giving a more accurate indication of MFRI in a given stand and is the most useful way of expressing the data.

Mapping fire size provides further insight to the pattern of historic fires (Heinselman 1973). Fire size at Lookout Mountain was probably larger than shown (Figures I-11 to I-16) because plots are separated by distance and topography (it was not possible to locate plots close together and still use the same vegetation community). The steeper slopes at Lookout Mountain would tend to increase fire size since flames become closer to fuel as slope increases, and fire spreads faster up a slope than on level terrain (Rothermal 1983). There is evidence that large fires did take place in this vegetation zone. On Lookout Mountain, a 1000 acre even-aged stand of ponderosa pine is believed to have been established by fire (D. Frewing, Silviculture Laboratory, personal communication).

The Cabin Lake site has a uniform vegetation that covers an extensive area with most sample plots located some distance apart. Unlike the Lookout Mountain site, topography is flat and fire spread would be slow unless climatic conditions were right. The low fuel load at Cabin Lake also limits fire size. Large fires may have taken place under the right climatic conditions but these fires would not be common.

Before fire suppression, heavy fuel accumulation at Pringle Butte was prevented by small frequent fires. There is little indication that very large fires occurred in this community type. Five of the plots are located adjacent to each other (Figure I-27) allowing detection of fires up to 200 acres in size. Although there were years in which trees on up to five plots were scarred, the location of scarred trees relative to unscarred trees suggests that the largest single fire was about 40 acres (16 ha) (Figure I-8). However, fires may not scar trees all the time and recent frequency of lightning in this area suggests that the pattern may have been a few large rather than many small fires (Robert Martin, personal communication).

Morrow's (1984) stand age analysis at the Research Natural Area (RNA) near Pringle Butte (Figure I-27) shows a major period of tree establishment shortly after 1550. In the fire history study, ten fire-scarred trees sampled in the Pringle Butte plots were established between 1550 and 1560, five of these from plot 7, the plot closest to the RNA (Figure I-27). Although the fire record at Pringle Butte does not indicate that a major fire occurred in the 1550's, the initiating factor nevertheless may have been fire. A fire could cover the area from the RNA to plot 7 since there are no topographic barriers to prevent spread or instead of one large fire, many small fires could have been ignited.

Morrow's analysis also indicates periods of poor regeneration that correlate with periods of high fire activity (Table I-5). An increase in regeneration began about 1886, at the time fire activity decreased, and has continued. Causes for the decrease in regeneration could be insect invasion, frost and drought. Decrease in regeneration following fire is not viewed as a normal occurrence, because fire is usually expected to prepare the way for new growth. Generally, all the conditions are right for tree establishment after a fire: a mineral seed bed has been exposed, trees of the right age class are nearby to provide seed, and competition for moisture is minimal. How could fire cause regeneration to decrease at Pringle Butte? One possible explanation could be that fires were so frequent that there wasn't enough time for seedlings to develop to an age in which bark would be thick enough to protect the tree. Fires may result in either increased or decreased regeneration, depending on the year or the season in which it occurs. Fire occurring in the summer during a year of abundant seed production could result in high regeneration success. In contrast, fire occurring after a period of regeneration, up to the time when seedlings are large enough to survive the fire (10-20 years), would result in a lost age class.

In this study, understory vegetation is indicative of MFRI. Bitterbrush is absent or infrequent and snowbrush or Idaho fescue are important where fire intervals are long. Where fire intervals are short, bitterbrush is the most important understory species (Figure I-26).

Bitterbrush has been found to develop and perpetuate in environments with high MFRI, partly by sprouting when fire severities are low but mostly by seedlings (Driver et al. 1980, Martin and Driver 1983). Ross's sedge, a fire resistant species (Volland and Dell 1981), is associated with bitterbrush at Pringle Butte. On Lookout Mountain, plots are dominated by snowbrush and bitterbrush is absent. At Cabin Lake Idaho fescue is more important than bitterbrush. Fire resistance of Idaho fescue and squirreltail [Sitanion hystrix (Nutt.) Smith], also found in the understory, is dependent on season and severity of burn; both grasses are more resistant to mid-summer burning then spring burning (Volland and Dell 1976). Since most fires occur from mid-summer to fall, these grass species have been successful.

Basal area, an indicator of moisture availability, seems to predict MFRI, apparent not only from this study, but from two prior studies which are incorporated in Figure I-26. Fire intervals are longer in sites of high basal area, where moisture enhances growth and limits burning, and low basal area where moisture limits growth and fuel. The intermediate basal area site has sufficient moisture for growth but is still dry enough to allow frequent fire. This pattern of MFRI versus basal area (Figure I-26) resembles the u-shaped model of fire return intervals from wet to dry sites by Martin (1982).

Fire exclusion has increased the danger of destructive wildfires at Pringle Butte, Lookout Mountain and Cabin lake. Excessive fuel has built up on the forest floor and in dense sapling stands creating ladder fuels (Martin et al. 1976). Growth stagnation can be seen in formerly productive stands (Weaver 1955). A wildfire at Pringle Butte with the present fuel load, which has accumulated since the late 1890's, could be catastrophic.

Whatever the historic frequency of fire was, there is no doubt that it is important to the ponderosa forests of eastern Oregon. The new fire management policies must consider the introduction of remedial fires to reduce fuel and danger of catastrophic wildfires. Then decisions can be made to introduce fire at a return interval that best fits forest management goals.

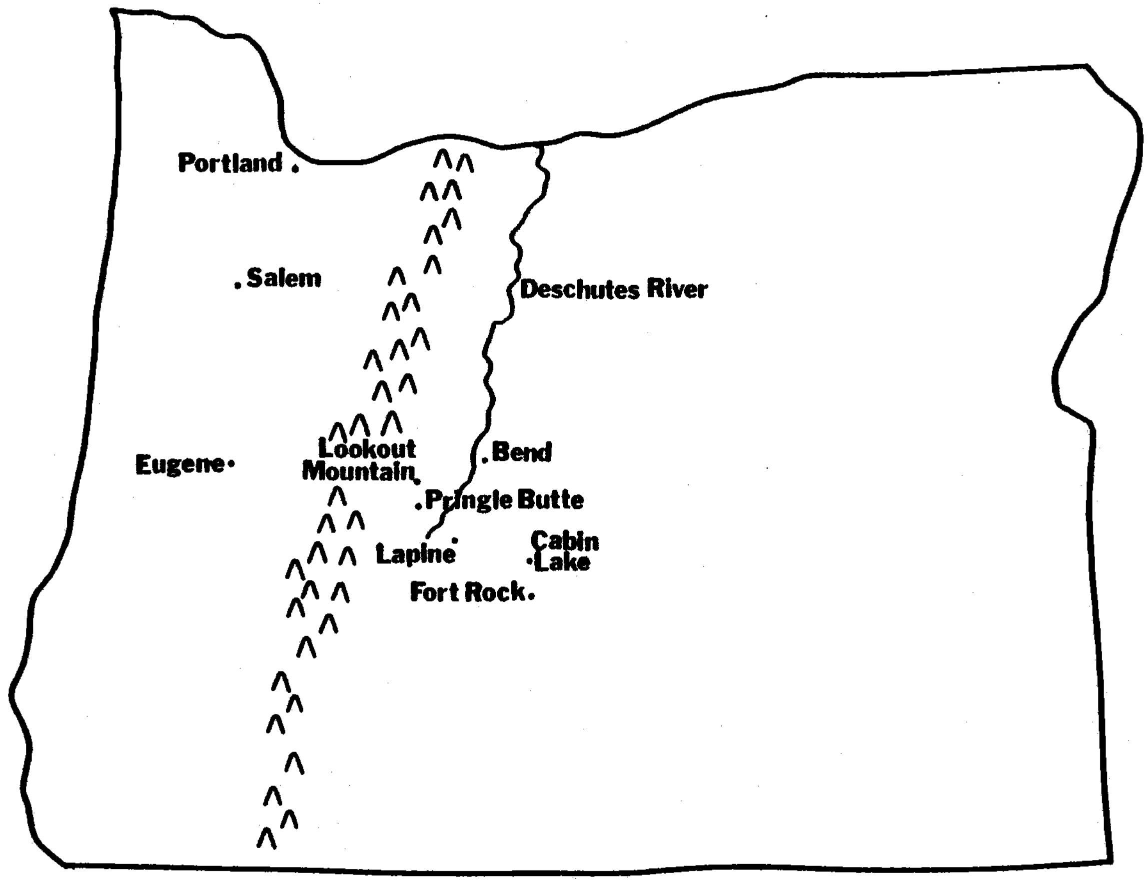


Figure I-1. Map of Oregon showing location of study sites, Cabin Lake, Pringle Butte and Lookout Mountain.

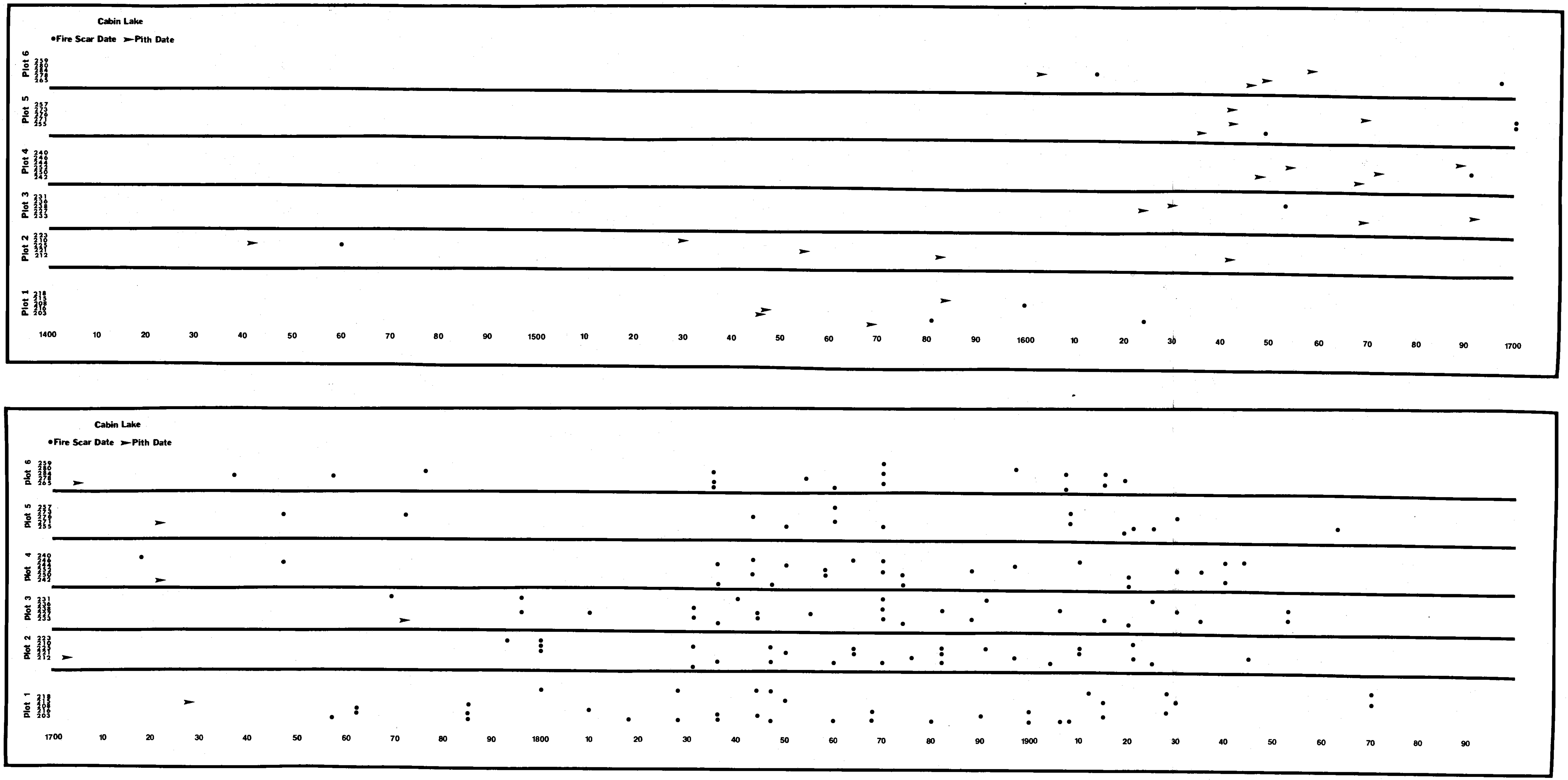
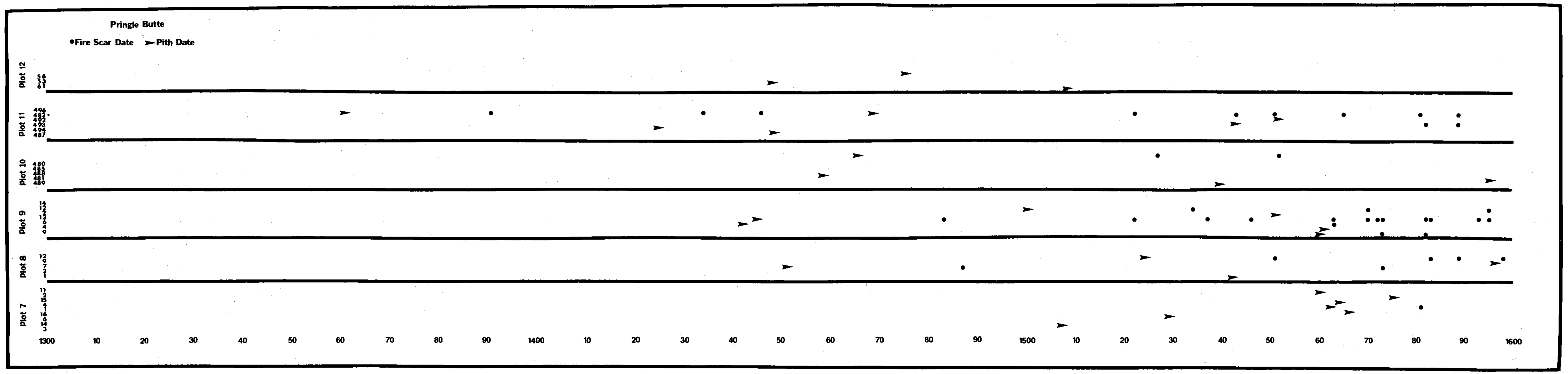


Figure I-2. Composite fire interval for Cabin Lake, time span 1443-1981.



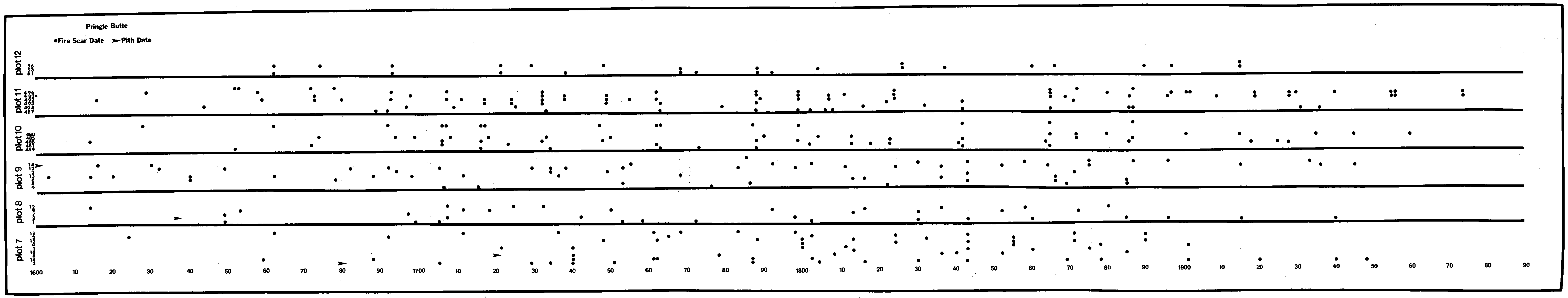


Figure I-3. Composite fire interval for Pringle Butte, time span 1362-1981.

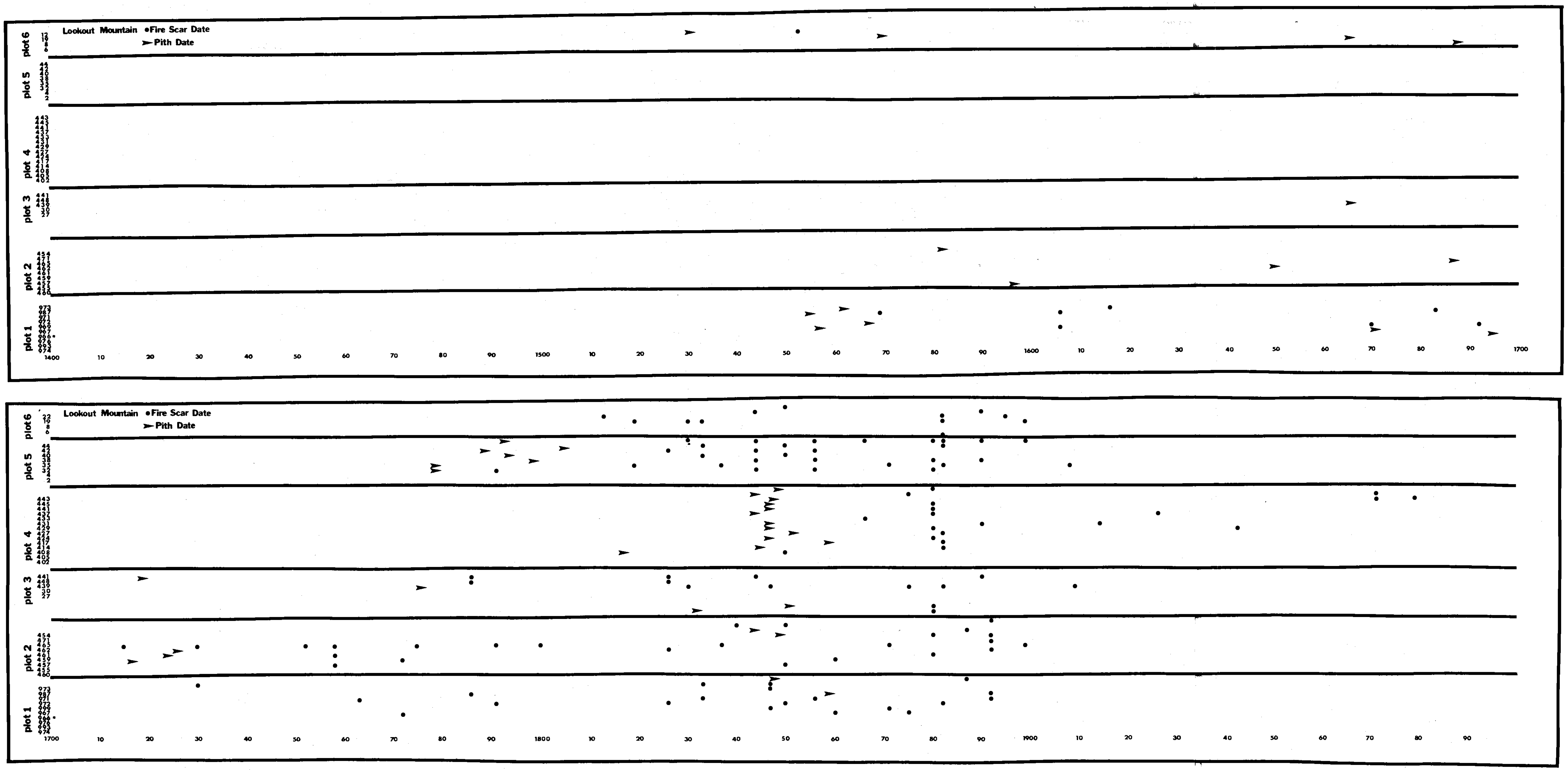


Figure I-4. Composite fire interval for Lookout Mountain, time span 1400-1982.

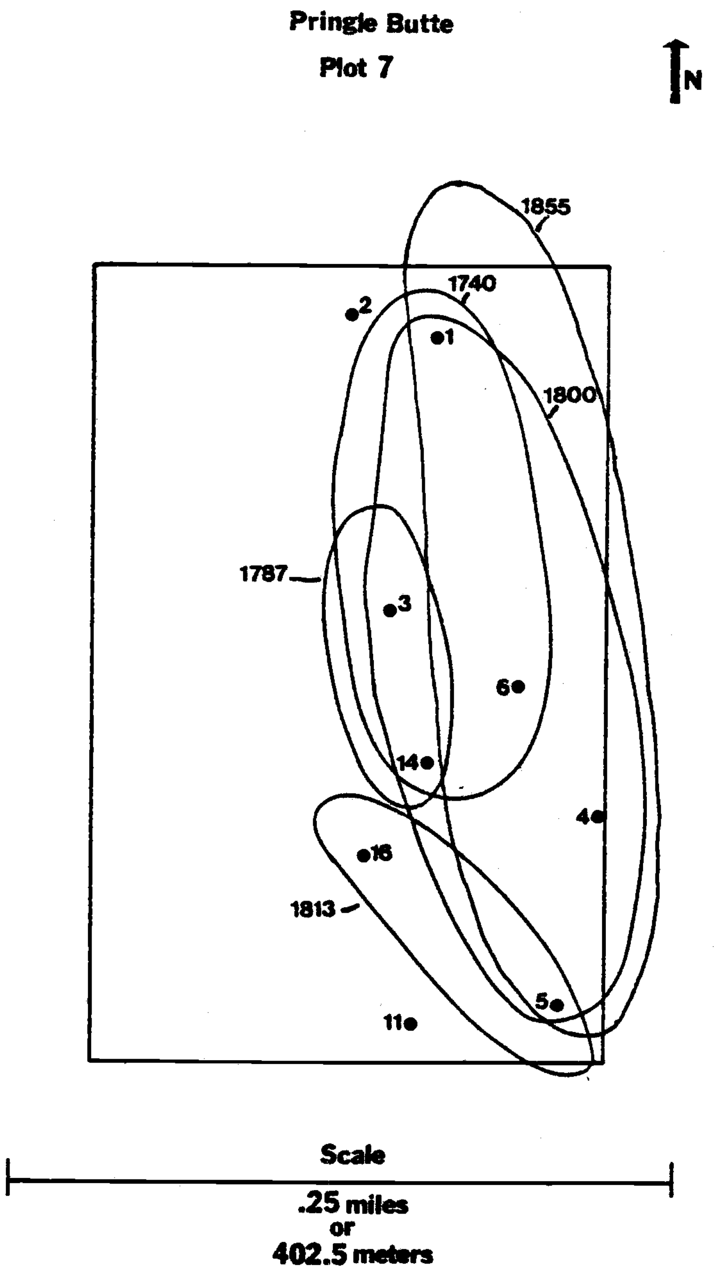


Figure I-5. Location and size of fires, Pringle Butte, plot-7. Number dots = tree, lines = fire extent in marked year.

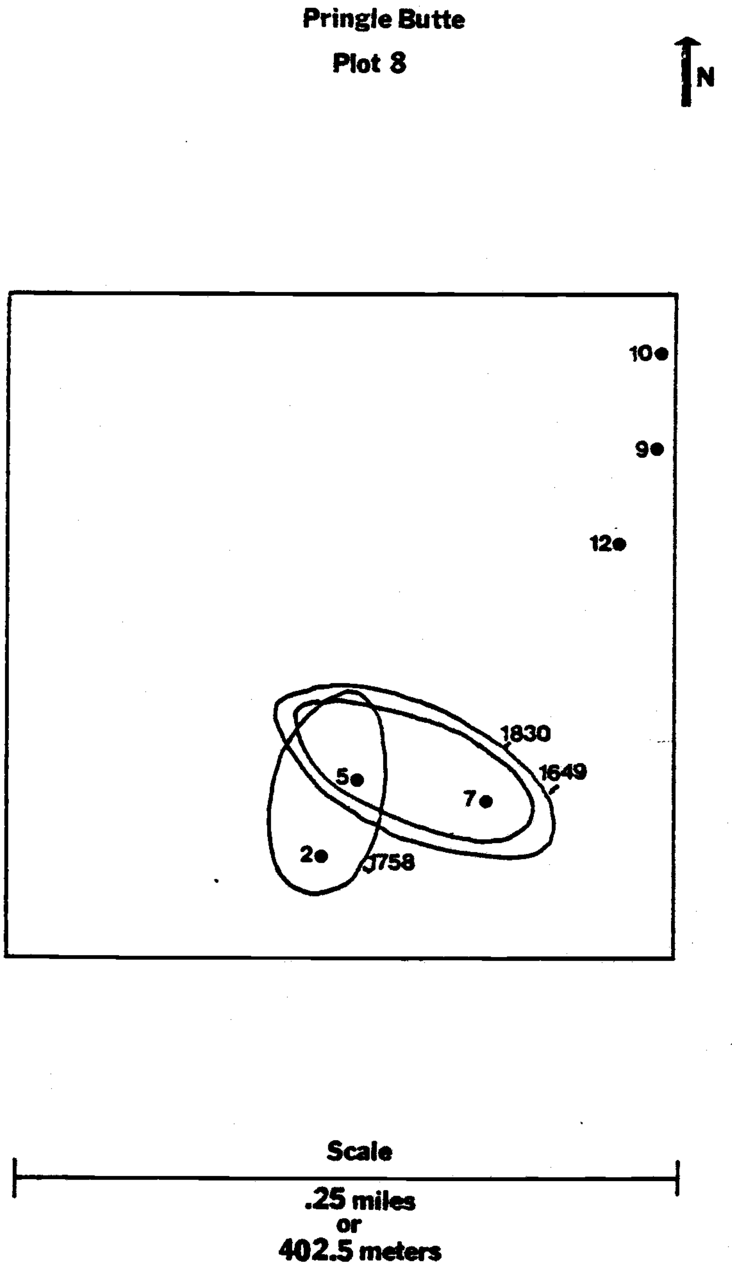


Figure I-6. Location and size of fires, Pringle Butte, plot-8. Number dots = tree, lines = fire extent in marked year.

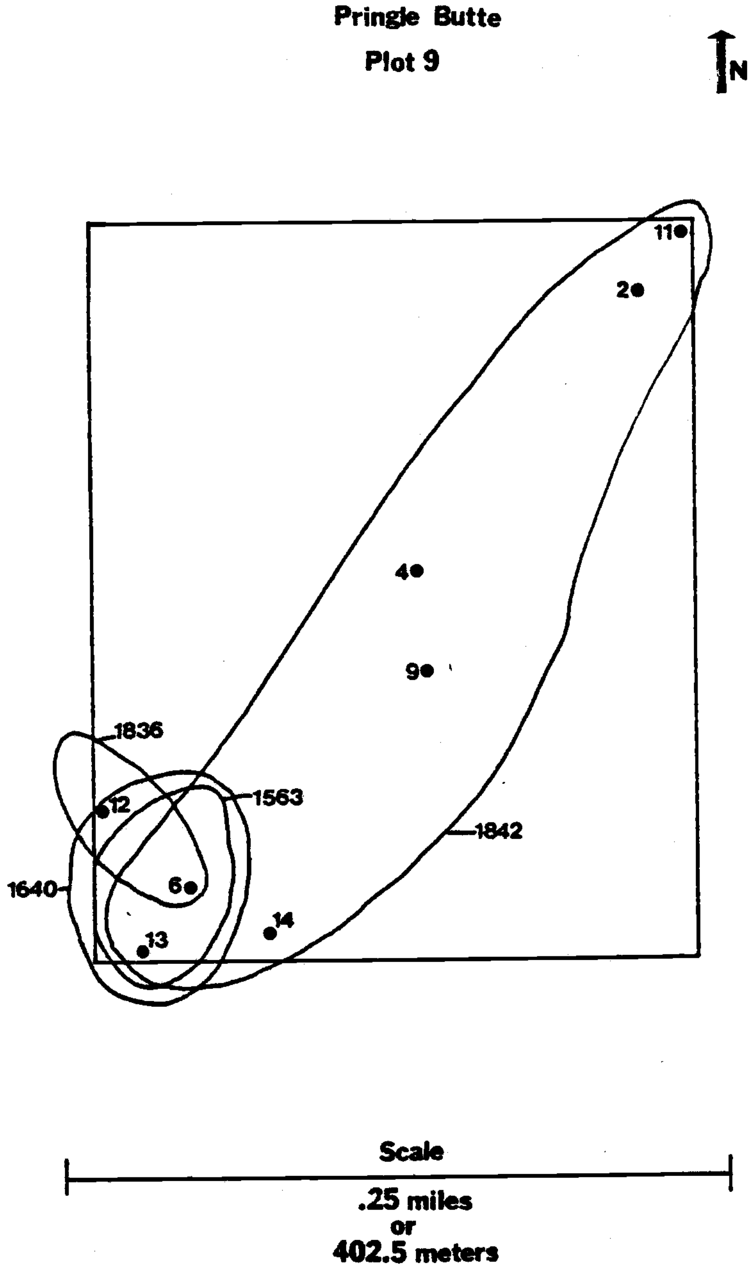


Figure I-7. Location and size of fires, Pringle Butte, plot-9. Number dots = tree, lines = fire extent in marked year.

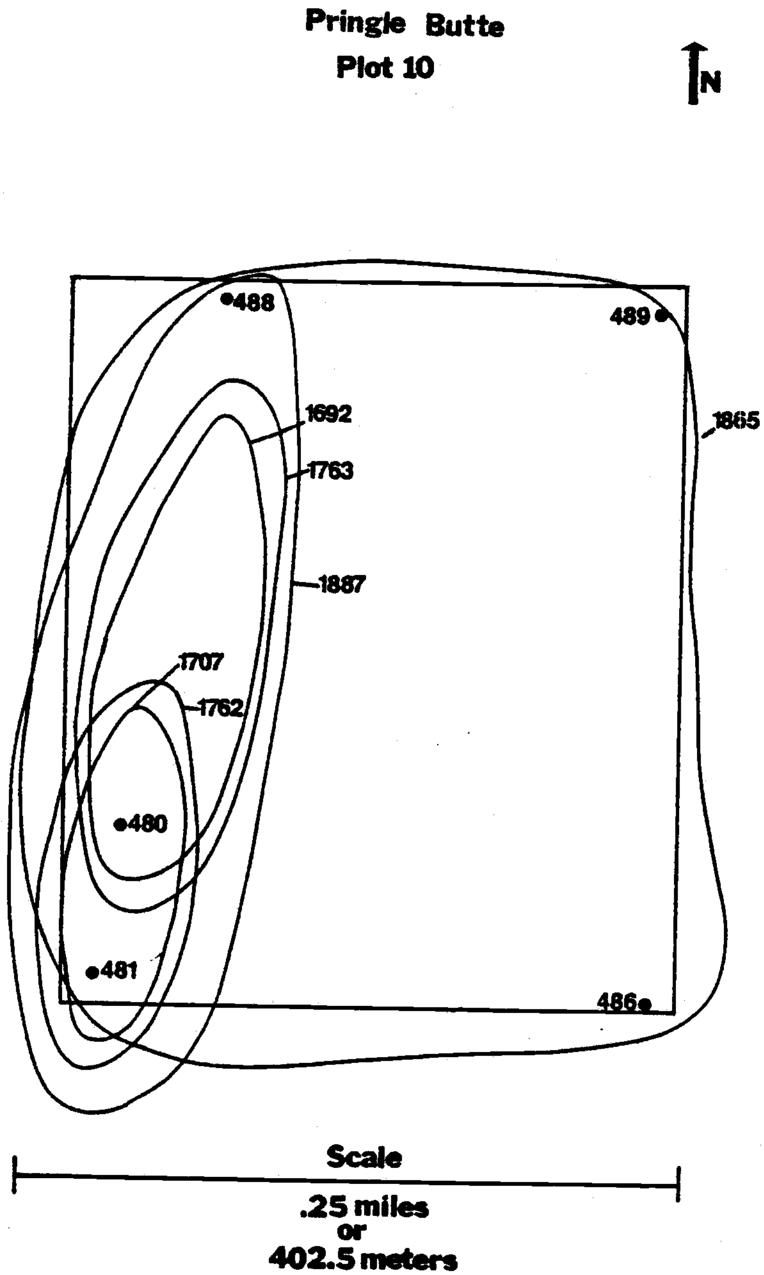


Figure I-8. Location and size of fires, Pringle Butte, plot-10. Number dots = tree, lines = fire extent in marked year.

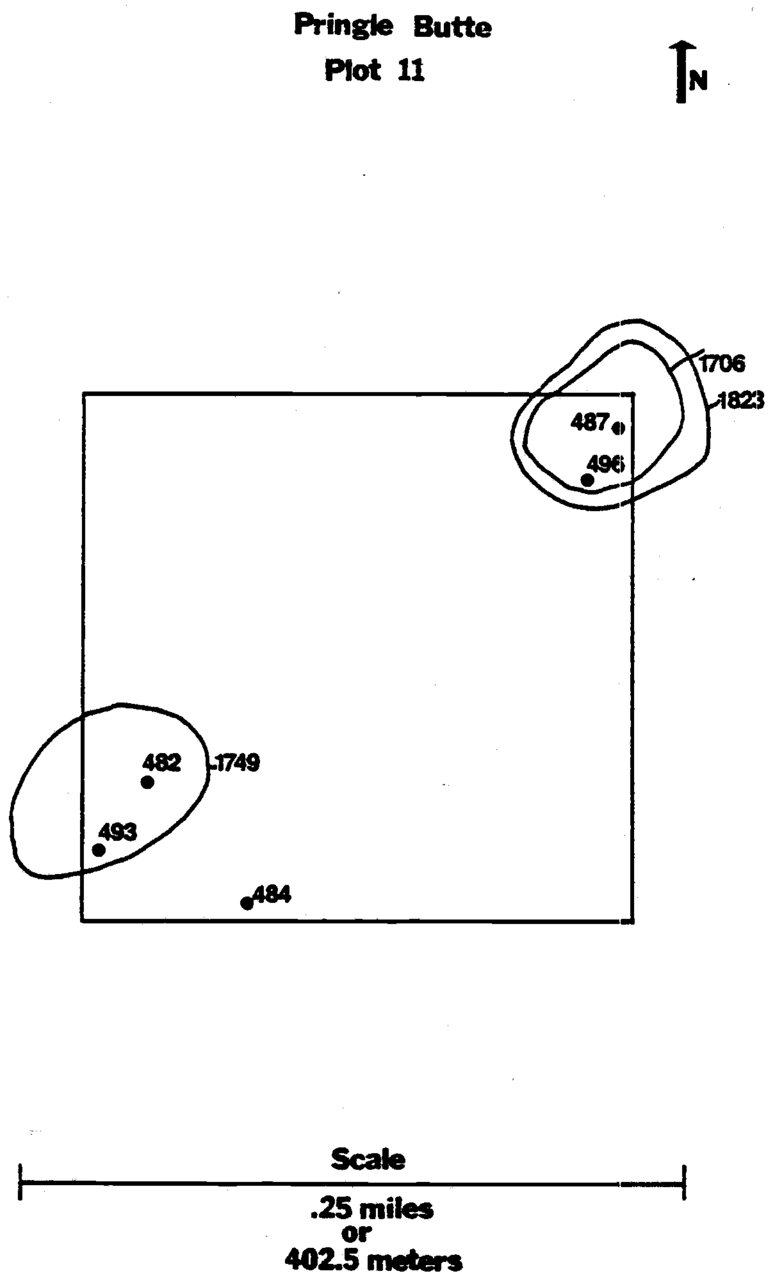


Figure I-9. Location and size of fires, Pringle Butte, plot-11. Number dots = tree, lines = fire extent in marked year.

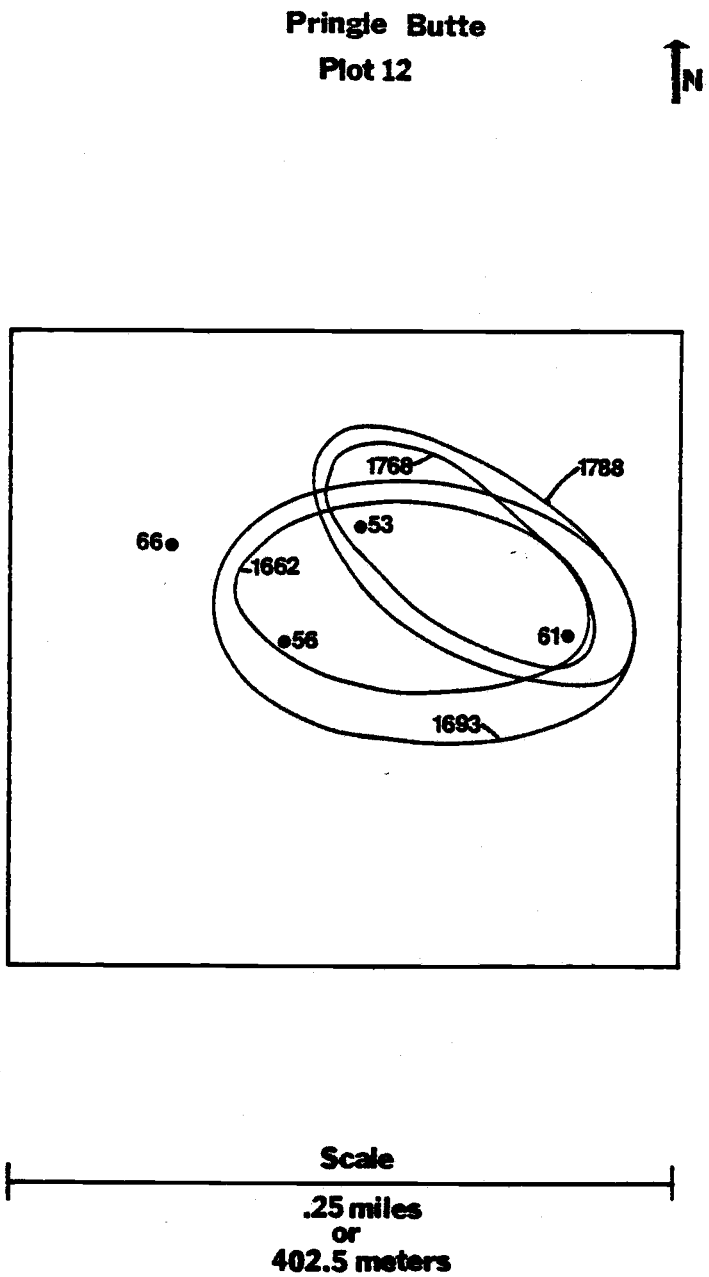


Figure I-10. Location and size of fires, Pringle Butte, plot-12. Number dots = tree, lines = fire extent in marked year.

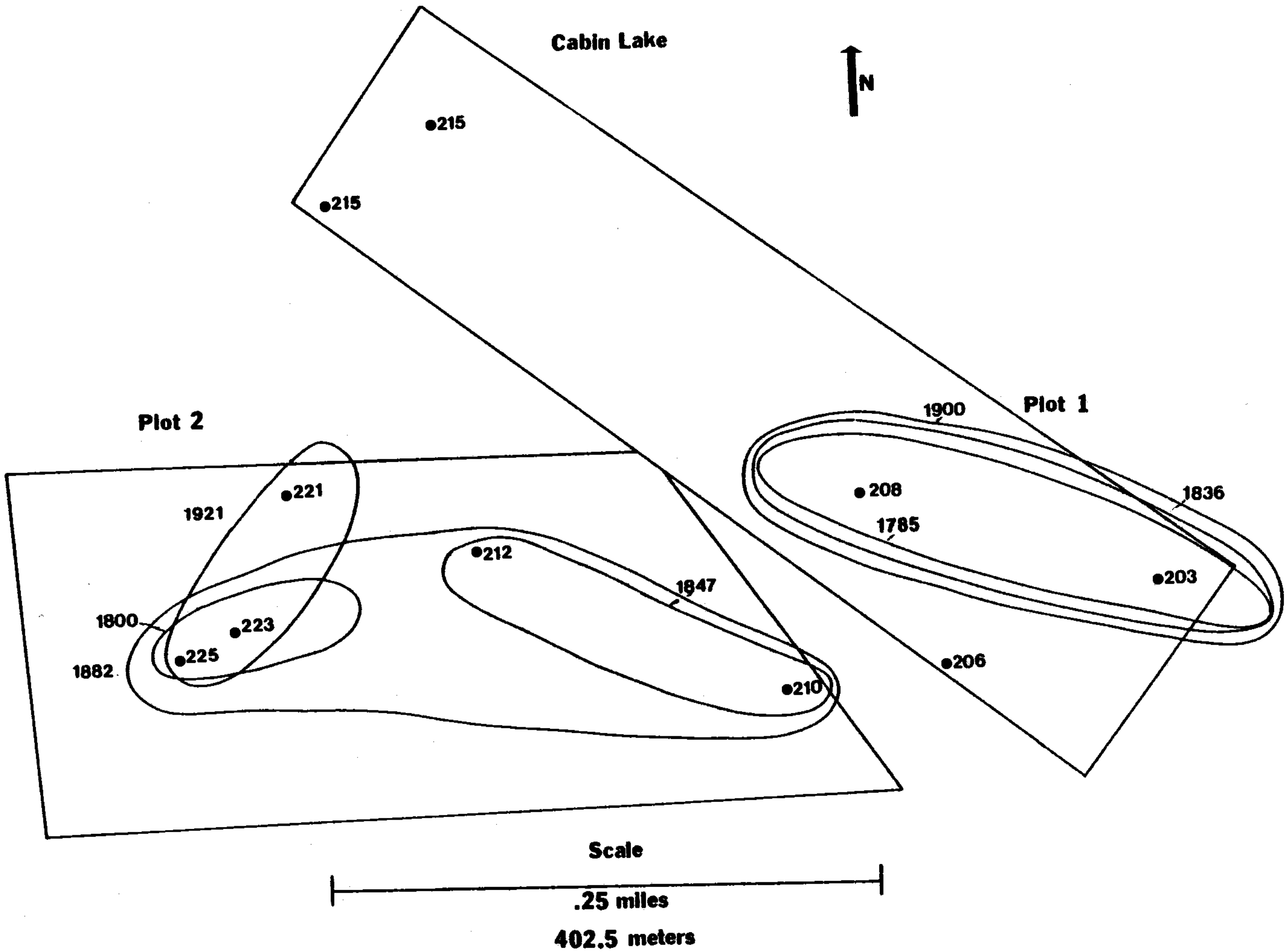


Figure I-11. Location and size of fires, Cabin Lake, plot-1 and 2. Number dots = tree, lines = fire extent in marked year.

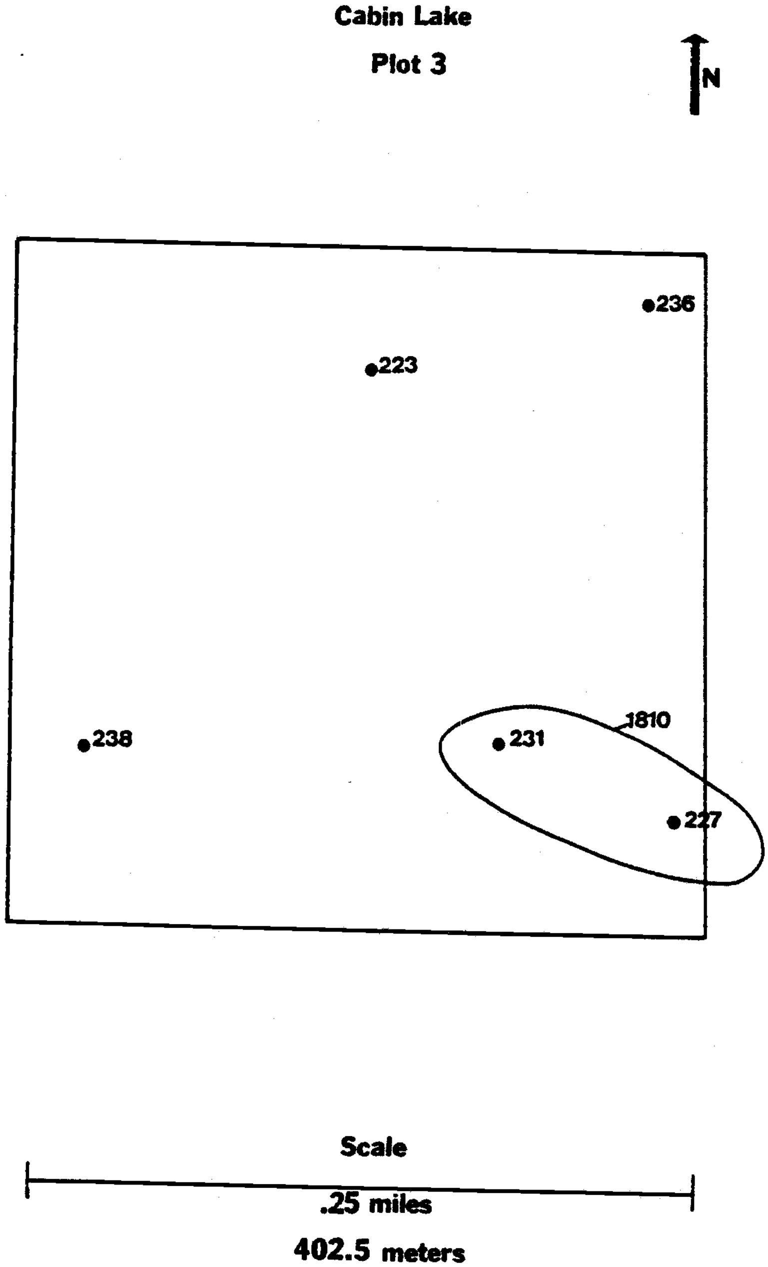


Figure I-12. Location and size of fires, Cabin Lake, plot-3. Number dots = tree, lines = fire extent in marked year.

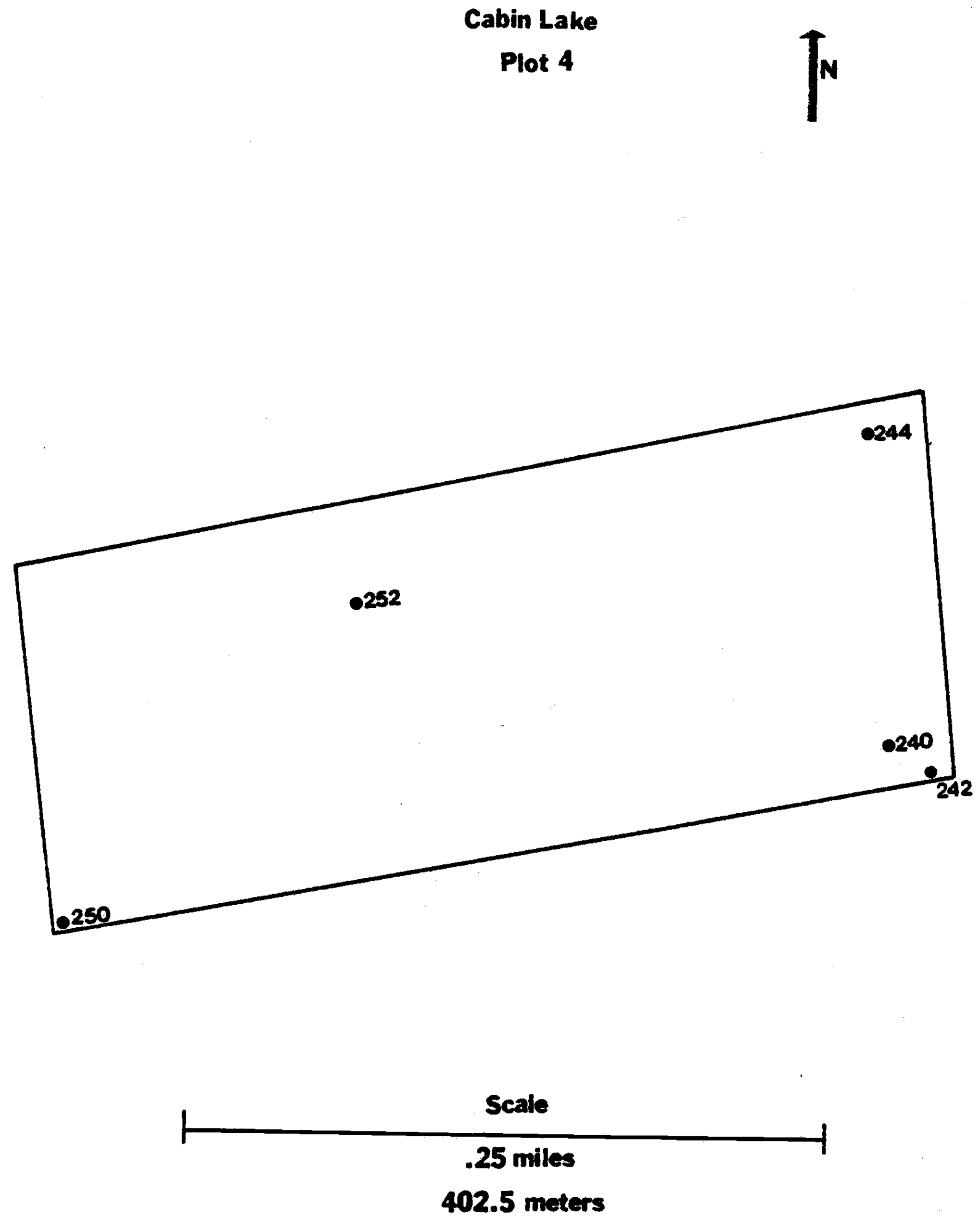


Figure I-13. Location and size of fires, Cabin Lake, plot-4.
Number dots = tree, lines = fire extent in marked year.

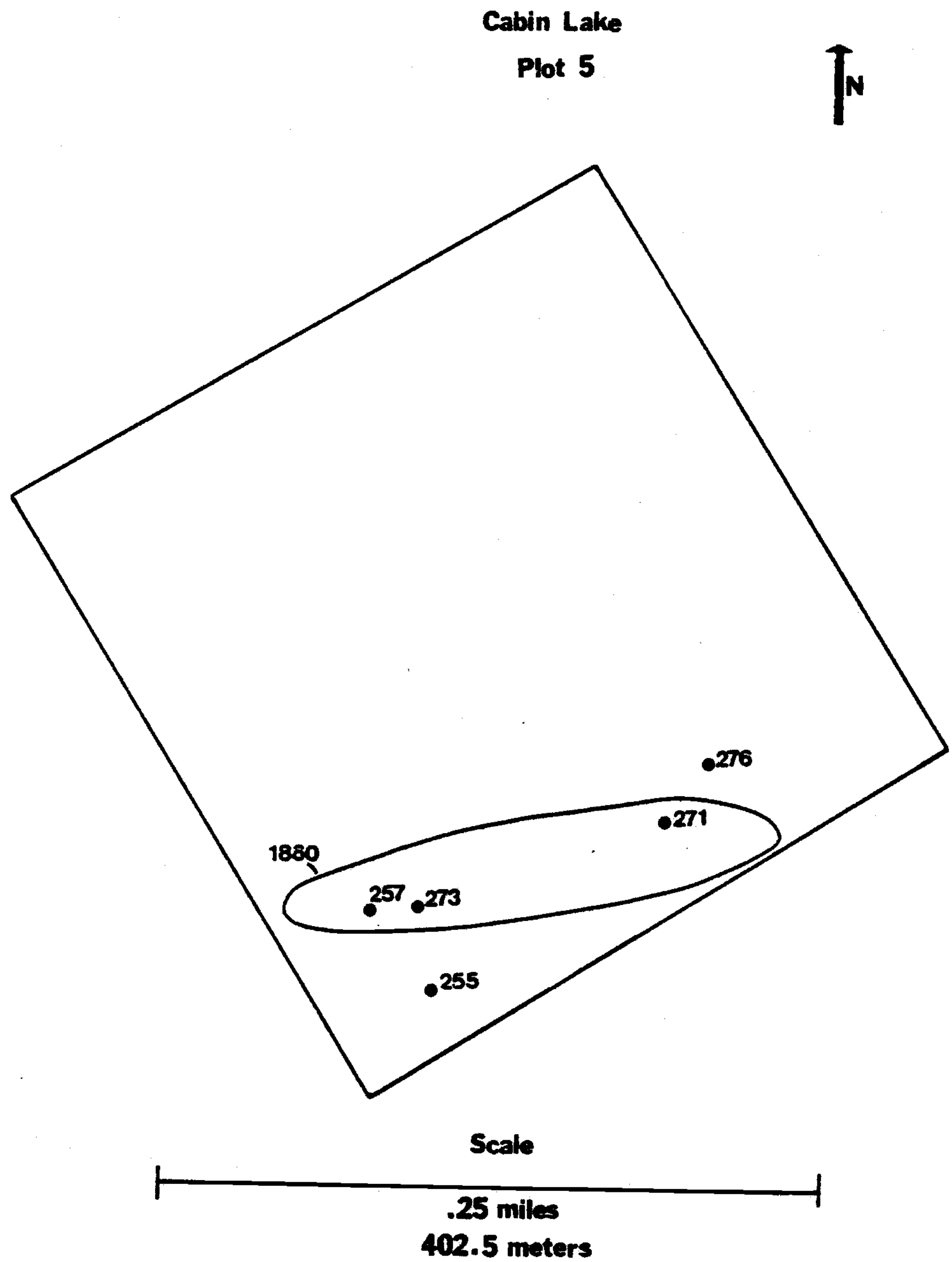


Figure I-14. Location and size of fires, Cabin Lake, plot-5. Number dots = tree, lines = fire extent in marked year.

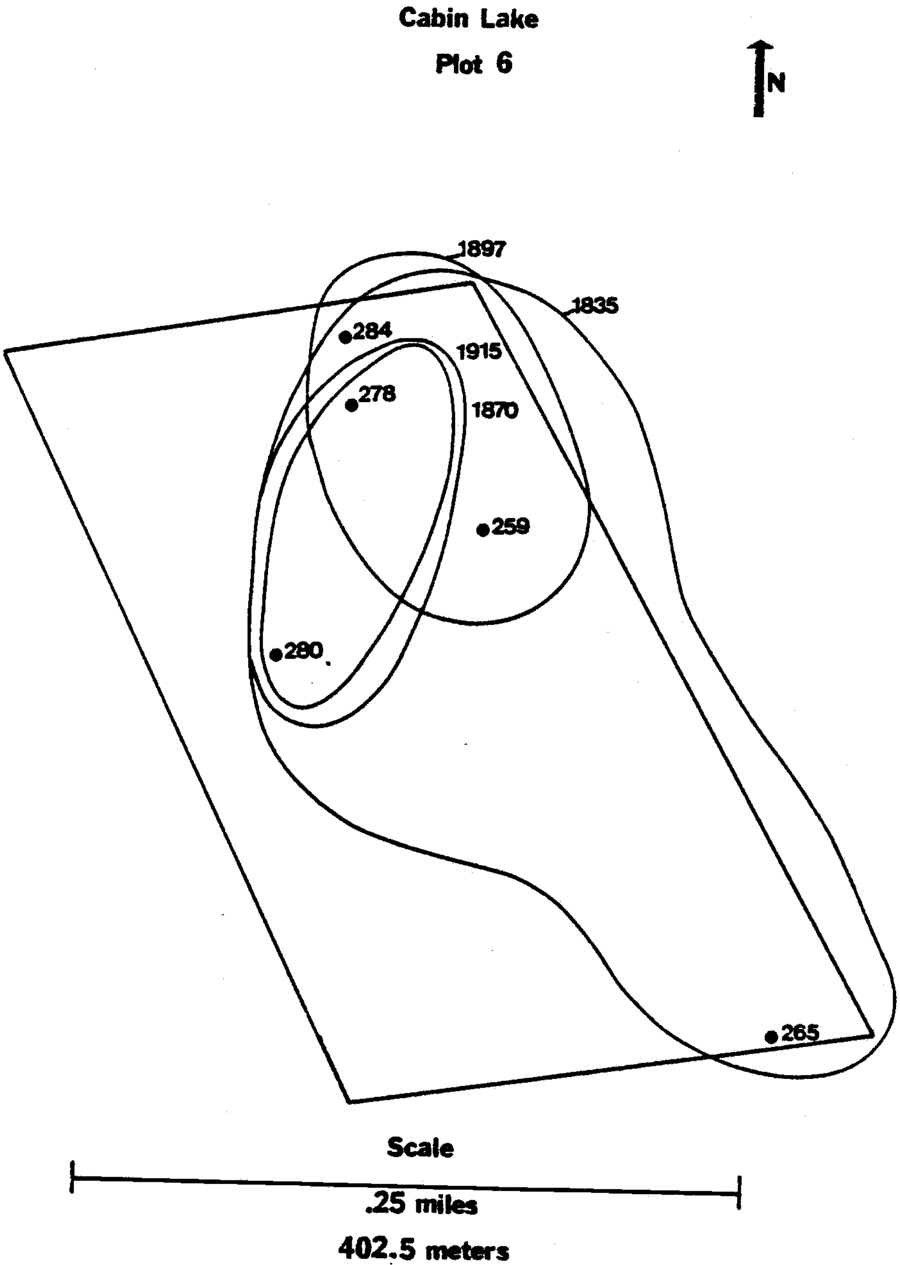


Figure I-15. Location and size of fires, Cabin Lake, plot-6. Number dots = tree, lines = fire extent in marked year.

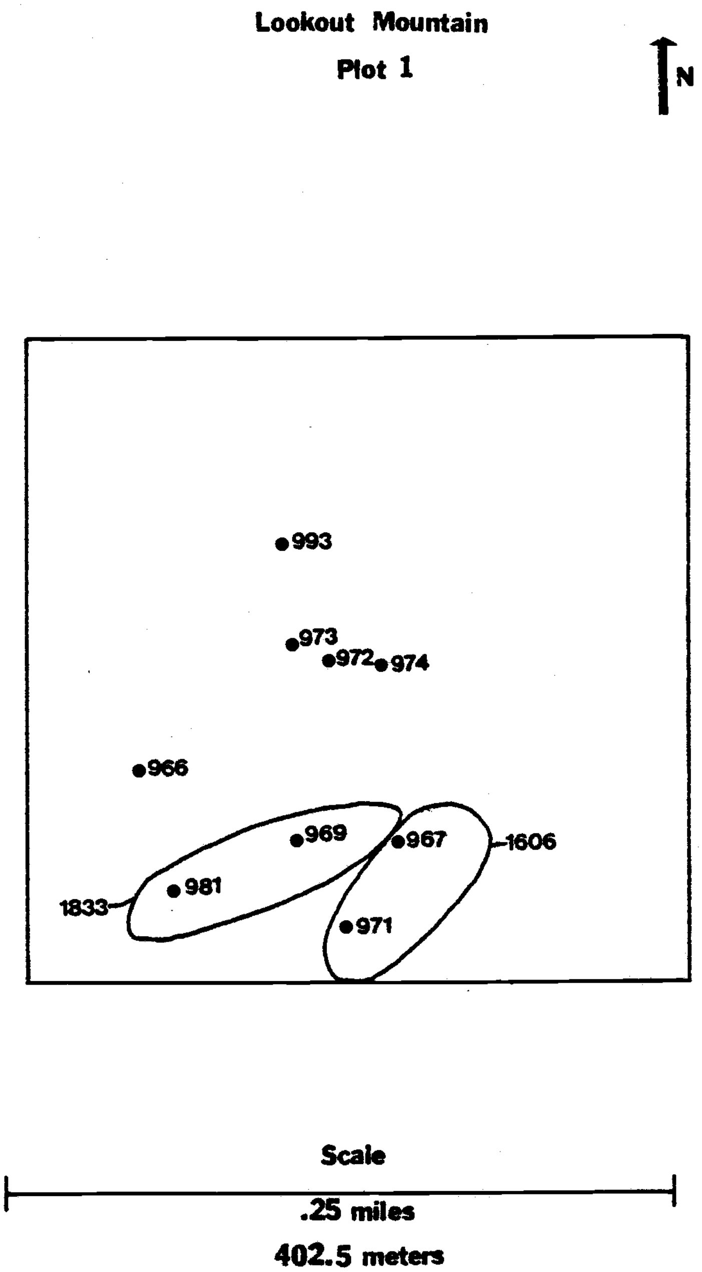


Figure I-16. Location and size of fires, Lookout Mountain, plot-1. Number dots = tree, lines = fire extent in marked year.

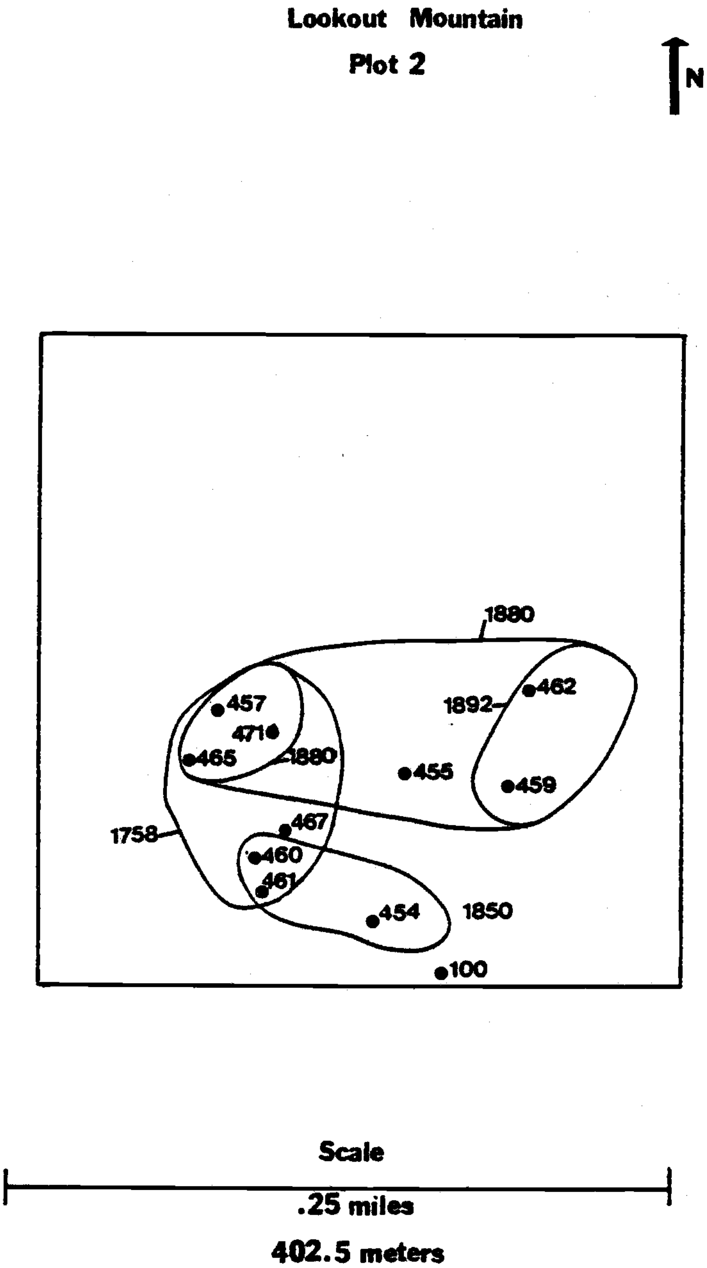


Figure I-17. Location and size of fires, Lookout Mountain, plot-2. Number dots = tree, lines = fire extent in marked year.

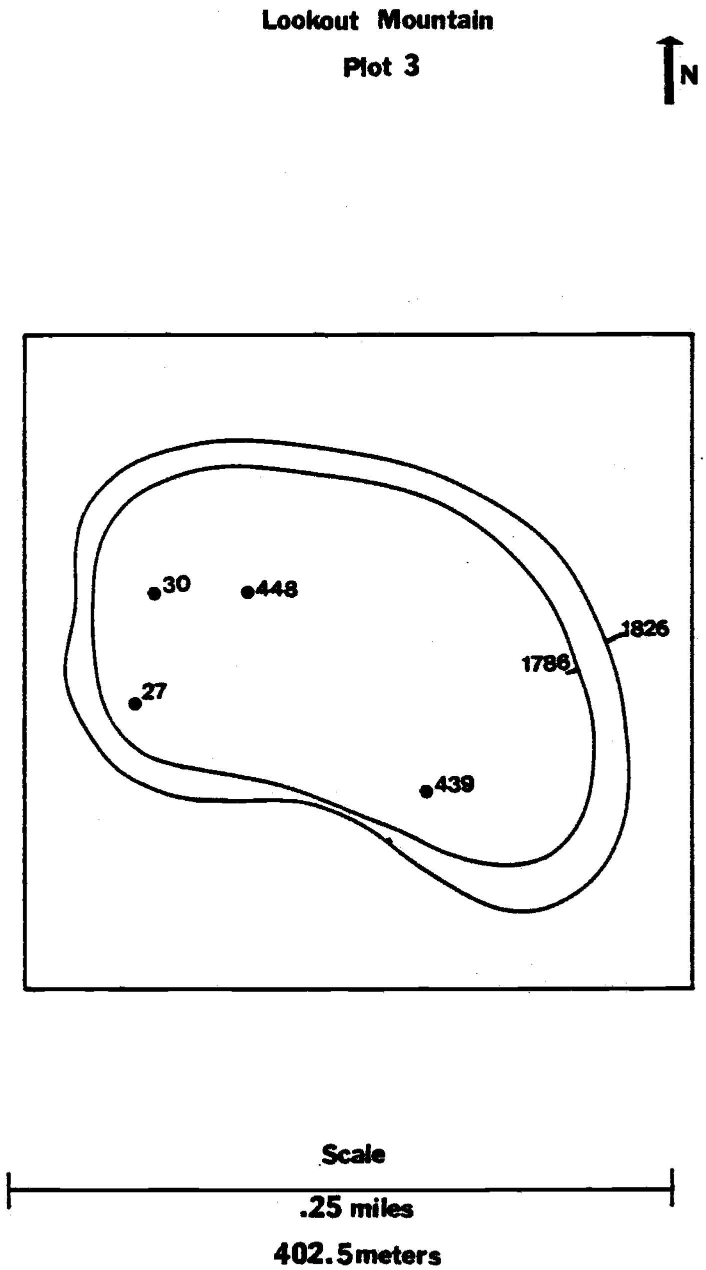


Figure I-18. Location and size of fires, Lookout Mountain, plot-3. Number dots = tree, lines = fire extent in marked year.

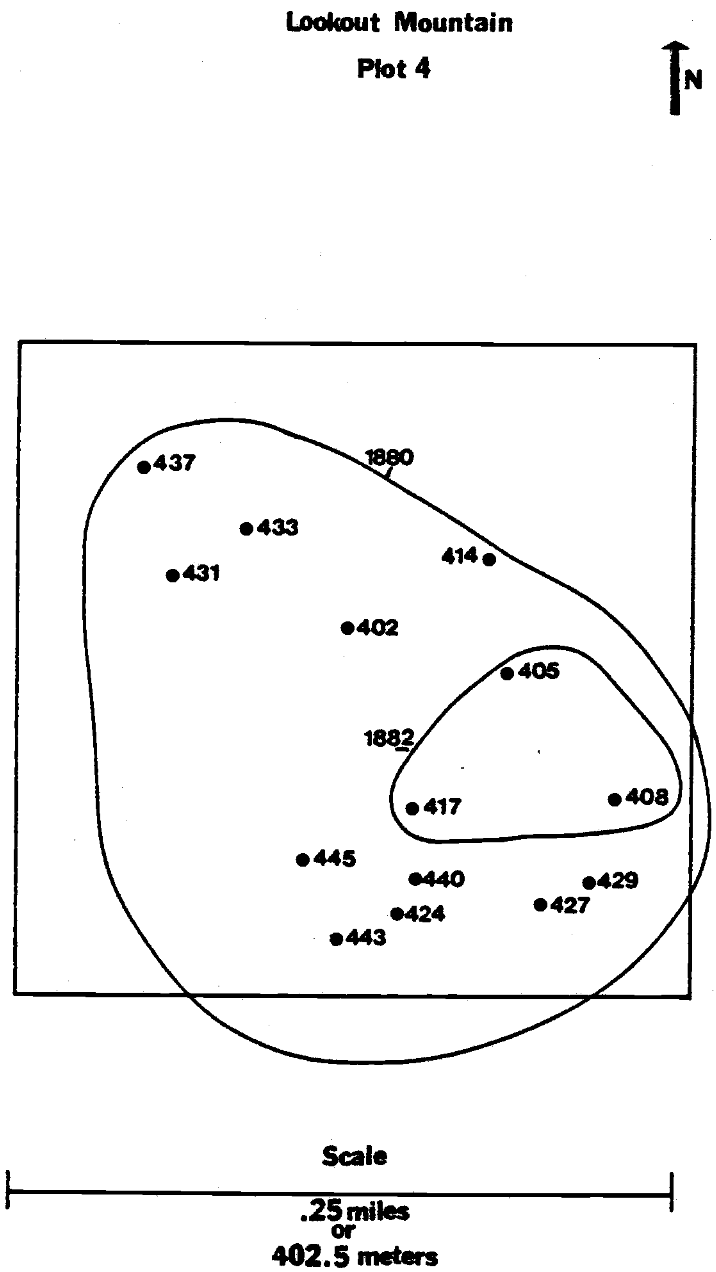


Figure I-19. Location and size of fires, Lookout Mountain, plot-4. Number dots = tree, lines = fire extent in marked year.

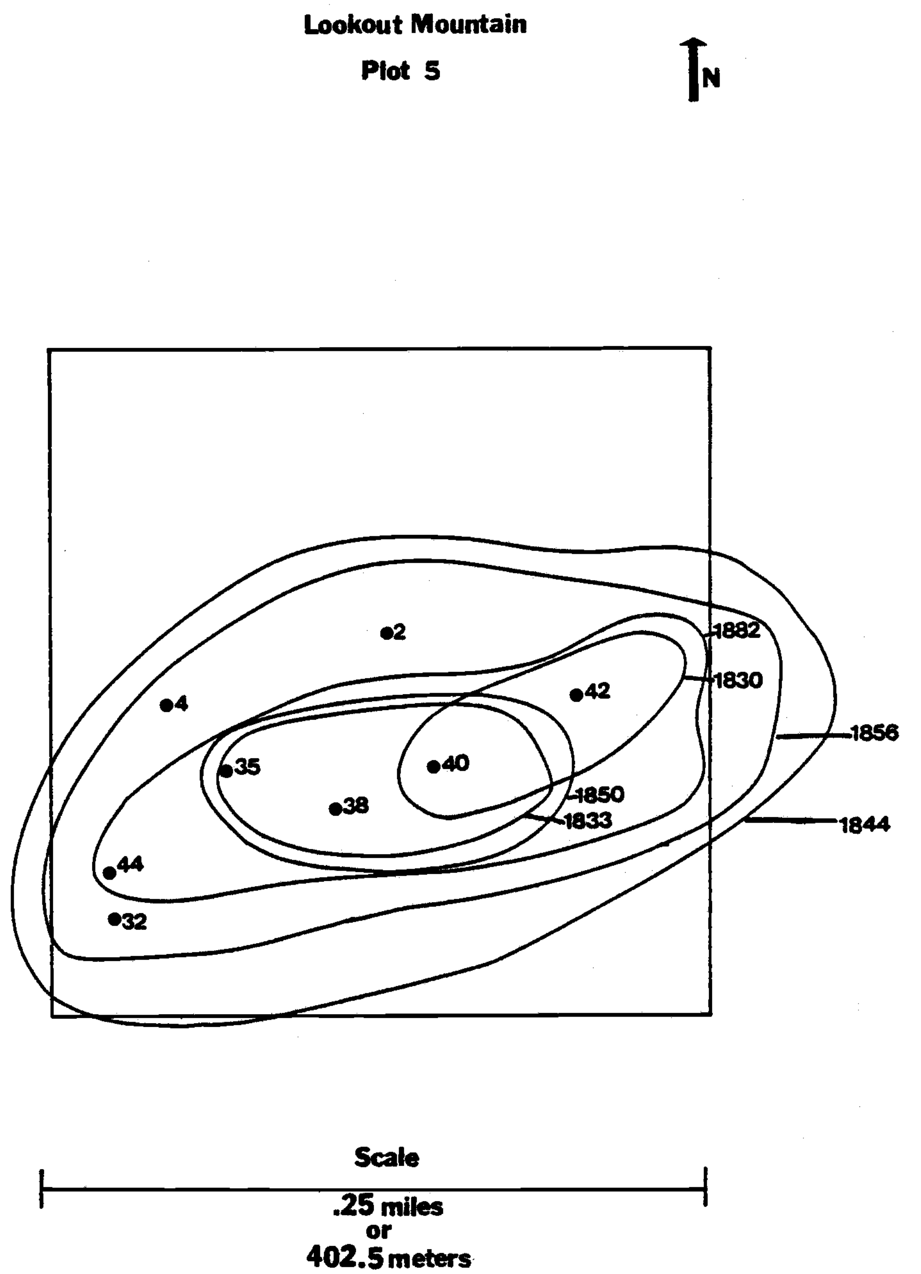


Figure I-20. Location and size of fires, Lookout Mountain, plot-5. Number dots = tree, lines = fire extent in marked year.

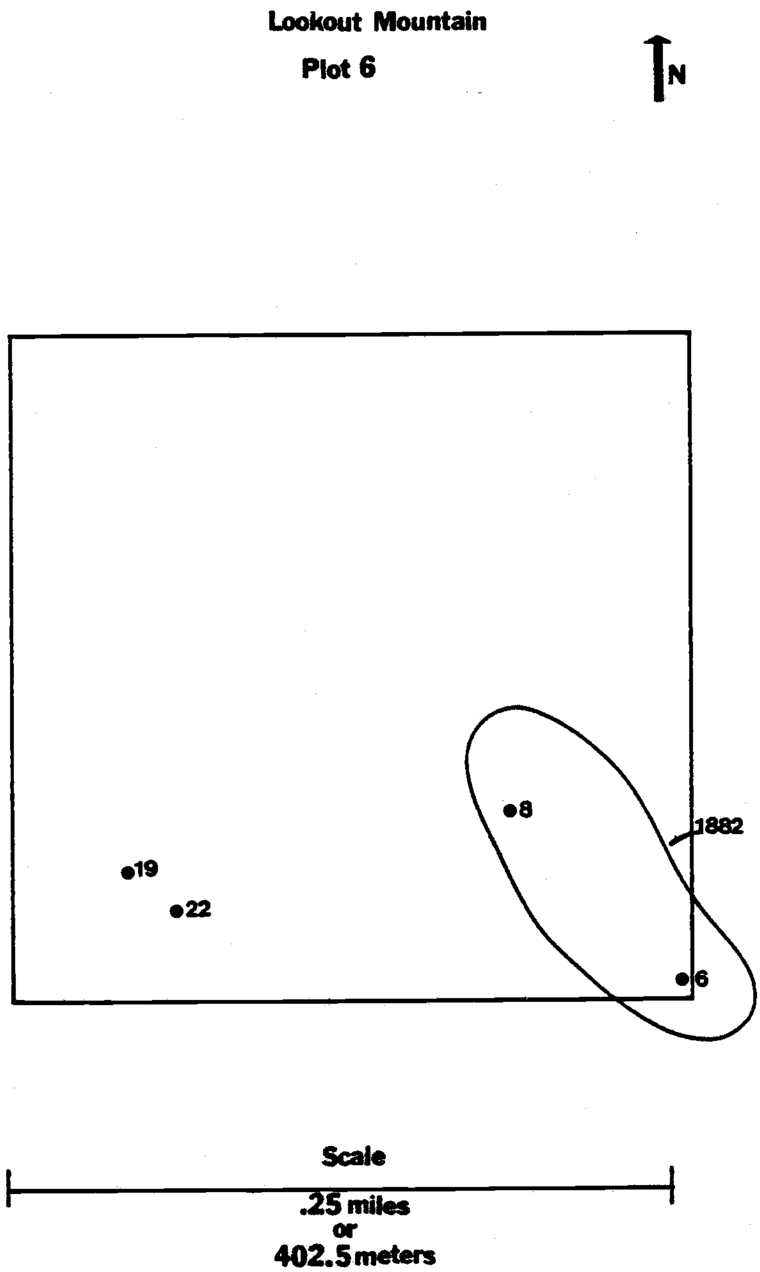


Figure I-21. Location and size of fires, Lookout Mountain, plot-6. Number dots = tree, lines = fire extent in marked year.

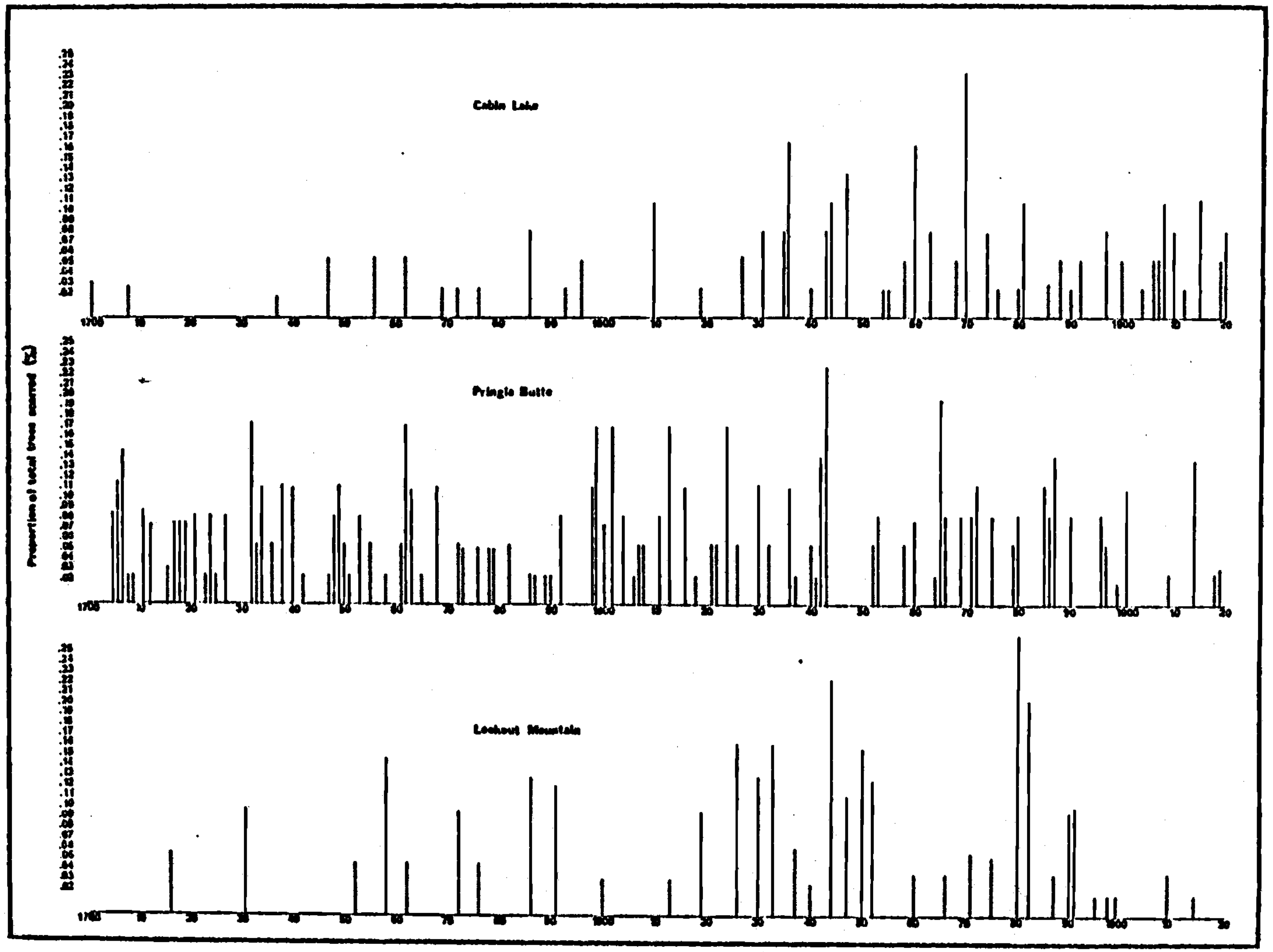


Figure I-22. Proportion of total trees scarred and their frequency. Bar length indicates the proportion of sampled trees scarred during a given year, which is an estimate of area burned.

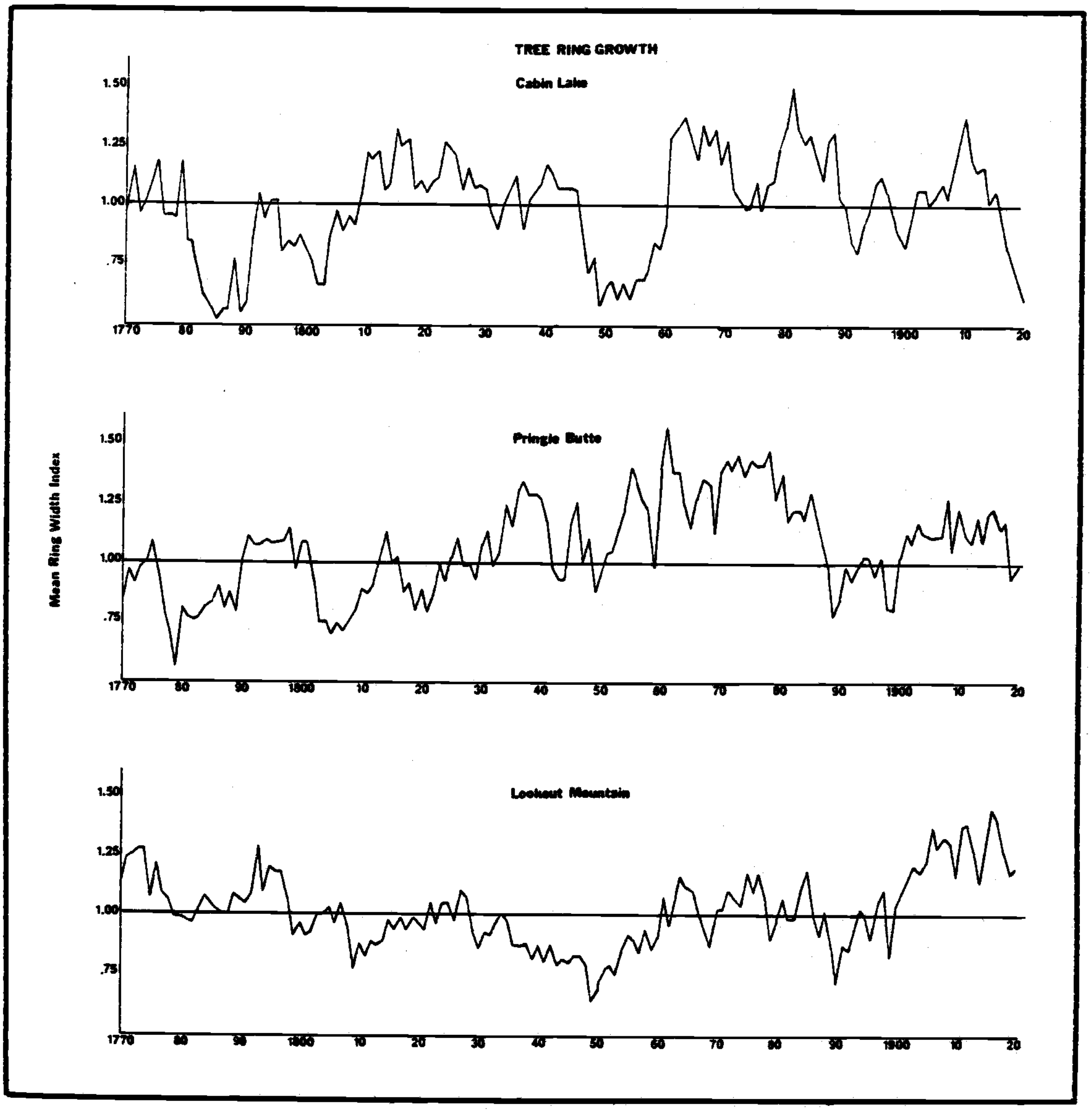


Figure I-23. Normalized ring-widths plotted over time.

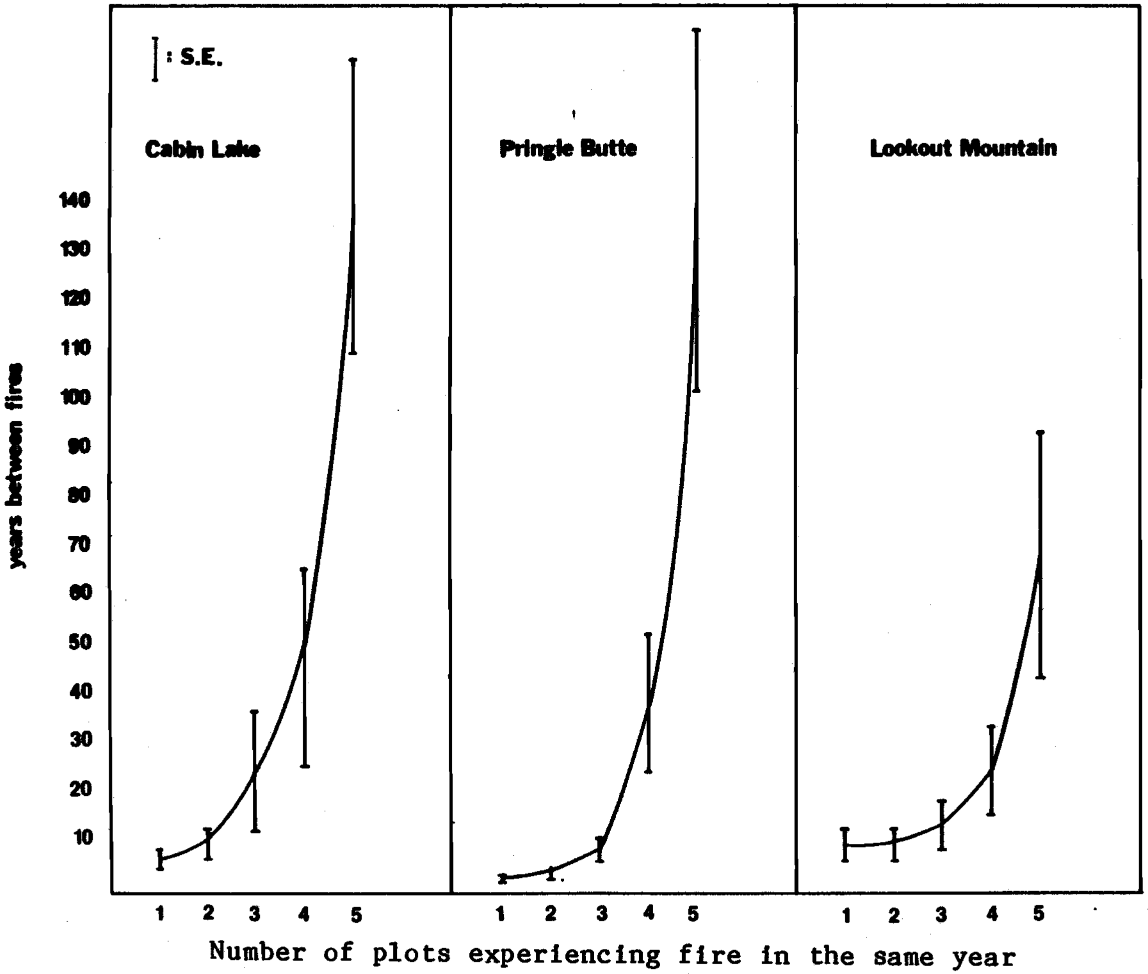


Figure I-24. Mean return interval (MFRI) for fires of different size or MFRI for a given level of fire activity, estimated by proportion of plots having at least two fire-scarred trees.

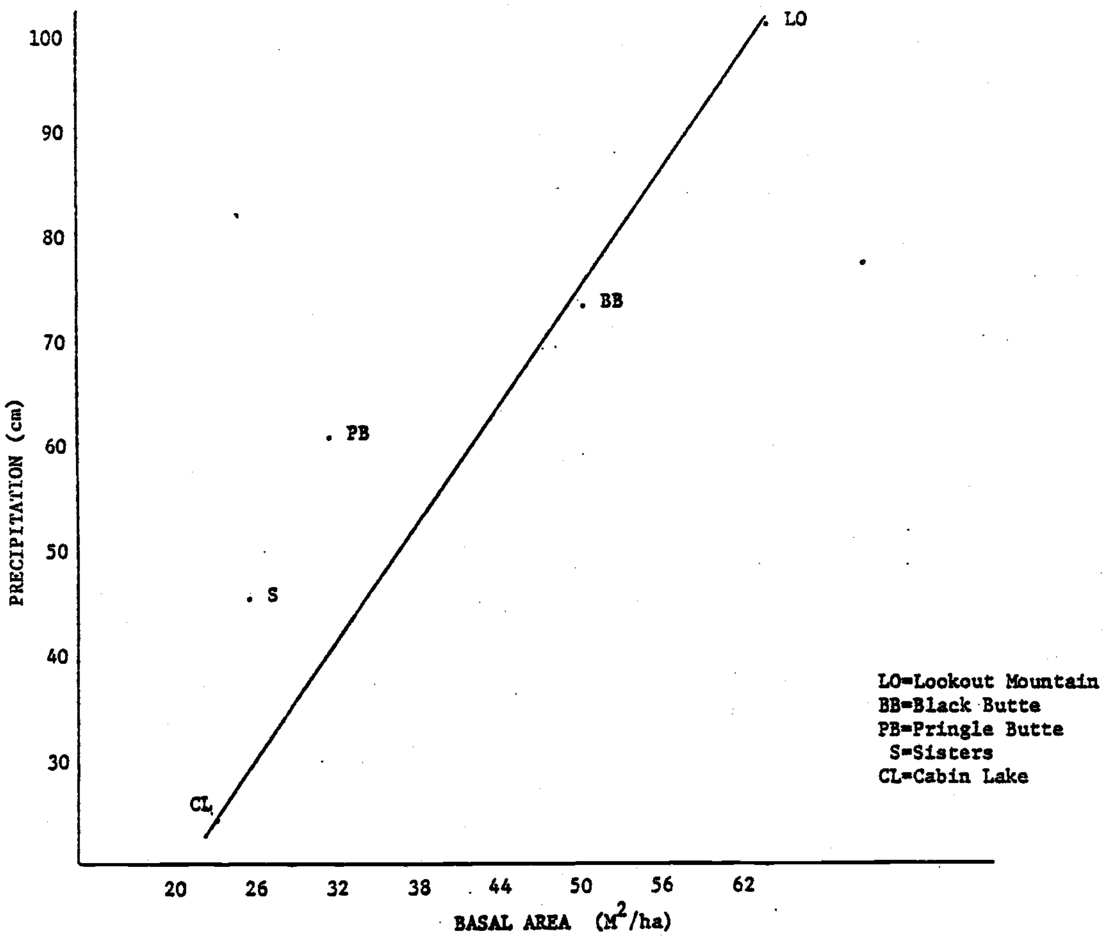


Figure I-25. Relationship between basal area and precipitation. Basal area increases with increasing precipitation. Precipitation and basal area data for Sisters from Sherman (1966) and West (1964), Black Butte from Sherman (1969), Cabin Lake from Volland (1976), Pringle Butte from D. Frewing (personal communication), Lookout Mountain from Barrett (1983) and Barrett and Newman (1974).

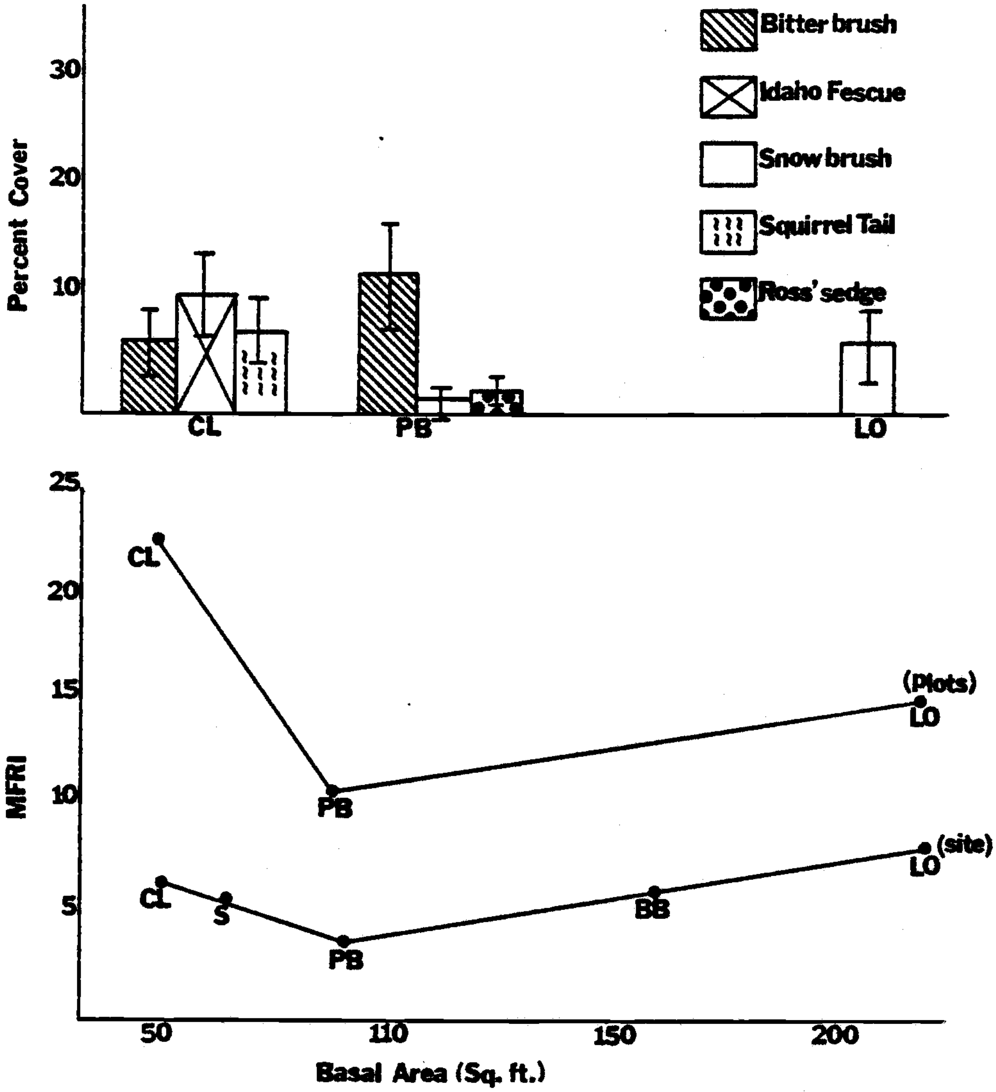


Figure I-26. Relationship between basal area, MFRI (site and plot), and percent cover. Sisters (S) MFRIs and basal area data are from Sherman (1966) and West (1964), Black Butte (BB) MFRIs and basal area are from Sherman (1969), Cabin Lake (CL) basal area is from Volland (1976), Pringle Butte (PB) basal area is from D. Frewing (personal communication), and Lookout Mountain (LO) basal area is from Barrett (1983) and Barrett and Newman (1974).

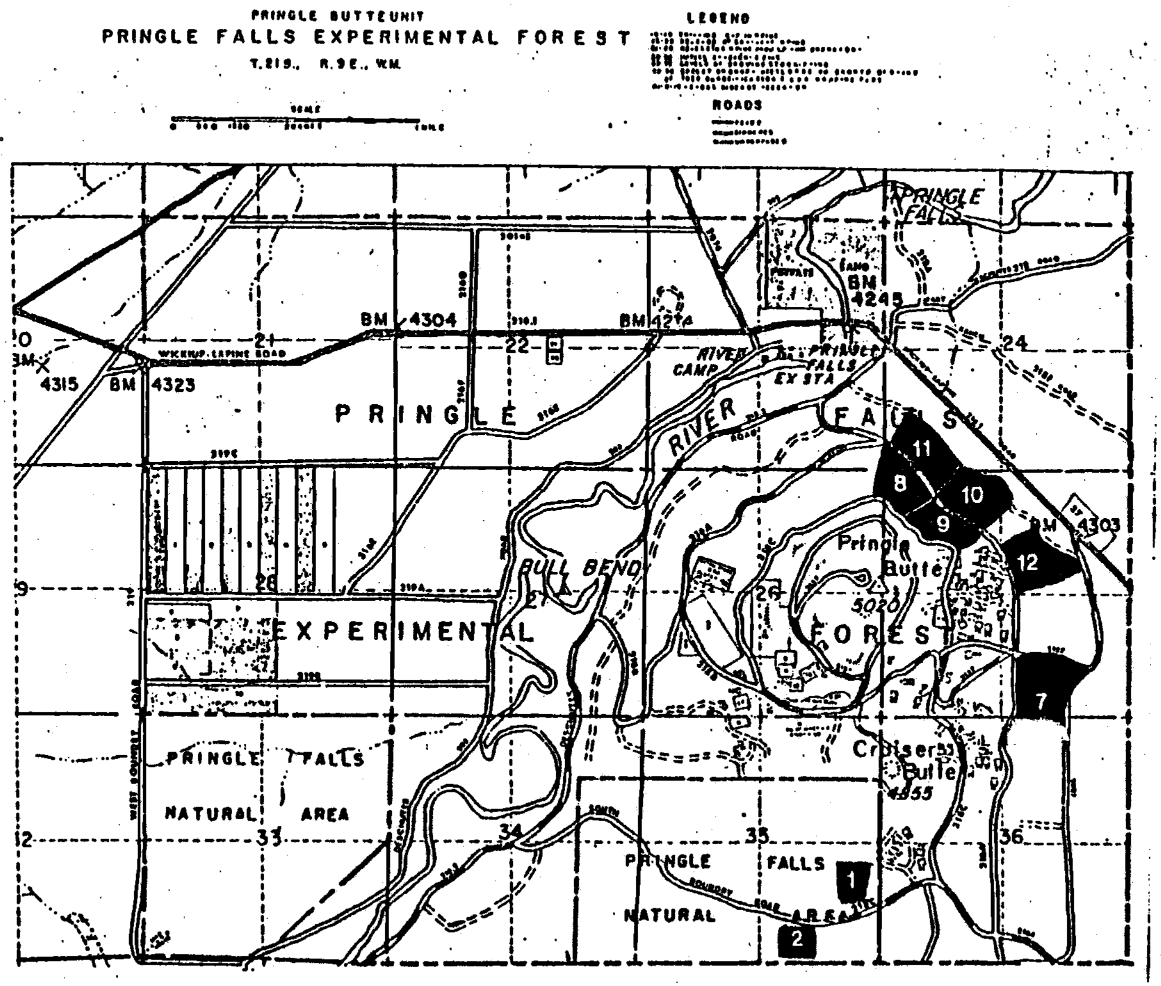


Figure I-27. Location of Pringle Butte plots (7-12) and location of Research Natural Area plots (1-2).

Table I-1. Summary of environmental characteristics for Cabin Lake, Pringle Butte and Lookout Mountain.

Location	Annual precipitation	Summer daytime high temperature	Elevation	Soil type	Vegetation type
Cabin Lake	24 cm[1]	21-32°C[1]	1190 m	Shanahan series[4]	Ponderosa pine/bitterbrush-sagebrush/Idaho fescue[2]
Pringle Butte	61 cm[3]	21-32°C[3]	1080-1130 m	Shanahan series[4]	Ponderosa pine/bitterbrush-snowbrush/needlegrass[2]
Lookout Mt.	102 cm[3]	21-32°C[3]	1190-1270 m	LaPine series[4]	Mixed conifer/snowbrush[2]

[1]D. Warner (Fort Rock Ranger District, personal communication).

[2]Volland (1976).

[3]D. Frewing (Silviculture Laboratory, Bend, Oregon, personal communication).

[4]P. Cochran (Silviculture Laboratory, Bend, Oregon, personal communication).

Table I-2. Summary of data collected from all three sites and for the region (all sites combined). MFRI calculated to 1900.

Variable	Cabin Lake	Pringle Butte	Lookout Mt.	Region
Number of trees sampled	31	35	48	114
Oldest tree at site	539 yrs(1443)*	619 yrs(1362)*	582 yrs(1400)*	619 yrs(1362)*
Range of no. of fires per tree	1-8	4-30	2-10	1-30
Oldest recorded fire	1460	1391	1416	1391
Most recent recorded fire	1970	1974	1969	1974
MFRI Range for individual trees	4-100 yrs	13-74 yrs	13-100 yrs	4-100 yrs
MFRI range for 40 acre plots	16-38 yrs	7-20 yrs	9-25 yrs	7-38 yrs
Average MFRI for all plots	24 yrs	11 yrs	15 yrs	17 yrs
MFRI	7 yrs	4 yrs	8 yrs	6 yrs

*(   ) = pith date.

Table I-3. Pith date of fire scarred trees sampled at Cabin Lake, Pringle Butte and Lookout Mountain.

Cabin Lake	Pringle Butte	Lookout Mt.
1443	1362	1400
1531	1426	1542
1547	1443	1556
1548	1449	1558
1556	1450	1563
1570	1452	1568
1584	1460	1572
1585	1463	1583
1604 (2)	1467	1598
1625	1470	1651 (2)
1631	1476	1667 (2)
1637	1501	1688
1638	1508	1696
1643 (3)	1509	1718
1647	1525	1720
1649	1530	1724
1650	1541	1727
1655	1542	1777
1659	1543	1780 (2)
1669	1544	1790
1670 (2)	1552	1795 (2)
1673	1553	1799
1675	1561 (2)	1800
1690	1562	1806
1693	1563	1833
1704	1565	1844
1706	1567	1845 (2)
1722	1576	1846
1723 (2)	1597 (2)	1848 (5)
1729	1601	1849 (2)
1773	1638	1850 (4)
	1681	1851
	1721	1852
		1853
		1861

( ) Number of trees with same pith date.

Table I-4. Comparison of mean values for percent cover of dominant understory species and of forest floor in burned and unburned plots at Cabin Lake, Pringle Butte and Lookout Mountain.

Site	Litter and duff		Bitterbrush		Fescue		Squirrel tail	
	B[2]	UB[3]	B	UB	B	UB	B	UB
Cabin Lake								
Means	59.50	53.48	7.38	5.42	10.87	10.00	1.30	6.23
S.E.[1]	(± 4.55)	(± 6.64)	(± 2.85)	(± 2.48)	(± 2.37)	(± 3.59)	(± 0.94)	(± 3.08)
Pringle Butte					Snowbrush			
Means	74.56	68.42	5.75	13.33	5.00	.083		
S.E.[1]	(± 5.39)	(± 6.81)	(± 3.45)	(± 4.66)	(± 3.46)	(± .08)		
Lookout Mt.							Logs	
Means	87.88**	51.20			0	7.30**	6.19	10.50
S.E.[1]	(± 3.83)	(± 6.5)				(> 3.20)	(± 3.50)	(± 3.77)

[1]S.E. = ± standard error.

[2]B = burned plots.

[3]UB = unburned plots.

**P < 0.01 between burned and unburned plots in each site.

Table I-5. Comparison between periods of decline in regeneration and years of high fire activity.

Periods of decrease in regeneration[1]	Years of high fire activity
1721-1741	1705
1762-1781	1711
	1762
1842-1861	1842
	1843
	1862
1882-1901	1863
	1886

[1]Data from Morrow (1984).

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CHAPTER II. CLIMATIC INFORMATION FROM PONDEROSA PINE (PINUS PONDEROSA LAWS.) IN CENTRAL OREGON

INTRODUCTION

Natural stands of ponderosa pine (Pinus ponderosa Laws.) occur from southern British Columbia to Mexico, and from Nebraska to the Pacific Coast. Ponderosa pine grows from sea level to 2743 m, usually in a climate with summer drought, July and August averaging 2.54 cm or less total precipitation (Fowells 1965).

A softwood tree of high economic importance, ponderosa pine in the Pacific Northwest has furnished timber to farms, mines, and settlements since 1860 (Barrett 1979). Ponderosa pine forests are widely distributed throughout eastern Oregon as both climax and seral communities (Franklin and Dyrness 1973).

In 1923 Keen began a study of climatic cycles in eastern Oregon. Two decades of drought and beetle attacks had seriously depleted ponderosa forests. Keen wanted to determine whether the climatic trend would continue or was merely a short lived cycle which would soon reverse itself.

Keen used tree-ring records to estimate climatic sequences for the past seven centuries, while recognizing that other events influencing growth, such as severe forest fires, insect defoliations and droughts would have to be separated from long-term climatic trends. Keen was not the first to apply the tree-ring method of analysis to the interpretation of growth and climatic cycles. Douglas developed the application of tree-ring studies to the climatic record in the late 1890's, as a tool to study sunspot cycles and their relationship to climate (Stokes 1980). Further development of dendrochronology and its application in Europe and America is reviewed by Fritts (1976) and Trenard (1982).

Tree-ring research is based on the interaction between tree growth and the climate in which a tree grows (Stokes 1980). Ring-widths of old trees growing on arid sites are highly related to fluctuations in annual precipitation (Fritts 1976). The Laboratory of Tree-Ring Research at Tucson, Arizona has developed tree-ring chronologies throughout North America. In 1967, 49 chronologies from western North America were selected and published (Stokes et al. 1973). Since then, more than 1000 chronologies have been developed from western North America (Fritts et al. 1975). A major goal of the Tree-Ring Laboratory is to make these data available to other researchers.

The main purpose of this study was to expand the tree chronology data for central Oregon, and to compare historical ring growth patterns among three different habitat types. Only one published chronology PLA (Paulina) (Figure II-1) is close to the three sites in this study. Three questions guided the preparation of the three tree-ring chronologies. First, are the chronologies from all three sites with different moisture regimes suitable for climatic interpretation. Second, would the growth pattern reflect an overall regional climatic influence or vary with local moisture availability? A third question developed from fire history studies done on the three sites (Chapter I). Trees from Pringle Butte consistently exhibited a marked reduction in ring width for five to ten years after a major fire. This pattern was assumed to have been caused by fire. However, climatic influences could also be involved. Could climate be the cause of the decrease in growth instead of fire?

STUDY AREA

Trees were sampled in three different vegetation types dominated by ponderosa pine within the Deschutes National Forest south of Bend, Oregon: (1) Pringle Butte, and (2) Lookout Mountain are located in the Pringle Falls Experimental Forest, and (3) Cabin Lake is in the Fort Rock Ranger District southeast of Lapine (Figure II-1).

Climate

The three study sites are under the influence of a dry continental climate. Summer daytime highs range between 21°-32°C and nights are cool as a result of radiative cooling. It is not uncommon for temperatures to drop slightly below freezing in July and August. Precipitation falls mostly as snow from October through March. In the winter, daytime high readings range from 15°C to -6°C; nights of -15°C are not unusual.

Cabin Lake is the driest of the three sites, receiving 24 cm annual precipitation. The wettest site is Lookout Mountain with 102 cm annual precipitation and Pringle Butte has 61 cm annual precipitation. The climate in the region is described in more detail by Hatton (1977).

Vegetation Types

Vegetation at Cabin Lake is a *Pinus ponderosa/Purshia tridentata-Artemisia tridentata/Festuca idahoensis* community (Volland 1976) at an elevation of 1190 m. This forest has low productivity and natural regeneration is sparse. Pringle Butte is a *Pinus ponderosa/Purshia tridentata/Stipa occidentalis* community with moderate productivity. Samples were collected at an elevation of 1100 m. *Pinus contorta* Dougl. is present in the understory along with *Carex rossii* Boott. and *Pinus ponderosa* regenerates easily. Lookout Mountain, at 1190 m, is a mixed conifer/*Ceanothus velutinus* community. *Pinus ponderosa* is dominant in the overstory with *Pinus contorta* and *Abies concolor* (Gord. and Glend.) Lindl. as subdominants. *Purshia tridentata* DC. is rare and *Arctostaphylos patula* Greene is occasionally present. Natural regeneration is effective for all species.

Fire

Fire was a natural, important influence in all three ecosystems. Mean fire return intervals (MFRI) were 24 years at Cabin Lake, at Pringle Butte 11 years and at Lookout Mountain 15 years (see Chapter I). The differences in frequency at the three sites is a reflection of moisture and vegetation (Chapter I). Limited moisture at Cabin Lake prevents rapid growth of any species and results in a sparse understory and low fuel accumulation. Favorable moisture conditions at Lookout Mountain maintain a vigorous understory but the higher moisture regime deters very frequent fires. Pringle Butte has a more favorable moisture regime than Cabin Lake, which contributes to better growth but does not arrest fire episodes.

METHODS

At each site two breast height increment cores were collected from opposite sides of a minimum of 10 ponderosa pine trees. Trees considered sensitive were sampled. Sensitive trees are those that are very responsive to a decrease in moisture and will exhibit variation in width from ring to ring (the lack of variability is called complacency). Ponderosa pine trees growing on steep slopes and rocky outcrops were sampled in locations likely to produce non-complacent ring chronologies. Cores were mounted in pregrooved sticks and sanded with a sequence of coarse to fine grit sandpaper. All rings were dated by cross-dating methods (Stokes and Smiley 1968) and measured to the nearest 0.01 mm with a Bannister incremental measuring machine. Cross dating assures that each ring width and climatic value corresponds between sequences (Fritts 1976). Cross dating matches ring width patterns among samples, detecting absent or false rings and finally generating a master chronology that reflects growth sequences of trees for a region (Fritts 1976).

Analysis used computer programs available through the Laboratory of Tree-Ring Research (Graybill 1979). From each chronology, ring-width measurements were standardized to form indices which account for the decrease in ring-width that occurs as the tree ages. This is done by fitting a polynomial, exponential, or liner curve to the ring measurements from each core and dividing each ring width by the value of the growth curve. The resulting indices from all rings formed in each year are averaged and graphed to display yearly growth variations for all trees in each site. The Pringle Butte chronology begins in

1562, Cabin Lake chronology in 1648 and Lookout Mountain chronology in 1759. All chronologies end after 1981. Indices from each chronology were compared and examined for frequent patterns of 5 to 10 years of depressed growth.

Serial (auto) correlation, standard deviation and mean sensitivity for each chronology were compared with chronologies from other Oregon sites (Drew 1975) and with means from all western North American chronologies (western chronologies) (Fritts and Shatz 1975) to determine suitability of the ponderosa data for climatic interpretation. Serial correlation determines the correlation between one year's growth and the preceding year's growth, by correlating each mean index value with the index value of the previous year (Fritts 1976). It measures how much the conditions of one year affect the next year's growth. Mean sensitivity measures the relative differences in the width between adjacent rings. Standard deviation is a measure of variation in both mean sensitivity and serial correlation.

Analysis of variance was computed for each site. All trees on a site are represented by two cores and the same years of growth (Table 1). For each site, Y represents the variance associated with single cores, YxT is the variance among single trees and YxCxT is the variance from two cores within a given tree. A large amount of ring variability in Y implies that some large scale factor such as climate has affected growth, while large differences in tree (YxT) and core (YxCxT) variation imply that a variety of other factors limit growth more than climate (Fritts 1976). Variance components were reduced to percentages for comparisons.

RESULTS AND DISCUSSION

Tree-ring chronologies for Pringle Butte, Cabin Lake and Lookout Mountain are presented in Tables II-2 to II-4. Evaluation of the suitability of chronologies for climatic interpretation is based on Fritts and Shatz (1975). Good information for climatic interpretation is found in chronologies with a mean sensitivity of .348. Rarely would mean sensitivities higher than .611 or lower than .086 be suitable for interpretation. The mean sensitivity of .113 at Pringle Butte, and .141 at Cabin Lake and .089 at Lookout Mountain (Table II-5) are relatively low as are previously published Oregon chronologies which range from .137 to .212 (Table II-5). Serial correlation of .452 is ideal but can be used in a range between .685 and .220 and the data still be useful. Serial correlation for previously published Oregon chronologies are within and out of the range, varying from .459 to .772. The three study sites show Lookout Mountain with .699, Pringle Butte at .812 and Cabin Lake at .745; all are higher than the range suggested for estimating climatic change. To be useful in climatic interpretation, standard deviation should be between .575 and .156 with best at .366. All of the Oregon chronologies and the study site chronologies fall within this range with Cabin Lake at .266, Pringle Butte at .292 and Lookout Mountain at .297 (Table II-5).

Although mean sensitivity values of less than .02 and serial correlations greater than .6 are infrequent for western chronologies, they appear to be common for chronologies from temperate sites above 40° latitude (Fritts and Shatz 1975). Since mean sensitivity measures the percent change in ring-width from year to year, values as low as those found in the three study sites indicate that fluctuations in growth were too small to be caused primarily by variation in climate. The high serial correlations show a linkage of one year's growth to that of the previous year. Climate undoubtedly plays a role in this correlation but other factors such as microsite differences or internal physiology which would be involved in excesses or deficiencies of water and carbohydrates for the next year must have a greater influence. If climate were more important than the linkage from year to year, the serial correlations would be smaller. Fritts and Shatz (1975) have found that ponderosa pine typically exhibits poor statistics and provides limited climatic information. None of the previously published Oregon ponderosa pine chronologies or chronologies from this study appear to be very suitable for climatic interpretation.

Analysis of variance provides a similar conclusion. The climatic signal is measured by average percent variance for all cores and trees (Y). Variance (Y) for western chronologies of 60 percent is much higher than in the present study (Table 1). Variances are not available for the previously published Oregon chronologies. Low variance (Y) indicates that nonclimatic factors account for a greater percentage of the variation found at each site. The differences in individual core chronologies (YxCxT) ranging from 48 to 75 percent from the study sites are higher than the variances between trees (YxT) which range from 14 to 42 percent, suggesting that crown irregularities, competition, disturbance or distribution of growth controlling substances are influencing ring variability within trees (Fritts 1976).

Growth indices for the three sites are displayed in Figures II-2 to II-5. High variability in growth among the three sites and within each site is evident. Cabin Lake exhibits the greatest ring-width variation of the three. Cabin Lake is near the dry margin of the ponderosa pine forest and thus would be most affected by drought, which in turn, should produce greater ring width variation (Fritts 1976). Precipitation records from Fremont, 10 miles south of Cabin Lake, are available for most of the period from 1925 to 1980. Low precipitation occurred in 1926, 1939, and 1959, corresponding with low growth at Cabin Lake (Figure II-5). The lowest growth period in the chronology for Cabin Lake is 1932 to 1937. Growth was also low at Pringle Butte and Lookout Mountain during this period, and Keen (1937) identified 1931 as a severe drought year. Precipitation data at Fremont are missing for 1931 to 1936 but all the evidence shows this to be a time of drought. Pringle Butte shows lower growth since 1900 than for the previous century (Figure II-3). Earlier episodes of low growth are evident from 1710 to 1790 and 1590 to 1640 (Figure II-4). Neither Cabin Lake nor Lookout Mountain exhibit such clear decades-long depressions of growth. Moisture is not as limiting to growth on Lookout Mountain as it is on Pringle Butte or at Cabin Lake; as a result ring-width variation is less and long term trends are not as evident. The alternate periods of short duration that show good and poor growth are more apparent at Cabin Lake than the other sites and reflect extremes rather than portray trends that are indicative of climatic patterns. The trees at Pringle Butte are not as responsive to decreased moisture as trees at Cabin Lake, but reveal longer term growth trends providing better climatic information.

Even though statistics indicate that the study chronologies are of marginal use for climatic analysis, growth patterns reflecting the influence of climate were found. Years of rapid and slow growth from the sites correspond with each other and with Keen's work (1937) (Table II-6). Not every year matches but there is a general agreement among all three sites, pinpointing possible years of drought and years of high precipitation. Standards normally applied to western chronologies may not be suitable for ponderosa pine in eastern Oregon. The climatic information that ponderosa provides should be used until better chronologies are developed.

The decrease in ring-width observed in the fire history study is not reflected in the ring-width indices, and most likely is the result of fire. Keen (1937) noted that young trees showed sharp decline in growth following fire, while older trees appeared relatively undisturbed. This was not true in the fire history study (see Chapter I) which showed decreased ring-width after every major fire regardless of tree age. Since the decrease in growth is only evident at Pringle Butte, some environmental or physiological factors must be influencing growth at Pringle Butte that are not in action at the other sites. The decrease in ring width following fire requires further study of forest productivity after disturbance.

CONCLUSIONS

Chronologies from this study appear to offer limited information for climatic interpretation compared to other chronologies from the western United States, because they show low mean sensitivities and high serial correlations. Analysis of variance lends support to this conclusion, since percent variance contributed by differences between all trees and cores is very low, indicating that nonclimatic factors account for a greater percentage of the variance found at each site. Percent variance among trees was also low, while percent variance between cores from a single tree was high, suggesting greater variation within trees than between trees. Factors other than regional climate are influencing tree growth. However, growth patterns do reflect climate and show a general agreement between sites displaying similar years of estimated drought and high precipitation. Pringle Butte exhibits more obvious long-term fluctuations than the other sites. Lookout Mountain has less variation in growth, probably because of higher annual precipitation, while growth at Cabin Lake is highly responsive and may be too sensitive to reflect long-term patterns.

Decreased growth found in fire scarred trees at Pringle Butte (see Chapter I) is not evident in trees sampled in this study. Climate can be eliminated as the major factor influencing this growth pattern.

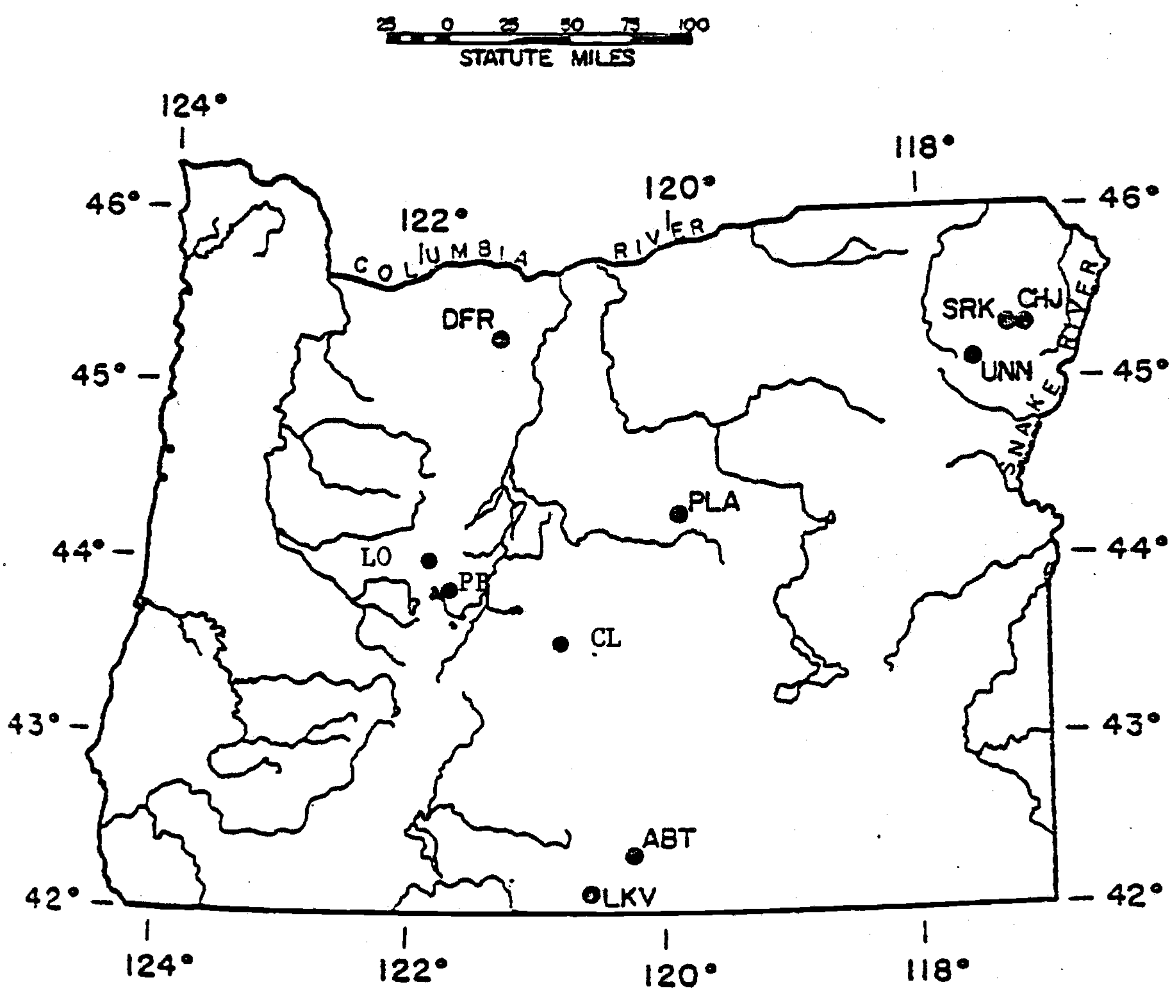

Figure II-1. Location of previously published tree-ring chronologies (Drew 1975) and study sites. CL=Cabin Lake, PB=Pringle Butte, LO=Lookout Mountain, DFR=Dufur, UNN=Union, SRK=Slickrock Creek, CHJ=Chief Joseph Mtn., PLA=Paulina, ABT=Abert Rim Lookout, LKV=Lakeview.

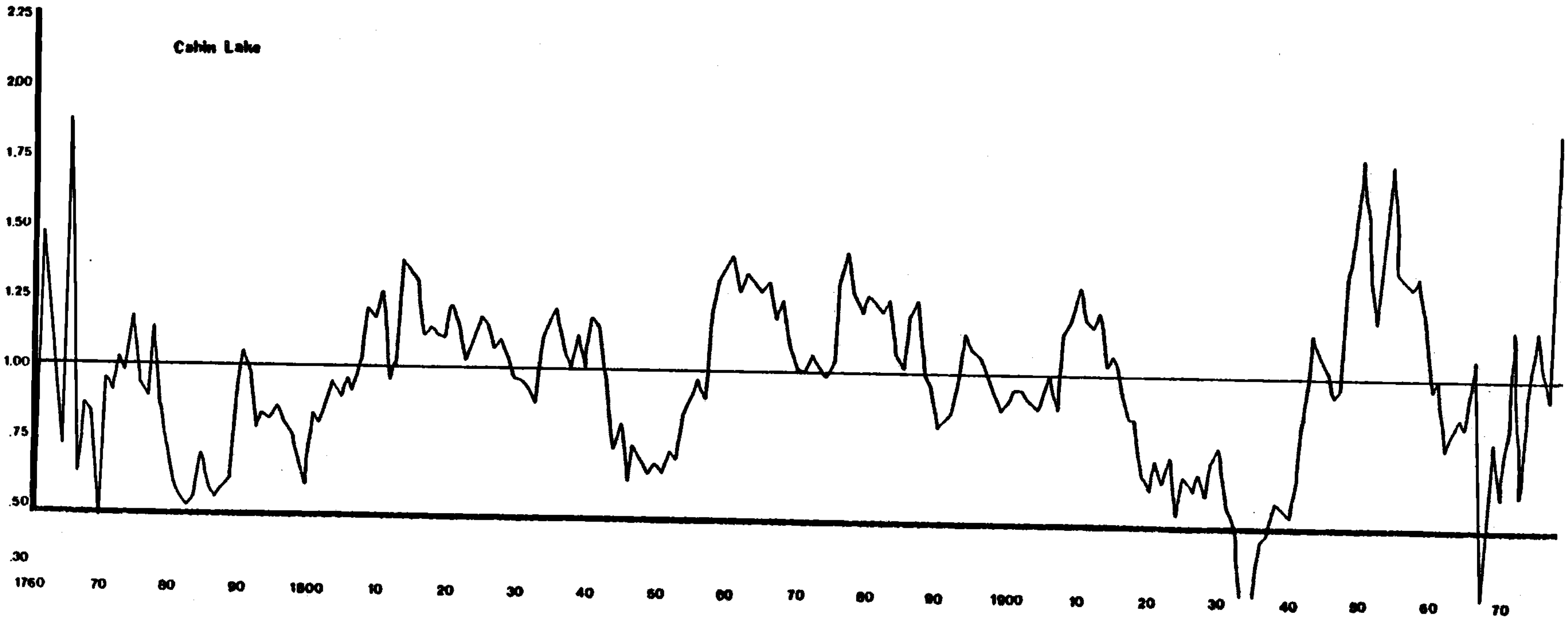

Figure II-2. Growth indices for Cabin Lake (1759-1981).

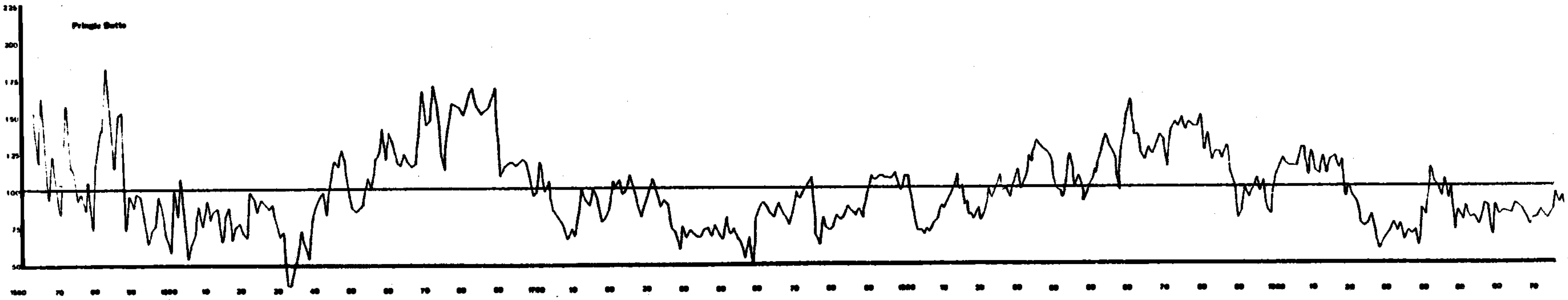

Figure II-3. Growth indices for Pringle Butte (1562-1982).

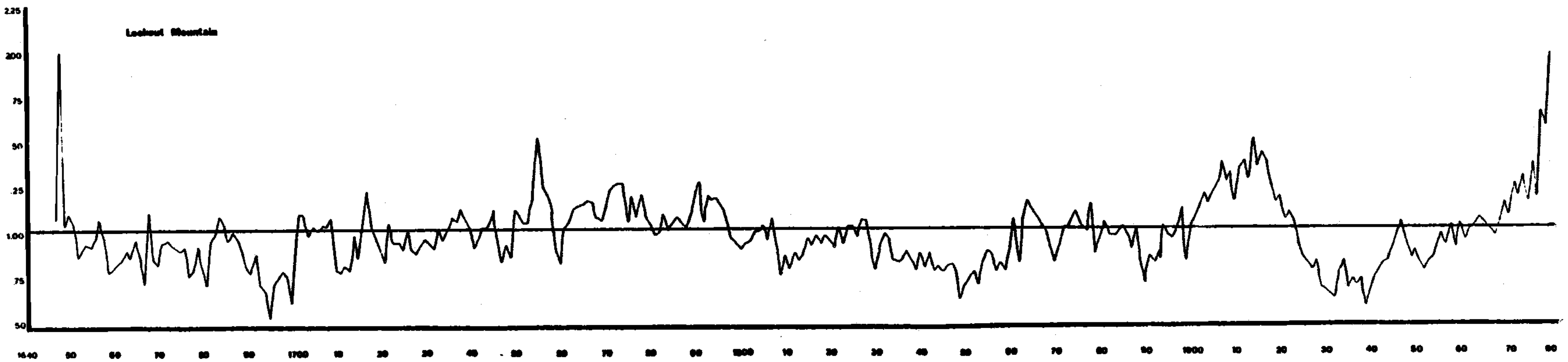

Figure II-4. Growth indices for Lookout Mountain (1648-1981).

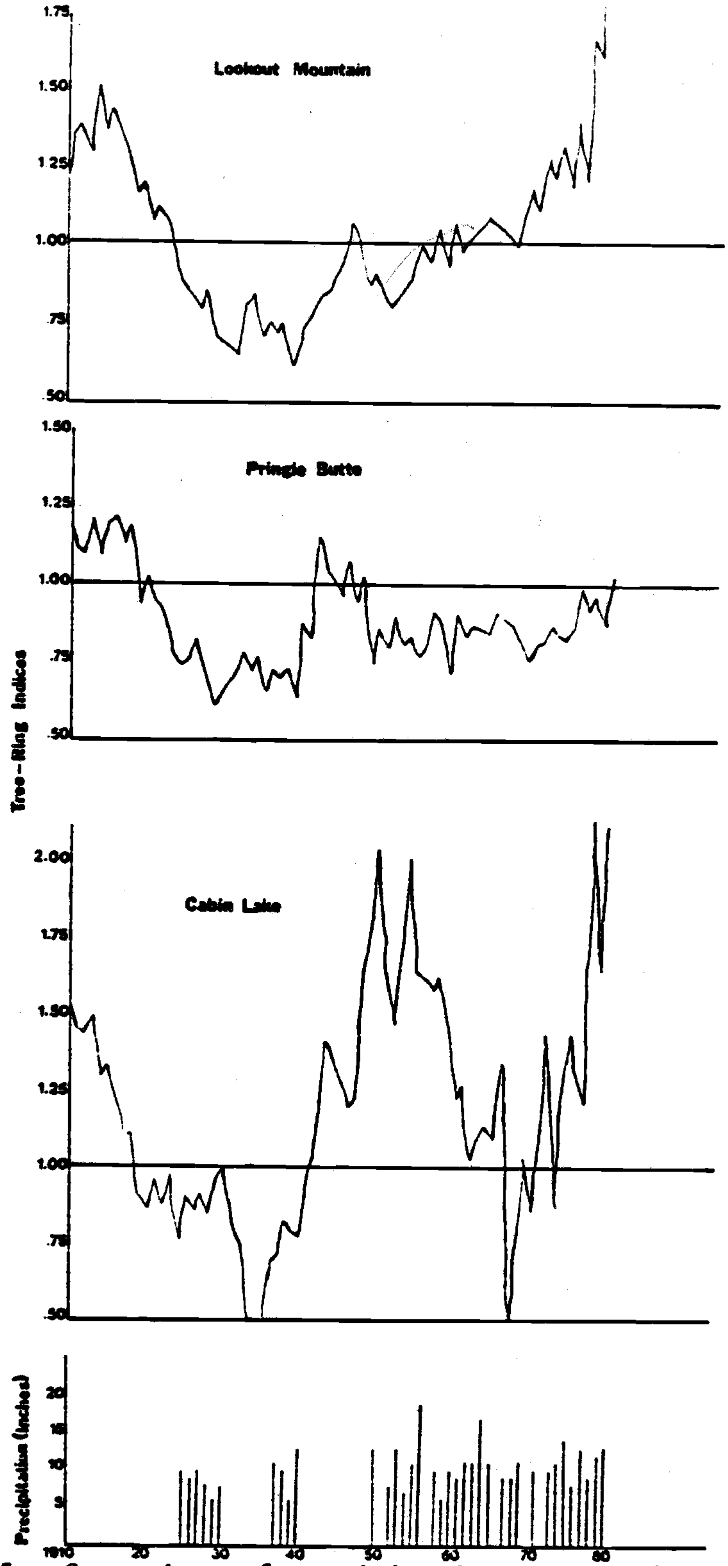

Figure II-5. Comparison of precipitation, measured at Fremont, Oregon with growth indices from Pringle Butte, Cabin Lake and Lookout Mountain time period 1925 to 1980. Missing precipitation data 1931-1936, 1941-1949, 1951, 1957, 1965, 1969, 1971.

Table II-1. Analysis of variance results for study sites. Trees are represented by two cores and the same years growth. Data used for Pringle Butte is 1778-1981, for Cabin Lake and Lookout Mountain 1825-1982.

Location	% Variance (Y) pooled trees and cores	% Variance (YxT) between trees	% Variance (YxCxT) between cores in a tree
Cabin Lake	24	14	62
Pringle Butte	10	42	48
Lookout Mountain	13	14	73

Table II-2. Cabin Lake chronology (1759-1981).

Decade	Tree-ring indices 0	1	2	3	4	5	6	7	8	9	Number of samples 0	1	2	3	4	5	6	7	8	9
1750										1.943										1
1760	.204	.548	1.501	1.102	.711	1.910	.644	.871	.862	.490	1	1	1	1	1	1	1	1	1	1
1770	.978	1.164	.927	1.038	1.103	1.197	.949	.963	.937	1.196	1	1	1	2	2	2	2	2	2	2
1780	.855	.854	.730	.634	.598	.521	.546	.562	.707	.550	3	3	3	3	3	3	3	3	3	3
1790	.593	.871	1.062	.968	1.035	1.038	.818	.852	.846	.876	3	3	4	6	6	6	6	6	6	6
1800	.817	.773	.677	.678	.911	.975	.907	.966	.934	1.050	6	6	6	7	8	8	8	8	8	8
1810	.220	1.202	1.216	1.073	1.101	1.332	1.276	1.284	1.089	1.128	8	8	9	9	10	11	11	12	12	12
1820	.074	1.112	1.135	1.277	1.240	1.232	1.072	1.163	1.094	1.103	12	12	12	16	16	16	16	16	16	16
1830	.097	.974	.917	1.010	1.069	1.143	.901	1.042	1.062	1.101	16	16	16	16	16	16	17	17	17	17
1840	.180	1.151	1.082	1.091	1.085	1.072	.895	.748	.812	.611	17	17	17	17	17	17	17	17	17	17
1850	.671	.702	.641	.686	.642	.723	.710	.743	.861	.843	18	18	18	18	18	18	18	18	18	18
1860	.942	1.316	1.340	1.400	1.334	1.185	1.352	1.283	1.341	1.206	18	18	18	18	18	18	18	18	18	18
1870	.289	1.094	1.040	1.012	1.026	1.131	.980	1.125	1.139	1.261	18	18	18	18	18	18	18	18	18	18
1880	.359	1.514	1.348	1.286	1.311	1.249	1.141	1.293	1.337	1.058	18	18	18	18	18	18	18	18	18	18
1890	.020	.879	.831	.935	1.028	1.110	1.147	1.076	.995	.909	18	18	18	18	18	18	18	18	18	18
1900	.854	.980	1.081	1.083	1.033	1.062	1.129	1.051	1.176	1.279	18	18	18	18	18	18	18	18	18	18
1910	.394	1.224	1.179	1.190	1.048	1.082	.969	.856	.875	.721	18	18	18	18	18	18	18	18	18	18
1920	.624	.663	.612	.635	.537	.649	.618	.659	.562	.696	18	18	18	18	18	18	18	18	18	18
1930	.703	.541	.489	.325	.386	.391	.451	.472	.554	.520	18	18	18	18	18	18	18	18	18	18
1940	.510	.683	.882	1.167	1.111	1.040	.937	.957	.872	.752	18	18	18	18	18	18	18	18	18	18
1950	.902	.948	1.202	1.579	1.864	1.516	1.228	1.819	1.469	1.046	18	18	18	18	18	18	18	18	18	18
1960	.990	.930	.798	.825	.922	.883	1.102	.836	.486	.797	18	18	18	18	18	18	18	18	18	18
1970	.685	.859	1.193	.601	1.046	1.211	1.041	1.000	1.784	1.396	18	18	18	18	18	18	18	18	18	18
1980	.912	1.863									18	17								

Serial correlation = .699. Mean sensitivity = .141. Standard deviation = .297.

Table II-3. Pringle Butte Chronology (1562-1982).

	Tree-ring indices										Number of samples									
Decade	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1560			3.220	2.368	1.577	1.211	1.647	1.309	.876	1.062			1	1	1	1	1	1	1	1
1570	.269	.804	1.621	1.186	1.726	.956	1.013	.827	1.092	.705	1	1	3	3	3	3	3	3	3	3
1580	.169	1.432	1.861	1.611	1.145	1.547	1.563	1.319	1.139	.749	3	4	4	4	4	6	6	6	6	6
1590	.981	.901	.993	.976	.799	.669	.756	.776	.978	.808	6	6	6	6	6	6	6	6	6	6
1600	.688	.597	1.018	.827	1.085	.804	.575	.654	.796	.658	6	6	6	6	6	6	6	6	6	6
1610	.926	.786	.944	.796	.844	.677	.826	.908	.688	.770	6	6	6	6	6	6	6	6	6	7
1620	.801	.772	.673	1.016	.987	.873	.943	.913	.876	.888	7	7	7	8	6	9	9	9	9	9
1630	.840	.715	.724	.408	.452	.500	.625	.744	.653	.579	9	9	9	9	9	9	9	9	9	9
1640	.816	.927	.999	.877	1.075	1.213	1.167	1.284	1.223	.942	9	9	9	9	9	10	10	10	10	10
1650	.919	.888	.904	.912	1.090	1.024	1.247	1.272	1.431	1.237	10	10	10	11	10	11	11	11	11	11
1660	.412	1.376	1.216	1.180	1.254	1.190	1.140	1.169	1.305	1.210	11	11	11	11	11	11	11	11	11	11
1670	.378	1.697	1.458	1.491	1.760	1.643	1.566	1.180	.970	.986	11	11	11	11	11	11	11	11	11	12
1680	.068	1.147	1.177	1.131	1.394	1.685	1.702	1.586	1.537	1.562	12	12	12	12	11	13	13	13	13	13
1690	.579	1.714	1.469	1.135	1.162	1.171	1.200	1.140	1.166	1.229	13	13	13	14	12	14	14	15	15	16
1700	.171	1.118	.984	.998	1.212	1.004	1.055	.894	.879	.689	17	17	17	18	14	18	19	19	19	19
1710	.730	.717	.858	1.029	.960	.928	1.021	.954	.937	.818	19	19	20	21	18	21	21	21	21	21
1720	.994	1.089	1.033	1.081	.996	1.017	1.131	1.002	.916	.851	21	22	22	22	21	22	22	22	22	22
1730	.080	1.010	.903	.958	.919	.740	.717	.717	.753	.601	22	22	22	22	22	22	22	22	22	22
1740	.746	.723	.690	.747	.788	.764	.714	.779	.703	.674	22	23	23	23	22	23	23	23	23	23
1750	.820	.744	.714	.731	.678	.642	.544	.683	.689	.615	23	23	23	24	23	24	24	24	24	24
1760	.809	.895	.934	.916	.851	.842	.931	.899	.833	.780	24	24	24	24	24	26	26	26	27	28
1770	.867	.976	.932	.985	1.026	1.090	.955	.794	.711	.635	28	28	28	28	25	29	29	29	30	30
1780	.828	.774	.768	.774	.833	.845	.905	.821	.877	.805	30	30	30	30	28	30	30	30	30	30
1790	.020	1.127	1.099	1.082	1.105	1.089	1.096	1.102	1.162	.986	30	30	30	30	30	30	30	30	30	30
1800	.086	1.082	.938	.765	.760	.726	.766	.734	.757	.825	30	30	30	30	30	30	30	30	30	30
1810	.903	.886	.934	1.007	1.144	1.027	1.045	.899	.935	.828	30	30	30	30	30	30	30	30	30	30
1820	.904	.826	.877	1.006	.943	1.045	1.126	1.017	1.018	.955	30	30	30	30	30	30	30	30	30	30
1830	.086	1.153	1.101	1.051	1.253	1.178	1.322	1.361	1.309	1.306	30	30	30	30	30	30	30	30	30	30
1840	.287	1.192	1.010	.958	.957	1.188	1.276	1.023	1.112	.903	30	30	30	30	30	30	30	30	30	30
1850	.998	1.068	1.070	1.143	1.257	1.424	1.365	1.271	1.253	1.013	30	30	30	30	30	30	30	30	30	30
1860	.423	1.611	1.419	1.400	1.264	1.197	1.311	1.374	1.362	1.154	30	30	30	30	30	30	30	30	30	30
1870	.401	1.454	1.426	1.471	1.396	1.465	1.424	1.426	1.508	1.281	30	30	30	30	30	30	30	30	30	30
1880	.381	1.206	1.246	1.248	1.216	1.320	1.239	1.132	1.022	.800	30	30	30	30	30	30	30	30	30	30
1890	.873	1.118	.959	1.002	1.054	1.041	.976	1.053	.846	.838	30	30	30	30	30	30	30	30	30	30
1900	.050	1.157	1.115	1.209	1.150	1.145	1.145	1.282	1.287	1.082	30	30	30	30	30	30	30	30	30	30
1910	.253	1.134	1.110	1.223	1.104	1.219	1.227	1.178	1.202	.963	30	30	30	30	30	30	30	30	30	30
1920	.021	.947	.978	.936	.792	.764	.809	.835	.712	.607	30	30	30	30	30	30	30	30	30	30
1930	.683	.738	.782	.739	.711	.654	.751	.713	.743	.624	30	30	30	30	30	30	30	30	30	30
1940	.884	.832	1.149	1.072	1.025	.960	1.097	.955	1.025	.723	30	30	30	30	30	30	30	30	30	30
1950	.863	.808	.880	.800	.812	.753	.790	.903	.895	.661	30	30	30	30	30	30	30	30	30	30
1960	.901	.815	.841	.844	.837	.907	.894	.879	.806	.753	30	30	30	30	30	30	30	30	30	30
1970	.812	.818	.857	.823	.810	.844	.989	.902	.970	.794	30	30	30	30	30	30	30	30	30	30
1980	.019	1.392	2.367								30	30	10							

Serial correlation = .812. Mean sensitivity = .113. Standard deviation = .292.

Table II-4. Lookout Mountain chronology (1648-1981).

Decade	Tree-ring indices										Number of samples									
	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
1648									1.095	2.033									1	1
1650	.054	1.098	1.083	.882	.953	.967	1.261	1.007	.806	.849	2	3	3	3	3	3	3	3	4	4
1660	.810	.866	.918	.780	.977	.903	.747	.902	1.145	.869	4	4	5	5	5	5	5	5	5	5
1670	.830	.980	.990	.962	.951	.917	.932	.789	.815	.960	5	5	5	5	5	6	6	6	7	7
1680	.777	.720	.989	1.025	1.096	1.074	.988	1.107	.986	.902	7	7	7	7	7	7	7	7	7	7
1690	.859	.810	.901	.729	.716	.640	.740	.773	.801	.787	7	7	7	7	8	8	8	8	8	8
1700	.636	.951	1.130	1.136	1.015	1.055	1.033	1.057	1.057	1.107	8	8	8	9	9	10	10	11	11	11
1710	.829	.818	.845	.829	1.012	.882	1.051	1.250	1.055	.987	11	11	11	11	12	12	12	12	12	12
1720	.840	1.066	.980	1.105	.981	.949	.800	1.034	.912	.906	12	12	12	12	12	12	12	12	12	12
1730	.862	.898	.901	.968	.949	1.052	.976	1.034	1.076	1.057	12	12	12	12	13	13	13	13	14	14
1740	.106	1.143	1.068	.944	.982	1.053	1.052	1.154	.975	.868	14	14	14	14	14	14	14	14	14	14
1750	.940	.887	1.132	1.063	1.056	1.224	1.571	1.285	1.252	1.148	14	14	14	14	14	14	15	16	16	17
1760	.937	.865	1.061	1.077	1.136	1.170	1.186	1.174	1.113	1.093	177	17	17	17	18	18	19	19	19	19
1770	.141	1.257	1.265	1.287	1.285	1.085	1.237	1.105	1.073	1.006	19	19	19	19	19	19	19	20	20	20
1780	.000	.998	.976	1.126	1.043	1.098	1.064	1.039	1.016	1.101	20	20	20	21	21	21	21	21	21	21
1790	.070	1.066	1.109	1.300	1.106	1.225	1.183	1.181	1.091	.932	21	21	21	21	21	21	21	21	21	21
1800	.970	.930	.942	1.024	1.021	1.045	.973	1.061	.945	.770	21	21	21	21	22	22	23	23	24	24
1810	.897	.843	.904	.883	.902	.991	.958	1.004	.953	1.009	24	24	24	24	25	25	26	26	26	26
1820	.979	.953	1.065	.966	1.069	1.060	.988	1.084	1.087	.942	27	27	27	27	27	27	28	28	28	28
1830	.877	.947	.930	.989	1.025	.985	.894	.883	.899	.831	28	28	28	28	28	28	28	28	28	28
1840	.899	.827	.880	.816	.833	.810	.843	.846	.806	.659	28	28	28	28	28	28	28	28	28	28
1850	.683	.796	.802	.761	.866	.930	.910	.859	.953	.864	28	28	28	28	28	28	28	28	28	28
1860	.932	1.095	.967	1.090	1.171	1.131	1.123	1.030	1942	.878	28	28	28	28	28	28	28	28	28	28
1870	.044	1.041	1.129	1.072	1.052	1.196	1.122	1.187	1.102	.923	28	28	28	28	28	28	28	28	28	28
1880	.984	1.089	1.001	1.002	1.122	1.201	1.030	.946	1.034	.865	28	28	28	28	28	28	28	28	28	28
1890	.734	.894	.865	.931	1.043	1.007	.905	1.060	1.128	.845	28	28	28	28	28	28	28	28	28	28
1900	.058	1.089	1.163	1.229	1.182	1.219	1.418	1.301	1.348	1.320	28	28	28	28	28	28	28	28	28	28
1910	.176	1.385	1.408	1.295	1.536	1.399	1.465	1.429	1.278	1.188	28	28	28	28	28	28	28	28	28	28
1920	.211	1.091	1.114	1.081	.974	.882	.859	.789	.856	.703	28	28	28	28	28	28	28	28	28	28
1930	.696	.780	.751	.801	.844	.717	.773	.758	.773	.614	28	28	28	28	28	28	28	28	28	28
1940	.675	.757	.816	.856	.869	.940	1.006	1.061	.978	.892	28	28	28	28	28	28	28	28	28	28
1950	.925	.875	.815	.869	.872	.930	1.013	.962	1.059	.936	28	28	28	28	28	28	28	28	28	28
1960	.076	.985	1.032	1.045	1.073	1.050	1.024	.992	.906	1.075	28	28	28	28	28	28	28	28	28	28
1970	.175	1.089	1.281	1.210	1.326	1.173	1.412	1.357	1.672	1.604	28	28	28	28	28	28	28	28	28	28
1980	.155	2.124	4.273								28	28	28							

Serial correlation = .745. Mean sensitivity = .089. Standard deviation = .266.

Table II-5. Statistics of ring-width indices.

Location	Species	Serial correlation	Standard deviation	Mean sensitivity
Western chronologies[1]	All	0.415	0.380	0.365
Oregon chronologies[2]	Ponderosa pine			
Dufur		0.587	0.214	0.153
Union		0.518	0.242	0.186
Slim Rock Creek	Limber pine	0.772	0.259	0.137
Slim Rock Creek		0.605	0.168	0.118
Chief Joseph Mt.	White bark pine	0.592	0.206	0.145
Paulina	Ponderosa pine	0.595	0.281	0.212
Abert Rim Lookout		0.459	0.199	0.165
Lakeview		0.583	0.224	0.161
Study sites				
Cabin Lake		0.745	0.266	0.089
Pringle Butte		0.812	0.292	0.113
Lookout Mountain		0.699	0.297	0.141

[1]From Fritts and Shatz (1975).

[2]From Drew (1975).

Table II-6. Comparison of Keen's data (1937) and study sites data showing years of slow and rapid growth.

Years of slow growth				Years of rapid growth			
Keen	Cabin Lake	Pringle Butte	Lookout Mt.	Keen	Cabin Lake	Pringle Butte	Lookout Mt.
1931				1913			
1929		1929		1907			
1924	1924	1924		1894	1894		
1918				1885		1885	
1899	1899	1899	1899	1877	1877		1877
1890	1890		1890	1875			1875
1883	1883	1883		1868			
1880		1880		1866			1866
1876	1876	1876		1861	1861	1861	
1871	1871	1871	1871	1857			
1859		1859		1855		1855	
1849	1849	1849	1849	1838	1838		
1844		1844		1832	1832		1832
1839				1828			
1833	1833	1833		1825	1825		
1831	1831			1818			
1800	1800	1800		1814	1814	1814	
1798				1809	1809		
1787	1787	1787		1805			
1783	1783	1783		1803	1803		
1777		1777		1799	1799		
1757		1757		1791	1791	1791	1791
1741			1741	1775	1775		1775
1739		1739		1773		1773	
1729		1729	1729	1766	1766	1766	
1721				1755			1755

Table II-6 (continued)

Years of slow growth				Years of rapid growth			
Keen	Cabin Lake	Pringle Butte	Lookout Mt.	Keen	Cabin Lake	Pringle Butte	Lookout Mt.
1695		1695		1752		1752	
1686		1686		1749			
1667		1667		1747			
1659			1659	1745			
1655				1738			
1652		1652	1652	1732		1732	
1646				1726			
1639		1639		1716		1716	
1633		1633		1713		1713	1713
1630				1702		1702	1702
				1681			
				1673		1673	1673
				1645			
				1642			
				1625		1625	
				1622			
				1611		1611	
				1588		1588	
				1559			

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