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Fire Frequency Analysis of Sierra Forests

ABSTRACT

The pattern and frequency of fire size reported for seven national forests and Sequoia–Kings Canyon National Parks were assessed by frequency analysis, a method commonly used in hydrology for establishing probabilities of future events from historical data. The common generality that throughout the Sierra frequently occurring fires have become smaller and infrequently occurring large fires are becoming larger is not supported by the data. In the Plumas and Sequoia National Forests size and frequency of fires have not changed significantly during this century; in the Sierra National Forest all fires were larger before 1950; in Sequoia–Kings Canyon National Parks frequent small fires have been larger since 1950, and infrequent large fires have been smaller since 1950. The pattern of smaller, frequent fires and larger, infrequent fires since 1950 was true, however, in the central-western Sierra, in the Eldorado and Tahoe National Forests, and—to a lesser extent—the Stanislaus National Forest and the Lassen National Forest. Since 1950 in the Eldorado National Forest, frequent fires (those with recurrence intervals from 2 to 5 years) were 70%–80% smaller than before 1950, and infrequent large fires (those with recurrence intervals from 10 to 40 years) were 250%–500% larger than before 1950. The average fire for all forests (taken as approximately the size at a 2-year recurrence interval) ranged from about 350 acres to 1,500 acres (142 to 607 hectares), illustrating the variation throughout the Sierra. There was large variation in diligence of fire data collection among the national forests and national parks, ranging from forty-eight years (Lassen National Forest) to seventy-nine years (Stanislaus and Sequoia National Forests) of record. With additional data other applications of frequency analysis may be useful in examining the patterns of fire on the landscape. By recognizing that fire patterns differ throughout the Sierra, we can begin to dispassionately examine causes of fire.

INTRODUCTION

The current popular and oft-repeated hypothesis about fires in the Sierra Nevada is that large fires are occurring more frequently and are larger and more intense than they were in the past (Knudson 1994; USFS 1995). Some reasons given to explain this hypothesis are drought, fire suppression, fuel buildup, silvicultural methods, livestock grazing, and higher human population. But the hypothesis of a change in fire size and frequency must first be examined. If it is not true, it may lead to inappropriate forest management, wasted resources, and even increased fire. Currently, there are no data to examine changes in degree of fire intensity. We have the data, however, to examine questions of frequency and fire size. We also have the tool—frequency analysis—adapted from hydrology, where it is used to estimate probabilities of floods, droughts, large waves, low oxygen concentration, and other water-quality conditions (Chow 1964; Dunne and Leopold 1978; Greb and Graczyk 1995).

With this tool we can answer some critical questions:

1. Do the forests in different Sierra regions have similar fire size at the same frequencies?
2. Have the fire frequencies changed over time?
3. If fire frequency is different, is the difference large or small?
4. Do all the forests exhibit a similar pattern in fire frequency?
5. Is there any regional pattern in fire frequency?

In the Sierra, all national forests and, to a somewhat lesser degree, national parks extend over a substantial elevational range and hence include several forest types. Ignition frequency and fuel loadings are therefore not uniformly distrib-

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uted. Forests also extend north to south along the axis of the Sierra, and east and west of the crest, over broad gradients of climate and change in species composition. Because of these and other differences, we must be cautious about making generalizations among forests.

The major objective of this study was to analyze the frequency and size of fires in this century using the method of frequency analysis borrowed from hydrology.

METHODS

Fire perimeter maps showing location, year, and cause of the fires were prepared for the California Spotted Owl Environmental Impact Statement in 1994 and stored in digital form for all Sierran national forests (USFS 1995). These data represent all fires greater than 1 hectare (ha) that were mapped from 1908 to 1993. Completeness of the record varied among the forests (for example, some years were missed, perimeters of fires were roughly estimated, some smaller fires were not recorded). In addition, fires were mapped at varying distances outside the national forest administrative boundaries. Digital maps of fire perimeters were also obtained for Yosemite and Sequoia–Kings Canyon National Parks. Data for Yosemite National Park consisted only of lightning fires from 1931 to 1993 (USGS 1994), whereas for Sequoia–Kings Canyon National Parks data for all fires from 1921 to 1993 were obtained (USGS 1993).

For this analysis, fires were included for a national forest if the majority of the burn area fell within the respective forest's administrative boundary. Data for analysis of fires classified as outside national forests are incomplete, and so our analysis is restricted to the regions of public land described earlier. Fire area within a perimeter was determined from the Arc/Info software program for geographic information systems (GIS). Care was taken to eliminate duplicate counting by examining the shape of the mapped fires as well as the date and cause of the fire. For all study areas, the great majority of fires were of human origin.

The earliest records began in 1908 but were not consistent for the study areas or reporting units; that is, many years are missing in agency records. Data from seven national forests—Lassen, Plumas, Tahoe, Eldorado, Stanislaus, Sierra, Sequoia—and Sequoia–Kings Canyon National Parks were used. The records for the Inyo National Forest and Yosemite National Park were too incomplete to use.

Frequency analysis is a statistical procedure for interpreting past events in terms of their chances of occurring in the future (Chow 1964). We used the extreme-event series (Chow 1964) or the annual maximum fire to determine the recurrence interval for fires of different sizes. The term recurrence interval here does not refer to the return of fires in a specific place as it does in other studies of fire (see McKelvey and Busse 1996; Skinner and Chang 1996) but, rather, to a probability of an event of a given size occurring somewhere in the unit.

The following methods are described briefly for professionals and others who may want to follow the procedure. The annual maximum fire for each unit was ranked from largest to smallest (largest is rank 1), and the recurrence interval was calculated as the number of years of record plus 1, divided by the rank of each annual maximum fire in the series. The resulting recurrence intervals (in years) were then plotted against the size of the fire (on logarithmic scales). The resulting plot shows the average interval of time within which the size of any given fire will be equaled or exceeded at least once. The inverse of the recurrence interval is the probability of the fire size in any year. Thus a fire size having a recurrence interval of 5 years has a 0.2, or 20%, chance of occurring in any year.

The scatter of points in the frequency analysis is used to determine a best fit (theoretical) distribution. (See Interagency Advisory Committee on Water Data 1981, the standard guide for fitting a distribution to the data points, for details of this procedure.) For some graphs, however, the data did not follow a simple distribution. In these cases, hand-smoothed curves (using a French curve) were used to fit portions of the distribution. All fitted curves differ somewhat from actual data points. To simplify comparisons, we selected the 2-, 5-, 10-, 20-, and 40-year recurrence intervals to highlight patterns. Properties of the frequency analysis also yield estimation of the overall average annual event (see Chow 1964), which is the fire with a 2.33 recurrence interval. For simplicity in our analysis, we have used the 2-year recurrence interval fire as a close approximation of the average fire.

We divided the fire records into those before 1950 and those from 1950 to 1993 to determine if fire frequencies have changed over time. This division gave two periods of approximately forty years, and we could test the assumption that fire frequency has changed in the latter half of the century. It also reduced the magnitude of recurrence interval estimation and explains why we used forty years as a maximum. To more closely examine the question of relative change in fire size after 1950 we subtracted the post-1950 fire size from the pre-1950 fire size, divided by the pre-1950 fire size for the five recurrence intervals, and expressed differences as a percentage.

RESULTS

The eighty-six-year period of record (1908 to 1993) for the study areas was incomplete in all cases (figure 42.1) and ranged from twenty-five years (Inyo National Forest) to seventy-nine years (Stanislaus and Sequoia National Forests). For particular years, the number of units with recorded fires ranged from two to ten (all units); however, all ten units re-

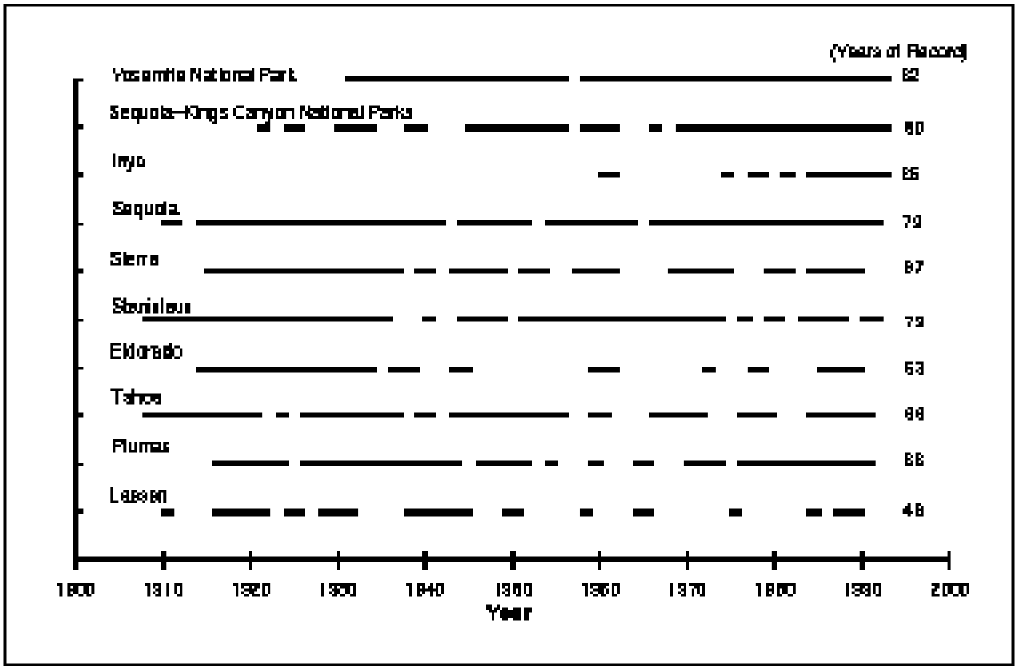


FIGURE 42.1

Years of record for fires in Sierra Nevada locations (national forests and national parks). Gaps in horizontal lines represent missing data.

ported fires from only six years in common. All the units had missing data for periods of two years in a row or more. Both missing data and years with no (zero) fires are likely explanations but were not discriminated in the records. Fires from the Inyo National Forest and Yosemite National Park were not analyzed further because of brief and incomplete records. Also, major gaps from the Eldorado and Lassen National Forests after 1950 weaken the analysis for those forests (figure 42.1).

Six national forests (Lassen, Plumas, Tahoe, Eldorado, Stanislaus, and Sierra) had smaller fires after 1950 at the 2-year recurrence interval, and all but Plumas had smaller fires at the 5-year recurrence interval. For illustration, fire frequency plots are shown for the Eldorado National Forest (figure 42.2) for all years of record (upper plot) and by pre- and post-1950 (lower plot); plots for other units are given in appendix 42.1. In the Eldorado National Forest the 2-year fire (the approximate average fire) was reduced from 700 acres (283 ha) before 1950 to 140 acres (57 ha) after 1950. Looked at in another way, the chance of a 700-acre fire occurring within a given year changed from 50% (chance of one year out of two) before 1950 to about 20% (chance of one year out of five) after 1950 (figure 42.2, lower plot). By contrast, frequent (2- to 5-year recurrence interval) fires were about the same or larger after 1950 than before in Plumas National Forest (for greater than 2-year fires), Sequoia–Kings Canyon National Parks, and Sequoia National Forest. The average fire (2-year recurrence interval) among the units ranged from 700 to 2,500 acres (283–1,012 ha) before 1950 and from 140 to 1,000 acres (57–405 ha) after 1950.

A comparison of fire size at recurrence intervals of 2, 5, 10, 20, and 40 years for all locations is summarized in figures 42.3–42.7. These results clearly show that the general hypothesis of large fires occurring more frequently throughout the Sierra is false. Frequency of large fires is highly variable among the regions. Only the Tahoe, Eldorado, and Lassen National Forests have a clear and consistent pattern of large fires occurring more frequently since 1950 (figures 42.5–42.7). In the Stanislaus National Forest, the 10- and 20-year recurrence interval fires (figures 42.5–42.6) were smaller or no different after 1950, but the 40-year recurrence interval fire was substantially larger after 1950. In the Plumas, Sierra, and Sequoia National Forests and in the Sequoia–Kings Canyon National Parks frequence of large fires either has not changed or has declined.

For forest units showing the pattern of smaller, more-frequent fires after 1950 and larger, less-frequent fires, the crossover point for frequency distributions from the two periods occurred from the 5-year to about the 11-year recurrence interval (see appendix 42.1).

The relative changes in fire size before and after 1950 are shown in figure 42.8. In the Lassen, Tahoe, Eldorado, and Stanislaus National Forests frequent fires (2- to 5-year recurrence interval) were 30%–85% larger before 1950, but infrequent fires (10- to 40-year recurrence interval) were generally larger after 1950 (30%–500%). However, the Stanislaus National Forest (about 85% larger 2- and 5-year fires before 1950) had no increase in the size of infrequent fires until the 40-year recurrence interval, when a very large fire, the result of a complex of fires in 1987, burned more than 100,000 acres (40,469 ha). The Eldorado National Forest differed dramatically from all others in the large increase in fire size for the infrequent fires. After 1950, fires in the 10- to 40-year recur-

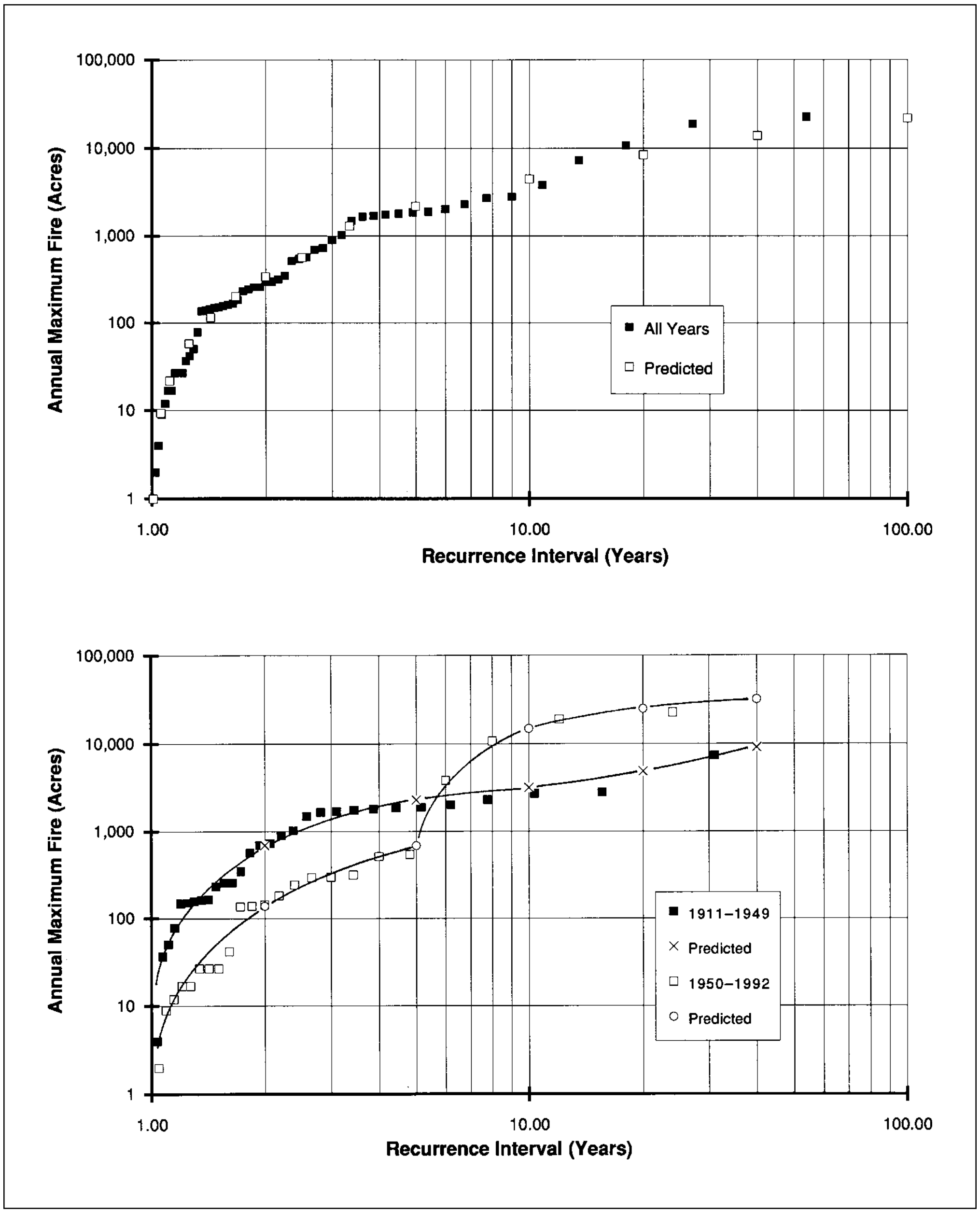


FIGURE 42.2

Fire frequency plots of the annual maximum fires for the Eldorado National Forest. The upper plot shows the actual and predicted fires for the full fifty-three years with data; the lower plot shows the same data divided into two periods, before and after 1950 with fitted points and lines.

rence interval increased in size from 250% to 500%. The patchy record of years with reported fires (figure 42.1) in the Eldorado National Forest (fifty-three years) and the Lassen National Forest (forty-eight years) is unfortunate and leaves some uncertainty about the pattern.

No clear pattern emerged for relative difference in fire size before and after 1950 in the Plumas and Sequoia National Forests (figure 42.8). In the Sierra National Forest all fires were larger before 1950. And in Sequoia–Kings Canyon National Parks the pattern of fire frequency is different from that in all the national forests: since 1950 frequent fires have been larger and infrequent fires have been smaller.

DISCUSSION

The five questions posed in the introduction have been answered by fire frequency analysis:

1. The forests in the different Sierra regions do not have similar fire size at the same frequencies. For example, the 2-year recurrence interval fire since 1950 ranged from 140 acres (57 ha) to 1,000 acres (405 ha), whereas the 40-year fire was from 12,000 acres (4,856 ha) to 99,000 acres (40,064 ha).

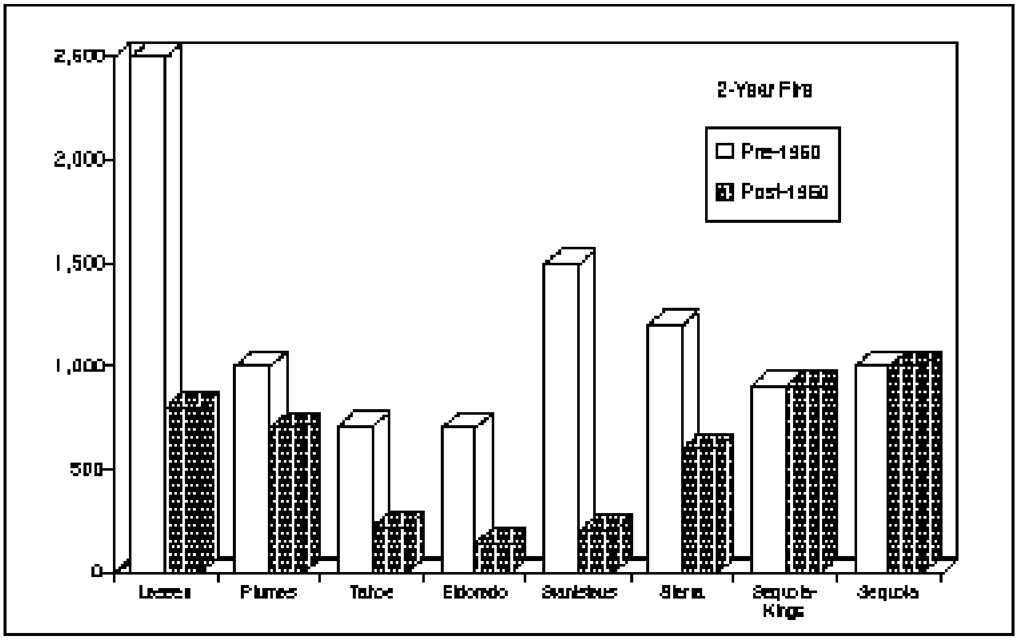


FIGURE 42.3

Estimated fire size for each forest location at the 2-year recurrence interval for the periods before and after 1950. Locations are arranged in order from the northern (Lassen National Forest) to the southern (Sequoia National Forest) Sierra Nevada.

2. The fire frequencies have changed over time for most but not all forests in this century.
3. The magnitude of the change in fire frequencies among the forests depends on the forest. Those in the central-western Sierra showed the greatest change.
4. Not all forests exhibit a similar pattern of fire frequency.
5. There is a regional pattern in fire frequency. The trend in the central-western Sierra, particularly the Eldorado National Forest, is for small, frequent fires to be smaller since 1950 and large, infrequent fires to be larger. A nearly opposite pattern occurs in the southern Sierra, particularly Sequoia–Kings Canyon National Parks. These opposite patterns lead to some questions about causes and management and indicate a new area for exploration. For example, has the prescribed burning program been responsible for the approximately 80% reduction in the size of the 40-year fire since 1950 in Sequoia–Kings Canyon National Parks?

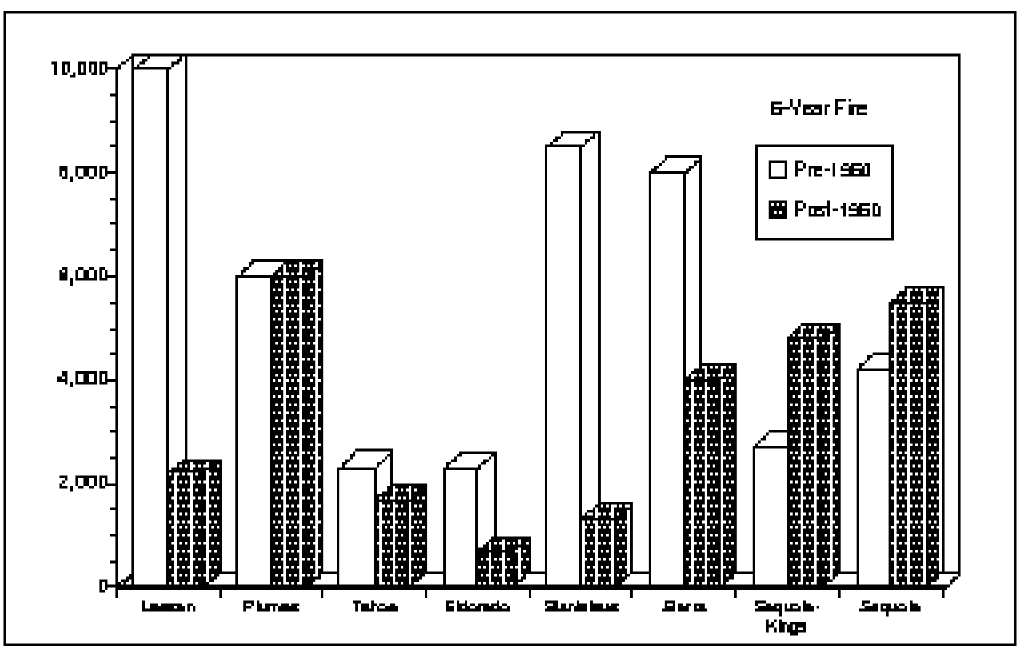
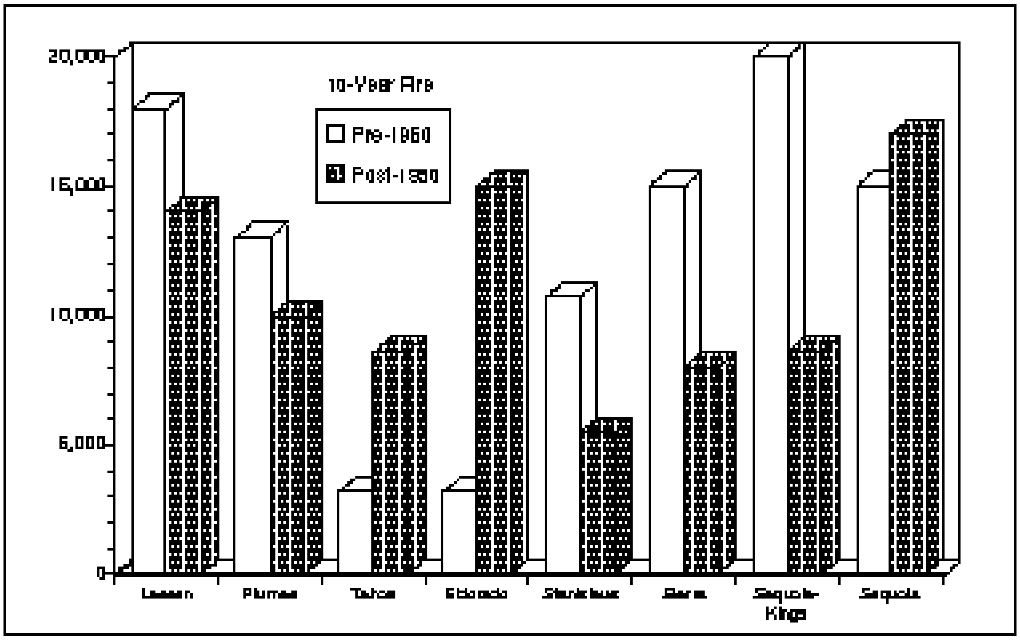


FIGURE 42.4

Estimated fire size for each forest location at the 5-year recurrence interval for the periods before and after 1950. Locations are arranged in order from the northern (Lassen National Forest) to the southern (Sequoia National Forest) Sierra Nevada.

FIGURE 42.5



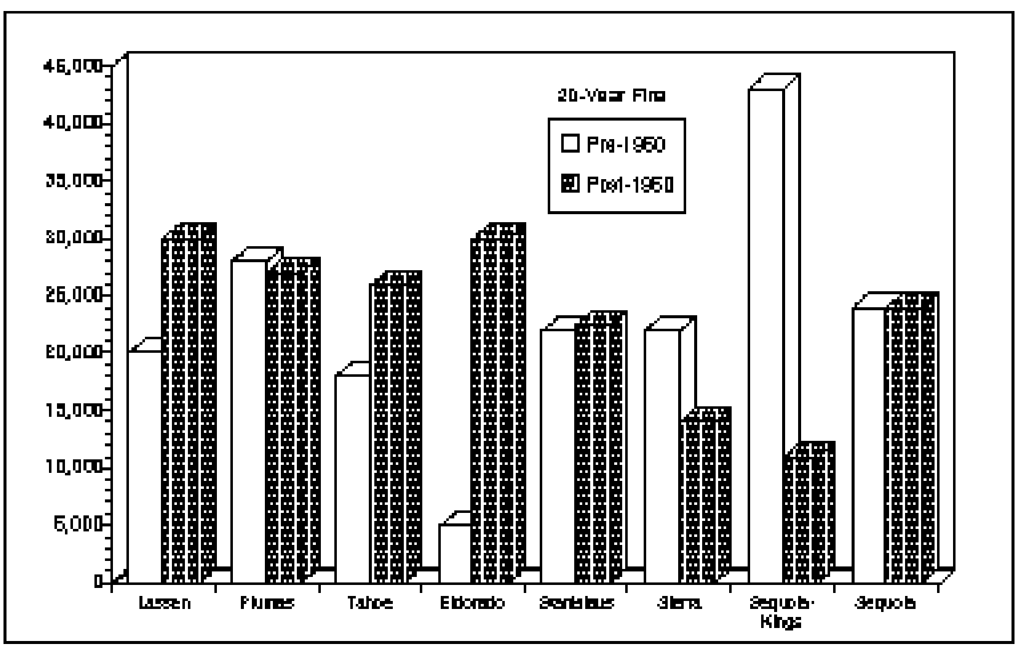
Estimated fire size for each forest location at the 10-year recurrence interval for the periods before and after 1950. Locations are arranged in order from the northern (Lassen National Forest) to the southern (Sequoia National Forest) Sierra Nevada.

Many of the popular generalizations about increasing probability of large fires seem to be borne out for the Eldorado National Forest and to a lesser extent for the Tahoe and Stanislaus National Forests. The reasons for this pattern—whether natural factors (weather, for example) or human factors (fuel modifications, fire-fighting strategies, human activity)—must be explored through other means.

The patterns of fire frequency also indicate regions where apparent risk of large fires has not changed substantially during the period of record. These regions may provide useful comparisons of institutions, climate, fire behavior, and other factors with regions that have changed.

In some forests, such as the Plumas National Forest, recent large fires that may seem unusual are, in our analysis, not out of the ordinary and are similar in frequency and size to those in the first half of the century. Thus, the entire record of fire frequency since 1910 can be used to examine fires with recurrence intervals greater than 40 years (appendix 42.1). For the Plumas National Forest the 100-year recurrence interval fire is on the order of 60,000 acres (24,281 ha).

FIGURE 42.6



Estimated fire size for each forest location at the 20-year recurrence interval for the periods before and after 1950. Locations are arranged in order from the northern (Lassen National Forest) to the southern (Sequoia National Forest) Sierra Nevada.

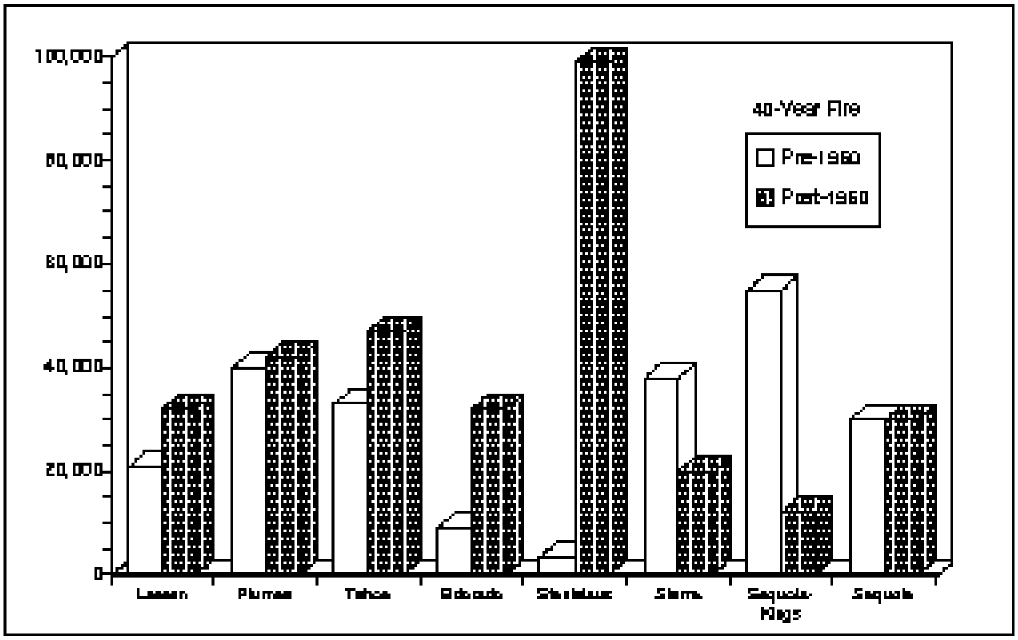


FIGURE 42.7

Estimated fire size for each forest location at the 40-year recurrence interval for the periods before and after 1950. Locations are arranged in order from the northern (Lassen National Forest) to the southern (Sequoia National Forest) Sierra Nevada.

What is not explained in our frequency analysis of fire size is possible changes in intensity. If data eventually become available or are collected in the future, fires could be sorted by intensity class and examined separately. However, in the absence of a robust method of testing, generalizations about the pattern of fires, as in the case of fire size, may be heavily influenced either by a few locations (such as the Eldorado National Forest) or by the vagaries of memory and human judgment about individual events.

With these questions about fire size answered, a new set of questions emerges about the reasons for these differences. Many possible causes for differences in fire frequency or changes over time have been offered, but the wide range in pattern among the forests analyzed suggests a variety or interaction of causes. Our results also suggest that fires in the 5- to 11-year recurrence interval range (where the lines cross over for the two distributions) may represent some limitation of human control or some natural process that deserves further investigation.

The method of extreme-event analysis that we applied to

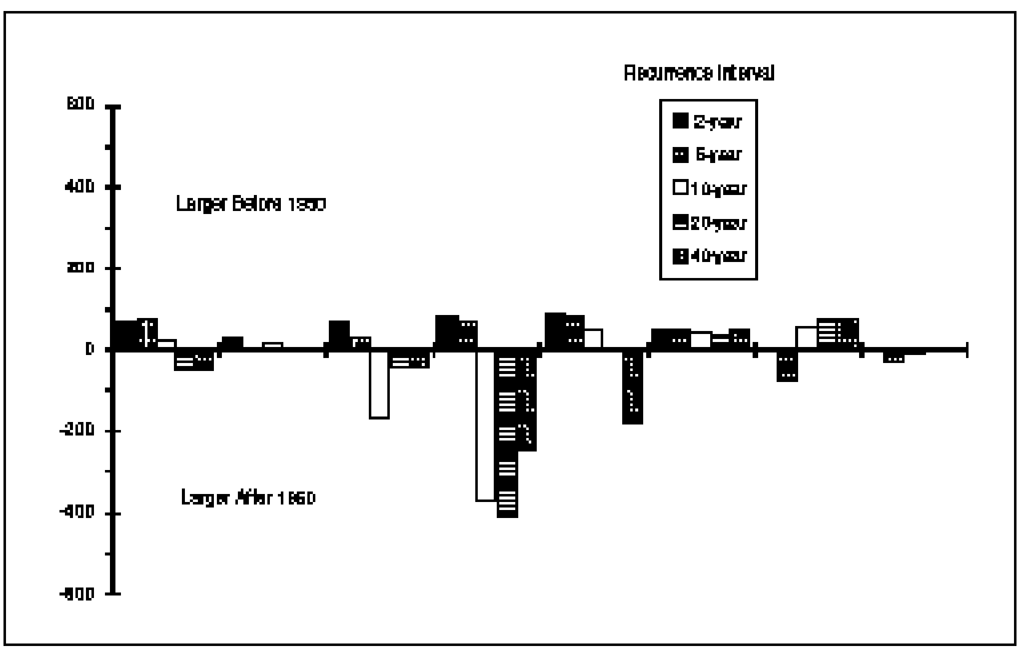


FIGURE 42.8

Relative change in fire size before and after 1950 for the five comparison recurrence intervals. The percentage difference in fire size for each recurrence interval is the fire size before 1950 minus the size after 1950 divided by the size before 1950 times 100. Locations are arranged horizontally from north to south. (Apparent data gaps represent zero difference between periods.)

the problem of fires could be improved and expanded in several ways. First, the problem of completeness of data may be rectified if true years of no fires can be identified and perhaps gaps in the record filled. Similar analyses could produce comparisons with private land under different management if sufficient records exist for the regions surrounding national parks and forests. In other applications the frequency curve provides a simple extraction of the overall average-sized event, which is the size of the 2.33-year recurrence interval event (Dunne and Leopold 1978). Our values for frequent events are probably overestimated in size because smaller fires may be less well recorded.

The analysis could be further improved or refined by assembling fire frequency data by elevation or vegetation type—critical elements considered in other studies of fire behavior (see McKelvey and Busse 1996; Skinner and Chang 1996). Different time periods, such as decade by decade, could be examined for other patterns of change in fire frequency by adopting the procedure of the partial series (all fires greater than some minimum size) rather than the annual maximum event (Chow 1964).

Nevertheless, the important conclusion from our analysis is that a Sierra-wide generalization about the pattern of fire size and change in frequency in this century is not supported by the data.

ACKNOWLEDGMENTS

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APPENDIX 42.1

Fire Frequency Analysis of Sierra Forests

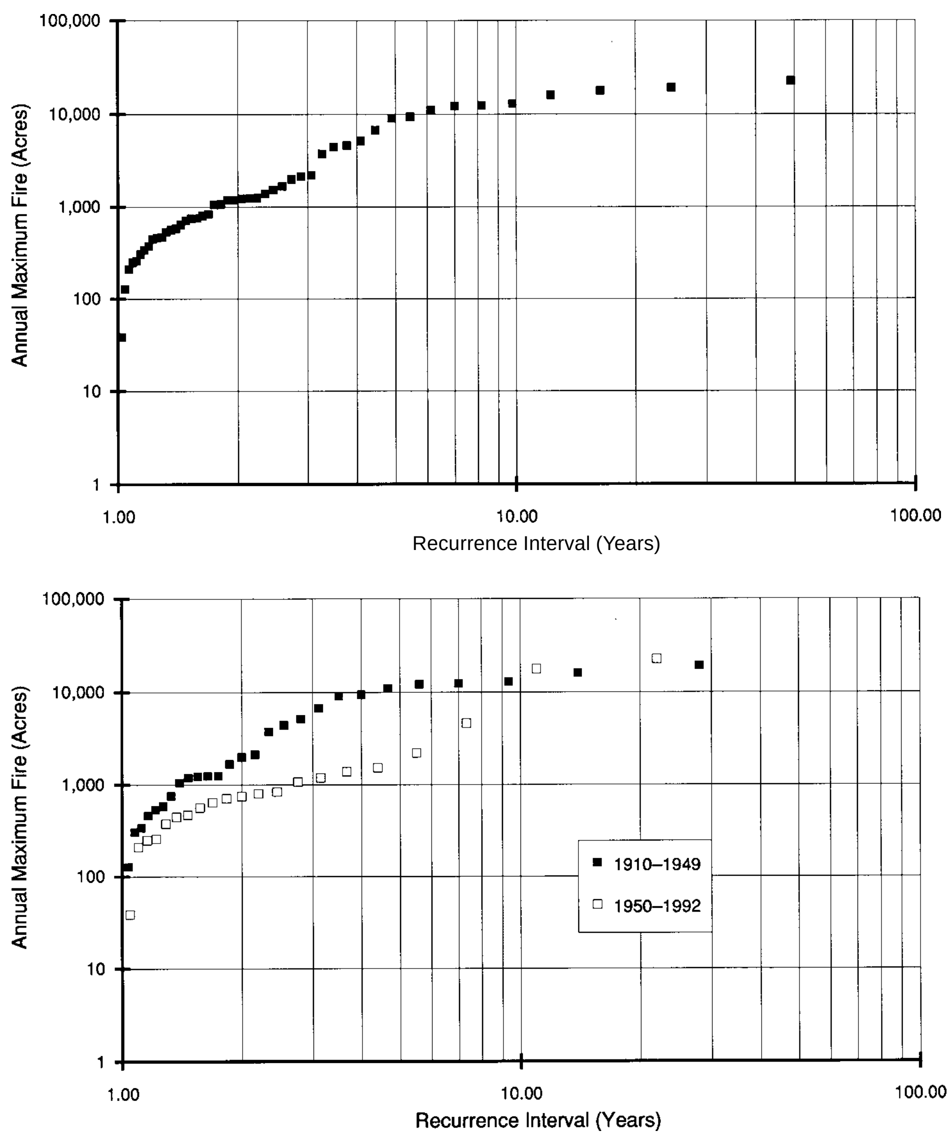
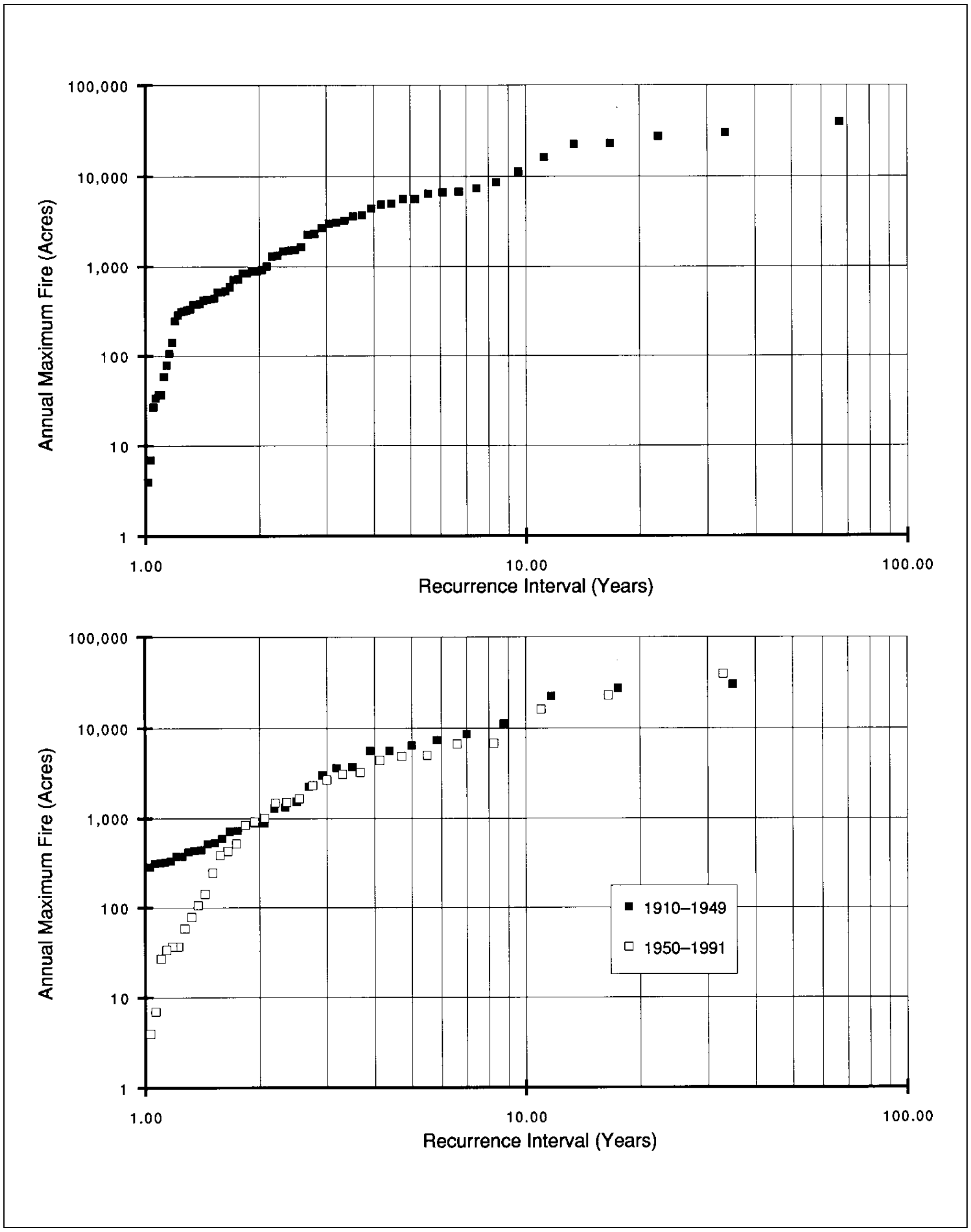


FIGURE 42.A1

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Lassen National Forest.

FIGURE 42.A2

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Plumas National Forest.



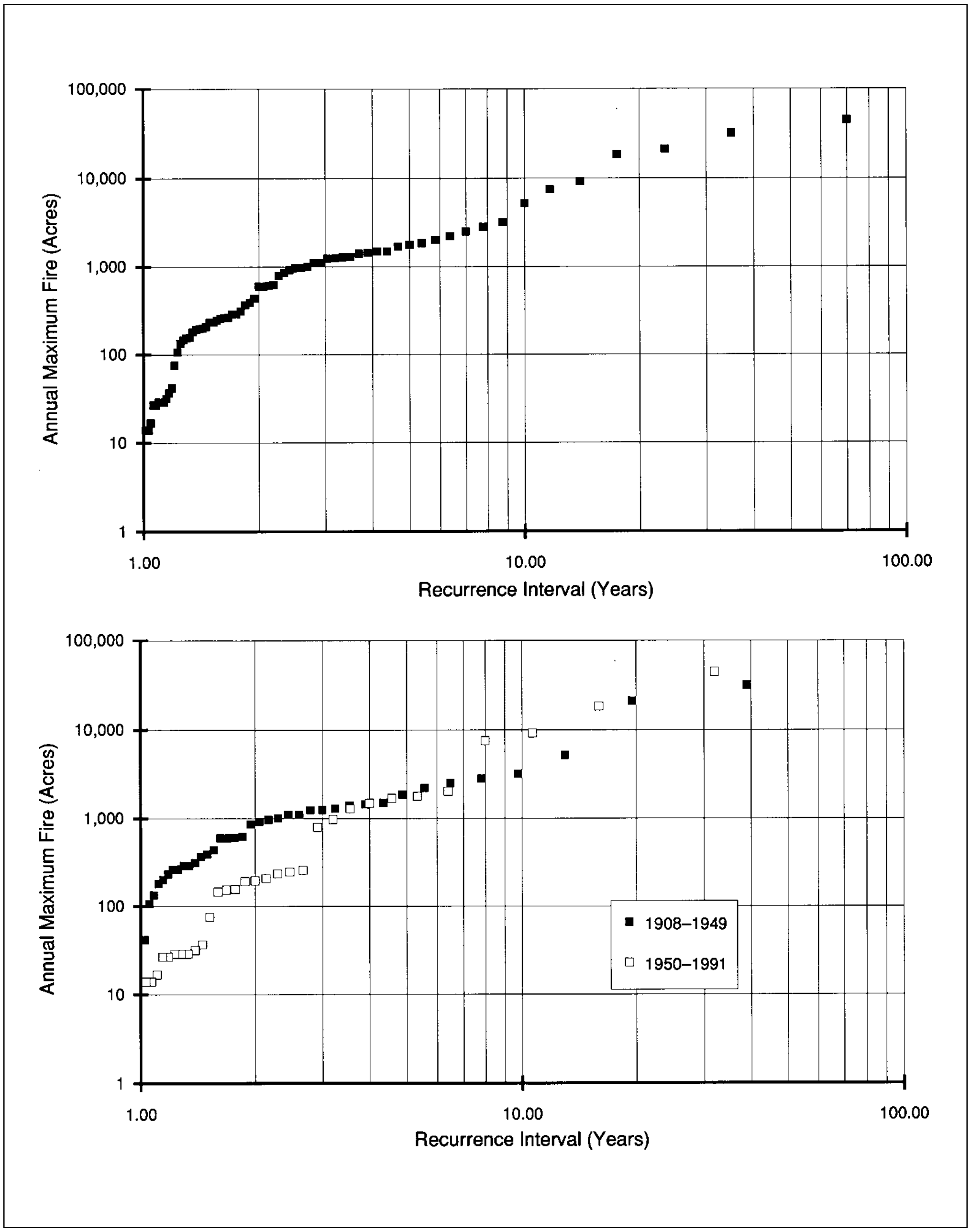
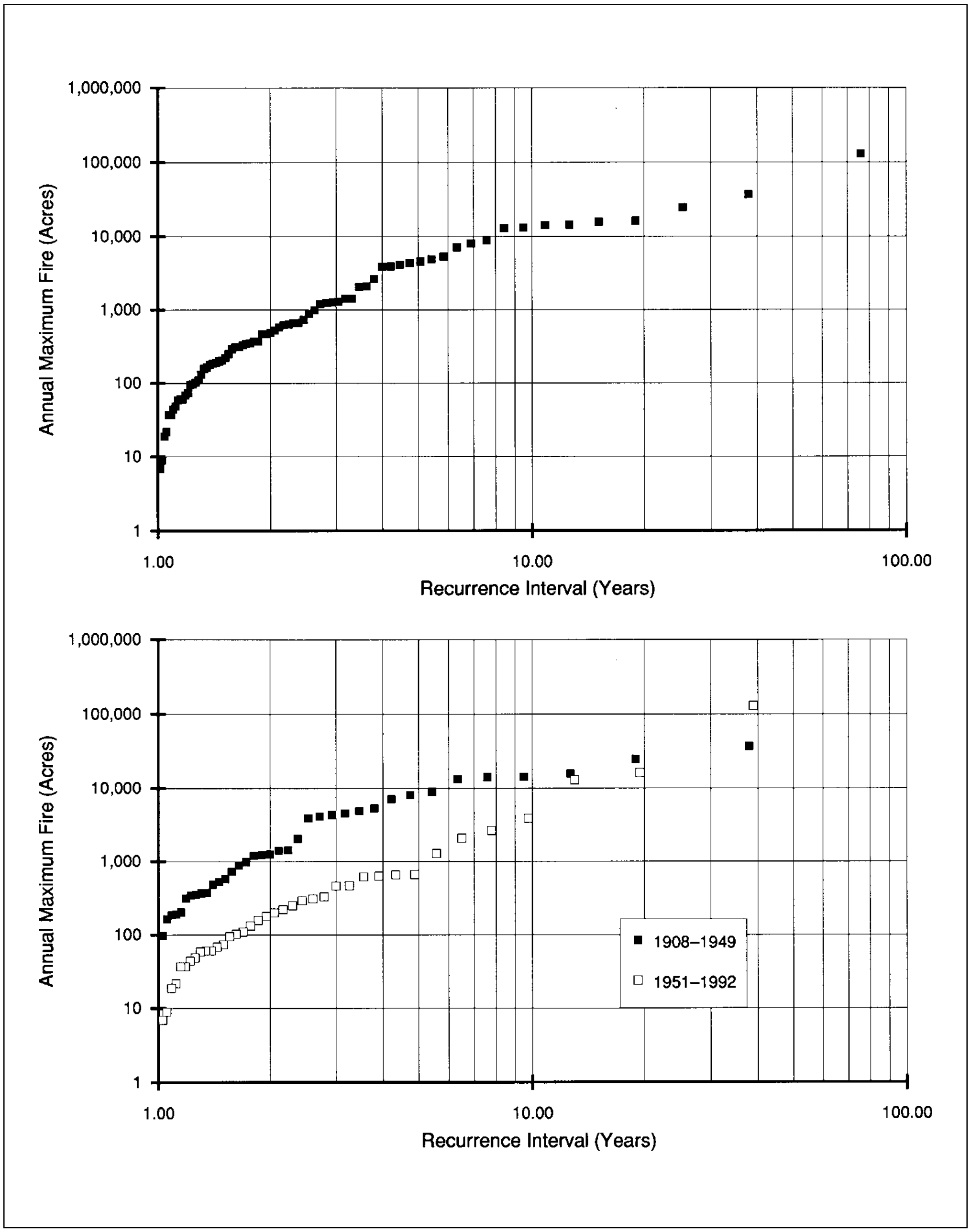


FIGURE 42.A3

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Tahoe National Forest.

FIGURE 42.A4

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Stanislaus National Forest.



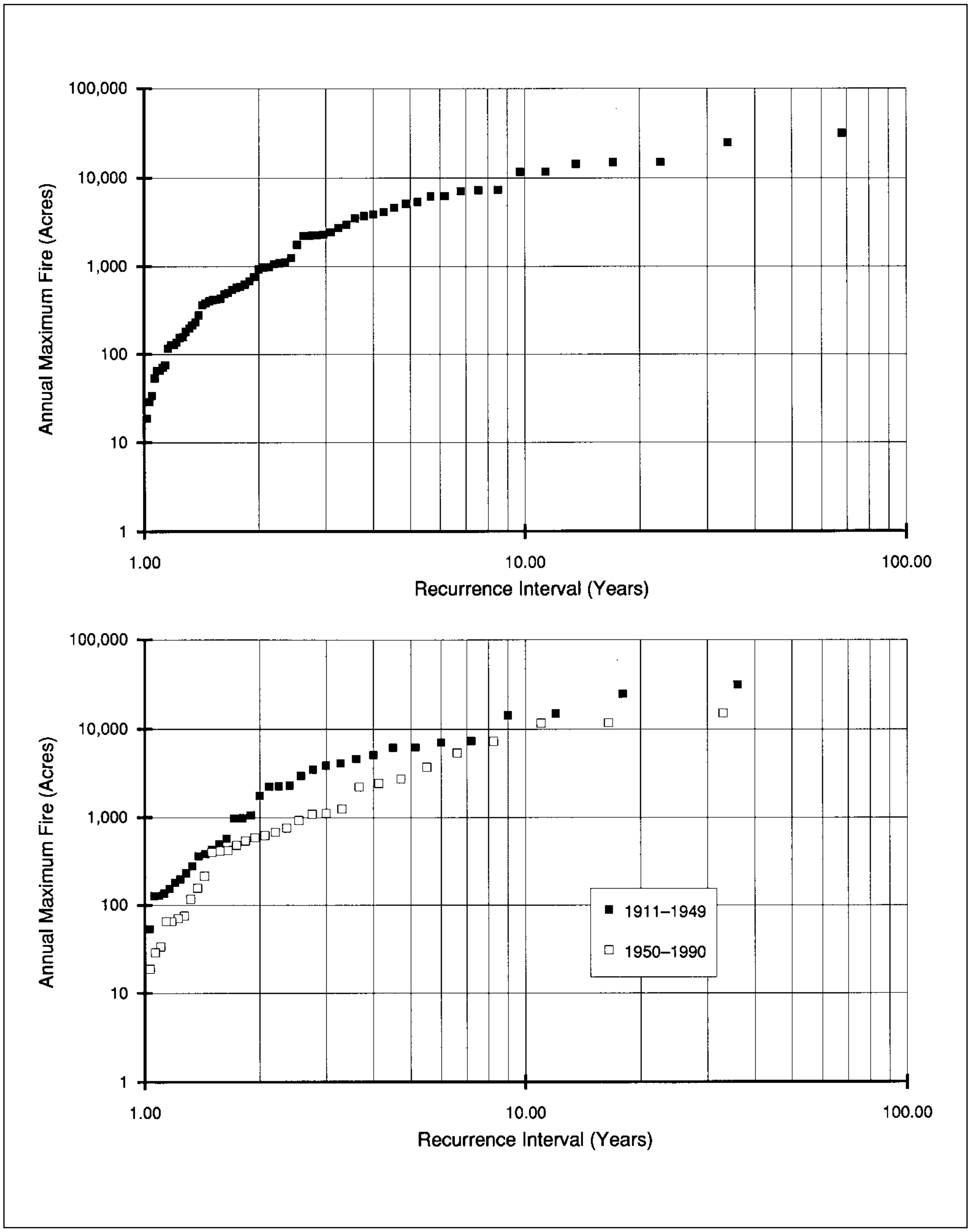


FIGURE 42.A5

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Sierra National Forest.

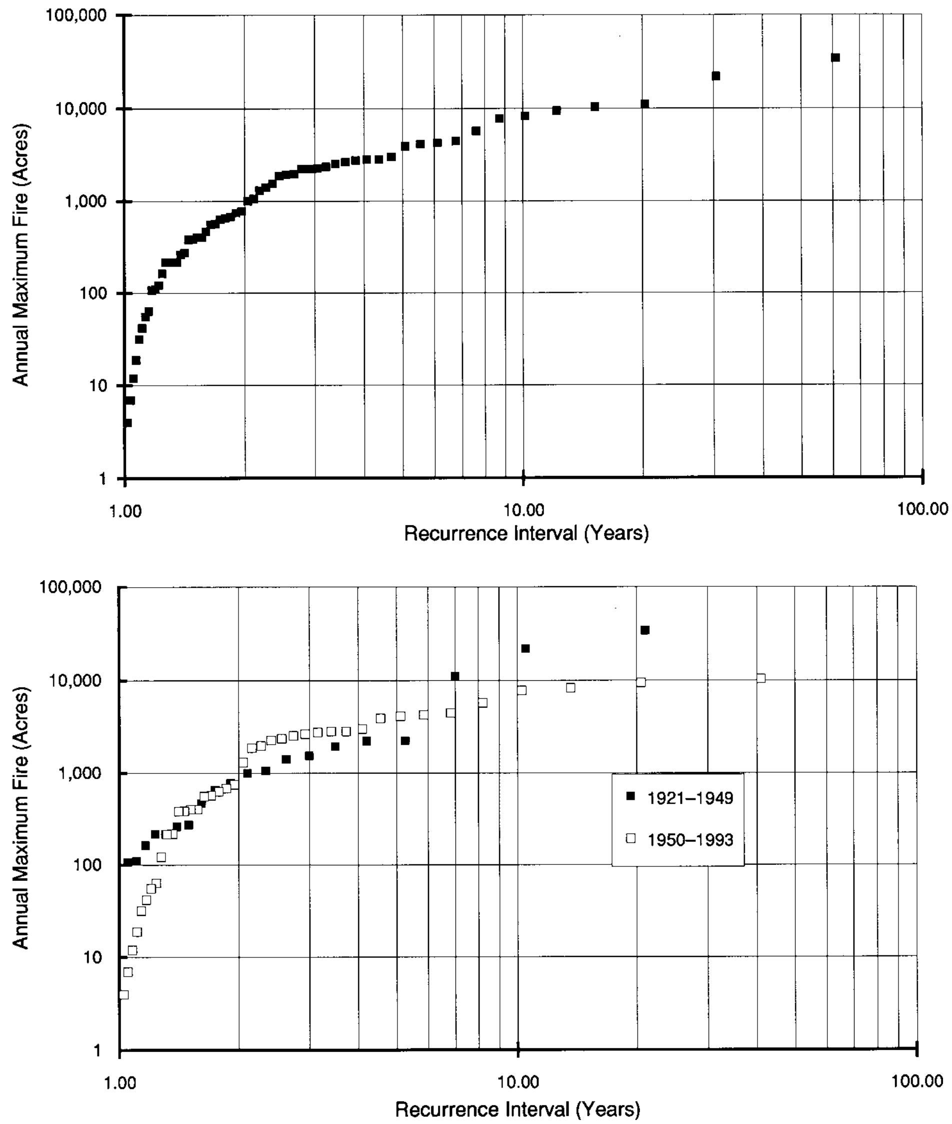


FIGURE 42.A6

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Sequoia–Kings Canyon National Parks.

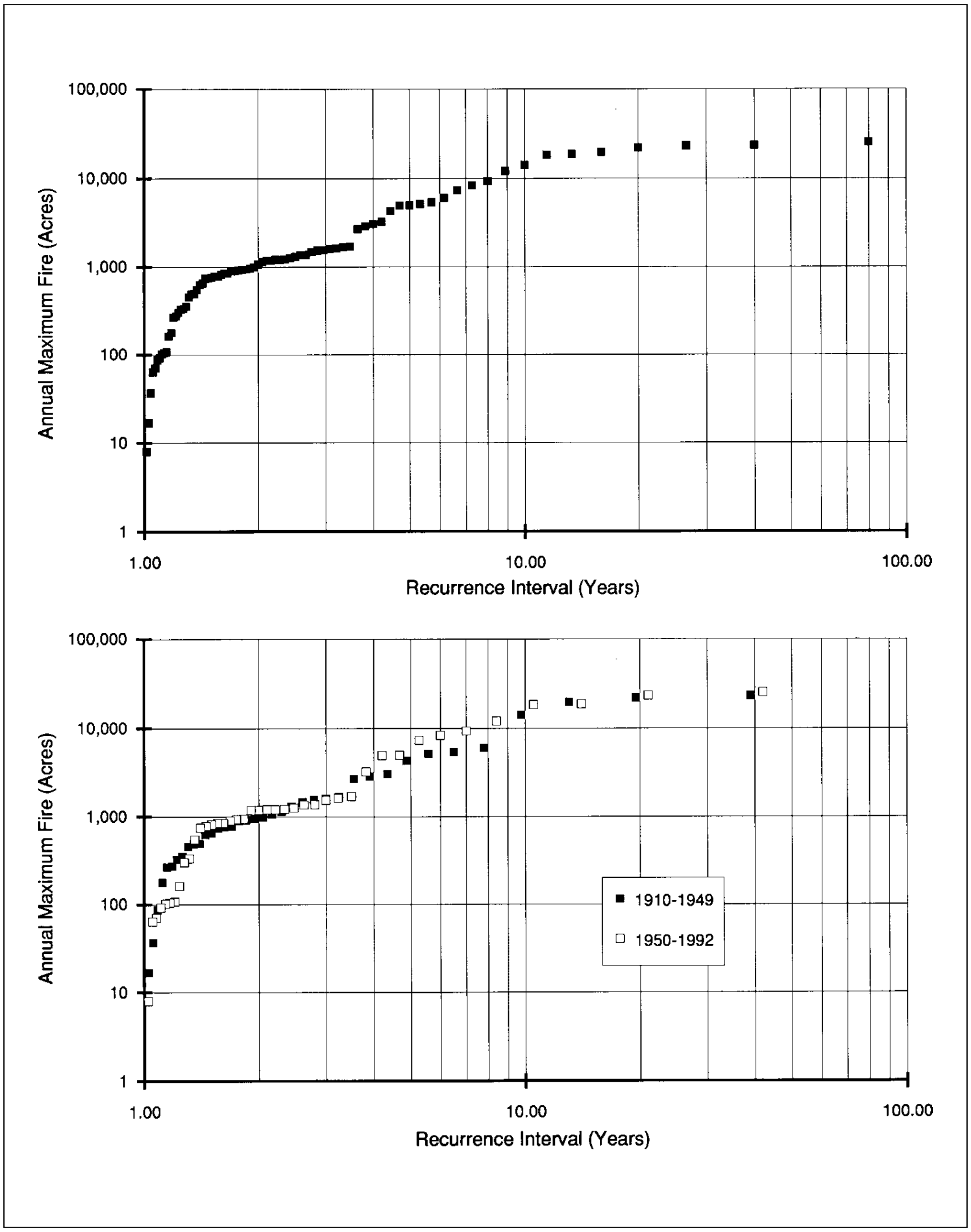


FIGURE 42.A7

Fire-frequency plots based on the annual maximum fire for all years of record (upper plot) and for the periods before and after 1950 (lower plot) for the Sequoia National Forest.

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