#2431

AN ABSTRACT OF THE DISSERTATION OF

Peter C. Impara for the degree of Doctor of Philosophy in Geography presented on June 27, 1997. Title: Spatial and Temporal Patterns of Fire in the Forests of the Central Oregon Coast Range.

Abstract approved: *[signature]*
Julia Allen Jones

Fire history and fire regime were interpreted from tree ring analysis of 4320 stumps at 178 sites in a 25 by 55 km area in the central Oregon Coast Range. A total of 27 fire episodes were identified in a 516 year period, with sizes estimated at 18 to 544 km^2 and a mean of 97 km^2. The mean fire return interval (MFRI) was 85 years; the natural fire rotation (NFR) for the 516 year period was 271 years.

Fire size estimates were smaller and frequency was lower in the pre-settlement period (1478 - 1845) than in the post-European settlement period (1846 - 1909) with a mean size of 66 vs.192 km^2 and NFR of 452 vs.78 years. Fire size and frequency both declined after fire suppression began in 1910 (mean fire size 86 km^2, NFR of 335 years).

Seventeen of the 27 fire episodes identified were low-severity and affected <15% of the study area, occurred between 1585 and 1844, and were concentrated in the eastern 1/3 "Valley Margin" portion of the study area. Less frequent, larger "widespread" fire episodes, two in the 1500s and two in the mid-1800s, each affected >50% of the study area and obliterated most pre-existing stands: only 347 trees

examined (8%) were >400 years old, and none exceeded 516 years. Upper hillslope positions experienced more frequent, more severe fires than lower hillslope positions, where 44% of the trees sampled exceeding 400 years of age were found.

Fire episode size varied by as much as 800% for the earliest fires depending on how much erasure was presumed to have occurred. MFRIs may have underestimated true return intervals by half, since many sites recorded only two fires.

Old-growth stands were more abundant than shown in previous studies. 48% of the sites sampled contained trees >200 years of age; most of the stands in the Interior/Coast appear to have been >200 years of age in 1850. The species composition, structure, and temporal variability of old growth stands probably differed between the eastern 1/3 and western 2/3 of the study area as a result of the contrast in fire regimes.

354 p.

Spatial and Temporal Patterns of Fire in the Forests of the Central Oregon Coast Range

by

Peter C. Impara

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APPROVED:

Major Professor, representing Geography

Chair of Department of Geosciences

Dean of Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Peter C. Impara, Author

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SPATIAL AND TEMPORAL PATTERNS OF FIRE IN THE FORESTS OF THE CENTRAL OREGON COAST RANGE

CHAPTER 1. INTRODUCTION TO FIRE IN THE CENTRAL OREGON COAST RANGE

1.1 INTRODUCTION

Forest fire is a critical disturbance process in western coniferous forest ecosystems (Mutch, 1970; Wright, 1974; Agee, 1993). Fire initiates stands when fires cause high mortality, and creates patterns of mixed-age classes within and between stands when fire occurrence is variable (Morrison and Swanson, 1990). Fire is important in the generation through tree mortality of woody debris, such as snags (Harmon and others, 1986; Spies and Cline, 1988), as an influence on forest vegetation types (Mutch, 1970; Agee and Kertis, 1987), and as a factor in forest structure and composition (Perry, 1994).

Long-term (ca. 500 - 1000 years) fire history studies have reconstructed the occurrence of fire in landscapes. The results of these studies have shed light on the importance of fire in coniferous forest ecosystems of the western United States and Canada (Heyerdahl and others, 1996). Fire and its importance in the western hemlock - Douglas-fir forest ecosystems of the Cascades have been investigated by Hemstrom and Franklin (1982), Teensma (1987), Agee and Huff (1987), Morrison and Swanson (1990), and Krusemark and others (1996). Each of these studies used direct observations of forest age class and fire evidence, such as scars on tree boles to reconstruct the size, frequency, and severity of past fires.

Multiple ecological factors contribute to the pattern of fire in a landscape. These factors occur at several spatial and temporal scales. Important scales for fire include the scale of climate and weather (Huff and Agee, 1980; Clark, 1990; Johnson and Larsen, 1991; Johnson and Wowchuk, 1992; Swetnam, 1993; Bessie and Johnson, 1995); landforms (Swanson and others, 1988; Swanson and others, 1990); topography (Romme and Knight, 1981; Swanson and others, 1988; Swanson and others, 1990); and fuel loads and vegetation types (Mutch, 1970; Agee and Huff, 1987).

Landscape ecology approaches have often been used when considering fires at large spatial and temporal scales. Landscape ecology studies address three important factors: the heterogeneity and patterns of landscape-level ecosystems (Forman and Godron, 1986); the interactions of ecological patterns and processes (Turner, 1989); and the scales at which those patterns and processes operate (Wiens, 1989).

Fire in the central Oregon Coast Range was investigated in this study as a process that creates and reacts to pattern at several spatial and temporal scales. Dendrochronologic data were used to identify fire episodes over the last 500 years (the maximum tree-age record in the study area) and to characterize the fire regime variables of frequency, severity and size for a 1375 km^2 study area of the central Oregon Coast Range. The extent of significant fire episodes was identified, mapped, analyzed, and compared to results of similar fire studies in the western Cascades (Teensma, 1987; Morrison and Swanson, 1990; Hemstrom and Franklin, 1982). This study lays the groundwork for an analysis of the interactions among the process of fire and the landscape patterns of climate, landforms, topography, and vegetation. The established fire episodes were compared to a long-term fire history developed from lake core analysis of charcoal in a separate study (Long, 1995). An analysis of the fire record was also used to reconstruct age classes in the study area over time as a method of assessing the effects of fire and estimating historical old growth occurrence.

This is the first study that has used primary observations of age class and fire scars to reconstruct the size, frequency, and severity of fire in the Oregon Coast Range. Historic fires in the Oregon Coast Range have been described from various secondary sources by Clark (1905), Morris (1934), Munger (1944), Zybach (1988) and Teensma and others (1991). Each study used a mix of descriptions from early explorers in the Coast Range, such as Douglas in 1826 (Davies, 1981) and Talbot in 1849 (Morris, 1934), newspaper and historical accounts, General Land Survey Office notes, and timber cruise and forest age records of private and governmental institutions. The picture of fire that emerged from these descriptions was of large-scale, highly destructive fires similar to the Tillamook burn of 1933 in terms of size and severity. The use of primary dendrochronological data in this study to determine the occurrence of fire in the Coast Range provided a higher spatial and temporal resolution than earlier accounts, and quantified fire occurrence in the Oregon Coast Range.

This study addressed three critical issues: 1) what was the nature of fire in the Coast Range over the past 500 years? 2) which environmental processes control or influence fire in the Coast Range? and 3) how has fire affected old growth in the Coast Range over time?

1.2. SIGNIFICANCE OF THIS STUDY

Resource managers in the Pacific Northwest have recently been faced with conflicts regarding approaches to forest management. The Endangered Species Act (ESA) of 1973 and the status of several endangered or threatened species such as the northern spotted owl (*Strix occidentalis caurina*), the marbled murrelet (*Brachyramphus marmoratus*) and several anadromous fish species, have initiated restrictions of management activities in forest ecosystems (James, 1994). In addition, the National Environmental Policy Act (NEPA) of 1969 and the National Forest Management Act (NFMA) of 1976 have been employed by both non-federal and federal entities to further restrict the activities of federal agencies charged with forest management (Keiter, 1994).

These restrictions reached a climax with the 1992 decision by Judge Dwyer of the U.S. District Court for the Western District, Seattle. His ruling placed an injunction on all timber sales on federal lands in the Pacific Northwest Region by the U.S. Forest Service (USFS) and Bureau of Land Management (BLM) until Environmental Impact Statements (EISs) and management plans were drawn up and implemented that satisfied the requirements of NEPA, ESA and NFMA.

Human communities dependent on forest resources have been economically impacted by restrictions on forest resource use (Rivlin, 1993). These impacts have generated pressure on resource managers to develop or find ways to balance short-term economic and related political pressures with long-term ecological priorities.

Ecosystem management is a relatively new approach to resource management that attempts to address these problems. An important aspect of ecosystem management from some points of view is the re-establishment and/or maintenance of the ecosystem within the range of natural variability for important ecosystem processes (Swanson and others, 1993). One assumption of ecosystem management is that organisms are dependent on ecosystems that varied within a certain range. If an ecosystem is managed so as to preserve the natural variation of important ecological processes and conditions (i.e. habitats) on which organisms depend, species should be faced with reduced extinction or extirpation pressures. From this perspective it is expected that the economic and political fallout related to threatened and endangered species should be reduced.

Disturbance is an important ecological process for which information is needed to carry out ecosystem management. As fire is the primary disturbance agent in many coniferous forests (Franklin and Dryness, 1973; Agee, 1993), there is a need to know about the fire regime of coniferous forest ecosystems in which ecosystem management activities are being implemented.

There is also a need to better understand disturbance regimes from an ecological perspective. Over long time periods relatively stable disturbance regimes play an important role in the evolution of species (Thompson, 1985). In the short term, disturbance influences species diversity, the successional trajectory of communities, and the functioning of ecosystems (Pickett and White, 1985). Understanding the role of fire as the primary disturbance agent in Coast Range forests should illuminate the importance of fire to biodiversity and to ecological processes such as succession and ecosystem function in the Coast Range.

This study was carried out to provide information useful in assessing and understanding the importance of the ecological process of fire in the Coast Range. In addition this study provides multi-scale information on the fire regime to be used in the design and implementation of diverse forest management goals and options. This study is the first large-scale study to systematically characterize at multiple scales the fire regime of the central Oregon Coast Range using dendrochronological information. A multi-scale analysis of fire controls, an evaluation of the effect of environmental patterns on the process of fire, and a sensitivity analysis of methods of fire regime determination were carried out to refine existing knowledge of the role of fire in Coast Range forests.

1.3. OBJECTIVES

This study seeks to provide: 1) the reconstruction of fire episodes; 2) an analysis of the fire regime developed from those episodes; 3) an analysis of the influence of the landscape controls climate, topography, and vegetation on fire; and 4) a description of the impact of fire on forests in the study area over time.

Several broad questions were developed which would provide a general characterization of the fire regime of the central Oregon Coast Range:

1) What historical fire episodes are recorded in the dendrochronologic record in the Central Oregon Coast Range?
2) What are the frequency, size and severity of these fire episodes?
3) How representative is this record of a longer (paleo) accessible record as revealed by Long's (1995) Little Lake sediment core?
4) Does the fire regime vary according to geographical variables such as climate, aspect, topography and vegetation within the Central Coast Range?
5) How has fire affected forest structure and composition in the study area over the past 500 years?

This dissertation is divided into four chapters to address these and other questions regarding the fire regime of the study area. In Chapter 2 fire episodes occurring in the study area over the last 500 years were identified and mapped using scar and tree ring data collected in the field. The fire regime measures of mean fire return interval, the natural fire rotation, fire size, and fire severity, were evaluated to identify spatial and temporal patterns of fire over the period of record. The pattern types identified were compared to identify potential environmental influences on the pattern of fire in the study area.

In Chapter 3 the influence of the pattern of environmental variables on the pattern of fire was addressed by fitting logistic regression models incorporating climate, landform, topography and vegetation to fire occurrence by site. Results of the influence of environmental patterns on fire patterns were used to evaluate the influence of environmental processes on the process of fire.

In Chapter 4 different methods to determine fire regime measures were compared to gauge the sensitivity of results to methodology and to address issues of scale, extent of study, and grain of sampling. Fire regime results from this study were compared to other fire studies carried out in the Douglas-fir forests of the Pacific Northwest to address differences in the fire regimes of the Coast Range and the western Cascades.

In Chapter 5 present day age class information and field observations were used to estimate past, present and potential future amounts of old growth in the study area. Fire episodes identified in this study were compared to the charcoal record of fires of the past 500 years developed by Long (1995) to evaluate potential spatial linkages between the tree ring and charcoal records of fire. The entire 9090 year charcoal record of fire reported by Long was analyzed to evaluate temporal patterns of old growth abundance in the Coast Range.

CHAPTER 2
RECONSTRUCTION OF FIRE EPISODES AND FIRE REGIME DETERMINATION

2.1. INTRODUCTION

This chapter describes the results of a dendrochronological analysis of Douglas-fir tree stumps in clearcuts in the study area. Events determined from the dendrochronological record are compared with known historical events in order to assess the ability of the sampling program and of the dendrochronological record to detect fire episodes.

This is the first large-scale fire episode reconstruction study in the Coast Range to use primary dendrochronological data collected with the goal of determining a fire history, chronology and regime. Previous fire studies in the Coast Range used secondary data from historical and newspaper accounts (Morris, 1934; Munger, 1944; Zybach, 1988;) early state-wide forest cover maps (Zybach 1988), and timber cruise records and General Land Office Survey Notes (Teensma and others, 1991; Ripple 1994). The primary data and interpretations of fire episodes and the fire regime described here will be compared with studies that used other data sources.

The inclusion in the study area of Little Lake, where charcoal deposits from a ca. 10,000 year sediment core were studied to determine the Holocene fire record (Long, 1995), permits comparisons of: 1) a broad spatial area with a single watershed study area; 2) multi-century (ca 500 years) with Holocene (ca 10,000 years) scale fire records;

and 3) two techniques: dendrochronology and charcoal core records. The spatial and temporal links between these two studies are examined in detail in Chapter 5.

Questions addressed in this chapter are:

1) Where and when did fire episodes occur in the study area?

2) How large, frequent and severe were fire episodes in the study area?

3) What were the spatial and temporal patterns of fire episode in the study area over the last 500 years?

2.2. METHODS

2.2.1 Fire Regime Reconstruction: Overall Approach

Dendrochronological data were collected from 4320 stumps sampled in 178 sites in the study area. The dendrochronological data set was used to develop a retrospective fire history, starting at the tree (stump) level, and progressing to the sample site (clearcut) and landscape (study area) level. Fire episodes were identified by dating scars on stumps at the site. The study area was selected because it encompasses geographical variation in climate, topography and vegetation and included Little Lake, the site of a paleoecological fire history study. Prior to field sampling, the study area was subdivided into zones based on environmental variables of interest using GIS and remote sensing. These zones were used to construct a hierarchical, proportional field sampling design.

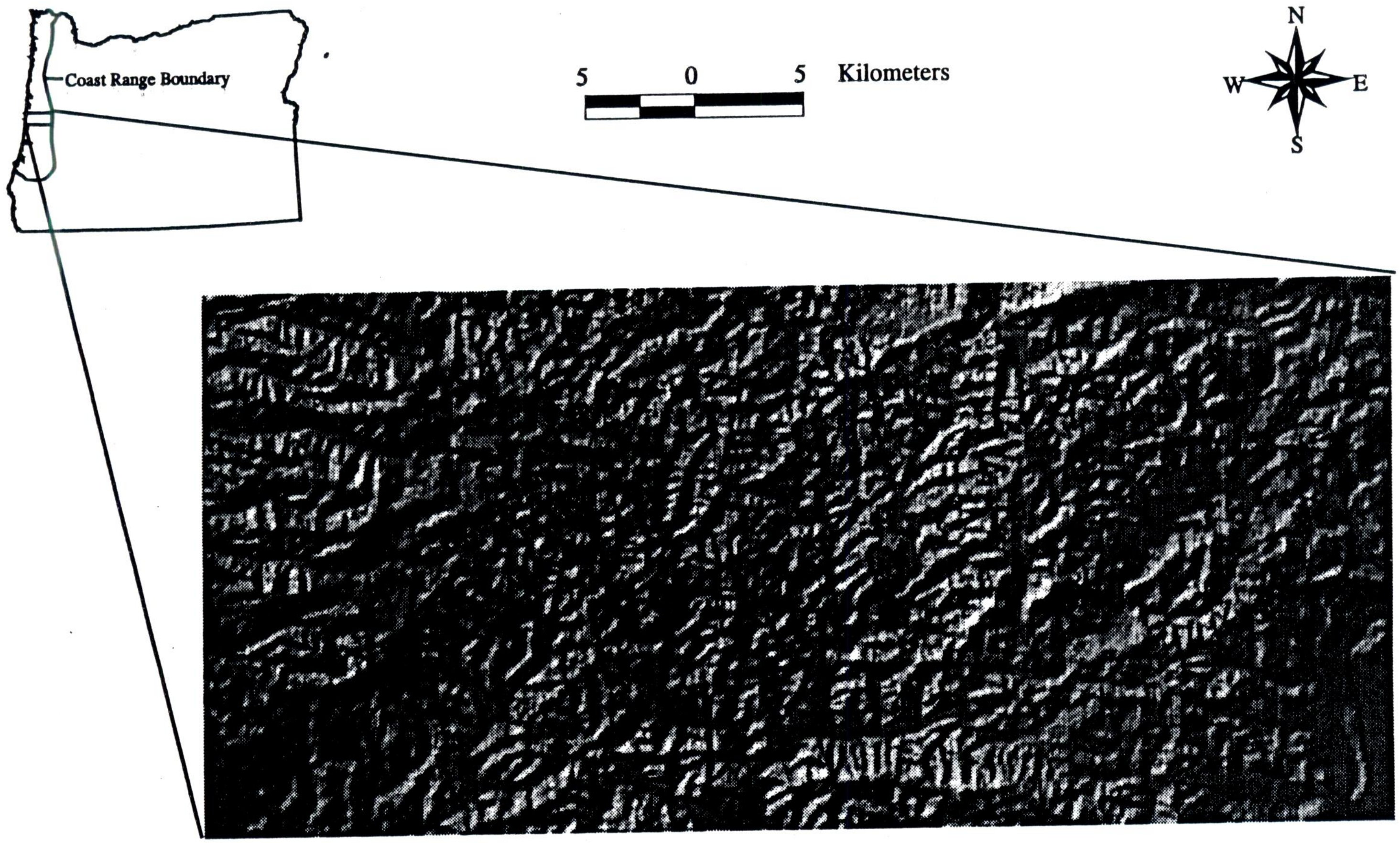
2.2.2 Study Area Description

The study area is located in the Central Oregon Coast Range encompassing a rectangle with the northwest corner at 44^0 16' N and 124^0 05' W and the southeast corner at 44^0 03' N and 123^0 25' W (Figure 2.1). The study area is 25km wide (N-S) and 55 km long (E-W) with a total area of 1375 km^2. The study area boundary was centered north to south on Little Lake, and was bounded by Prairie Peak to the north to Walker Point to the south. The study area extended from the Pacific Ocean to the Willamette Valley (Figure 2.2).

2.2.2.1 Geology and Landforms

The geology of the study area is predominantly composed of the Tyee Formation, composed of layered sandstone and siltstone (Baldwin, 1976), which gives rise to short, steep slopes with tightly spaced dendritic drainage patterns (Figure 2.3). The Basaltic Headlands in the northwest part of the study area display strong east-west valleys and ridges (Berry and Maxwell, 1981; USDA Forest Service 1995; Figure 2.3). In the interior of the Coast Range, the underlying sandstone has a westward dip expressed in moderate west facing slopes and steeper east facing slopes (Corliss, 1973). Important peaks and surrounding higher-elevation portions of the study area include Prairie, Windy, and Klickitat Peaks, which influence precipitation patterns through

Figure 2.1 The Oregon Coast Range and the Location of the Study Area



Study Area and Physical Features (from USGS 90m DEM)

Figure 2.2 Location of Landmarks in the Study Area

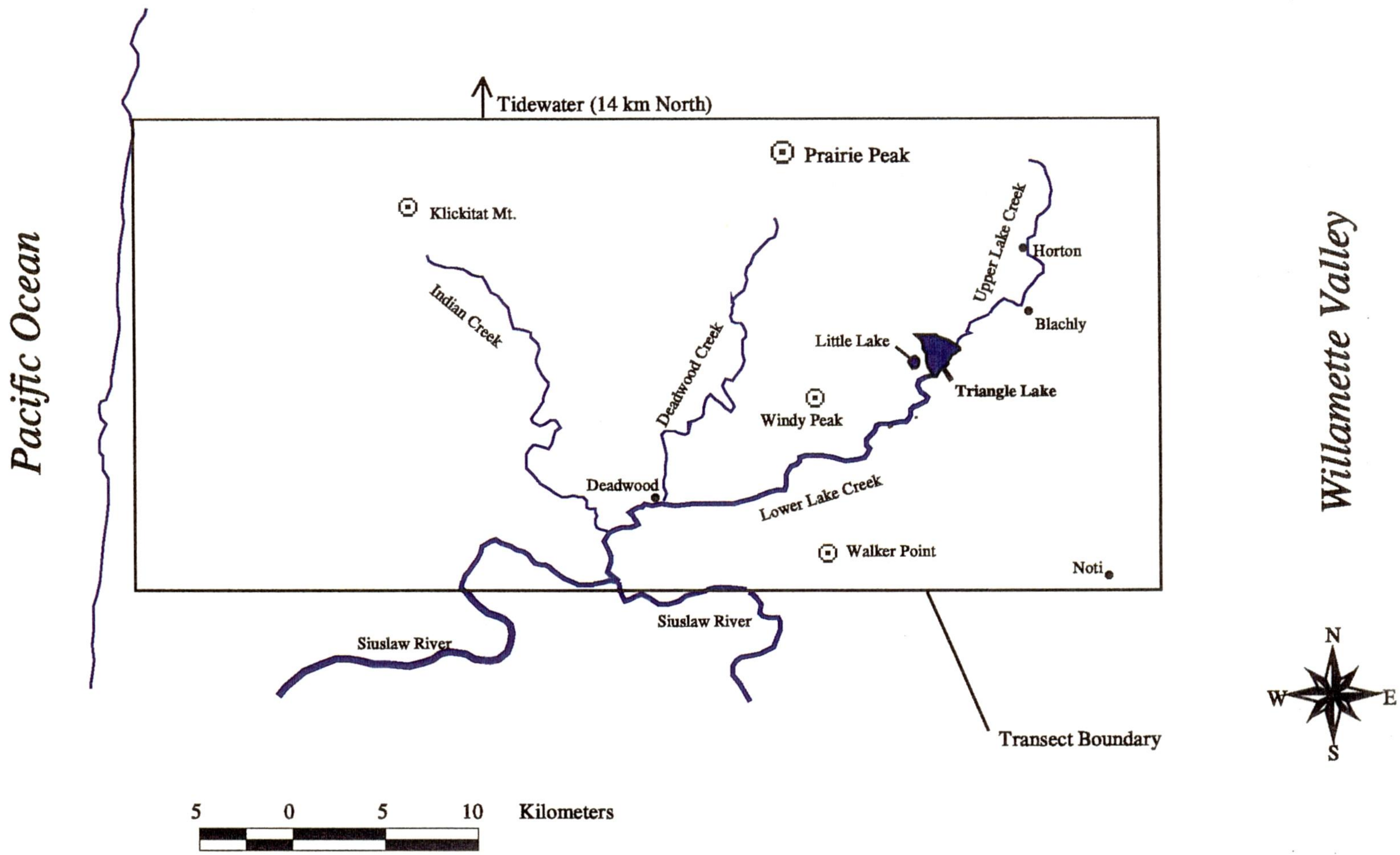
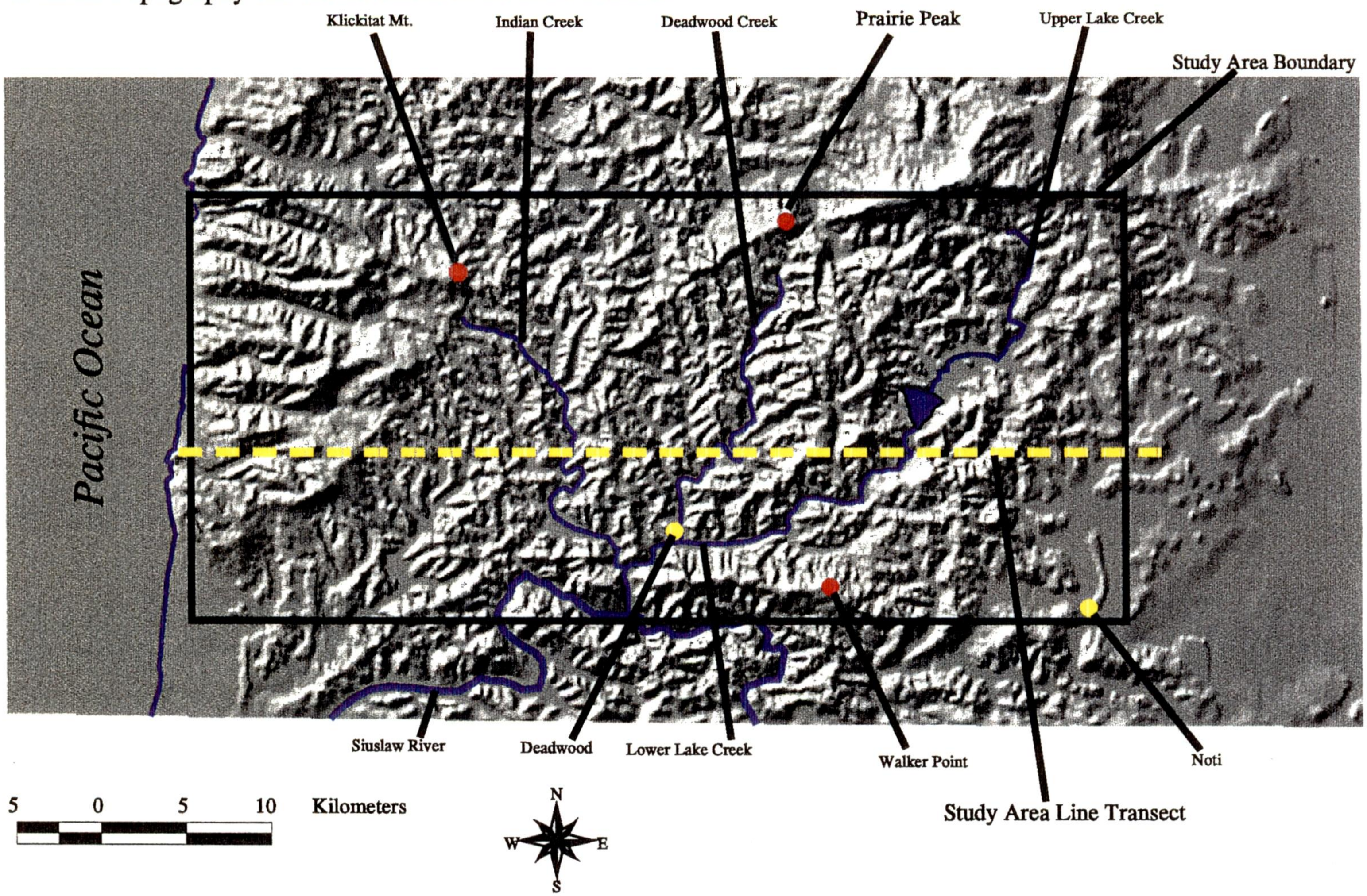


Figure 2.3 Shaded Relief Map based on USGS 90m DEM of the Study Area showing General Topography and the Location of the Line Transect



orographic lifting (Daly and others, 1994). Elevation in the study area ranges from sea level to 1000m at Prairie Peak.

The landforms of the study area are highly dissected relative to other parts of the Coast Range and topography is strongly influenced by geology. Berry and Maxwell, (1981) and USDA Forest Service (1995) described a set of landtype associations based on geology, topography, drainage, soils, climate, and vegetation. Six of these occupy significant portions of the study area: 3M, 3T, 3B, 3C, 3F, and 3H (Figure 2.4). These landtype associations have predominantly short, steep slopes, fine to medium relief and drainage texture, medium to deep soils, and high (west) to moderate (east) forest productivity.

2.2.2.2 Climate

As in much of the Pacific Northwest, precipitation in the Coast Range derives from the moist air masses which move in from the Pacific Ocean during fall, winter, and spring, especially in November through January (Taylor and Bartlett, 1993). Mean annual precipitation is relatively high on the coast and in the interior Coast Range, but declines near the Willamette Valley, while mean annual temperatures rise (Daly and others 1994; Taylor and Bartlett, 1994). The 1961-1991 mean annual mean precipitation from Tidewater, Oregon (Table 2.1a) is 232 cm, with 66% of the precipitation falling between November and March (Taylor and Bartlett, 1993). The 1961-1991 mean annual mean precipitation from Noti, on the eastern edge of the study

Figure 2.4 Study Area Landtype Associations

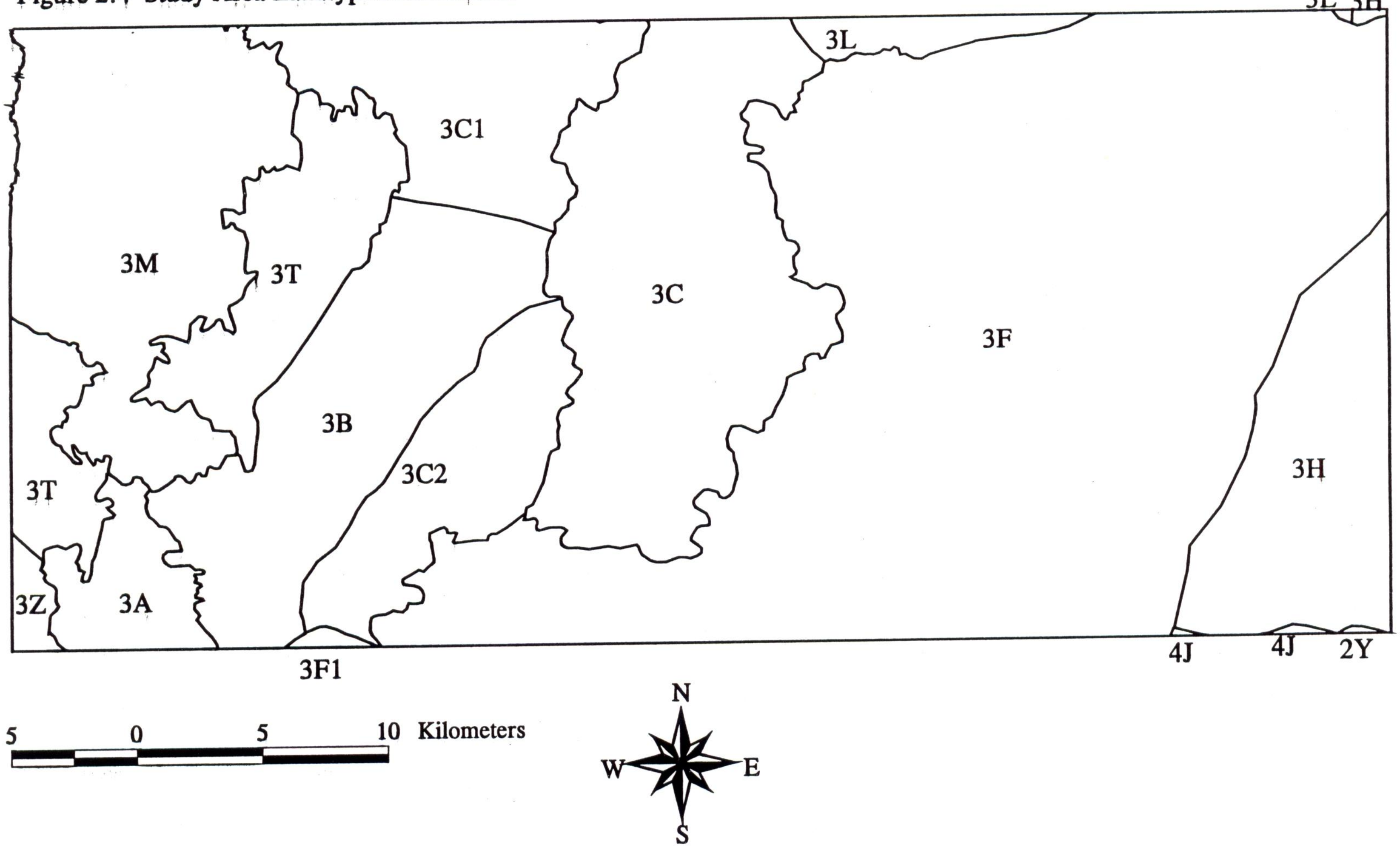


Table 2.1 30 Year (1961 - 1990) Climate Data Averages for Weather Stations Near the Study Area

a. Monthly and Annual Mean Precipitation (cm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Tidewater, OR	35	25	26	15	11	8	4	4	10	18	33	35	232
Noti, OR	26	20	18	10	6	3	1	2	4	10	25	28	154

b. Monthly Mean Temperatures (^{o}C) for Tidewater, Oregon

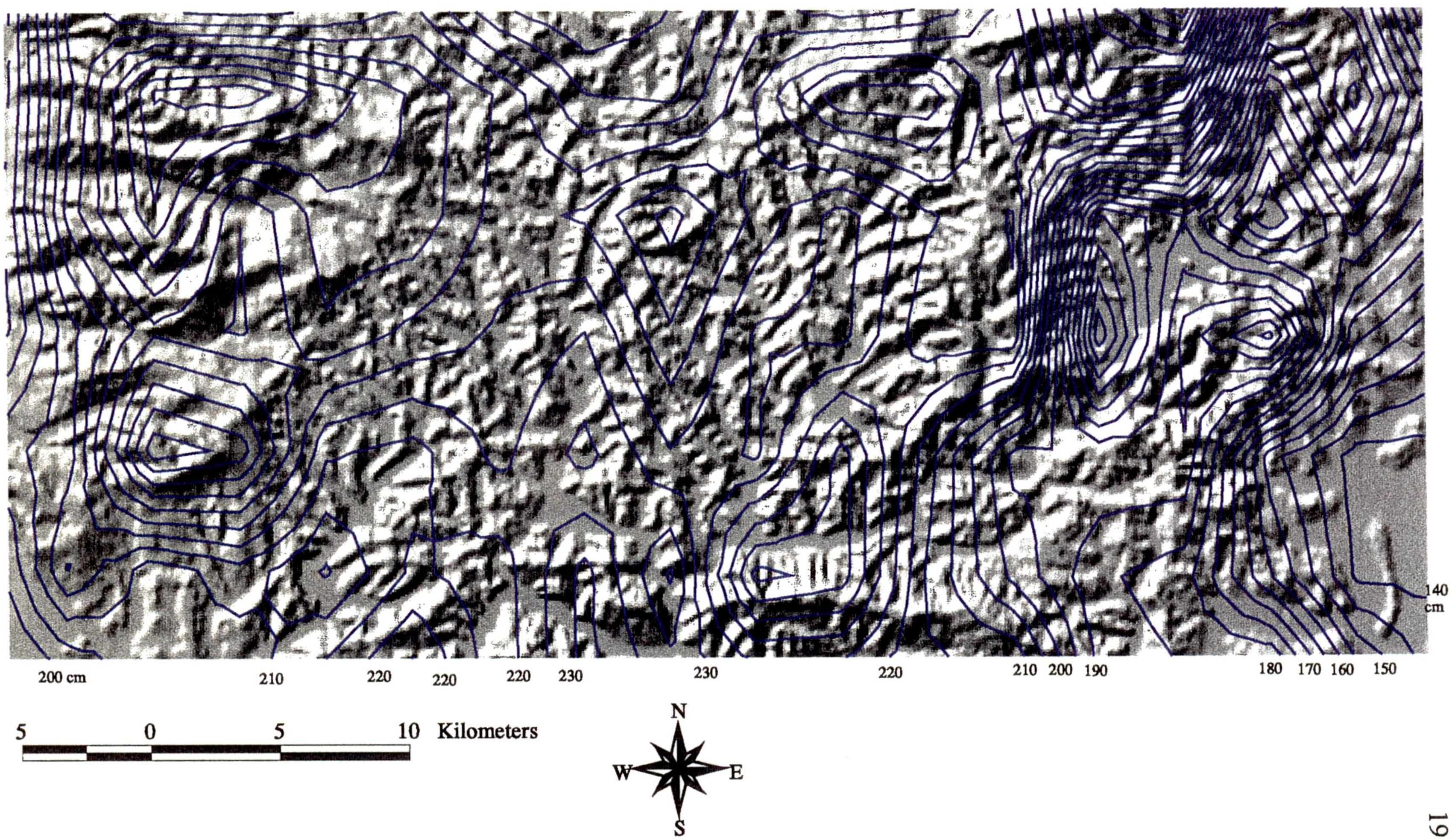
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean Max	10	12	13	14	16	18	20	21	21	18	13	11	17
Mean Min	2	3	4	4	7	9	11	11	10	8	5	3	7
Monthly Mean	6	8	9	10	13	15	17	18	17	14	9	6	12

area, is 154 cm (Taylor and Bartlett, 1994) with 76% of the precipitation falling between November and March (Table 2.1a). The mean annual monthly temperature at Tidewater is 11.7^0 C, ranging from 6.3^0 C in January to 18.0^0 C in August (Table 2.1b). Median frost dates for Tidewater extend from mid-November to mid-April, reflecting mild temperatures and a long growing season conducive to developing high fuel loads (mean annual temperatures are not available for Noti).

A strong orographic effect is evident in the drop in precipitation between the wetter west and central Coast Range and the dryer eastern margin (Daly and others, 1994) (Figure 2.5). This also influences fog, forest, and vegetation patterns as described below.

Since 1986 lightning strikes in the western U.S. have been recorded by the Western Regional Climate Center at the University of Nevada, Reno. A series of lightning detectors record 70 - 80% of all strikes within the western U.S. The detectors record location, polarity, magnitude, and date and time of strike. Location accuracy is +/- 1 km and is recorded in latitude and longitude. The data are available as 1 degree latitude by 1 degree longitude cells. Lightning data from 1986 to 1994 were acquired for the study area to determine the occurrence of positively charged lightning strokes during the fire season (June to October). Polarity is important in fire ignition as positive polarity is associated with ignition from the flow of electrons to the ground from the atmosphere. Positively charged lightning strokes cause fires as they tend to strike away from rain and are of longer duration with continuing current and return

Figure 2.5 Study Area 5 cm Precipitation Contours as modeled by Daly and others, 1994.



strokes (Fukuay, 1980). Longer-duration strokes provide more energy to ignite fuel. Strikes occurring during the fire season (June to October) were analyzed to evaluate the potential importance of lightning as an ignition source and to analyze the spatial and temporal occurrence of lightning in the study area and surrounding region. The spatial distribution of all lightning strikes from June 15 to October 15 in the study area and the surrounding central Oregon Coast Range, and all positive lightning strikes for the same areas and seasonal period, were saved as GIS layers (Figures 2.6 through 2.9).

The hourly wind record at the Eugene Airport from 1964 to 1991 was obtained from the Oregon Climate Service and analyzed for the summer (June - October) frequency of east winds relative to other wind directions, the average and maximum wind speeds for all wind directions, and the relative frequency (percent of east wind only) of east wind speeds over the period of record. Additionally, east wind occurrence was examined compared to two Coast Range fires known to have occurred when wind data were available: the Oxbow fire of August 21 - 26, 1966, a 183 km^2 fire which occurred 50 km southwest of Eugene; and the Rockhouse fire of 1987, a 20 km^2 fire which occurred 30 km west of Salem. The frequency of east winds relative to other wind directions was used to assess the potential for east wind to dry out fuels and drive fires. The relative frequency of strong east winds is an indication of the extent that fires in the Willamette Valley might spread into the Coast Range. The recordings from the Eugene Airport show percentage frequency by direction based on hourly observations.

Figure 2.6 All Summer Lightning Strikes in the Central Oregon Coast Range, 1985 - 1993

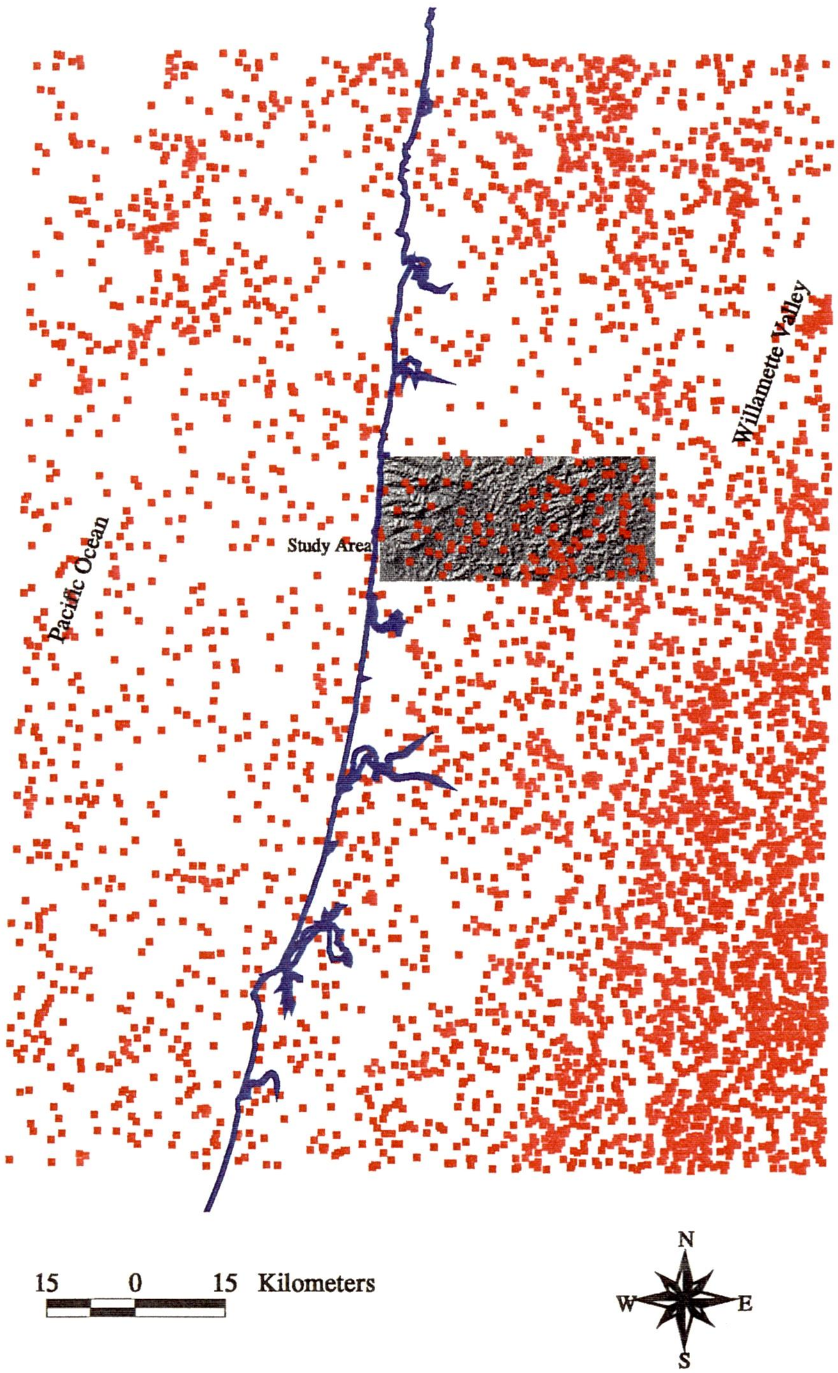


Figure 2.7 All Positive Summer Lightning Strikes in the Central Oregon Coast Range 1985 - 1993

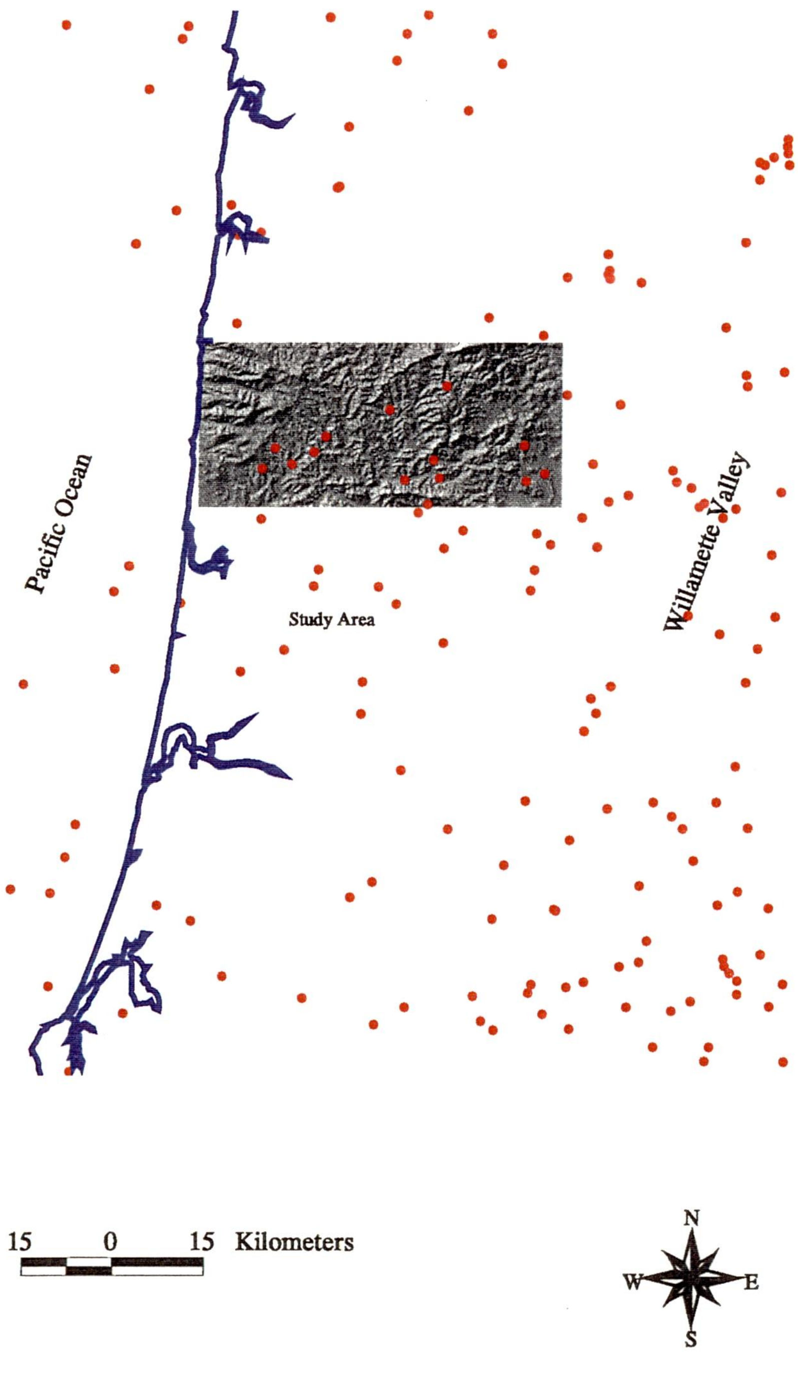


Figure 2.8 All Summer Lightning Strikes in the Study Area, 1985 - 1993

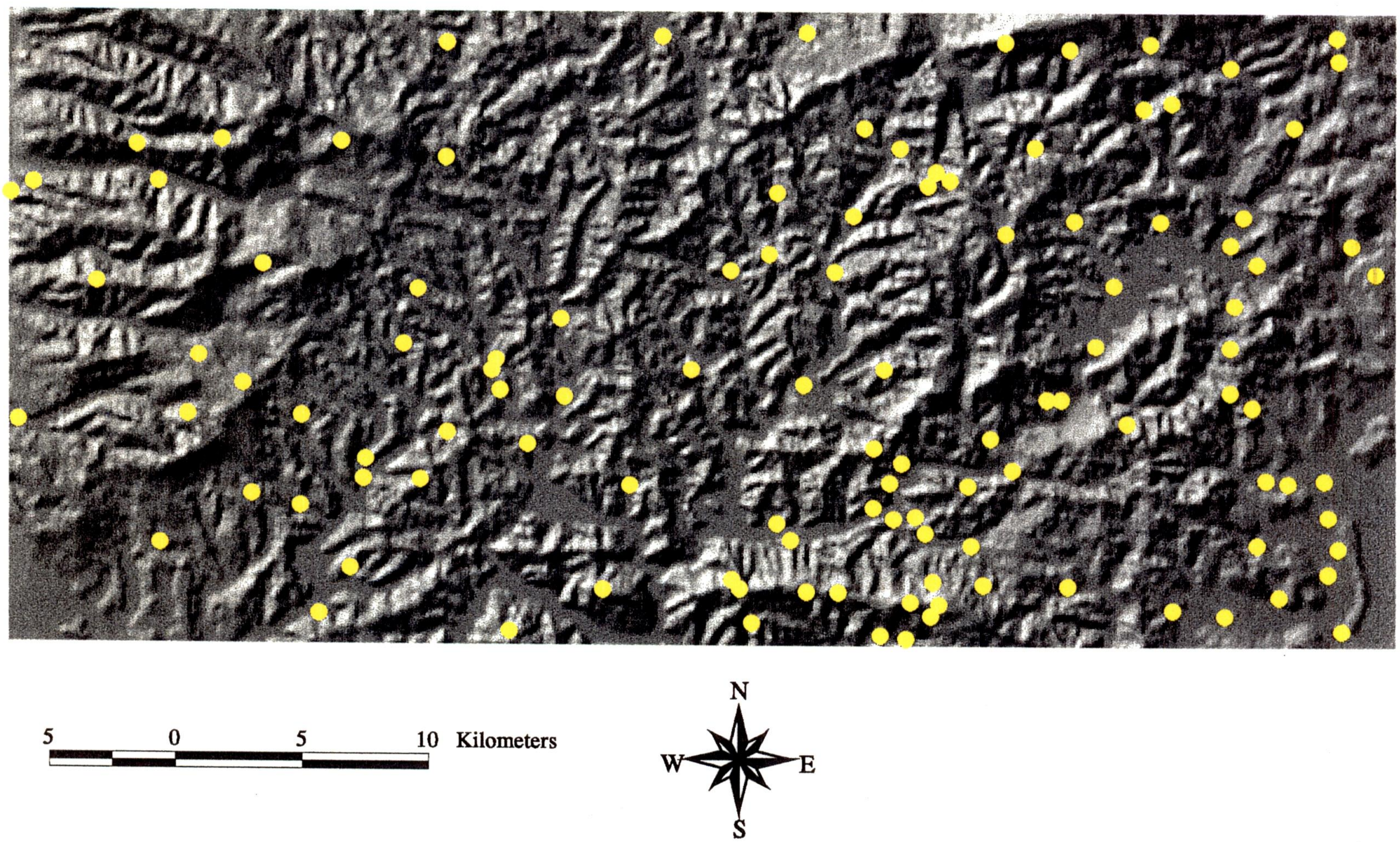
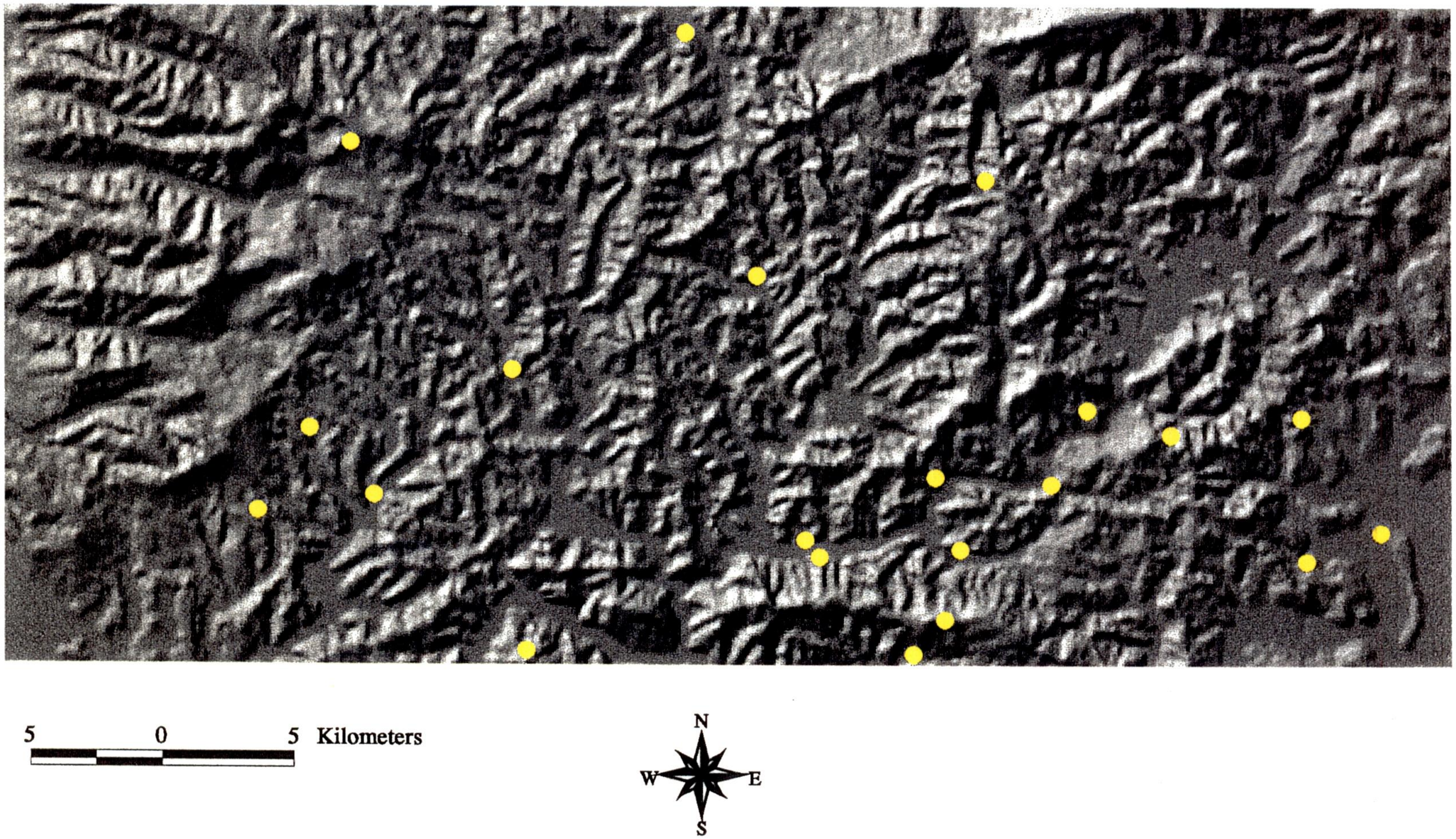


Figure 2.9 All Positive Summer Lightning Strikes in the Study Area, 1985 - 1993



2.2.2.3 Vegetation Groups

The medium to deep soils, abundant moisture and consistent above freezing temperatures of the Coast Range are conducive to rapid vegetation growth; the Oregon Coast Range has one of the most productive coniferous forests in the world (Fujimora, 1971; Waring and Franklin, 1979). The predominant vegetation association in the study area is the western hemlock (*Tsuga heterophylla*) series, with Douglas-fir the principal tree species (Franklin and Dyrness, 1973). Along the coast, where fog frequently occurs in summer and the dry season is less pronounced, the Sitka Spruce (*Picea sitchensis*) series predominates (Franklin and Dyrness, 1973; Hemstrom and Logan, 1986). Significant amounts of the study area are occupied by western hemlock-silal, western hemlock-sword fern, western hemlock-salmonberry and western hemlock-rhododendron vegetation associations (Hemstrom and Logan, 1986). Vegetation, precipitation, fog, and temperature display west to east environmental patterns which were expected to affect fire patterns. Information and observations about precipitation, vegetation association group, elevation, and fog were used to identify west to east patterns along a transect through the center of the study area (Figure 2.3).

2.2.2.4 Cultural Fire History in the Central Oregon Coast Range

Within the period of study, ca. 500 years B.P. to present, two important changes in the cultural use of fire in the Coast Range have occurred: the decline in Native American populations from the 1820s and the settlement of the area by Europeans in the

1870s - 1880s (Beckham, 1977; Steinhauer, 1974; Ruby and Brown, 1981; Boyd, 1986) and the institution of managed fire suppression across the western U.S. in 1910 (Agee, 1993). Decline in Native American populations due to exposure to disease started with the first contact with Europeans in the 1770s, but became more significant starting in 1820-1830 (Beckham, 1977; Ruby and Brown, 1981). Fire suppression has varied through time, with improvements in detection, access from air and by roads, and other factors (Pyne, 1982; Agee, 1993).

Three corresponding periods have been designated in this study: the Pre-European Period (1478 - 1844); the Settlement Period (1845 - 1909); and the Fire Suppression Period (1910 to present). Similar periods have been used in fire history studies in nearby areas, including those of Burke (1979), Teensma (1987), and Morrison and Swanson (1990).

Native American Use of Fire in the Pre-Settlement Period

The Kalapuya of the Willamette Valley used fire extensively as a tool for resource management activities, such as hunting, and the maintenance of plant foods such as camas (*Cammissia quamash*), tarweed (*Madia* spp.), and the rhizomes of bracken fern (*Pteridium aqulinum*) (Brown and Ruby, 1981; Boyd, 1986). The introduction of diseases such as smallpox and measles sometime around the 1820s (Beckham, 1977; Ruby and Brown, 1981; Boyd, 1986) decimated Native American populations in the area and by the 1840s - 1850s likely reduced the potential for forest fire ignition from Native American uses of fire. However, little is actually known about

Native American use of fire within Coast Range forests; all records and historical accounts focus on their use of fire in the Willamette Valley.

The Settlement Period: Early European Resource Use and Settlement in the Central Oregon Coast Range

In 1849 Talbot traveled through the central Coast Range, north of the study area (Morris, 1934; Zybach, 1988). He was one of the few early explorers recording their travels to traverse the Coast Range forest. Talbot noted a significant amount of hemlock, large Douglas-fir, cedar, and spruce. He found large areas of dense forests, large diameter timber, and patches of open bracken fern or brush, as well as grassy areas and alder near rivers. He also encountered burnt forests.

Talbot's travels are important as they were used by Morris (1934) to date and delineate the northern limit of the 1849 Siletz-Siuslaw/Yaquina burn. His account also provides an indication of forest conditions at that time. Talbot described parts of the landscape he visited as recently burned, and saw smoke from fires south of his route, but apparently he did not pass through the 1849 burn and most of the landscape he traversed was unaffected by fire.

At the time of Talbot's exploration, hunting, trapping and fishing by Europeans had been occurring in the Coast Range since the 1820s. Because it contained dense forests, limited flatlands, poor transportation and heavy brush, the central Coast Range was not settled by Europeans until land became limited in the Willamette Valley during the 1850s (Carey, 1971; Clark, 1981). By the 1860s the Upper Lake Creek area had several settlers (Steinhauer, 1974). The lower Lake Creek area had early settlers in the 1870s. In 1875 existing Indian reservations were annulled and opened to settlers in the Lower Lake Creek area. In 1880 the first claim to land was listed, and the first homestead was deeded in 1881. By the 1880s settlers had moved into the Upper and Lower Lake Creek areas as well as the Deadwood and Indian Creek bottom lands. Road building in the late 1880s led to further increases in settlers to the area.

European settlement may have affected fire in several ways. The increase in settler populations and the subsequent use of fire for clearing land (Steinhauer, 1974; Mintner, 1963; Rust, 1984) may have initiated several fires. Land clearing and grazing may have affected fuel loads. Restrictions on Native American burning in the 1880s and 1890s (Morris, 1934) would have reduced a source of fire ignition. The early mechanized logging of the 1900s would have reduced live fuel loads associated with natural stands, but increased fuel loads from slash. Ignitions from logging operations may have increased fire occurrence.

The Fire Suppression Period

In 1902 the Pacific Northwest experienced widespread fires, such as the well known Yacolt burn, in over 80 locations (Morris, 1934). In 1910, the intermountain west experienced similar fires (Agee, 1993). These fires were perceived as destructive to resources that had become increasingly valuable as mechanized logging and milling technologies were developed that allowed the extraction and use of previously unusable timber. This perceived large-scale waste of resources triggered a coordinated effort to contain fires in the forests of the western U.S. By 1910 local, state and federal agencies coordinated, funded and implemented fire fighting activities across the western U.S. (Pyne, 1982; Agee, 1993). These activities drastically reduced the occurrence, spread and severity of fire in the western U.S. and the Coast Range between 1910 and the present.

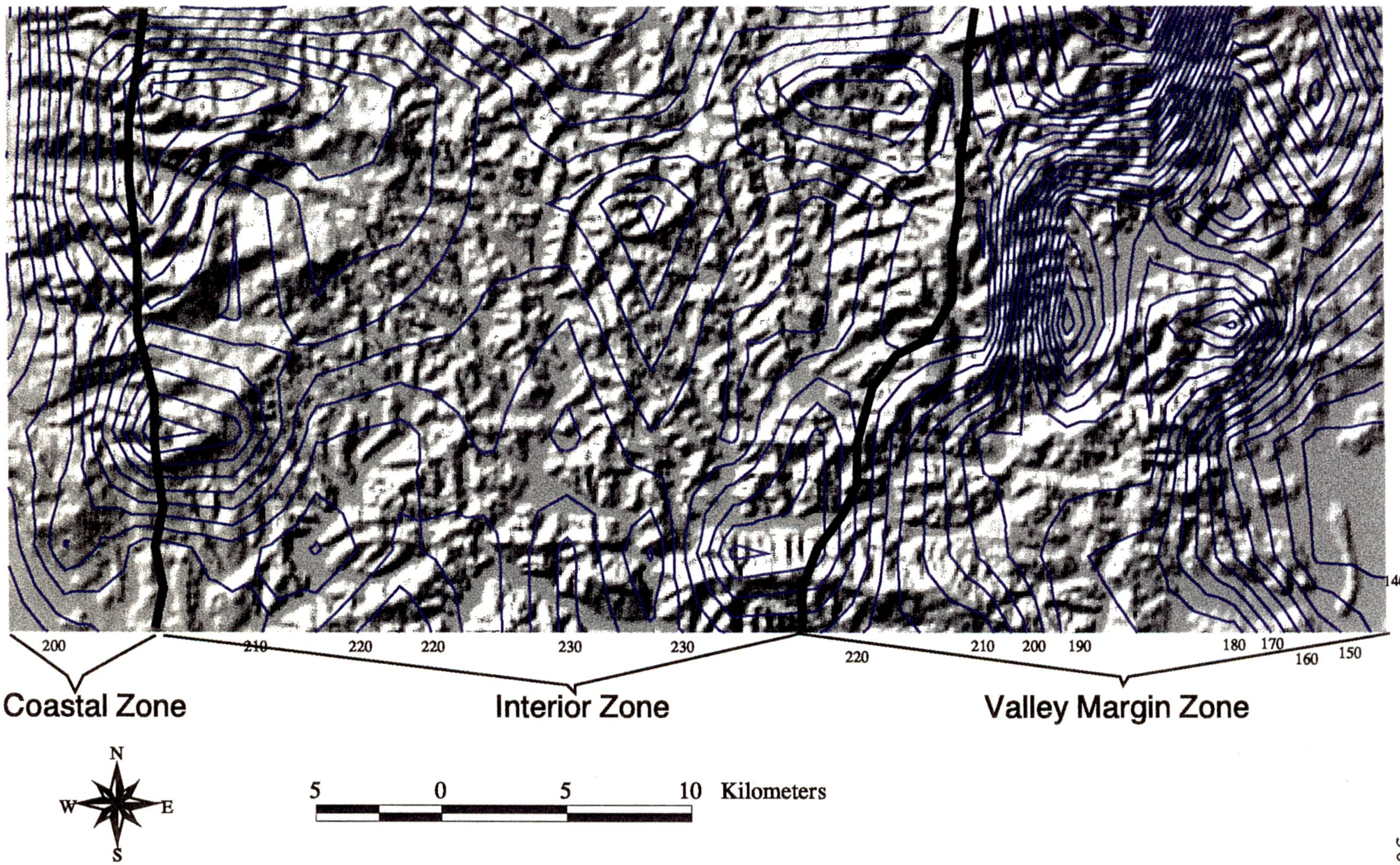
2.2.3. Field Sampling Approach

Sampling was designed to test hypotheses concerning environmental controls operating on fire at various scales: broad climatic effects across the Coast Range, aspect and hillslope position effects of microclimate and fire spread, and effects of vegetation type, landtype association, elevation and slope steepness.

Field data were collected over the summers of 1993 to 1995. A total of 178 clearcuts were sample sites in the study area. The rings of 4320 stumps were sampled. The data from these sites were entered into a database and a GIS for statistical and spatial analysis.

A scale-hierarchical sampling design was carried out to address the influence of fire and influences on fire in the ecosystem at three nested scales. The sampling design accounted for zones of precipitation, landtype association, aspect and topography through sampling strata corresponding to "zone," aspect and hillslope position. Zones were defined based on precipitation maps of the study area (Figure 2.10).

Figure 2.10 Zones Based on Annual 5 cm Precipitation Contours as Modeled by Daly and others, 1994



To facilitate sampling design and analysis, GIS layers were obtained from the Siuslaw National Forest and the Eugene Bureau of Land Management District showing clearcut location and cut dates, remnant old growth stands, and landtype associations. A series of 1990 1:12,000 orthophoto maps was used to identify likely patches of remnant old growth and adjacent clearcuts.

2.2.3.1 Field Sampling Stratification and Methods

Precipitation maps were based on the PRISM model (Daly and others, 1994) and were obtained as ARC/INFO coverages from the Oregon Climate Service (OCS) at Oregon State University. PRISM is a precipitation model that uses weather station point data with topographic features derived from a DEM to develop isolines of precipitation. Three zones were identified: Coastal, Interior and Valley Margin. The western Coastal Zone corresponded with the eastern edge of the Sitka spruce zone and a weakly identifiable high (west) to low (east) precipitation gradient (Figure 2.10). The Interior Zone extended from the Coastal Zone to a steeply decreasing precipitation gradient starting just west of Triangle Lake and progressing eastward. The Valley Margin Zone extended from the Interior Zone to the Willamette Valley (Figure 2.10).

Data collected during the 1994 field season showed no significant difference in age class distribution between the Interior and the Coastal Zone. Therefore these two Zones were combined into a single Zone (Interior/Coast) for the remaining field sampling. The proportion of sample sites (clearcuts) and stumps sampled in each zone reflect the relative area of that zone in the study area (Table 2.2).

The proportions of the study site in each aspect class were identified from a USGS 90m DEM, and the distribution of aspects in the study area was saved as a GIS layer. Sample sites were stratified by aspect by overlaying a 5km^2 grid on the study area and sampling one site in each cell on each aspect: north (315° to 44°), east (45° to 134°), south (135° to 224°), and west (225° to 314°). Whenever possible, sample sites were selected that were within +/- 25° of center of aspect. The resulting distribution of sample sites reflected the overall distribution of aspects in the study area (Table 2.2).

Sample sites were stratified by hillslope position by subdividing each sampling site evenly among the three hillslope positions (upper, mid and lower) and sampling an equal number of stumps for each hillslope position at a site.

2.2.3.2 Layout of Sampled Sites

The UTM coordinates of the 178 sites sampled in 1993, 1994 and 1995 were used to develop a point coverage in ARC/INFO v.7.0 using the commands GENERATE, BUILD, ADDITEM, DEFINE, and JOINITEM (Figure 2.11). In the 1993 field season nine sites were sampled. One 25m diameter circular plot was randomly located at each of the three slope positions and all stumps in the plot were sampled (Figure 2.12).

Table 2.2 Proportions of Total Sites Sampled (178)

Area Proportions of Zones and Aspects

By Zone	Number of Sample Sites	%Area	% Sample Sites	%Area / % Sample Sites
Valley Margin	73	39	41	0.95
Interior/Coast	105	61	59	1.03
Study Area, By Aspect				
N	44	25	26	1.00
E	42	25	24	1.05
S	45	23	25	0.90
W	47	27	25	1.06
Valley Margin, by Aspect				
N	20	26	27	0.96
E	17	23	23	1.00
S	17	25	23	1.08
W	19	27	26	1.04
Interior/Coast, by Aspect				
N	24	26	23	1.13
E	25	23	24	0.96
S	28	25	27	0.93
W	28	27	27	1.00

Figure 2.11 Study Area Sample Sites and Year Sampled

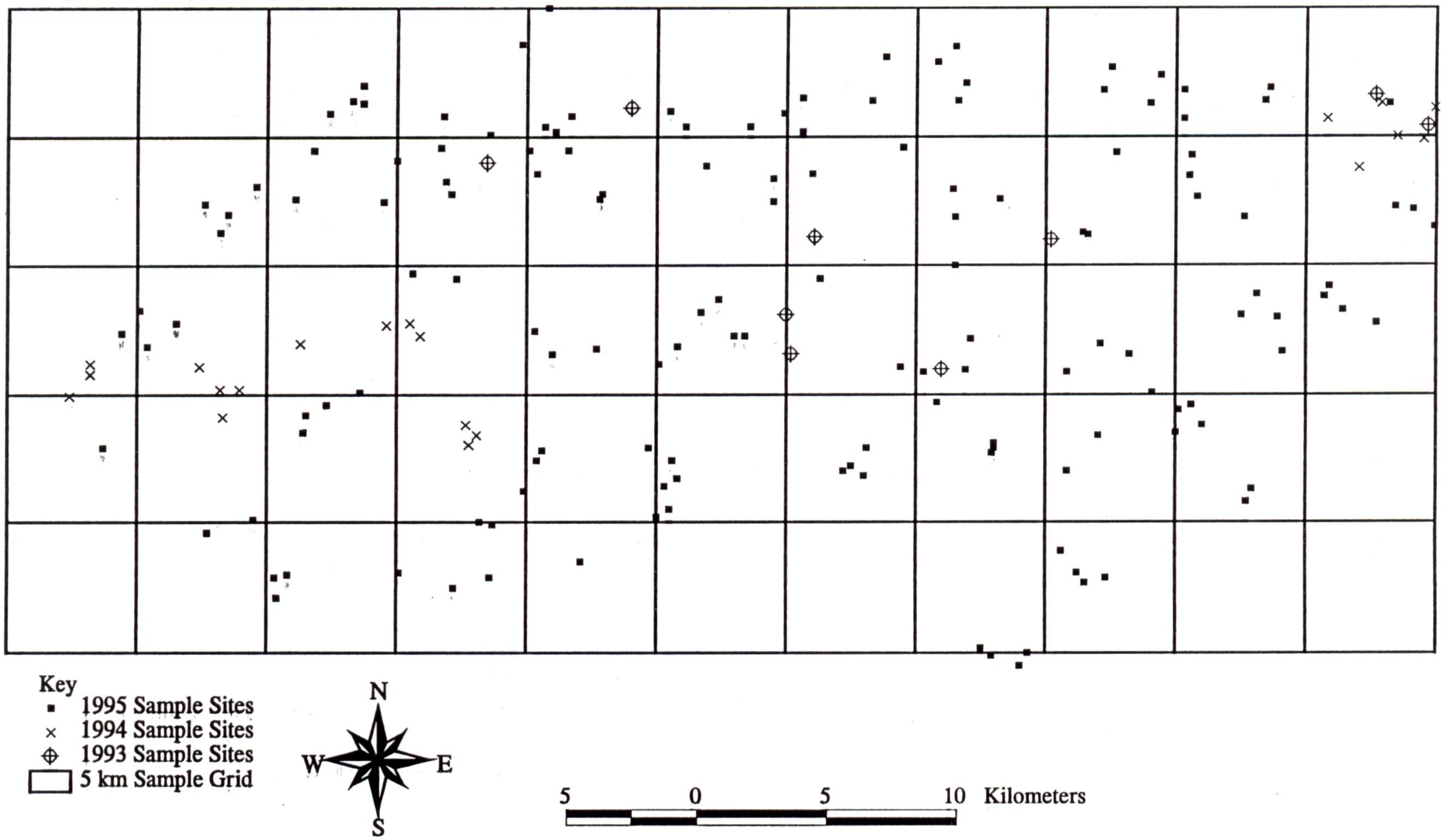
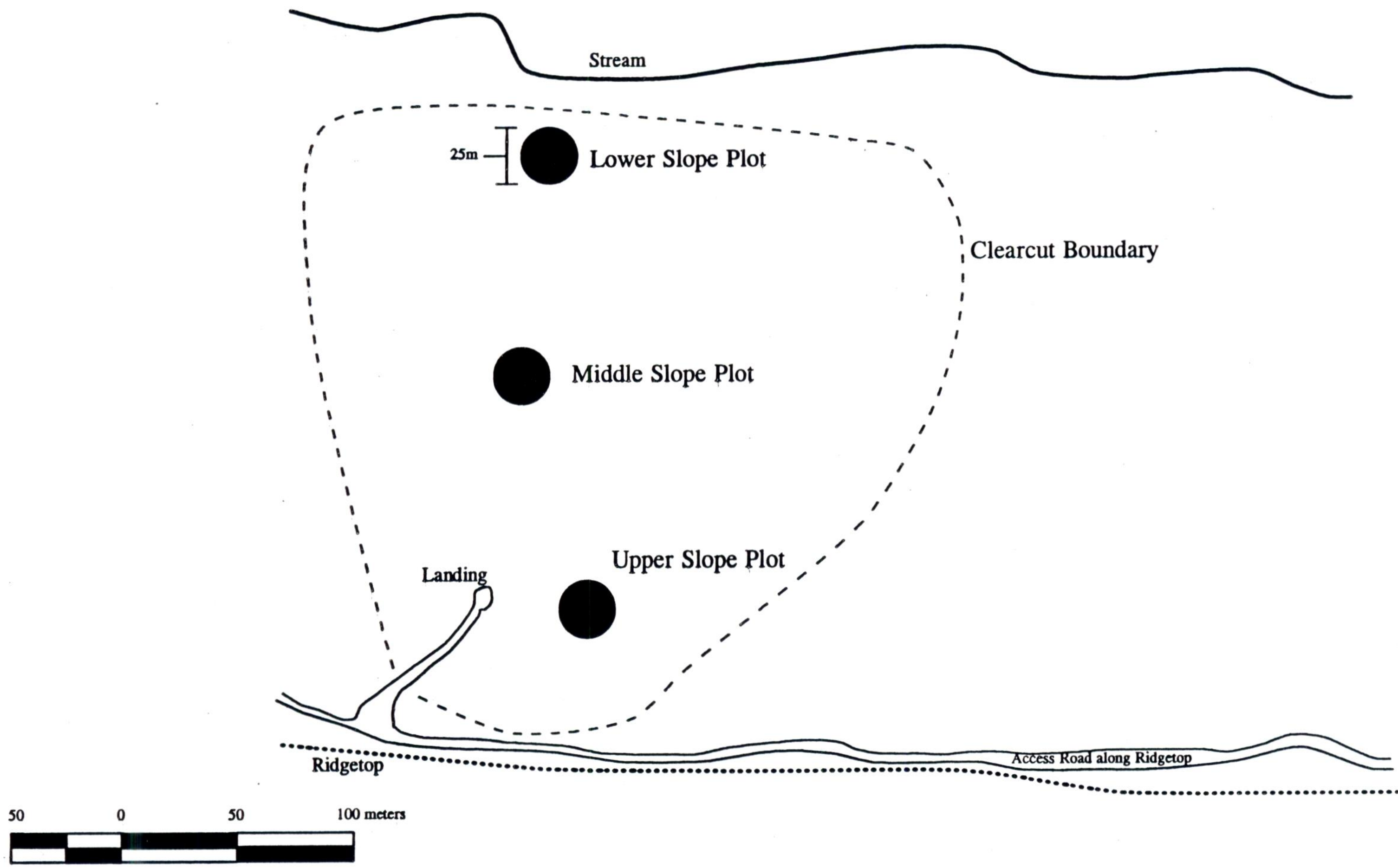


Figure 2.12 Schematic Diagram of Clearcut Plot Sampling Approach used in 1993



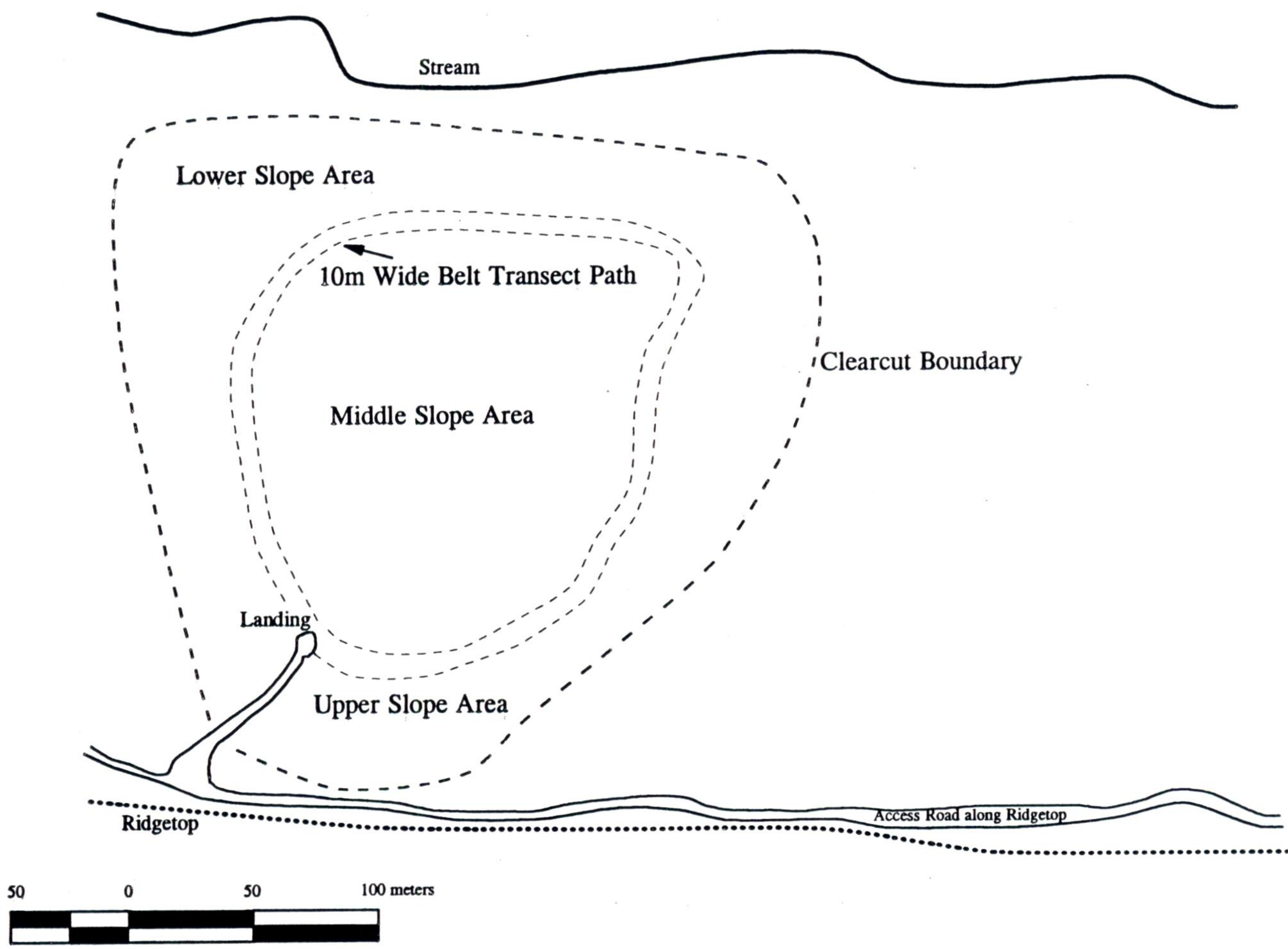
In 1994 a total of 20 sites were sampled (Figure 2.11): six sites in the western (Coastal), seven in the central (Interior) and seven in the eastern (Valley Margin) zones. A further 20 sites were sampled in three areas in the Hebo Ranger District of the Siuslaw National Forest; these data were not utilized in the analysis. In 1994 a circular/oval-shaped 10m-wide belt transect was laid out at each site (Figure 2.13). Every third stump in the transect was sampled until approximately 30 stumps (or a factor of three, such as 18, 24 or 27, for an equal number of stumps at each hillslope position) had been recorded. In most cases 10 stumps were sampled in each of the three hillslope positions.

In 1995 the study area was divided into 55 5x5 km grid cells. In each cell an attempt was made to sample a site representing each of the four aspects. A total of 149 sites were sampled using the same sampling design as in 1994 (Figure 2.13). Every old growth stump observed at a site was sampled unless the dominant age class at the site was >200 years old at cutting. If the predominant age class was >200 years old at cutting, then only up to 30 stumps were sampled.

2.2.4 Tree Level Data Collection

At each stump tree age at cutting (number of rings), number of scars, date of scars, stump height, stump number, diameter, slope position, number of rings in the first 10 cm from center, and radius at age 40 years were recorded. The following properties of each scar were noted: the percent circumference of the affected cambium,

Figure 2.13 Schematic Diagram of Clearcut Belt Transect Sampling Approach used in 1994 and 1995.



location relative to hillslope (upslope, sideslope, downslope), age, and distance from stump center.

Fire scars have been important in estimating fire date and location in other studies in the Douglas-fir forests of the Pacific Northwest (e.g. Teensma, 1987; Morrison and Swanson, 1990). Fire scars are caused when the entire cambium of a tree is killed from the heat of a fire (Gill, 1974). A distinctive pattern is developed in the tree rings as the tree grows new cambium to repair the scar damage (Figure 2.14). This pattern is identifiable on stumps. Once a scar has been determined to be from fire damage, counting the number of growth rings since the scar was formed gives the age of the scar and associated fire.

The stump height and mean width of the inner three rings was recorded to adjust for age at height of cut, following Hall's formula (Morrison and Swanson, 1990):

$$Age = RC + (0.1852 * SH/RW) \text{ (for } RW > 2mm)$$

$$Age = RC + (0.1852 * SH/2) \text{ (for } RW < 2mm)$$

where

Age	=	adjusted age at stump height
RC	=	ring age count in field
SH	=	Stump height (cm) measured mid slope on stump
RW	=	average ring width of the inner three rings (mm).

Approximately one third of the stumps required treatment to prepare them for counting. Scars often required cleaning before they could be dated, as pitch often flowed from them after cutting. Stump treatment involved cleaning the stump of any

Figure 2.14 Schematic Diagram of Fire Scars on a Douglas-fir Stump

Derived from Morrison and Swanson, 1990

overgrowth, dirt, tar or pitch so that the rings were easily counted. The eastern, drier part of the study area had a higher proportion of stumps requiring treatment than the central and western parts of the study area.

Counting rings was easier when the stump had weathered for a few years and the softer early spring growth had decomposed, leaving the harder late summer growth rising slightly above the plane of the stump. In other cases, the softer parts of the rings could be eroded away by brushing the rings with a wire brush, exposing the harder late summer growth.

2.2.5 Site-Level Data Collection

Several variables were measured to characterize each sample site. The date of clear cutting was recorded from files or maps prepared by the Siuslaw National Forest or the Bureau of Land Management maps. When file or map information was not available, the date of cutting was estimated in the field using the age of planted trees, degree of coverage by underbrush, and age of alders along roadcuts. Average slope (degrees) and aspect were determined using an inclinometer and compass. Each site was located based on major and adjacent roads and UTM coordinates were determined from topographic maps and a GPS receiver. In the field a map was drawn which included the boundaries of the site, primary and secondary roads, nearby remnant old growth trees (>200 years), if present, locations of visible snags, and topographic features such as ridges, noses, draws, and stream drainages. The locations of the transect and all old growth stumps sampled were recorded, as well as the size and density of snags.

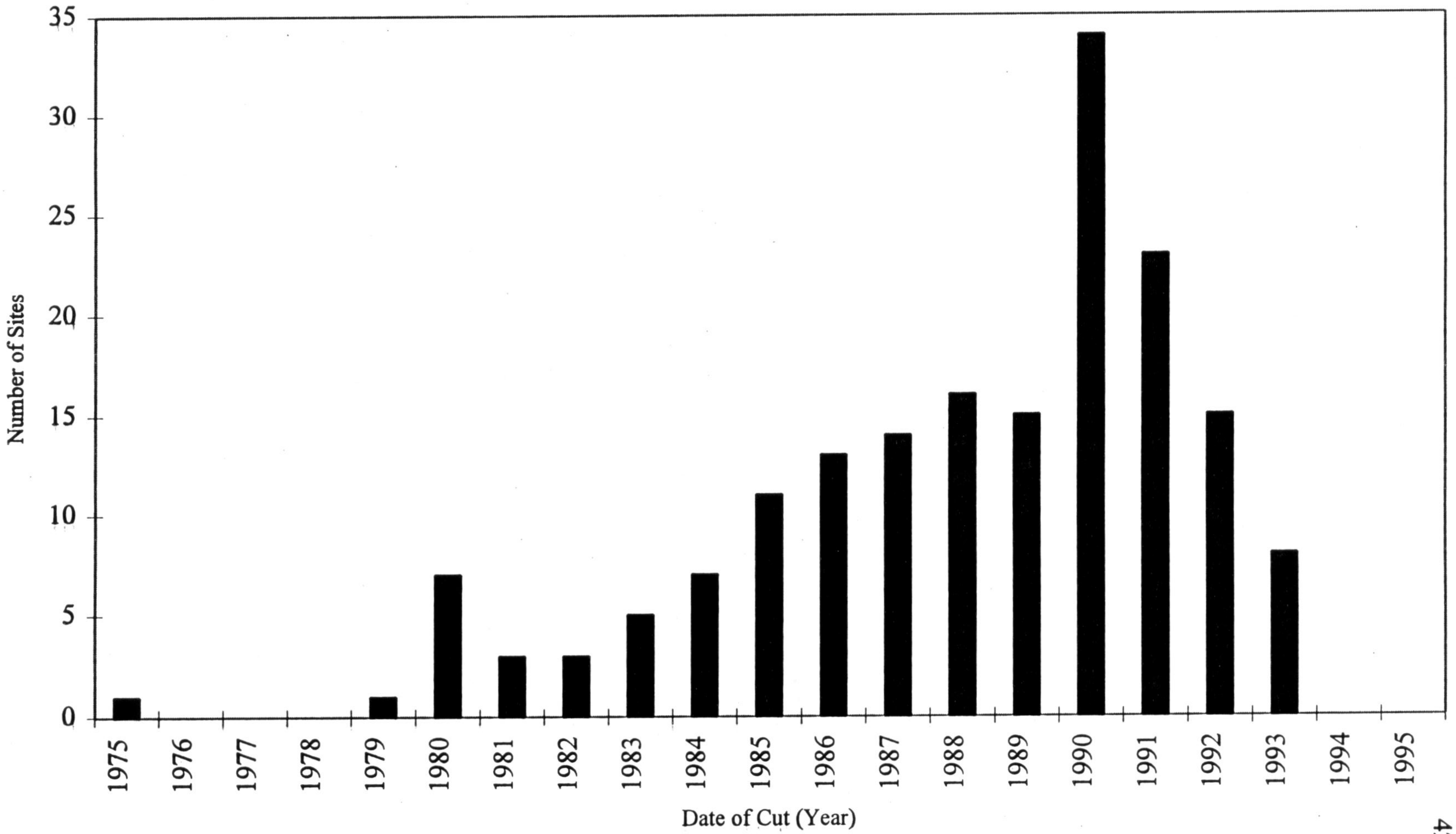
The predominant vegetation association for the entire site and the vegetation association for each slope position of the site was recorded based on the Siuslaw National Forest Vegetation Association Guide (Hemstrom and Logan, 1986). Existing nearby undisturbed forest stands were characterized by their vegetation association, snag size and density, approximate similarity of age class to the sampled site, and the presence or absence of signs of previous fires such as charcoal or scars on boles.

Only sites of previously unharvested stands were sampled. Almost all sampled sites had been cut between 1979 and 1993 (Figure 2.15). Forest harvesting began in the study area around the turn of the century (Steinhauer, 1974; Rust 1984), and some clearcuts appeared to have been harvested once before at that time. Any site judged to be a remnant from this previous cutting was not sampled; these sites had age class distributions clustered around 70-90 years, and very old and decayed stumps. Sites with dense undergrowth or poison oak that prevented easy passage through the clearcut were also avoided.

2.2.6 Fire Episode Reconstruction

In this study, fire history was reconstructed by identifying fire *events*, fire *episodes*, and constructing a fire *chronology*. In this study a fire *event* was defined as a

Figure 2.15 Number of Sites Sampled vs. Date of Cut



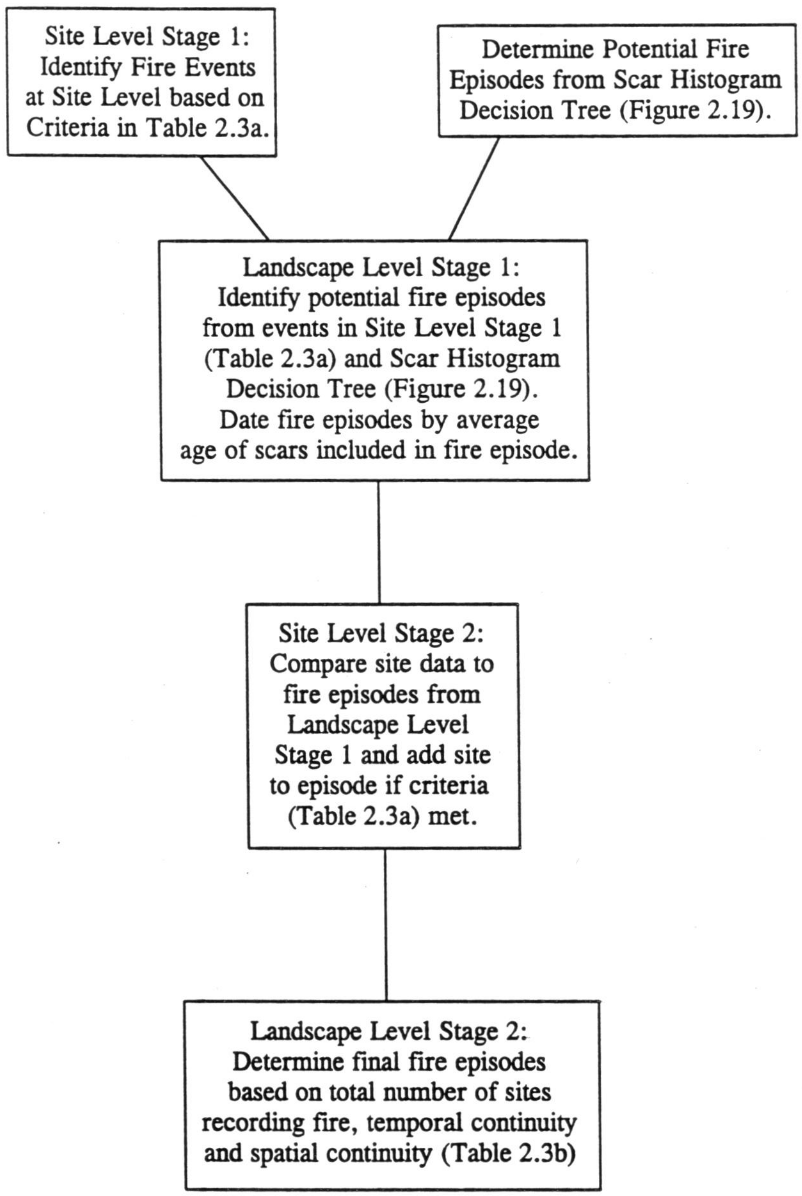
fire that has been recorded at a site. A fire *episode* was defined as fire events recorded at several sites that coincide in time. A fire *chronology* is a final tabulation of the record of fire for all sites. A degree of subjectivity is involved in the final analysis (Teensma, 1987), but that subjectivity is based on knowledge of the process of fire within the study area. Each fire episode was displayed as a map, and its size and severity at each site evaluated.

2.2.6.1 Fire Episode Identification

Dates of fire episodes were estimated using an iterative process, in which the data were analyzed and compared at the site and landscape scale. In this study there were two stages of reconstruction: primary and secondary (Figure 2.16). In the primary stage, scar and regeneration information at each site were analyzed to identify fire events. Fire event dates and associated scar and regeneration data were then compared across the landscape to define fire episodes. The primary site-level rule set was comprised of the numbers of scars and regeneration trees chosen to define a fire event at a site, while the primary landscape-level rule set was comprised of the maximum distances in space between sites and time intervals between events that could be included in an episode.

At the secondary stage, sites in which scar or regeneration information did not qualify as an event at the primary stage were re-examined to see if they contained

Figure 2.16 Flow Chart Describing Fire Episode Identification Process



Significantly more scars were found after 1830 than before (Figure 2.17). Also, there were far fewer trees older than 150 years at cutting than younger than 150 years at cutting (Figure 2.18), and the ages determined for older trees (>200 years at cut) were less accurate because outer ring thickness averaged 0.5-2mm and are harder to accurately count, whereas inner ring thickness averaged 5-10mm for younger trees. Consequently, two rule sets were developed to identify fire events and episodes: before and after 1830 (Table 2.3).

At stage 1 the site level data were tabulated to identify fire event dates, and at the landscape level fire episodes were identified using a decision tree to define clusters in time of fire scars (Figure 2.19). A decision tree was required to clarify the temporal pattern of scars used to define fire episodes after 1830 only; prior to 1830 scars were limited (Figure 2.17) and a simple rule set (Table 2.3a) was adequate to define fire events and episodes. In stage 2, sites were added to the fire episodes using a less rigorous set of criteria involving numbers of sites, and temporal and spatial factors (Table 2.3b).

2.2.6.3 Construction of the Fire Chronology

The fire chronology is a tabulation of fire episodes by sites (Appendix A). Each cell of the table contains a number indicating the severity of the fire episode at that site (0=no occurrence, 1=low, 2=moderate, 3=high; see below for explanation of severity rankings). Reading down each column, one can determine which sites comprise each

Figure 2.17 Study Area Scar Age Class Distribution (N = 450)

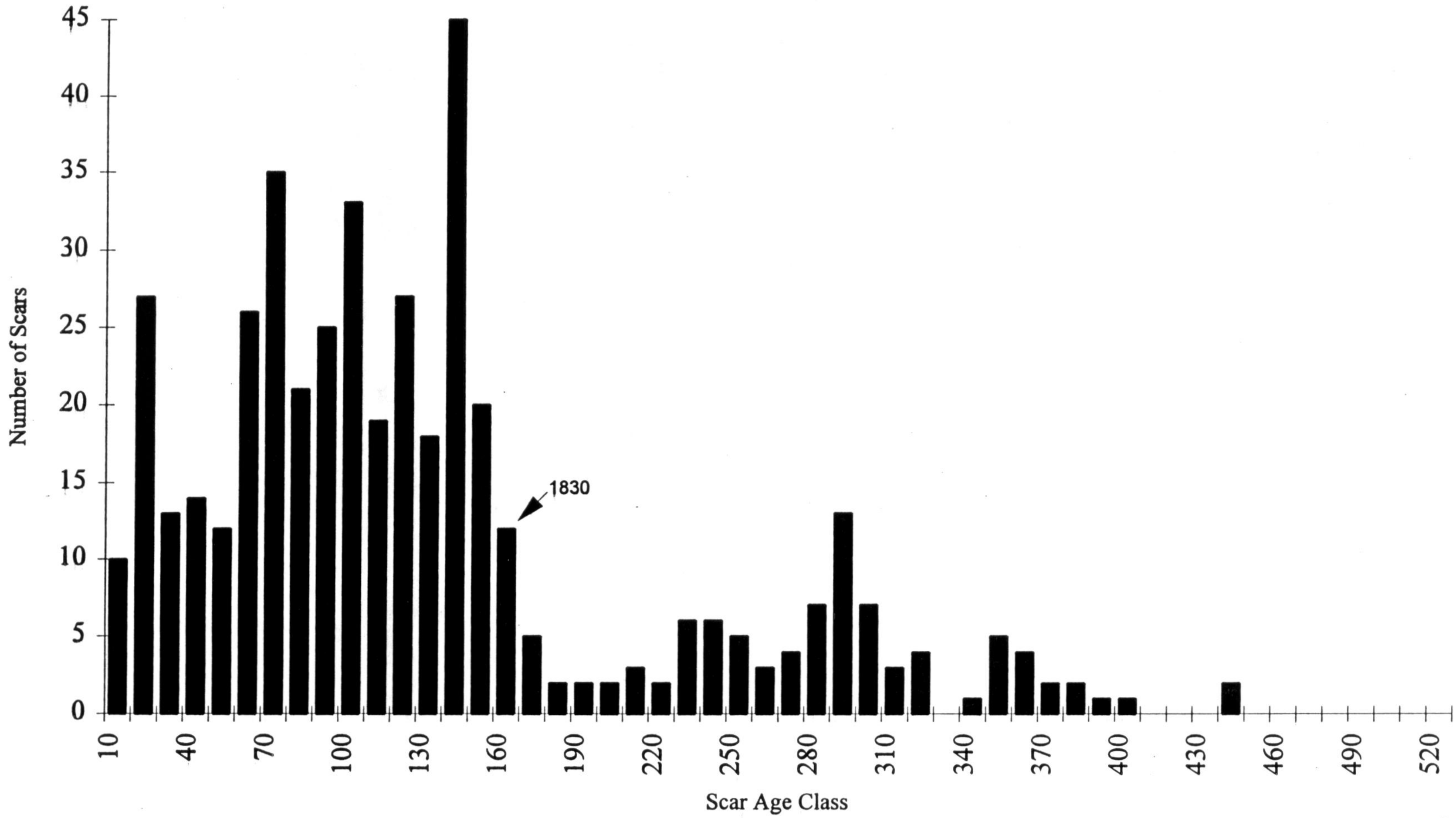


Figure 2.18 Study Area Tree Age Class Distribution

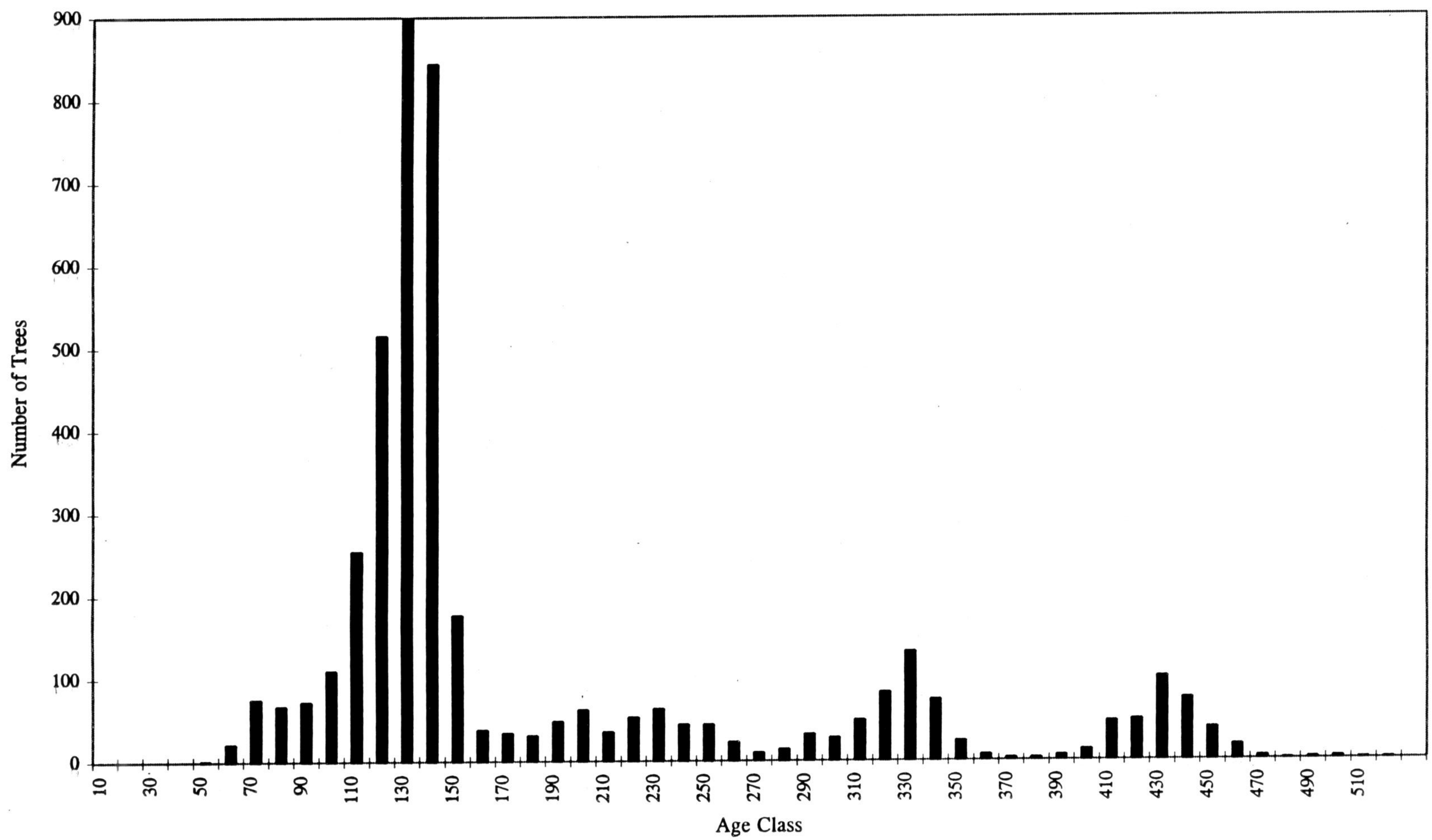


Table 2.3a Rule Sets for Fire Event Determination

	Stage 1[1]		Stage 2[2]	
	Before 1830	After 1830	Before 1830	After 1830
Scar Data Only	2 scars within 5 years	3 scars within 3 years	1 scar within a fire episode	1 scar within a fire episode
Scar and Regeneration Data	1 scar and 2 regeneration trees within 5 years of scar	2 scars within 3 years and 3 regeneration trees within 5 years of scars	----	----
Regeneration Data Only	3 regeneration trees within 5 years	----	1 regeneration tree within 10 years after a fire episode	3 regeneration trees within 5 years after a fire episode
Oldest Regeneration Tree	----	----	Assigned to nearest fire episode within 20 years prior to establishment	----

[1] Site level data meeting these criteria alone were adequate to identify a fire event
[2] Sites meeting these criteria could be added to a Fire Episode that is based on events in Stage 1 and Landscape level analysis of data

Table 2.3b Rule Sets for Fire Episode Determination

	Stage 1[1]		Stage 2[2]	
	Before 1830	After 1830	Before 1830	After 1830
Number of Sites	At least 3 sites recording a fire event	At least 5 sites recording a fire event	At least 5 sites recording a fire event	At least 5 sites recording a fire event
Scar and Regeneration Data	1 scar within scar cluster OR 3 regeneration trees within 5 years following scar cluster average	1 scar within scar cluster OR 3 regeneration trees within 5 years following average date of scar cluster	----	----
Time Frame	----	----	3 sites recording the fire within a 10 year period	4 sites recording the fire within a 5 year period
Spatial Continuity	----	----	At least 3 sites recording the fire must be within 20km of another site recording the fire. A site not within 20km of one other site recording the fire is eliminated from the episode[3]	At least 5 sites recording the fire must be within 10km of another site recording the fire. A site not within 10km of one other site recording the fire is eliminated from the episode[4]

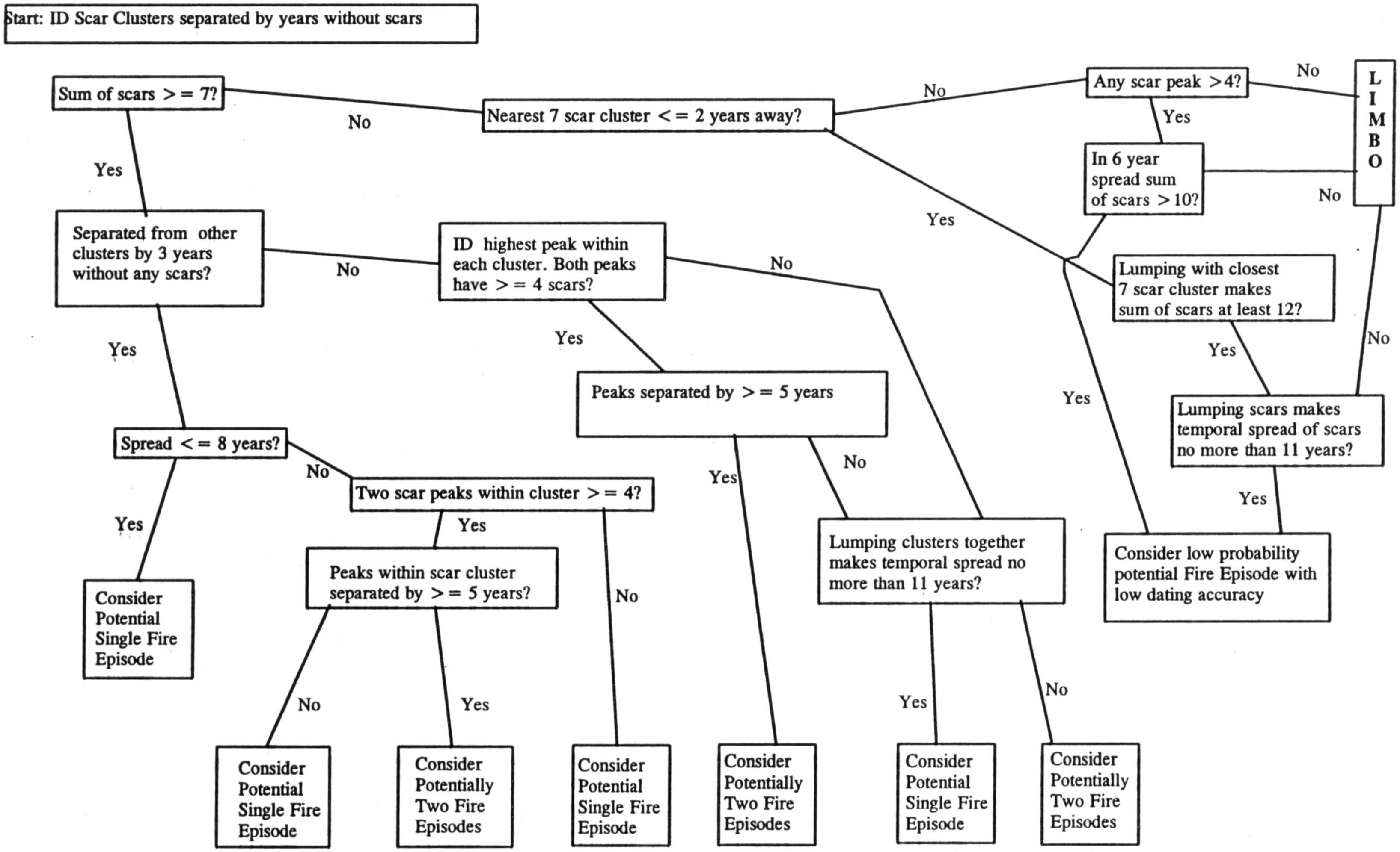
[1] Site level events integrated with study area scar clusters (Figure 2.19)

[2] Final fire episode identification based on number of sites, temporal and spatial continuity

[3] All sites included in the fire episode up to this point must be within 20km of another site recording the episode

[4] All sites included in the fire episode up to this point must be within 10km of another site recording the episode

Figure 2.19 Decision Tree Used to Define Post-1830 Landscape Scar Clusters as a Basis for Dating Fire Episodes



fire episode. Reading across each row one can determine how many episodes were recorded at each site. Additional columns contain the clearcut number, UTM locations of each site, zone, aspect, number of events at the site, area of the polygon associated with the site, and site mean fire return interval (MFRI).

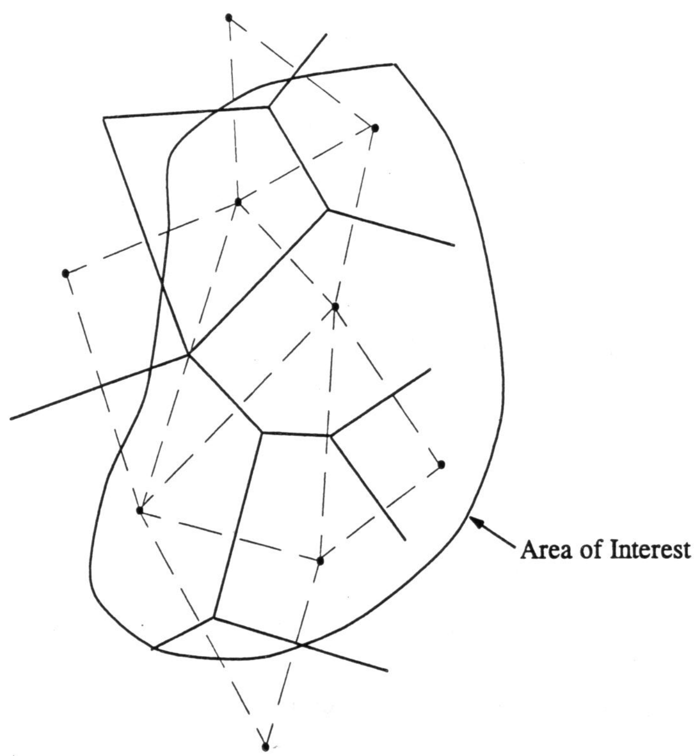
The fire chronology spreadsheet was generated in EXCEL 5.0. Fire chronology data were imported into ARC/INFO v.7.0 and used to attribute the sample site point coverage (Figure 2.11) with the JOINITEM, CALCULATE and DEFINE commands. The resulting layers were used to produce maps of fire episodes in ARCVIEW v. 2.1 and 3.0. The spreadsheet was used for the calculation of fire episode area, MFRI, natural fire rotation (NFR), percent available burned, estimated capture, and indices of old growth forest.

2.2.6.4 Determination of Size

Fire episode size was calculated by using Thiessen polygons to interpolate from points to areas. A Thiessen polygon is that polygon around a sampled point (sites in this study) such that any other point within the polygon is closer to the sample point than to any other sample point in the dataset (Dunne and Leopold, 1978). Thiessen polygons are constructed by 1) drawing lines connecting each point to its nearest neighbor; 2) drawing the perpendicular bisectors of these lines; and 3) extending them only as far as needed to intersect another perpendicular bisector (Figure 2.20).

Figure 2.20 Schematic Diagram of Thiessen Polygon Construction.

Hashed lines connecting neighboring points are intersected by perpendicular lines at their midpoints to form polygons. From Dunne and Leopold, 1978.



Thiessen polygons were generated for the sample sites using the THIESSEN command in ARC/INFO (Figure 2.21). The size of each fire episode (called the "Thiessen fire episode size") was determined by adding up the area of the Thiessen polygons associated with sites in that episode. The areas of exterior polygons, which were much larger than the interior polygons, were adjusted by setting them equal to the average size of interior Thiessen polygons (5.9 km^2).

Sensitivity of fire episode size estimates to the Thiessen fire episode size estimation method was tested by comparing them to the results of three other methods. Each of these additional methods were developed to account for the erasure problem described earlier; and are described in Chapter 4.

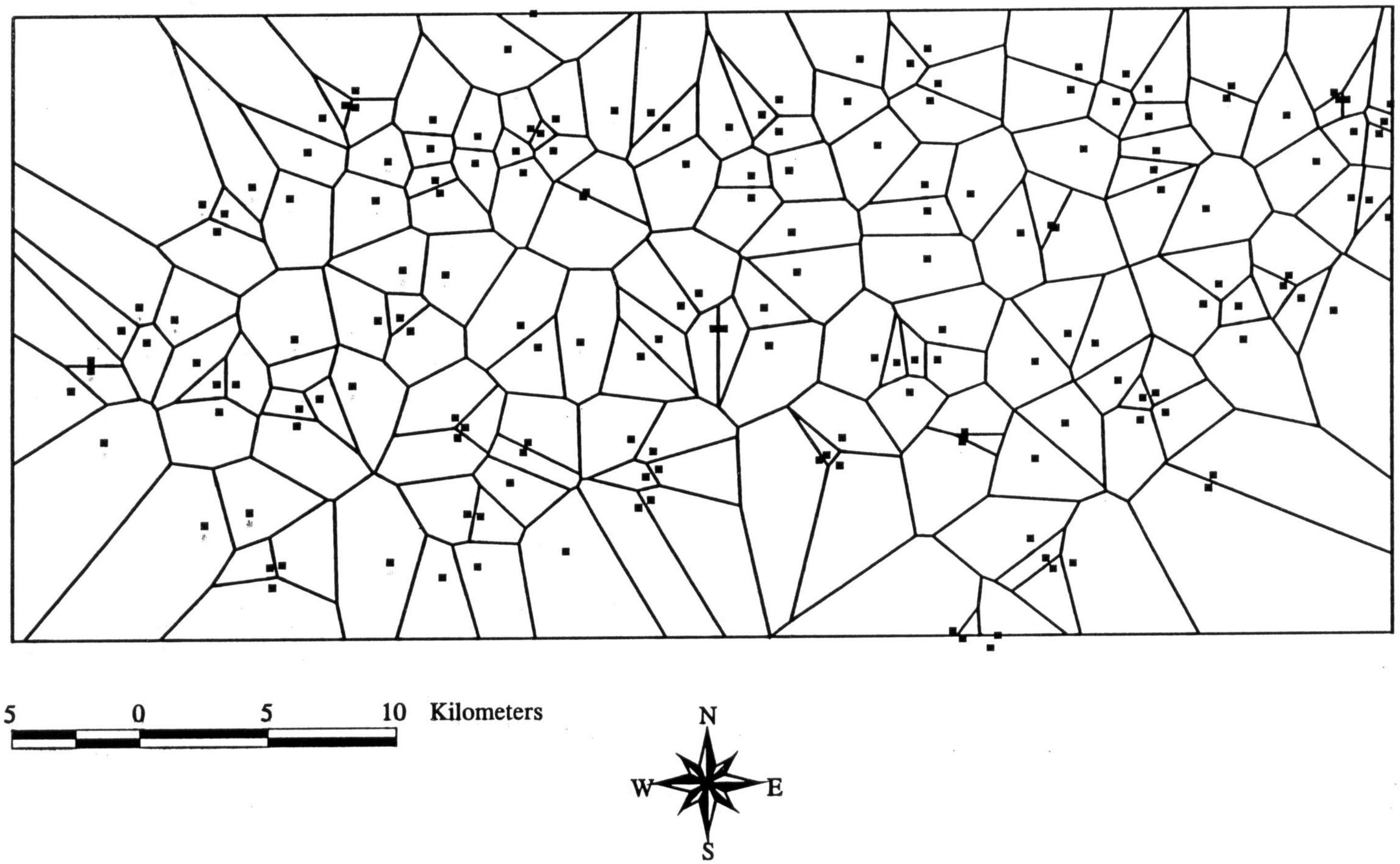
2.2.6.5 Determination of Severity

Fire severity was determined on a site-by-site basis and at the landscape level. The severity determination method used is based on fire episode evidence at a site. Four severity classes were described and entered into the fire chronology for each site recording a fire episode:

0: A site showed no evidence of the fire episode.

1: A site showed low severity for a fire episode: the site had only scar data and no regeneration was found at the site.

Figure 2.21 Study Area Thiessen Polygons and Site Locations



2: A site showed moderate severity for a fire episode: the site had survivors from the fire episode, but also regeneration associated with the fire episode. Scars from the fire episode may have been present.

3: A site showed high severity for a fire episode: the site had only regeneration associated with the fire episode, and no scars. No survivors remained from before the fire episode.

2.2.6.6 Accounting for Record Erasure over Time

The "percent available burned" is a measure of the area of site polygons included in a fire episode divided by the area of all polygons defined as "available" to record that fire episode; i.e., sites that did not have subsequent record erasure by a stand replacement fire episode. Higher values of percent available burned may indicate a greater chance that the fire episode was larger than estimated if there are many sites in which the record was subsequently erased.

2.2.6.7 Accounting for Fire Episodes Larger than the Study Area

Fire episodes recorded may have extended beyond the study area. The "percent of available perimeter area burned" is the area of perimeter polygons included in a fire episode divided by the area of perimeter polygons available to record that fire episode; i.e., those sites with records not erased completely by subsequent fire episodes. Higher values of percent of available perimeter area burned may indicate a greater chance that the fire episode extended beyond the study area boundaries.

2.2.6.8 Accounting for Contiguity

Contiguity of fire episodes was evaluated by calculating the adjacent area of polygons showing evidence of a fire episode. Any patch of two or more polygons recording the fire episode was considered contiguous area. The percent of contiguous area for a fire episode was the area of contiguous polygons divided by the total area of a fire episode.

2.2.6.9 Determination of Fire Frequency

Fire frequency was characterized by the natural fire rotation (NFR) and the mean fire return interval (MFRI). The NFR is the time period required for an area equal to the study area to be burned (Heinselman, 1973). It is calculated as:

$$\text{NFR} = \frac{\text{Total time period considered}}{\text{Proportion of area burned in time period}}$$

The NFR is a useful measure of the turnover of the forest landscape by fire for a defined study area and time period of interest. In this study, NFR values for different periods (e.g. pre-European, settlement) were compared to evaluate changes over time in forest landscape turnover by fire.

The MFRI is the average time in years between fire episodes within a defined area. It is calculated as:

$$\text{MFRI} = \frac{\text{(Date of last fire at a site - date of first fire at a site)}}{\text{Number of fire intervals}}$$

The number of fire intervals is equal to the number of fires at a site - 1. The MFRI can be calculated for areas ranging from a point (one tree) to the entire study area. In this study, MFRI was calculated at the site level for sites with evidence of three or more fire episodes. Sixty of the 178 sites had three or more fire episodes; of those 44 were in the 426 km^2 Valley Margin Zone and 16 were in the 949 km^2 Interior/Coast Zone.

2.3 RESULTS

A total of 27 fire episodes were recorded in the study area over the 516 year period for which a dendrochronologic record was available. The characteristics of these fire episodes were quite variable, and show gradual trends over time (Table 2.4). Fire episode size estimates ranged from only 18 to as much as 544 km^2. Only six fire episodes (1478, 1531, 1555, 1637, 1655 and 1852) were of high severity (regeneration trees only) at more than 50% of the sites; five of these occurred prior to 1700. In contrast, only two of ten fire episodes prior to 1800, but eleven of thirteen fire episodes after 1800, showed evidence of low severity fire at >50% of sites (Table 2.4).

Seventeen of the 27 fire episodes affected <15% of the sites available to record the fire episode; ten of these fire episodes occur after 1800. Only four fire episodes

Table 2.4 Summary of Fire Episode Characteristics
(See text for description of metrics)

Fire Episode Date	Number of Sites	Thiessen Size of Fire Episode (km^2)	Severity Classes Percent of Sites			Available Area Burned (%)	Available Perimeter Area Burned (%)	Contig. Area (%)	Fire Episode Pattern Type*
			Low	Moderate	High				
1478	3	18	0	0	100	100	0	94	----
1531	21	133	0	4	96	93	100	80	1
1555	27	171	0	18	81	59	59	66	1
1585	7	57	17	67	17	19	3	87	2
1629	5	35	60	20	20	12	0	31	2
1637	12	68	17	17	67	20	21	79	2
1655	15	90	0	20	80	22	7	73	2
1666	10	65	30	30	40	15	12	39	2
1689	6	29	50	33	17	6	0	56	2
1699	13	62	38	54	8	14	1	88	2
1737	11	58	25	42	33	12	7	90	2
1751	11	97	45	45	9	21	6	69	2
1763	12	65	25	50	25	13	6	70	2
1794	8	35	12	62	25	7	3	88	2
1815	5	33	50	50	0	7	8	100	2
1831	6	36	57	43	0	7	7	77	2
1844	14	66	50	50	0	13	14	35	2
1852	100	544	8	28	64	65	44	97	1
1871	32	199	19	35	45	21	10	90	1
1881	16	94	50	6	44	9	3	43	3
1888	29	172	69	17	14	17	11	81	3
1900	11	66	92	8	0	7	2	27	4
1909	13	77	100	0	0	8	2	26	4
1920	27	148	89	3	7	14	4	80	4
1928	16	80	93	6	0	8	4	41	4
1934	9	61	78	22	0	6	2	90	4
1974	9	55	100	0	0	5	0	89	4
Mean	17	97	43	27	29	22	12	70	
Std. Dev	18	101	33	21	32	26	22	24	

*Type 1: Widespread
*Type 2: Valley Margin
*Type 3: Mixed
*Type 4: Modern

affected >50% of the available sites: the 1478 (100%); 1531 (93%); 1555 (59%) and 1852 (65%) fire episodes. Twenty-one of the 27 fire episodes affected <15% of the sites available at the perimeter of the study area. Only three fire episodes affected >40% of the sites available at the perimeter: the 1852 (44%); 1531 (100%) and 1555 (59%) fire episodes. Seven of the 27 fire episodes had <50% contiguous area, 15 fire episodes had <75%. Therefore, the majority of the fire episodes affected few sites, were of low severity, fell largely within the study area, and affected only one or a few discrete patches at this sampling scale. For the period of record in the entire study area, the mean fire episode size was 97 km^2, NFR was 271 years, and less than one third (29%) of the sites showed evidence of high severity fires. Average percent available burned was 22%, average percent perimeter available burned was 12% and average percent contiguous area was 70% (Table 2.4).

The MFRI was 85 years for the entire study area (60 sites), 75 years for the Valley Margin Zone (44 sites), and 115 years for the Interior/Coast Zone (16 sites). The limited number of sites available to calculate the MFRI is due to the many sites which showed evidence of only one or two fire episodes (Figure 2.22).

2.3.1 Temporal Patterns of Fire

Fire episode characteristics varied by time period in relation to human activities (Table 2.5a) and by century (Table 2.5b). Average fire episode size since 1910 was estimated at only 86 km^2, compared to 192 km^2 in the European settlement period. In

Figure 2.22 Distribution of Number of Events per Site

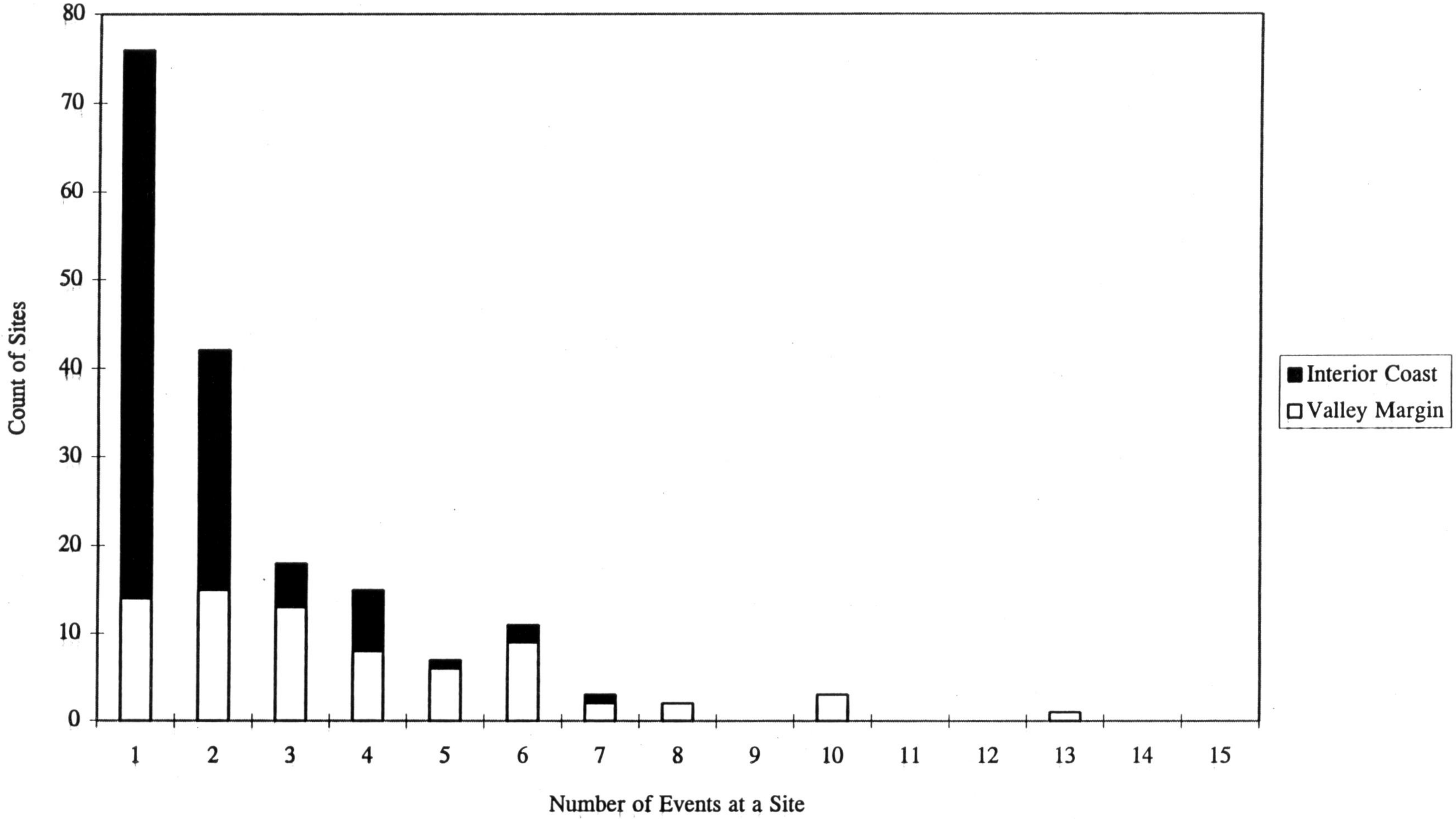


Table 2.5a Summary of Fire Regime Measurements by Period
(See text for description of metrics)

Period	Number of Fire Episodes	Thiessen Fire Episode Size (km^2) Average	Thiessen Fire Episode Size (km^2) SD	NFR (years)	Average Severity Classes Percent of Sites: Low	Average Severity Classes Percent of Sites: Moderate	Average Severity Classes Percent of Sites: High	Available Area Burned (%) Average	Available Area Burned (%) SD	Available Perimeter Area Burned (%) Average	Available Perimeter Area Burned (%) SD	Contiguous Area (%) Average	Contiguous Area (%) SD	Number of Sites per Fire Episode Average	Number of Sites per Fire Episode SD
Period of Record (1478-1994)	27	97 (18 - 544)	101	271	44 (0 - 100)	27 (0 - 67)	29 (0 - 100)	22 (5 - 100)	26	12 (0 - 100)	22	70 (26 - 100)	24	17 (3 - 100)	18
Pre-Settlement Period (1478-1845)	17	66 (18 - 171)	39	452	28 (0 - 60)	36 (0 - 67)	36 (0 - 100)	26 (6 - 100)	29	15 (0 - 21)	26	72 (31 - 100)	21	11 (3 - 27)	6
Settlement Period (1846-1909)	6	192 (66 - 544)	181	78	56 (8 - 100)	16 (0 - 35)	28 (0 - 64)	21 (7 - 65)	22	12 (2 - 44)	16	60 (26 - 97)	32	34 (11 - 100)	34
Fire Suppression Period (1910-1994)	4	86 (55 - 148)	43	335	90 (78 - 100)	8 (0 - 22)	2 (0 - 7)	8 (5 - 14)	4	3 (2 - 4)	2	75 (41 - 90)	23	15 (9 - 27)	9

Table 2.5b Summary of Fire Regime Measurements by Century

(See text for description of metrics)

Century	Number of Fire Episodes	Thiessen Fire Episode Size (km^2) Average	SD	NFR (years)	Average Severity Classes Percent of Sites: Low	Moderate	High	Available Area Burned (%) Average	SD	Available Perimeter Area Burned (%) Average	SD	Contiguous Area (%) Average	SD	Number of Sites per Fire Episode Average	SD
1400s*	1	18*	--	--	0*	0*	100*	100*	--	0*	--	94*	--	3*	--
1500s	3	120 (57 - 171)	58	382	5 (0 - 17)	30 (4 - 67)	65 (17 - 96)	57 (19 - 93)	37	54 (3 - 100)	49	78 (66 - 87)	11	18 (7- 27)	27
1600s	6	58 (29 - 90)	23	395	33 (0 - 60)	29 (17 - 54)	39 (8 - 80)	15 (6 - 20)	6	7 (0 - 21)	8	61 (31 - 88)	23	10 (5 - 15)	28
1700s	4	64 (35 - 97)	26	537	27 (12 - 45)	50 (42 - 62)	23 (9 - 33)	13 (7 - 21)	6	6 (3 - 7)	2	79 (69 - 90)	11	11 (8 - 12)	24
1800s	7	163 (33 - 544)	180	121	43 (8 - 69)	33 (6 - 50)	24 (0 - 64)	20 (7 - 65)	21	14 (3 - 44)	14	75 (43 - 100)	26	29 (5 - 100)	27
1900s	6	81 (55 - 148)	34	283	92 (78 - 100)	7 (0 - 22)	1 (0 - 7)	8 (5 - 14)	3	2 (0 - 4)	2	59 (26 - 90)	31	14 (9 - 27)	26

*Only one fire episode in this century

part due to record erasure, estimated fire episode size prior to 1846 was only 66 km^2.

The NFR decreased dramatically from 452 years in the pre-settlement period to 78 years in the European settlement period starting in 1846; since fire suppression (1910) it has increased again to 335 years. A relatively higher proportion of the sites in the pre-settlement period (36%) showed evidence of high severity (i.e. only regeneration trees), whereas nearly 60% of sites during the settlement period and 90% of the sites in the fire suppression period showed evidence of low severity fires (i.e. scars only) (Table 2.5a). Fire episodes in the Suppression period were smaller (8% available area burned on average) and more contained in the study area (3% available perimeter area burned on average) compared to the entire period of record. Fire episode contiguity was similar for all three periods, with 60% contiguous during the Settlement period, 72% during the pre-Settlement period, and 75% during the Suppression period (Table 2.5a).

Fire episode characteristics also varied by century (Table 2.5b). The average size of fire episodes was greatest in the 1800s (163 km^2), followed by the 1500s (120 km^2). The NFR was lowest in the 1800s at 121 years following higher values in the 1500s, 1600s and 1700s. Fire episodes in the 1900s were much less severe than in other centuries (Table 2.5b).

2.3.2 Spatial Patterns of Fire

Visual examination of spatial occurrence and severity from the maps of the 27 fire episodes (Appendix B) revealed four spatial patterns: (1) widespread, high-severity fire episodes (n=4); (2) small, mixed-severity fire episodes concentrated in the eastern third of the study area (n=14); (3) fire episodes with a mixed pattern of severity and spatial occurrence (n=2); and, (4) widespread, low-severity fire episodes (n=6). The 1478 fire episode was not categorized as it was recorded at only three sites. Pattern types 2 and 4 correspond roughly with early and recent time periods, respectively (Table 2.4).

Widespread fire episodes (pattern type 1) were defined as those recorded at >20 sites spread throughout the study area, with fire episode size >100 km^2, >45% of sites showing evidence of high severity fire, and >66% percent contiguous area (Table 2.6). Type 1 fire episodes include the fire episodes of 1531, 1555, 1852 and 1871 (Figure 2.23 a and b). The earlier fire episodes of 1531 and 1555 are less contiguous than the fire episodes of 1852 and 1871 (Table 2.4), perhaps because of erasure.

From 1585 to 1844 all fire episodes recorded were concentrated in the eastern third of the study area (pattern type 2, Figures 2.24 a - g). These fire episodes were recorded at <16 sites, had areas <100 km^2, and mixed severity and patchiness (Table 2.6). These fire episodes burned small areas (<22% of available area) and were mostly contained within the study area (<21% available perimeter area burned) (Table 2.6). Average percent of available area burned (13%) and percent available perimeter area burned (7%) were low compared to widespread (type 1) fire episodes.

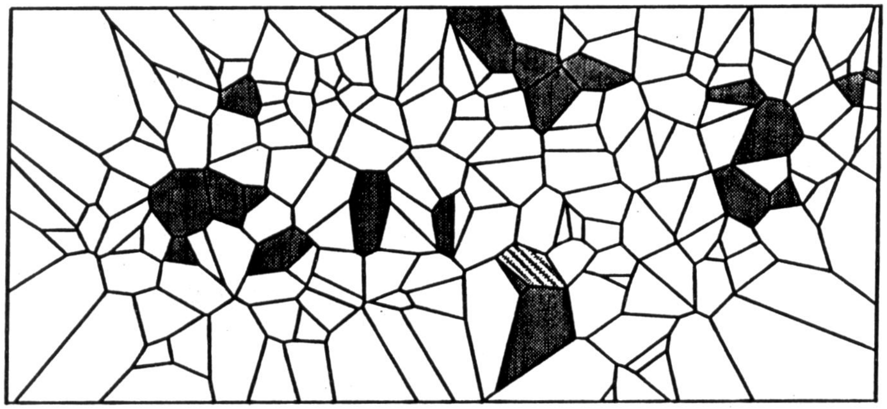
Two fire episodes (1881 and 1888) showed a mixed pattern (type 3)(Figure 2.25). Both are large (94-172 km^2) fire episodes recorded at >15 sites across the study

Table 2.6 Summary of Fire Regime Measurements by Pattern Type

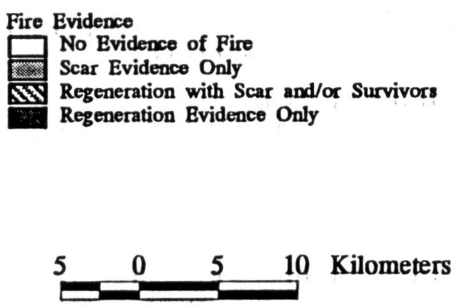
(See text for description of metrics)

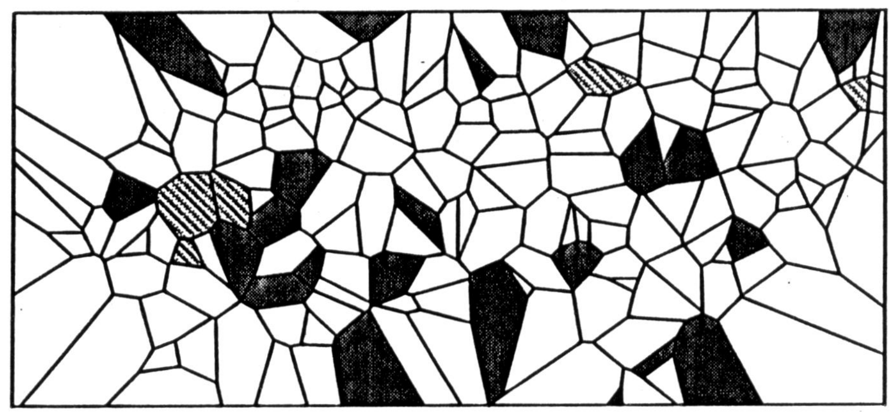
Pattern Type (Fire Episodes)	Number of Fire Episodes	Thiessen Fire Episode Size (km^2) Average	SD	Average Severity Classes Percent of Sites: Low	Moderate	High	Available Area Burned (%) Average	SD	Available Perimeter Area Burned (%) Average	SD	Contiguous Area (%) Average	SD	Number of Sites per Fire Episode Average	SD
Widespread	4	262	190	7	21	72	59	30	53	37	83	13	45	37
(1531, 1555, 1852, 1871)		(131 - 544)		(0 - 19)	(4 - 35)	(45 - 96)	(21 - 93)		(10 - 100)		(65 - 96)		(21 - 100)	
Valley Margin	14	57	21	34	42	24	13	6	7	6	70	22	10	3
(1585 - 1844)		(29 - 90)		(0 - 60)	(17 - 67)	(0 - 80)	(6 - 22)		(0 - 21)		(31 - 100)		(5 - 14)	
Mixed	2	133	55	60	12	29	13	6	7	6	62	27	23	9
(1881, 1888)		(94 - 172)		(50 - 69)	(6 - 17)	(14 - 44)	(9 - 17)		(3 - 11)		(43 - 81)		(16 - 29)	
Modern	6	81	34	92	7	1	8	3	2	2	59	31	14	7
(1900 -1974)		(55 - 148)		(89 - 100)	(0 - 22)	(0 - 7)	(5 - 14)		(0 - 4)		(26 - 90)		(9 - 27)	
	26	(1478 fire episode not characterized)												

Figure 2.23a Fires Showing Widespread Pattern (Type 1)



1531 Fire





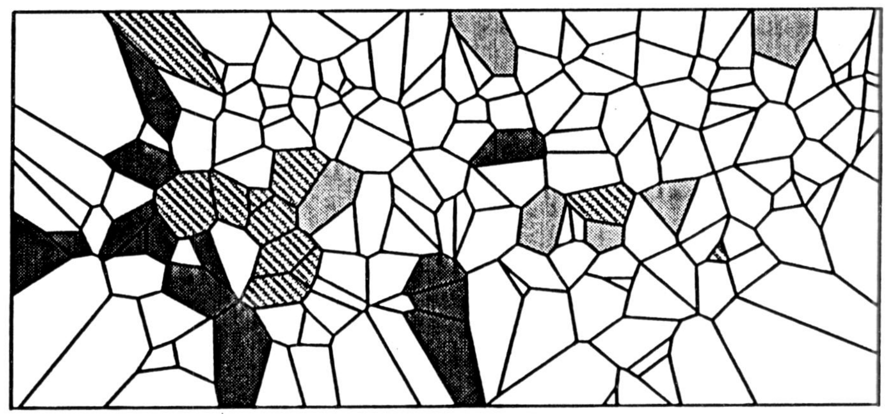
1555 Fire

Figure 2.23b Fires Showing Widespread Pattern (Type 1)

1852 Fire

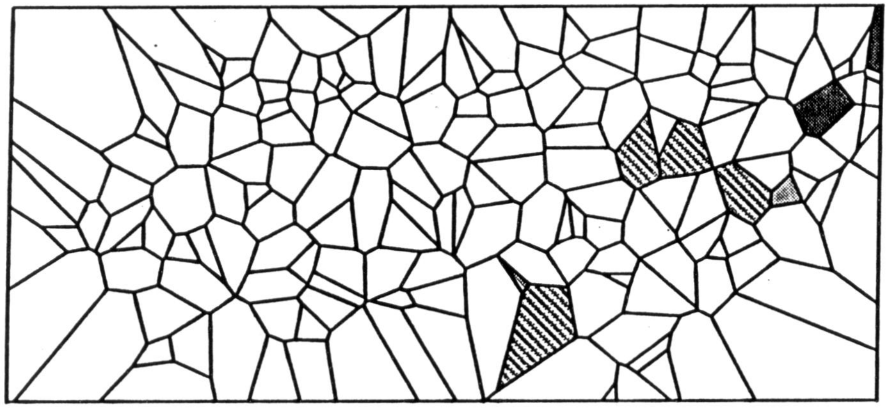
Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only

5 0 5 10 Kilometers



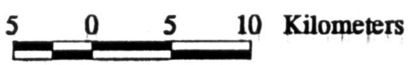
1871 Fire

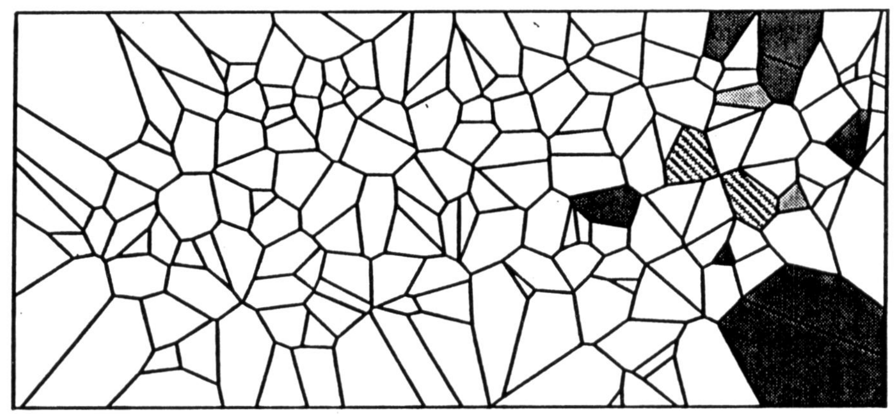
Figure 2.24a Fires Showing Valley Margin Pattern (Type 2)



1585 Fire

Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only





1629 Fire

Figure 2.24d Fires Showing Valley Margin Pattern (Type 2)

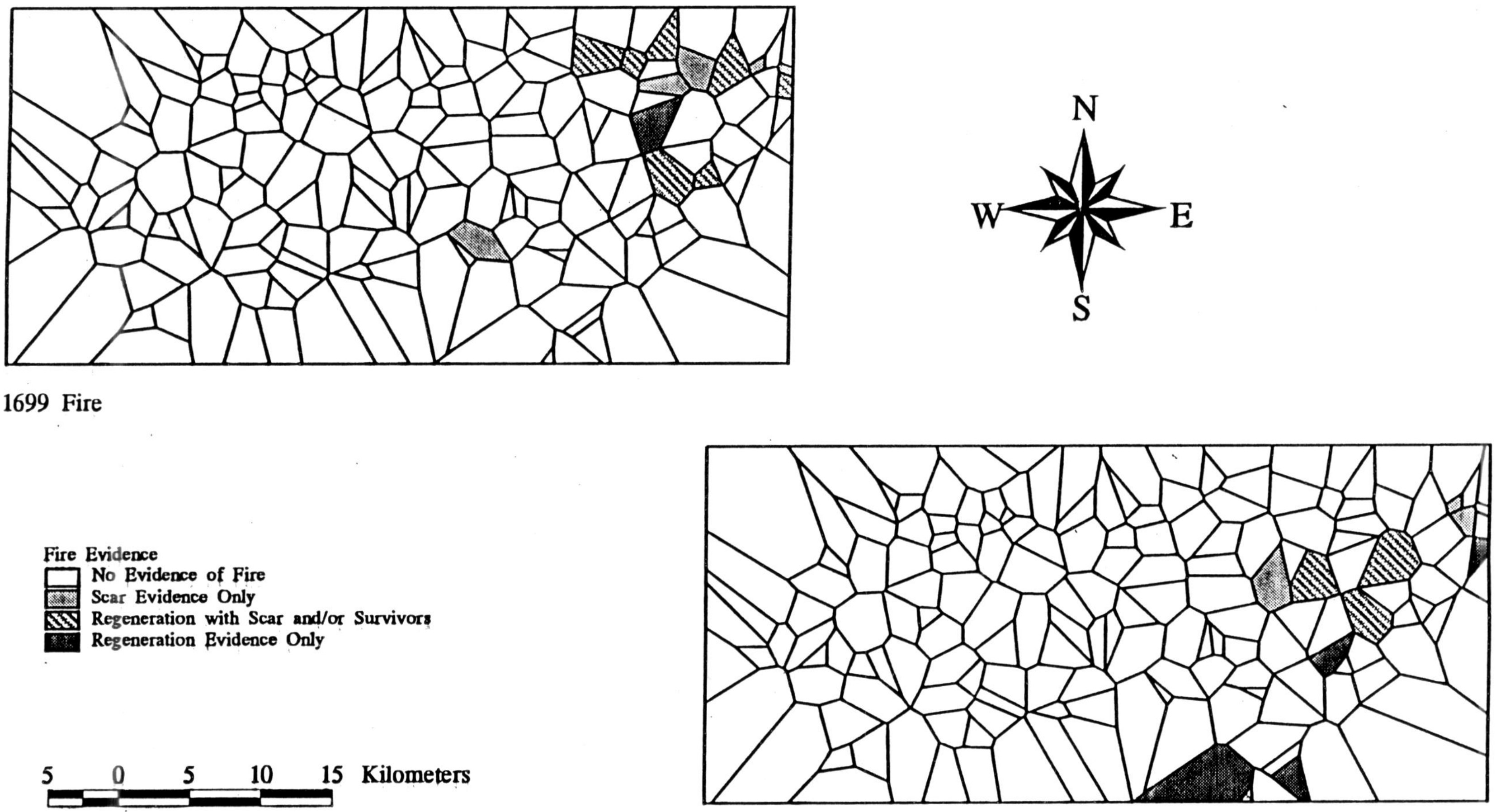
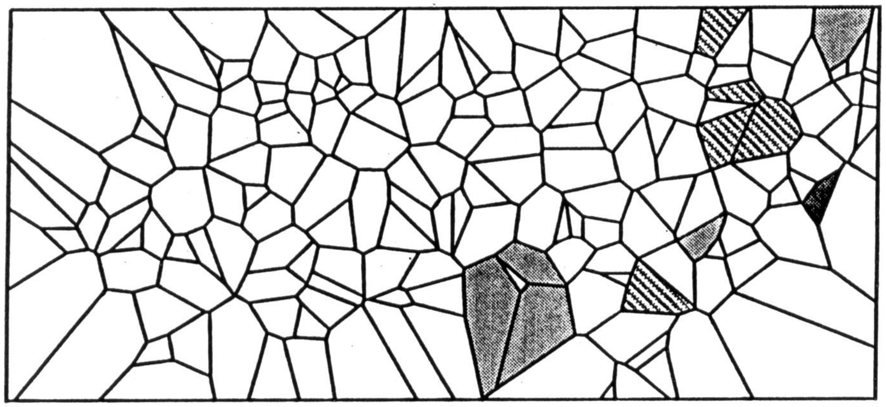
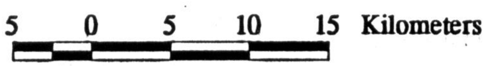


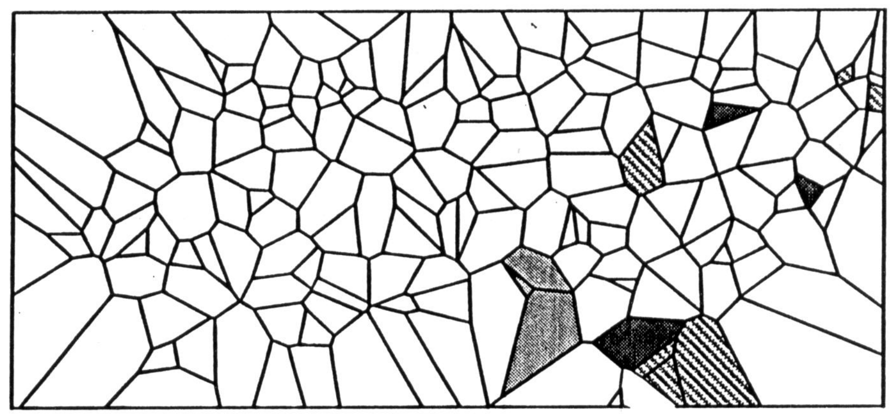
Figure 2.24e Fires Showing Valley Margin Pattern (Type 2)



1751 Fire

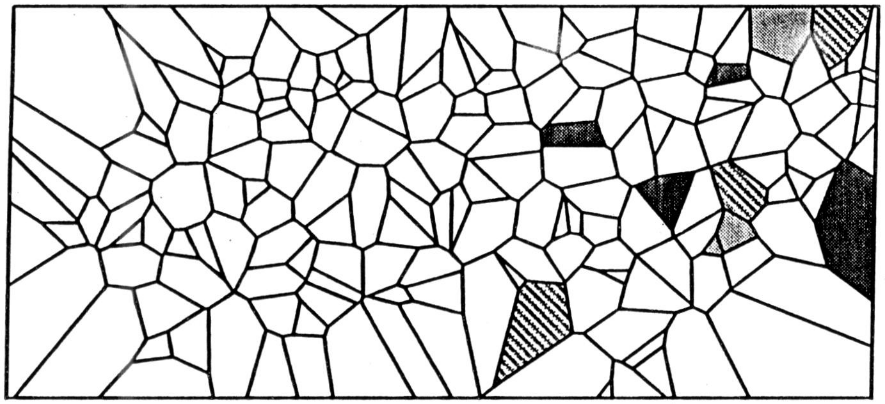
Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only





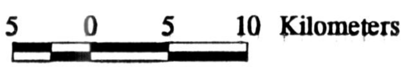
1763 Fire

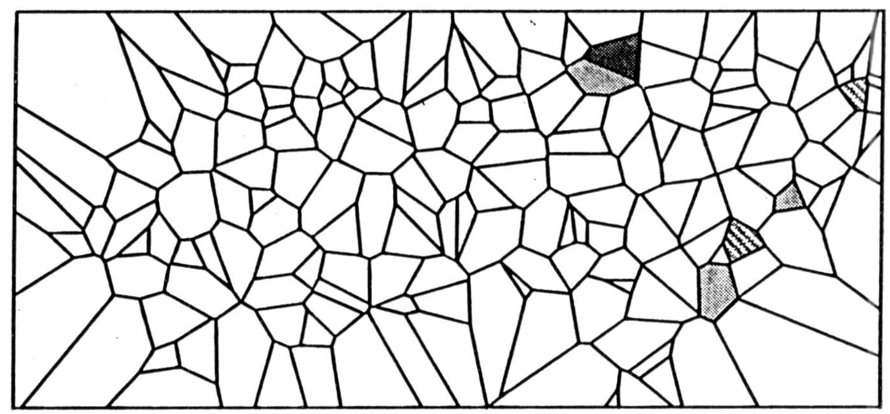
Figure 2.24c Fires Showing Valley Margin Pattern (Type 2)



1666 Fire

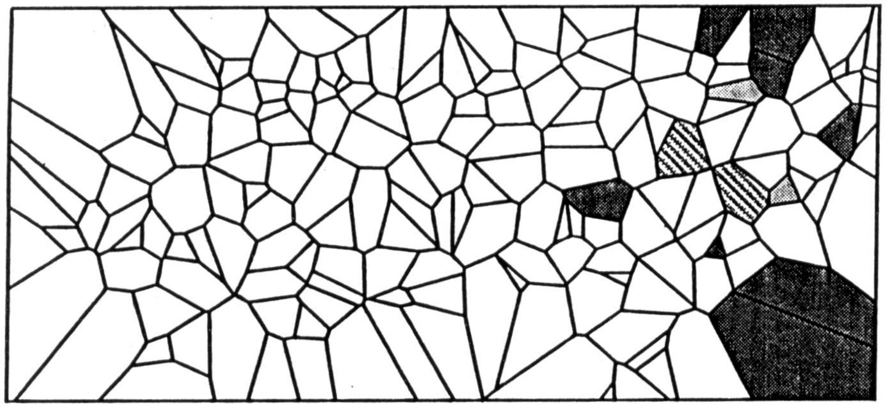
Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only



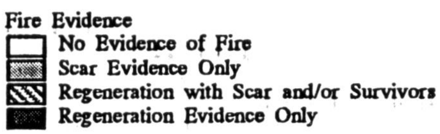


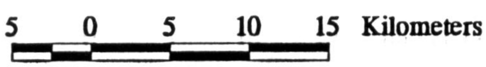
1689 Fire

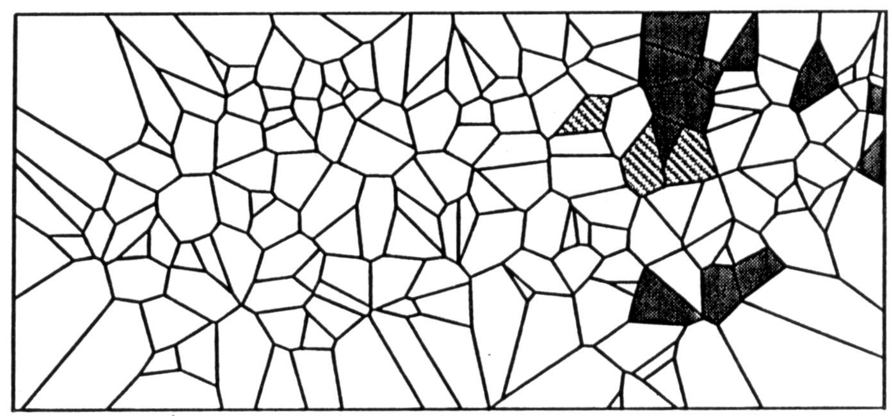
Figure 2.24b Fires Showing Valley Margin Pattern (Type 2)



1637 Fire

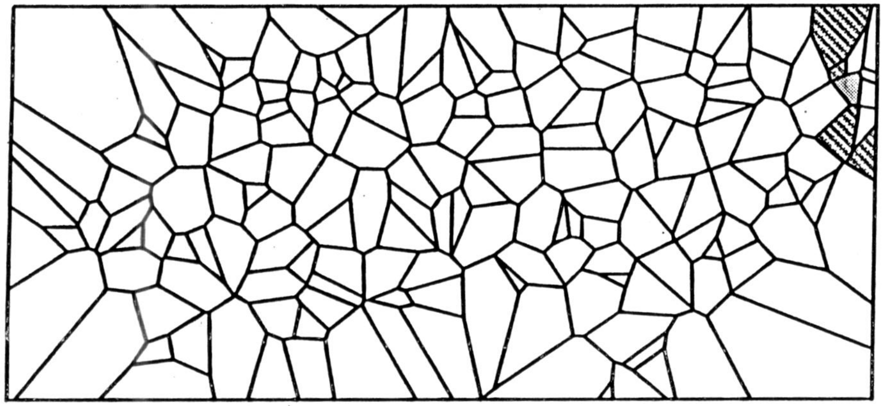




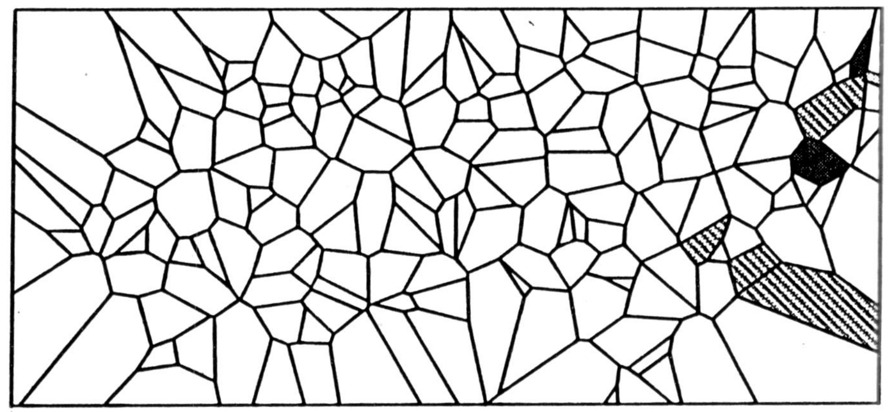


1655 Fire

Figure 2.24f Fires Showing Valley Margin Pattern (Type 2)



1815 Fire



1794 Fire

Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only

5 0 5 10 Kilometers

Figure 2.24g Fires Showing Valley Margin Pattern (Type 2)

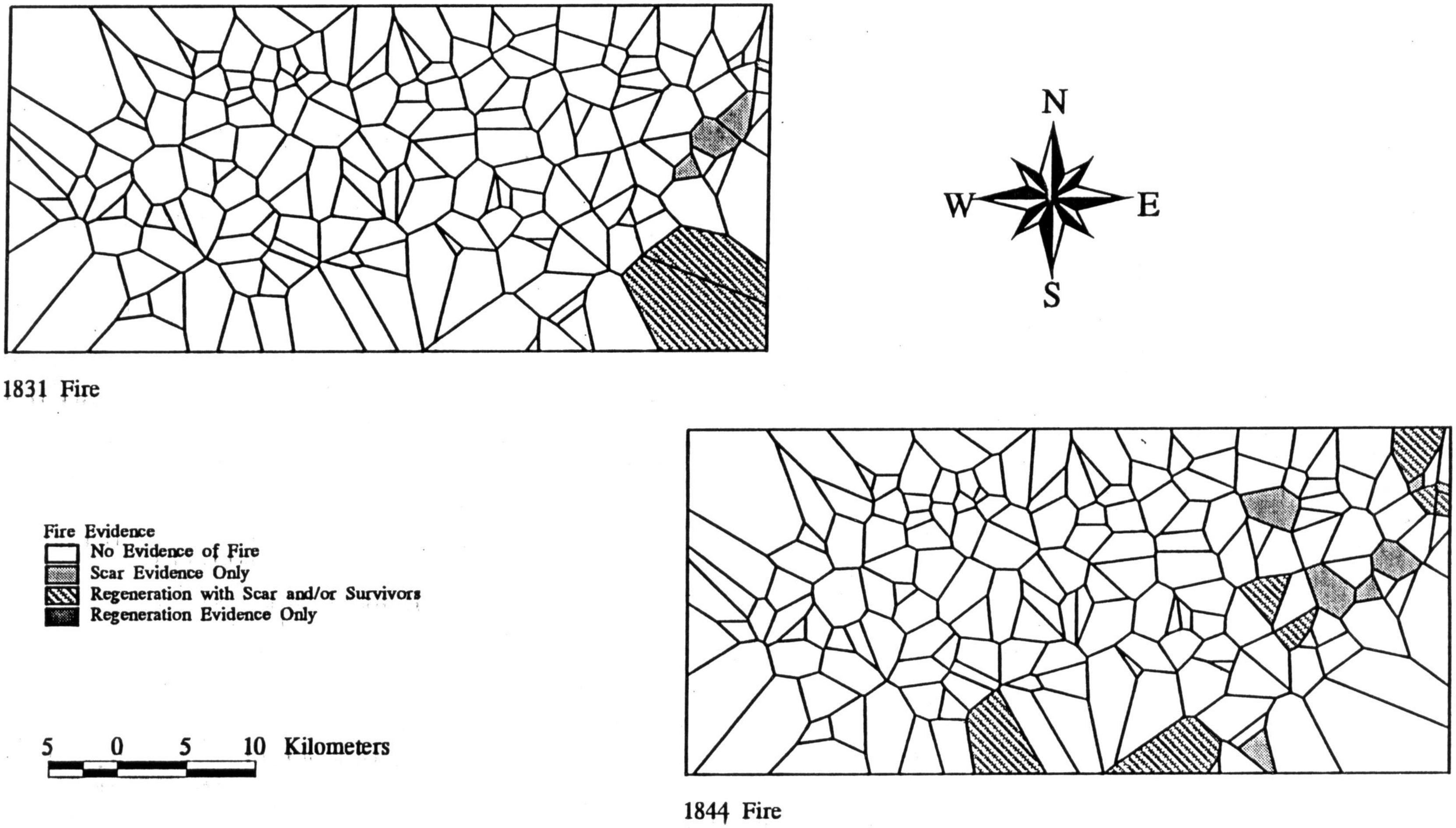
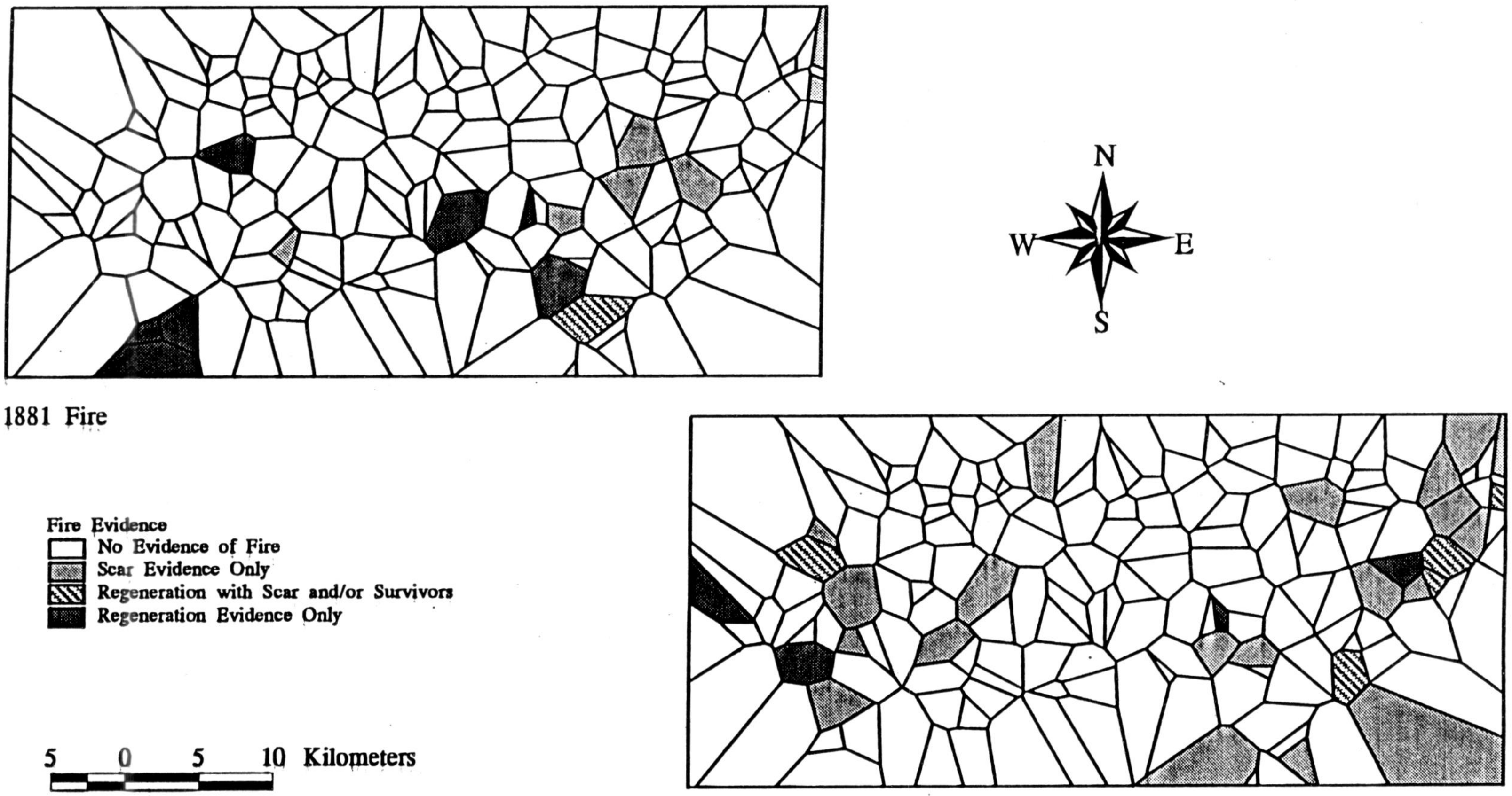


Figure 2.25 Fires Showing Mixed Pattern (Type 3)



1888 Fire

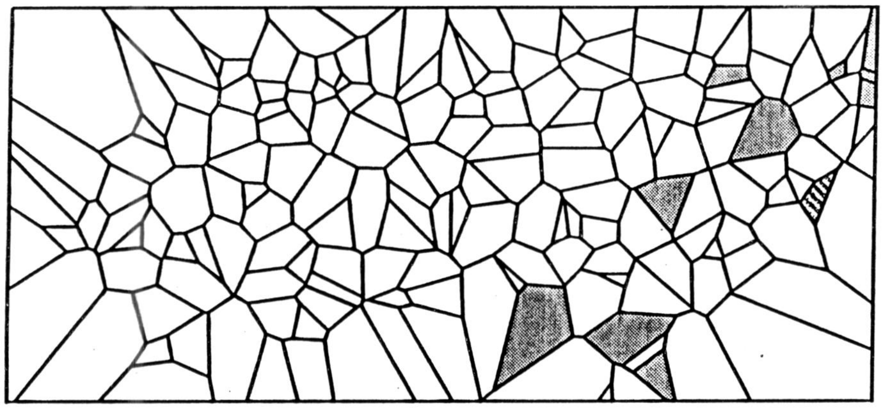
area (Table 2.6). While 60% of sites showed low severity, 29% of sites showed regeneration evidence only. These fire episodes also burned little of the area available. The mixed pattern fire episodes had an average 7% percent available perimeter area burned, indicating a reduced chance of having extended beyond the study area (Table 2.6).

Pattern type 4 fire episodes occurred after 1900 (Figures 2.26 a - c). These fire episodes were recorded at 9 to 27 sites, were predominantly low severity (>78% of sites), were small (<14% of available area was affected), and had the lowest probability of having extended beyond the study area (average percent available area burned <2%; Table 2.6).

The low and moderate severity of the fire episodes of 1585 - 1844 is reflected in the current mixed age class distribution in the eastern third of the study area, whereas the western two thirds of the study area has a much more even-age distribution, indicative of infrequent high severity fires (Figure 2.27). The western two thirds of study area is dominated by two age classes starting at approximately 150 and 450 years before 1994, corresponding to the fire episodes of 1531 and 1555; and 1852 and 1871 (Figure 2.27a). The eastern third of the study area had additional age classes at 240 and 350 years before 1994 and possibly at approximately 170-180 years before 1994 (Figure 2.27b).

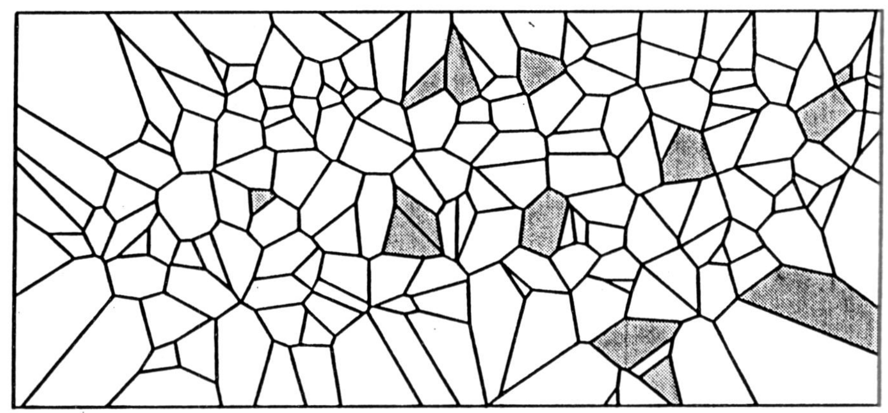
Regeneration trees were evenly distributed among the four aspect classes. In the western two-thirds of the study area, slightly more surviving trees of the older age

Figure 2.26a Fires Showing Modern Pattern (Type 4)



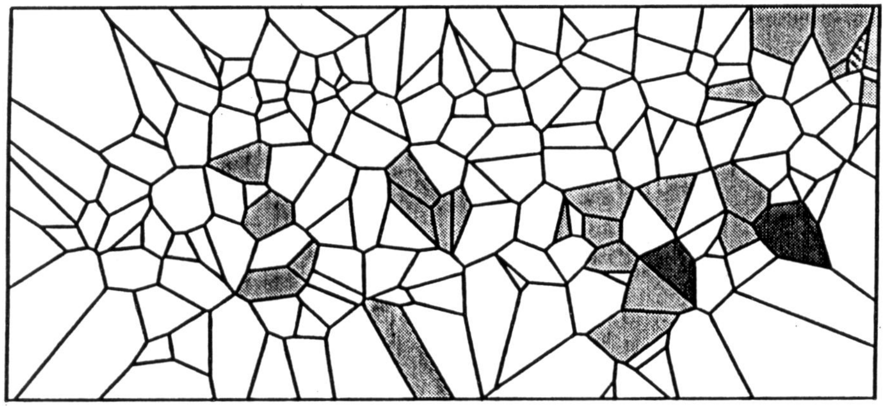
1900 Fire

Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only

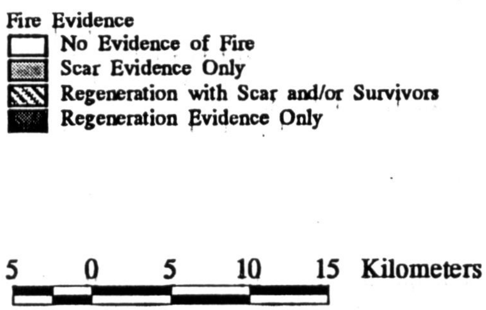


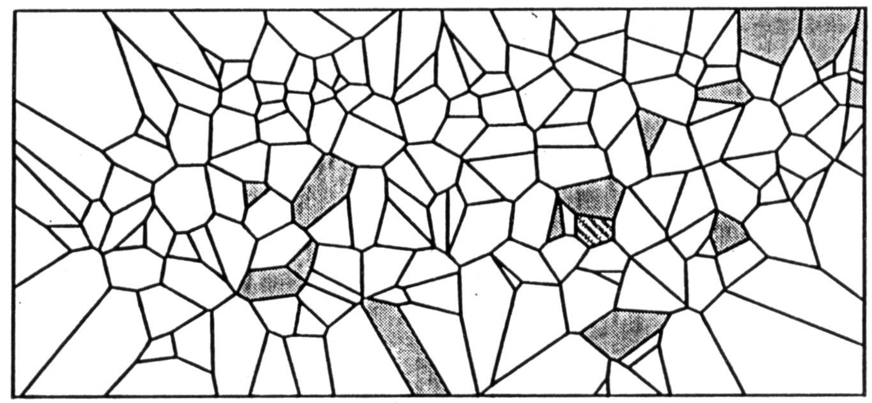
1909 Fire

Figure 2.26b Fires Showing Modern Pattern (Type 4)



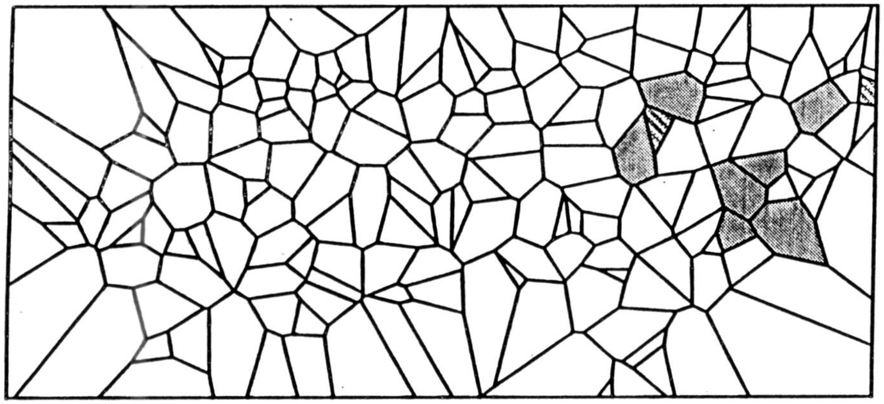
1920 Fire



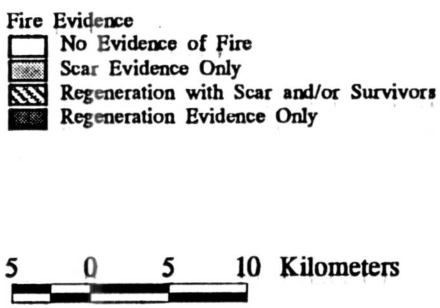


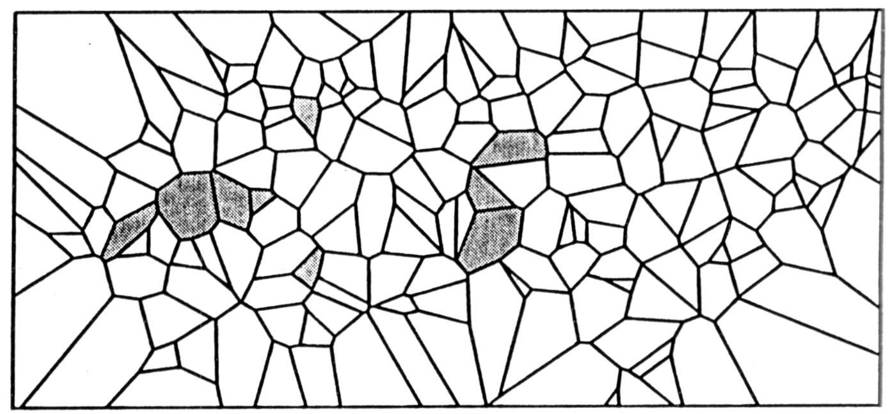
1928 Fire

Figure 2.26c Fires Showing Modern Pattern (Type 4)



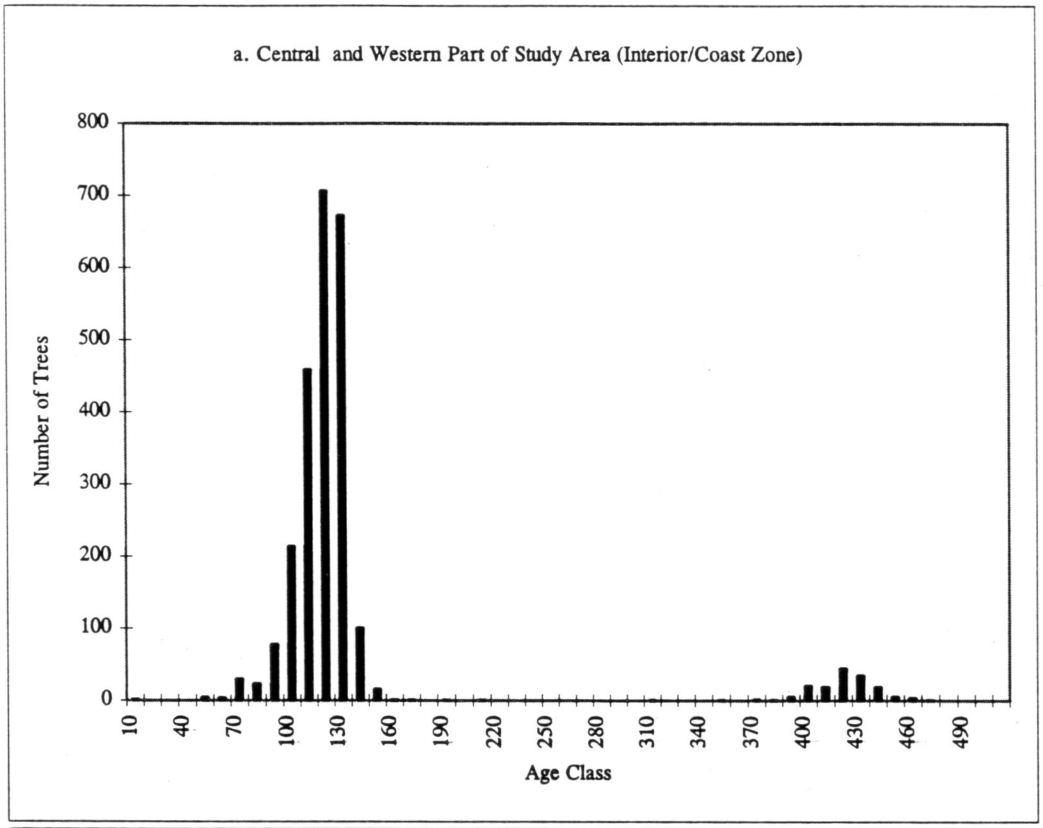
1934 Fire

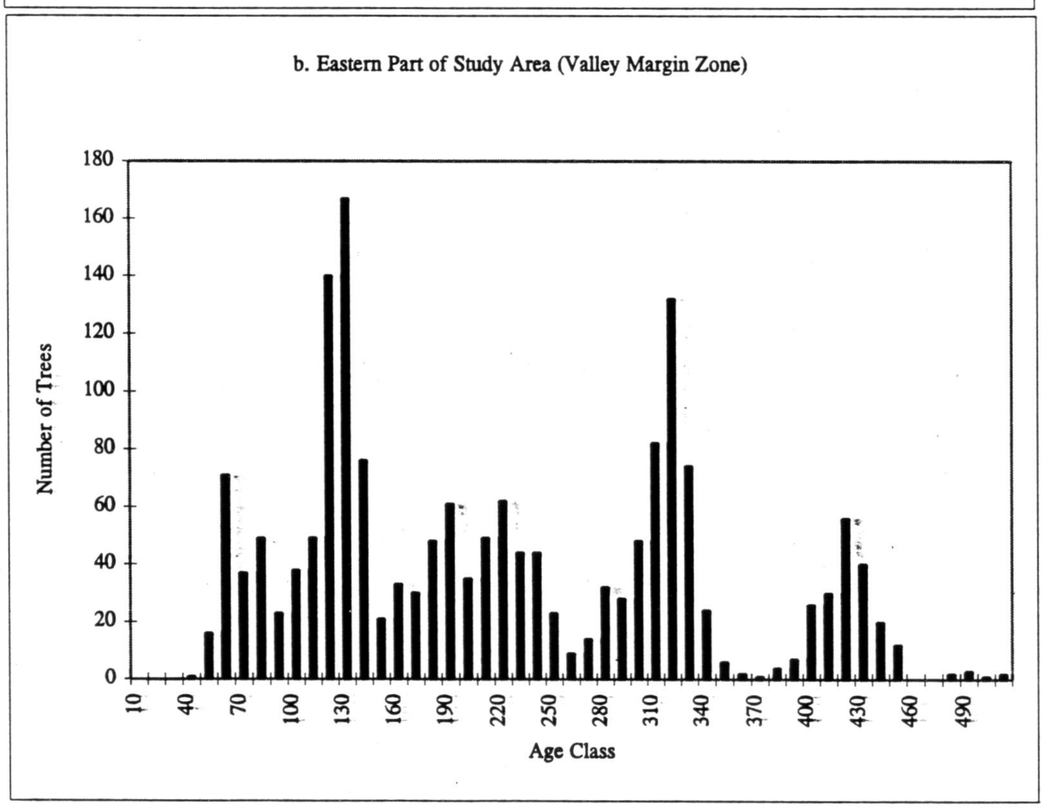




1974 Fire

Figure 2.27 Comparison of Age Class Distributions for the Central and Western vs. the Eastern Parts of Study Area





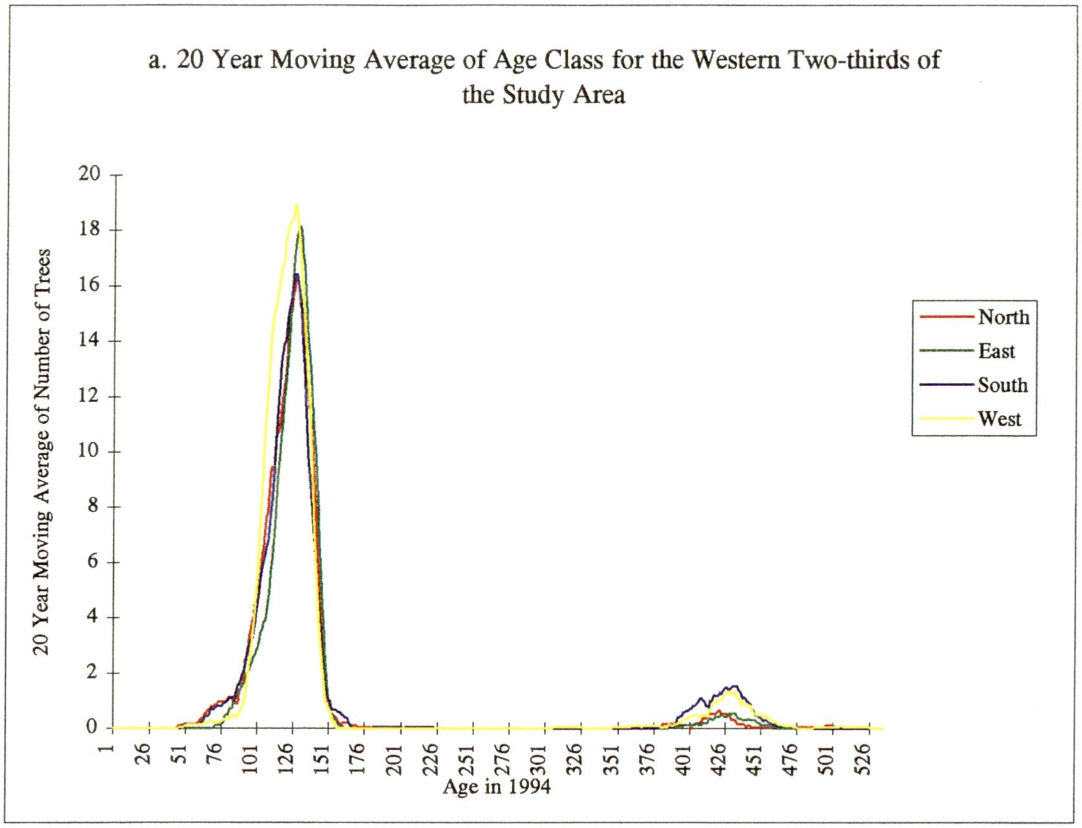
class, associated with the 1531 and 1555 fire episodes, were located on south and west aspects than on north and east aspects. In the age class associated with the fire episode of 1852 and to a lesser extent with the fire episode of 1871, north, east and south aspects have similar age class distributions (Figure 2.28a). Aspect differences in the eastern third of the study area appear somewhat more distinct (Figure 2.28b), although these differences are based on a smaller sample. Age class distributions are similar for the 1852 fire episode (130 and 140 year age classes). Western aspects show a higher peak for the 1500s fire episodes (400 to 460 year age classes), whereas eastern aspects show a higher peak for the fire episode in the early 1600s (300 to 350 year age classes). Fire episode patterns with respect to aspect are investigated in more detail in Chapter 3.

Regeneration trees were also evenly distributed among upper, middle, and lower hillslope positions (Figure 2.29), especially for the widespread fire episode of 1852. Greater numbers of surviving trees from earlier fire episodes (1531, 1555 and 1655) were found at lower slope positions. Fire episode patterns with respect to hillslope position are investigated in more detail in Chapter 3.

Not surprisingly, record erasure was greatest in earlier fire episodes and lowest in later fire episodes (Appendix C). Fewer trees are associated with earlier fire episodes than later episodes in the age class distribution for the study area.

The erasure maps indicate that early fire episodes had the potential to have been much more widespread than the record shows. Sites which recorded the fire episodes of 1531 and 1555 tend to be separated by one or two sites where evidence of fire episodes

Figure 2.28 Comparison of Age Class Distributions by Aspect



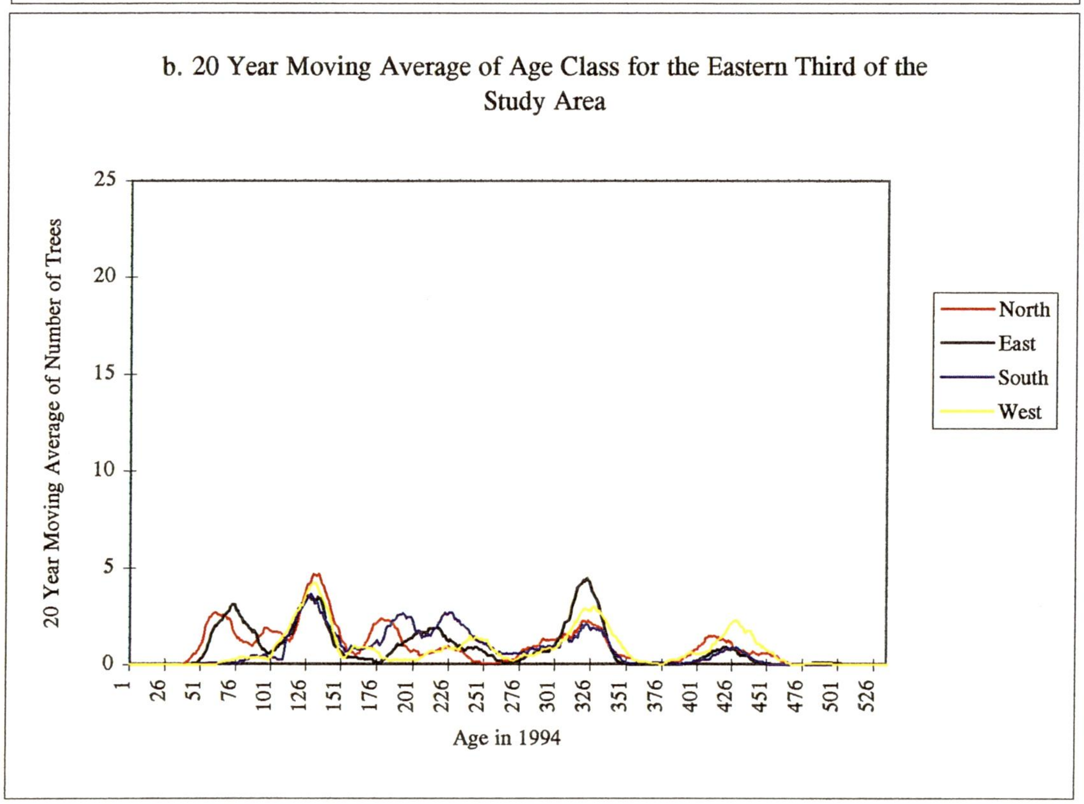
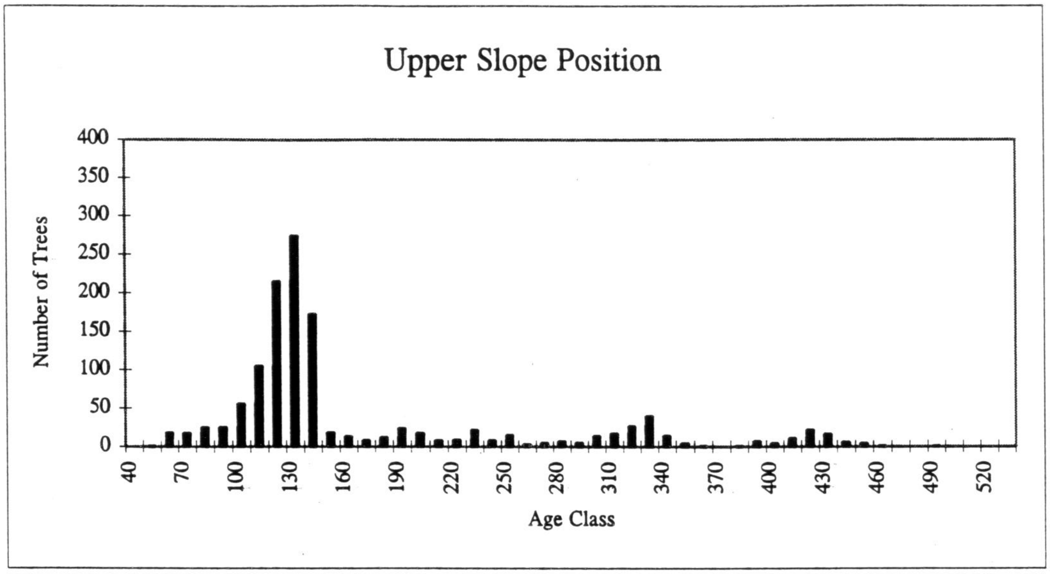
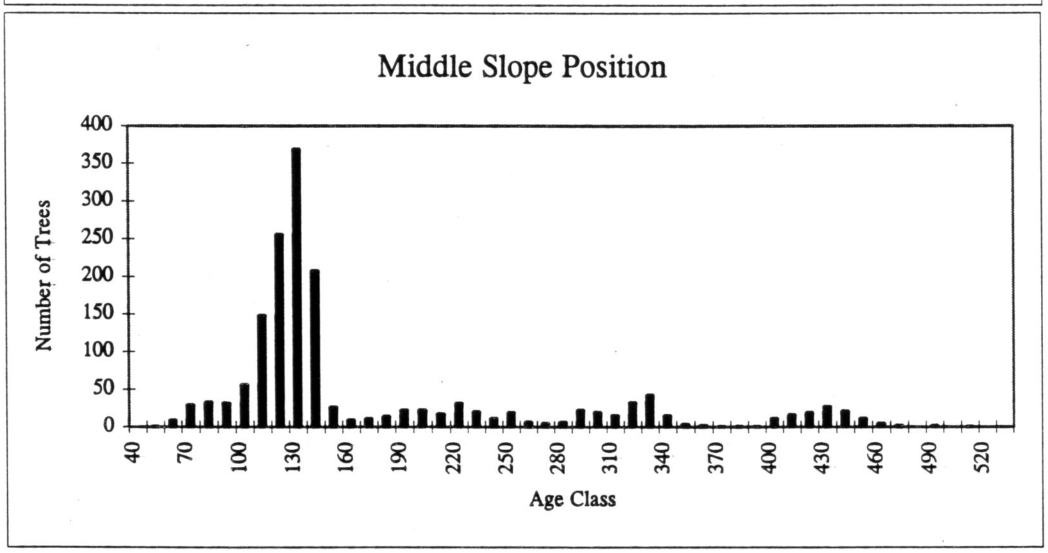
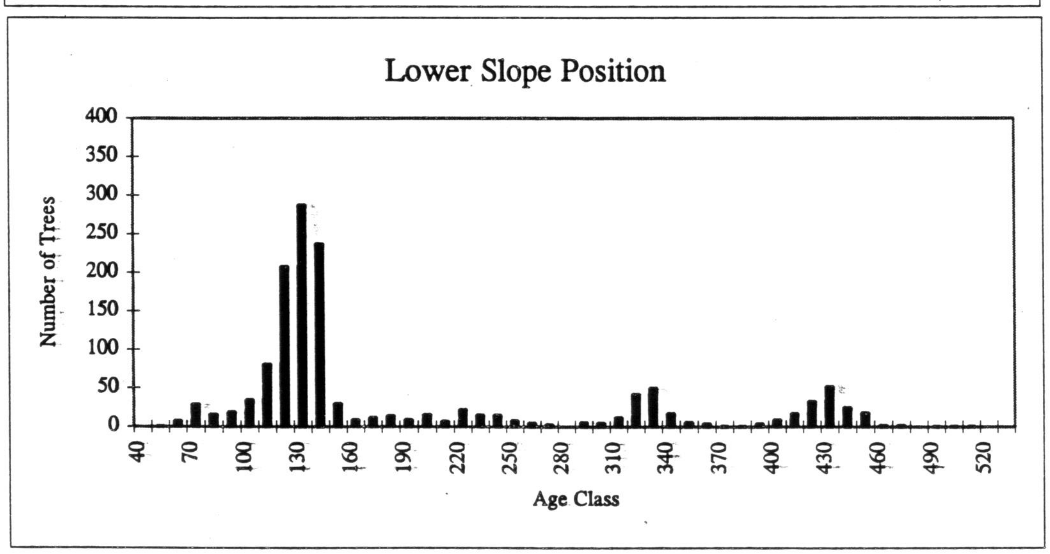


Figure 2.29 Comparison of Hillslope Age Class Distributions







was erased. To a lesser extent this is also true for the fire episodes of 1637, 1655, 1737 and 1751. In Chapter 4 erasure maps were used to interpolate fire episode size and occurrence by including sites where the record may have been erased, based on rule sets for adding sites to a fire episode.

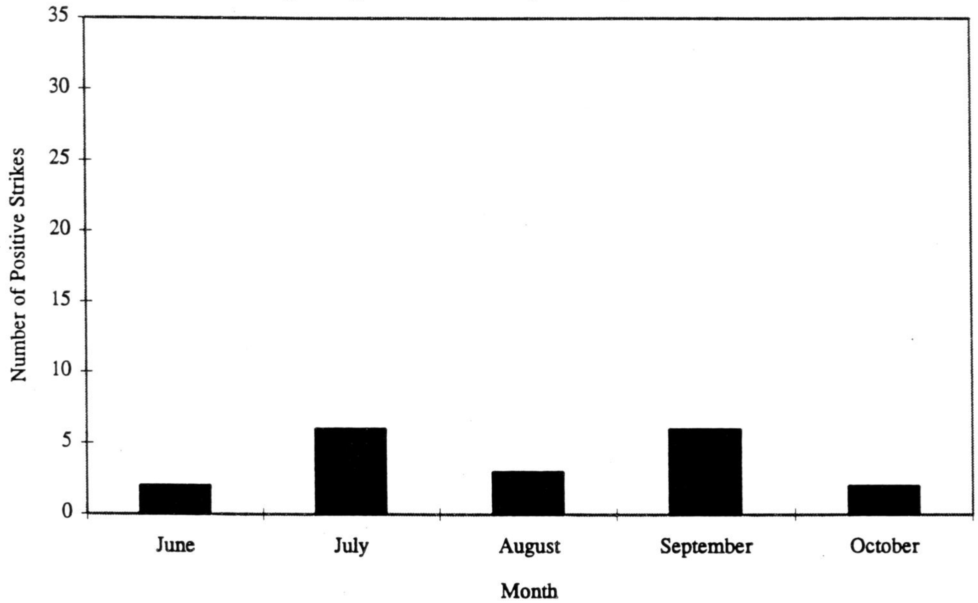
In the study area 19 positively charged lightning strokes occurred during the fire season between June 15 and October 15 for the years 1985 through 1993 (Figures 2.9 and 2.30a). This was an average of 2.4 positive strokes per year in the study area for this limited record. In the Central Coast Range, a larger area surrounding the study area including the lightning datasets from the 44° N 124° W cell and the 44° N 123° W cell had 93 positively charged lightning strokes during the fire season between June 15 and October 15 for the years 1985 through 1993 (Figures 2.7 and 2.30b). This was an average of 11.6 positive strokes per year in the two 1 degree by 1 degree cells encompassing the study area.

There is a weak spatial pattern of lightning strikes over this nine-year period, with slightly more strikes having occurred in the eastern part of the study area and surrounding areas (Figures 2.6 and 2.8). Over half of the positive strikes (12) occurred in the southeast corner of the study area (Figure 2.9).

The record of east winds at the Eugene Airport between 1964 and 1991 indicate that east winds were rare and slow. East winds (from compass bearings 40° to 140°) were the prevailing wind direction for only 6% of the record (Figure 2.31). The cumulative frequency of east wind speeds shows east winds rarely exceed 12 - 15 km/hr

Figure 2.30 Frequency of Positive Summer Lightning Strikes in the Central Oregon Coast Range 1985 - 1993

a. Positive Lightning Strikes in Study Area by Month 1985 - 1993



b. Positive Lightning Strikes in Surrounding Coast Range by Month 1985 - 1993

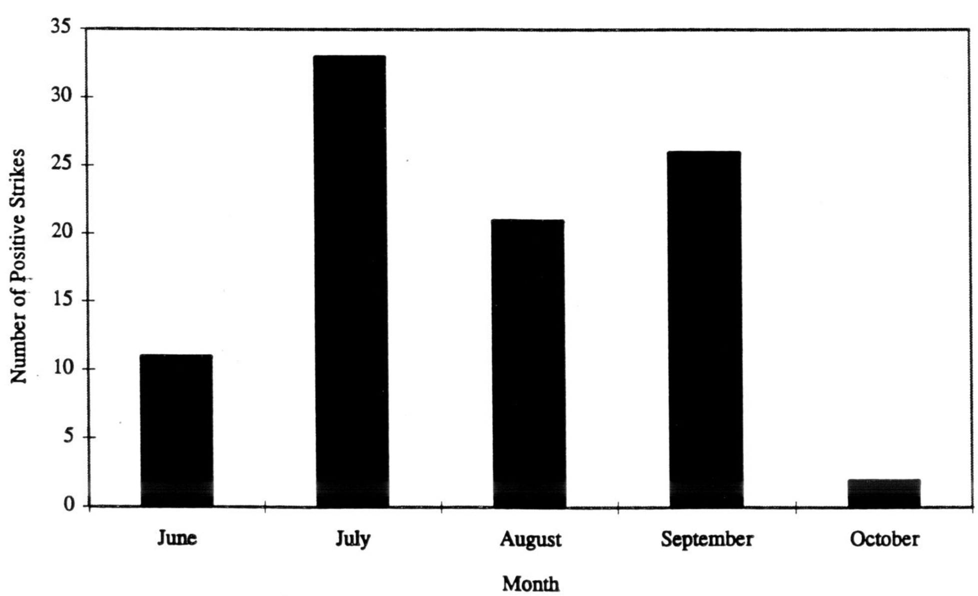
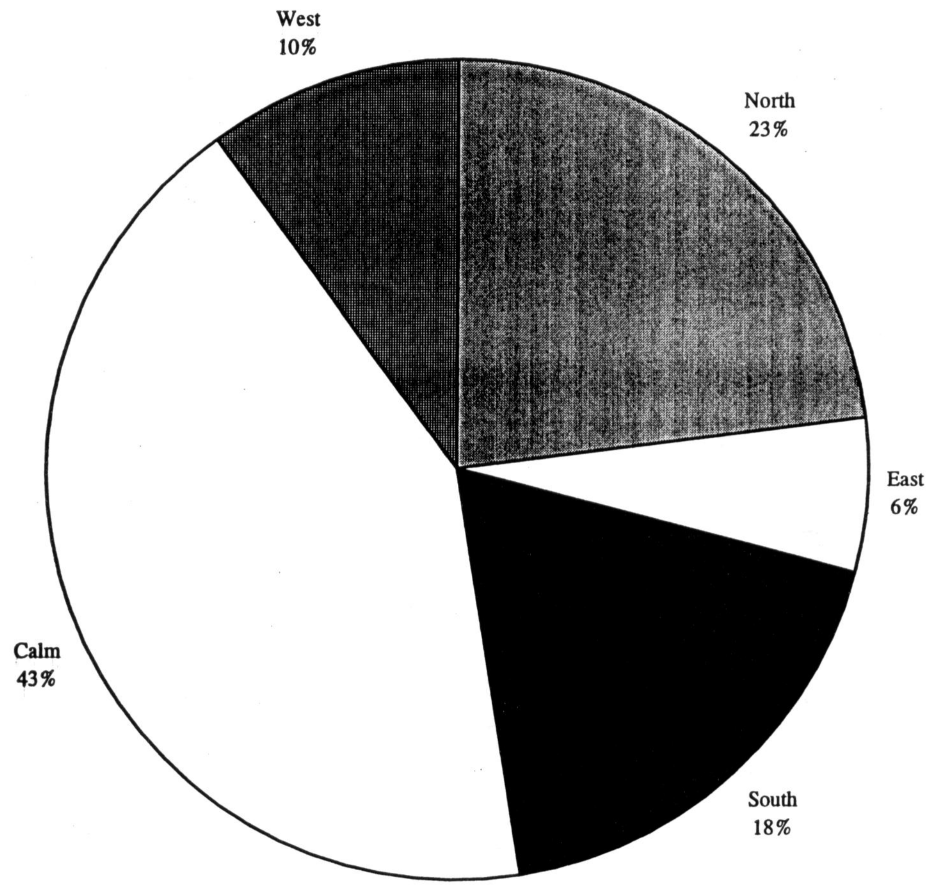


Figure 2.31 Summer Month (June - Oct.) Wind Direction Frequency from Eugene Airport Hourly Data, 1964 - 1991



(Figure 2.32). For only 2% of the time did east winds recorded have speeds > 25 km/hr; wind speeds exceeded 16 km/hr for 7% of the time east winds were recorded (Figure 2.33).

East wind occurrence as measured at Eugene Airport was only slightly coincident with fires that occurred in the Coast Range. Two large fires occurred during the period for which wind data are available, 1964 - 1991: the Oxbow fire of 1966 and the Rockhouse fire of 1987. The Oxbow fire burned a 183 km^2 area 50 km southwest of Eugene from August 21 to August 26, 1966. The Rockhouse fire burned a 20 km^2 area 30 km west of Salem from October 10 to October 23, 1987; it occurred approximately 120 km N/NE of the Eugene Airport.

East wind occurred prior to and during both the Oxbow fire and the Rockhouse fire. East winds associated with the Oxbow fire occurred primarily in the early hours of the morning, and ranged in speed from 6 to 15 km/hr (Table 2.7). The Oxbow fire recorded fewer total hours than the Rockhouse fire in which the wind average was primarily from the east for at least one hour; however this total is not reflective of actual east wind occurrence as wind speeds were averaged over three hour periods at the Eugene Airport from 1964 to 1974. For only one day (August 24, 1966) was east wind not recorded for at least one hour during the Oxbow fire (Table 2.7).

East winds associated with the Rockhouse fire (as measured at Eugene) occurred for short periods two days before the fire, then occurred for at least one hour during the day for all fire days except October 11, 14, 20 and 21 (Table 2.7). East wind speeds

Figure 2.32 Cumulative Frequency of Summer Month (June - Oct.) East Wind Speeds from Eugene Airport Hourly Wind Data, 1964 - 1991

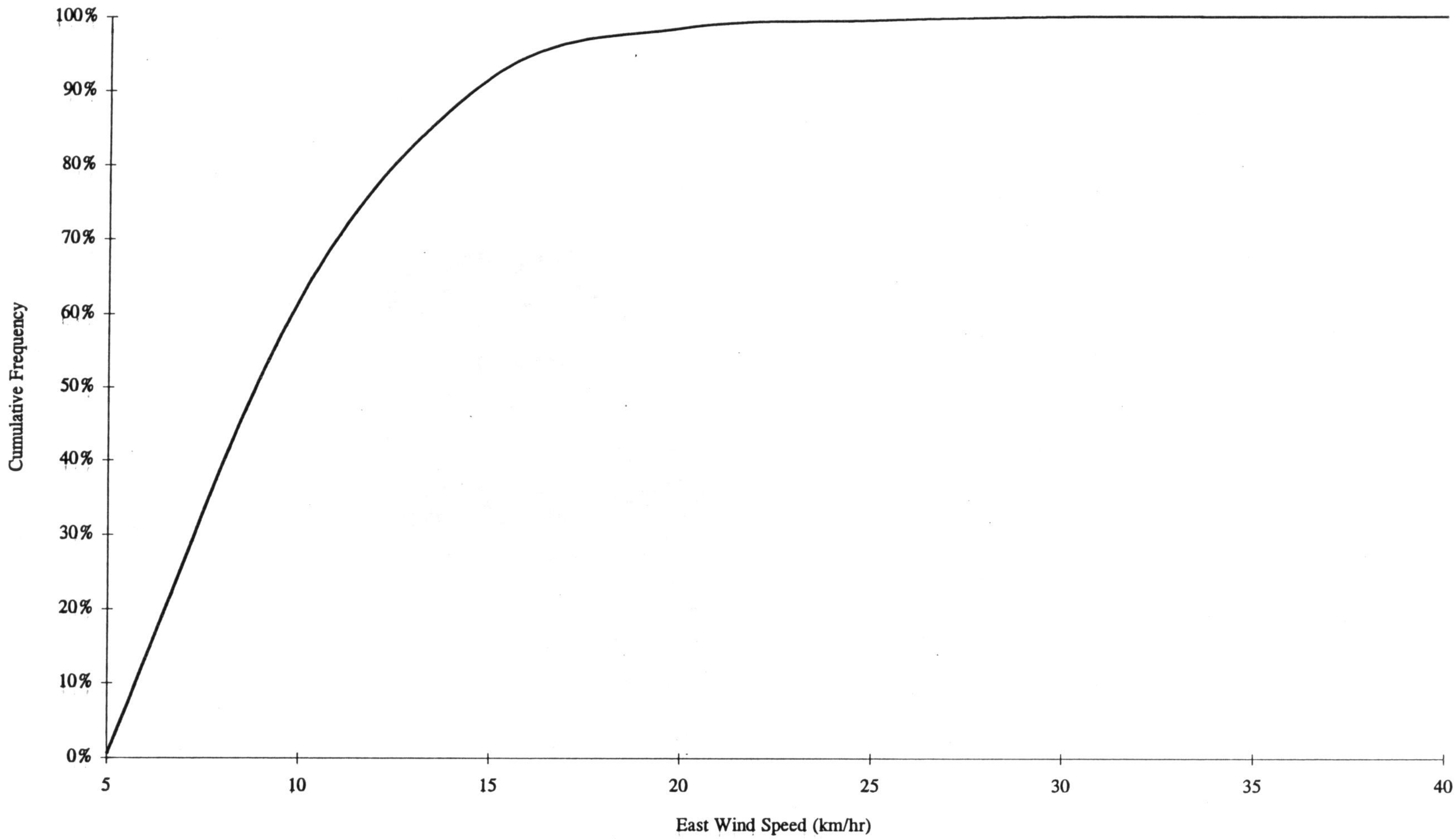


Figure 2.33 Relative Frequency of Summer Month (June - Oct.) East Wind Speeds from Eugene Airport Hourly Data, 1964 - 1991

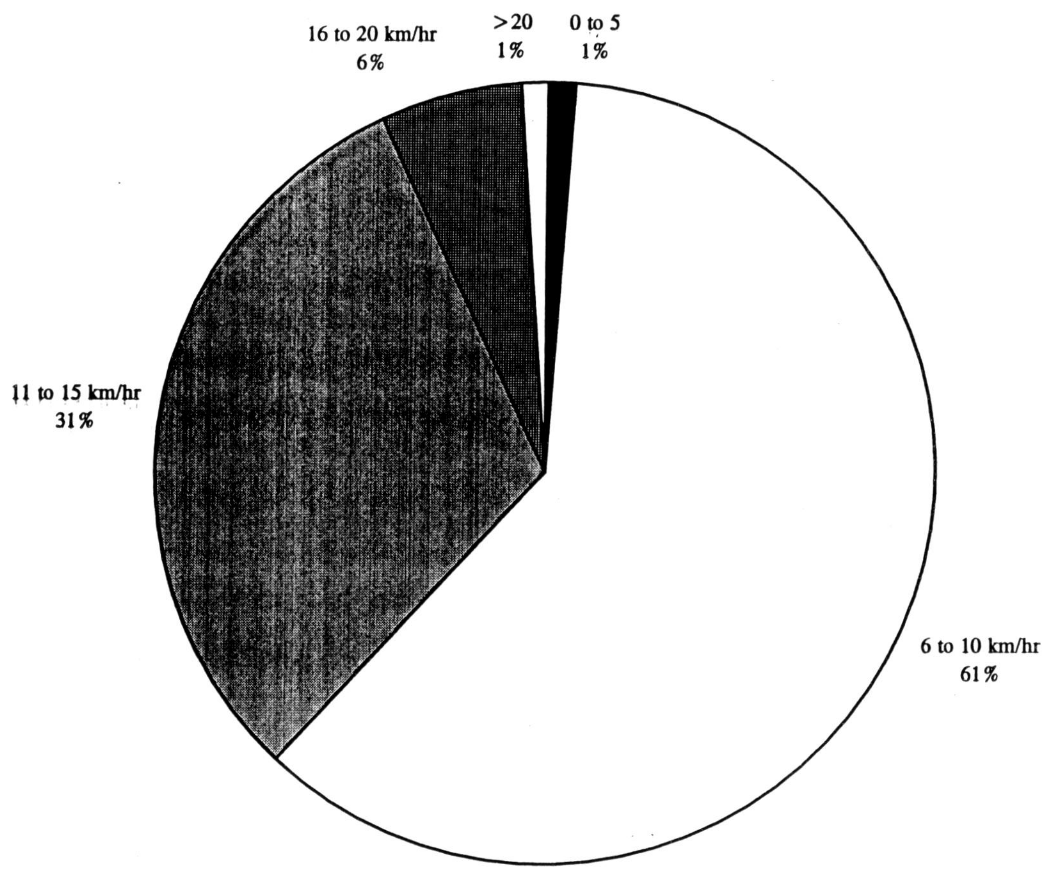


Table 2.7 Coincidence of Recent Known Coast Range Fires and East Wind

Oxbow Fire: 8/21/66 to 8/26/66 (controlled)

Date	Hour*	Wind Direction (Degress)	Wind Speed (km/hr)
8/17/66	11:00 PM		15
		40	
8/18/66	5:00 AM		7
8/18/66	8:00 AM	130	7
		60	
8/19/66	5:00 AM		9
		140	
8/20/66	2:00 AM		11
		130	
8/20/66	5:00 AM		9
		40	
8/21/66	2:00 AM		9
8/21/66	5:00 AM	120	6
		100	
8/22/66	5:00 AM		7
8/22/66	5:00 PM	70	11
8/22/66	8:00 PM	100	6
		90	
8/23/66	2:00 AM		9
		90	
8/25/66	5:00 AM		13
		140	
8/27/66	5:00 AM		7
		140	

*Wind data was calculated using 3 hour averages until 1974

Rockhouse Fire: 10/10/87 to 10/23/87 (controlled)

Date	Hour	Wind Direction (Degress)	Wind Speed (km/hr)
10/8/87	8:00 AM		6
10/8/87	9:00 AM	60	7
10/8/87	12:00 PM	80	4
		40	
10/9/87	10:00 AM		7
10/9/87	1:00 PM	40	19
		40	
10/10/87	11:00 AM		11
		40	
10/12/87	2:00 AM		9
10/12/87	8:00 AM	140	11
10/12/87	9:00 AM	140	13
		140	
10/13/87	1:00 PM		9
		70	
10/15/87	8:00 AM		6
		90	
10/16/87	1:00 AM		9
		40	
10/17/87	2:00 AM		7
10/17/87	3:00 AM	140	9
10/17/87	8:00 AM	90	6
		140	

Date	Hour	Wind Direction (Degress)	Wind Speed (km/hr)
10/18/87	3:00 AM		6
		70	
10/19/87	1:00 AM		7
10/19/87	9:00 PM	140	7
10/19/87	10:00 PM	40	9
10/19/87	12:00 AM	40	9
		40	
10/22/87	5:00 AM		9
10/22/87	10:00 PM	50	6
		40	
10/23/87	4:00 PM		7
		60	
10/24/87	8:00 AM		6
		130	
10/25/87	2:00 AM		7
10/25/87	1:00 PM	130	13
10/25/87	12:00 AM	40	9
		60	
10/26/87	3:00 AM		6
10/26/87	4:00 AM	140	11
10/26/87	8:00 AM	110	9
		120	

ranged from 4 to 19 km/hr at Eugene airport. By comparison over the period of record wind speeds of >15 km/hr occurred approximately 7% of the time the wind was from the east (Figure 2.33).

2.4 DISCUSSION

The fire regime of the portion of Coast Range studied is more complex than indicated by historical accounts. Small, low severity fire episodes were common, primarily in the eastern third (Valley Margin Zone) of the study area. These fire episodes may have gone unrecorded because they occurred before settlement, were small, or had limited economic or safety impact on communities. Moderate severity fires also occurred in this area, leaving natural stands of mixed age class.

Comparisons show marked differences between fire episode size in the Coast Range and with other studies, which could be due to methods differences or to real differences in the fire regimes studied. The average size of fire episodes based on this method (97 km^2) appears much larger than in other studies. By comparison, the fire sizes (not averaged) measured in Hemstrom and Franklin, Teensma, and Morrison and Swanson are measured in hectares, normally below 2,000 ha. Chapter 4 addresses the methods-related effects on fire size for comparisons among regimes.

The study quantified the scale of widespread, severe fires mentioned or discovered in historical sources. Morris (1934) and Zybach (1988) identified several large, destructive fires in or near the study area according to historic and newspaper accounts. Many of these fires, and other fires in the study area documented from interviews of Lake Creek inhabitants by Mintner (1963), Steinhauer (1974) and Rust (1984), correspond to fire episodes identified from the dendrochronologic record (Table 2.8). The largest difference in dates is five years, for the earliest fire on record (1826) and the average difference in dates is 2.5 years.

Observed fire episodes fall into three time periods with distinct characteristics:

1) The pre-settlement period (1478 - 1845) was characterized by smaller, moderate to low severity fire episodes that, except for the fire episodes of 1531 and 1555, occur exclusively in the eastern third of the study area.

2) The settlement period (1846 - 1909) was dominated by the widespread, high severity fire episodes of 1852 and 1871 that have initiated or influenced much of the forest in the study area. Other fire episodes of this period have mixed severity and extent.

3) The fire suppression period (1910 - present) was characterized by predominantly small, low severity fire episodes that are scattered in their occurrence.

The most dramatic contrast in spatial patterns of fire episodes identified in this study was between (1) widespread, severe fire episodes of the mid-1500s and 1850; and, (2) fire episodes confined to the eastern third of the study area (1585-1844). This contrast may be related to climatic and/or cultural influences on the fire regime.

Graumlich and Brubaker (1986) used tree ring chronologies of Northern Cascade mountain hemlock (*Tsuga mertensis*) to assess regional climate trends and to infer relative temperature changes from 1650 to the present. They identified a period of

Table 2.8 Comparison of Dendrochronologically Determined Fire Episodes with Historic Fires

Fire Episode Date from Dendrochronologic Data	Date of Historic Fire (Source)	
1831	1826*	(Douglas' accounts in Davies, 1981)
1844	1840	Elk Mt. Fire (Zybach, 1988)
1852	1849	Siuslaw-Siletz/Yaquina Fire (Clark, 1905; Morris, 1934; Zybach, 1988)
1871	1868	Coos Bay/Coastal Fire (Morris, 1934; Zybach, 1988)
1881		Period of Intense Settlement in Study Area (Mintner, 1963; Steinhauer, 1974; Rust, 1984)
1888		
1900	1902*	Widespread fires in PNW (Morris, 1934)
1909	1910	Lake Creek Valley Fire (Steinhauer, 1974; Rust, 1984)
1920	1919*	Fire year in the Oregon Coast Range (Teensma and others, 1991)
1928	1930	Low Severity Fire in Lake Creek Valley (Steinhauer, 1974)
1934	1936*	Fire Year in Oregon Coast Range (Zybach, 1988); Brandon and Big Creek Fires near Coast
1974		

*Fire year, no specific location in sources relatively cool temperatures for most of the 18th century, from approximately 1680 to 1770. If sub-alpine tree ring chronologies from an interior/continental mountain range can be considered representative of the Oregon Coast Range, this relatively cool period would have been expected to produce fewer fires of lower severity.

In fact, from 1585 to 1844 fire episodes in the study area did tend to have lower severity. From 1666 to 1844, a time period similar to Graumlich and Brubaker's cool period, the severity of fires identified in this study was predominantly moderate or low. Fire episodes occurred at a similar to other time periods during the study, but with lower size and severity during this cool period. These fire episodes may have been concentrated in the eastern third of the study area because the cool period may have prevented fire from starting or entering the western part of the study area, which is in general wetter and cooler than the eastern part.

A shift in the climatic conditions may have triggered the large-scale, high severity fire episodes of the 1850s in the Oregon Coast Range and contributed to their pattern of occurrence. The low severity fire episodes between 1666 and 1844 may have cleared out underbrush and other fuels in the eastern third, but not in the western two-thirds of the study area, thus contributing to increased fuel loads in the western two-thirds of the study area. Fuel loads in the western two-thirds of the study area may have been further amplified by the higher growth rates associated with higher precipitation. Graumlich and Brubaker indicate that a warming period similar to the warmer present-day temperatures started sometime during the 1840s. This transition, combined with high fuel loads, may have set the stage for the severe fire episode of 1852 (1849 in Morris, 1934) described in this study. Sites registering regeneration evidence only for the 1852 and 1871 fire episodes (indicating that the previous stand was replaced by the existing one by the fire episode) are predominantly in the western two-thirds of the study area, whereas fewer sites in the eastern third of the study area record these fire episodes, generally at lower severities.

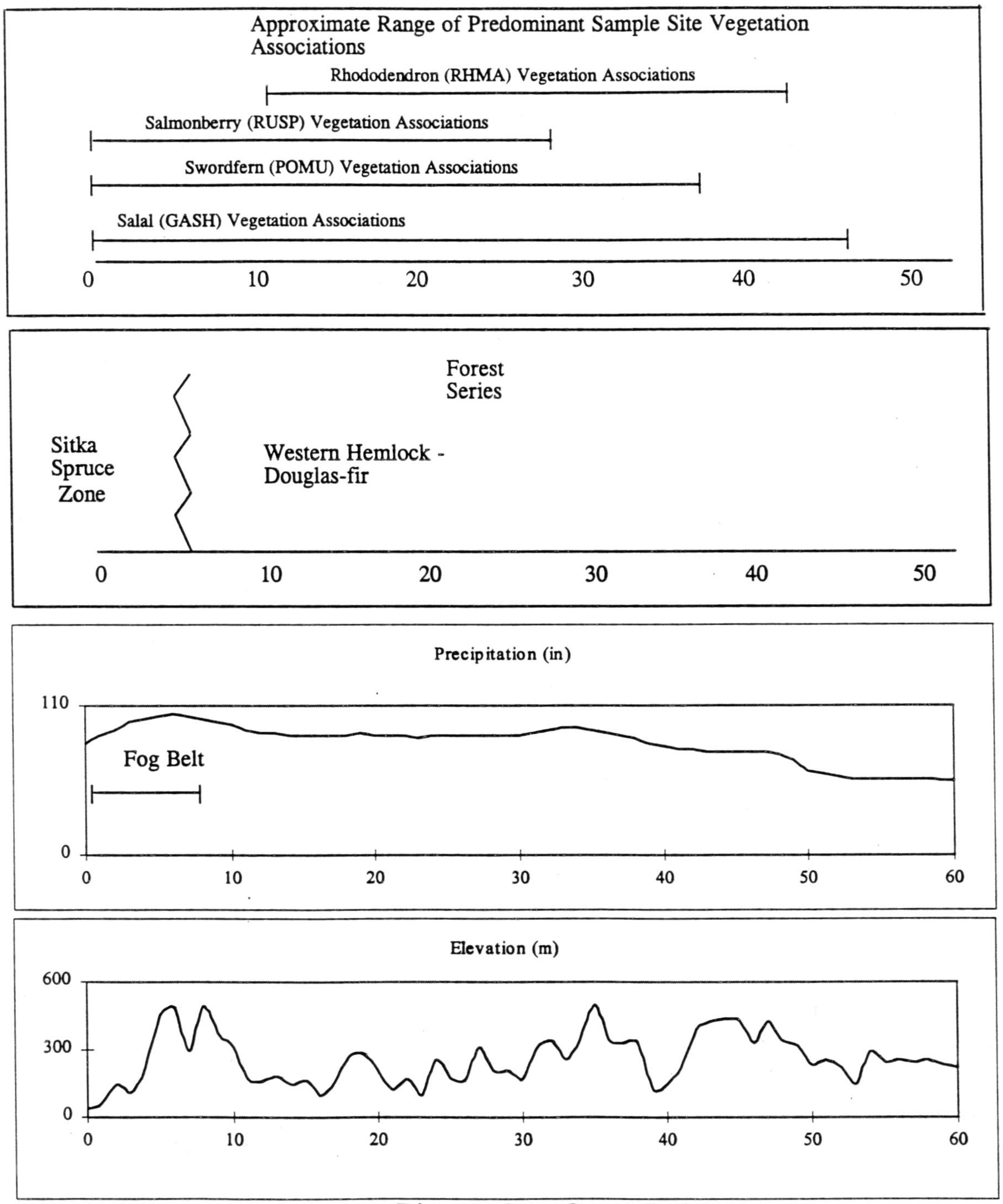
The 1531 and 1555 fire episodes may also have been climate-related. Both the 1531 and 1555 fire episodes are widespread and have many sites recording high severity for the fire episode. These two fire episode dates follow an eight-decade long series of charcoal peaks suggestive of long-term fire, ending approximately 490 years ago (1500) (Long, 1995). Virtually all dendrochronologic fire studies in the Douglas-fir region (Hemstrom and Franklin, 1982; Teensma, 1987; Morrison and Swanson, 1990; and Krusemark and others, 1996) provide evidence of high severity fires in the early 1500s. Hence, climatic cycles may be related to fire episodes that occur at a regional scale.

Cultural factors provide an alternate explanation for the contrast between widespread, high severity fire episodes and Valley Margin fire episodes. The timing of the large-scale, high severity fire episodes of 1852 and 1871 coincides with European settlement in the Coast Range. Activities such as agricultural clearing and other activities may have increased fire ignition and spread fires beyond areas occupied by Native Americans. Except for the fire episodes of 1531 and 1555, fire episodes occurring prior to European settlement were primarily in the Valley Margin and were small-scale with low severity. This pattern could be explained as Kalapuya burning activities in the Willamette Valley that spread into the Coast Range during weather conditions favorable to fire, especially during east wind events.

Changes in the observed fire behavior of the central Oregon Coast Range over time coincide with change in both climate and settlement patterns, hence both sets of causal factors are plausible explanations. Based on the limited wind and lightning data available, fire can be ignited by lightning and driven by east winds in the central Coast Range, even if the combination of circumstances occurs infrequently. Further study would help resolve the climate versus human debate. A region-wide fire regime study, in which information is drawn together from previous studies and on-going work, would clarify these issues from a dendrochronological and archival approach.

Several broad-scale east to west spatial patterns exist which may have influenced the pattern of fire in the study area. The eastern third of the study area was closer to areas in which Native Americans, specifically the Kalapuya, used fire as a resource management tool (Johannessen and others, 1971; Boyd, 1986). For the nine year record available the eastern third of the study area experienced slightly more lightning strikes and positively charged lightning strikes (Figures 2.8 and 2.9). Precipitation, forest type, and vegetation groups change with distance from the ocean (Figure 2.34). Yearly precipitation (Daly and others, 1994) remains relatively high until 40 - 50 km from the ocean, then declines towards the Willamette Valley. The fog belt occurs up to approximately 5 - 10 km inland from the ocean, and is dominated by the Sitka spruce

Figure 2.34 A Study Area Transect of Vegetation Type, Precipitation and Elevation



Distance from Ocean (km)

forest type. The western hemlock - Douglas-fir forest type predominates from the edge of the fog belt to the Willamette Valley. Vegetation association groups (Hemstrom and Logan, 1986) exhibit overlapping distributions across the transect in terms of distance from the ocean. The Salmonberry (*Rubus spectabilis*; RUSP) association is located within 30 - 35 km of the ocean, whereas the Rhododendron (*Rhododendron macrophyllum*; RHMA) association is found in closer proximity to the Willamette Valley (Figure 2.34).

The higher vegetative growth, milder temperatures and greater precipitation, including fog close to the ocean, of the western and central areas of the Coast Range compared to eastern areas likely produce differences in fuel loads of these two areas. Greater plant growth produces higher fuel loads which can sustain and increase the energy available for a fire. Higher precipitation reduces the depletion of total water stored in plants, and increases plant growth and associated fuel loads. Relatively low average temperatures reduce the potential for fire, because fuels dry out more slowly, and fire, if started, is less likely to maintain the heat necessary to continue. Fog along the ocean maintains high relative humidities, and prevents the spread (and at times start) of fires (Agee, 1993). Lower frequency of fire that would be expected from the interaction of temperature, precipitation and humidity would also add to fuel loads. In contrast, in the eastern portion of the study area the higher frequency of fire, resulting from drier conditions and closer proximity to human and possibly lightning ignitions, would have removed a greater quantity of fuels.

In Oregon, Sitka spruce is the predominant forest type in the fog belt along the ocean (Juday, 1977; Agee, 1993). Sitka spruce is a fire "avoider" (Rowe, 1981), it occupies environments where fire is extremely rare. The principal disturbance agent affecting Sitka spruce is windthrow (Ruth and Harris 1979). With dense, low branches and shallow roots, Sitka spruce has very little fire resistance. When fire does occur in the Sitka spruce zone, it will often have very high severity and related mortality even though the intensity of the fire was moderate to low (Agee 1993). Consequently, the record is easily erased by fire. The long history of land use, resulting in ease of access and an intensive period of extraction of spruce for airplane production during World War II, has added to record erasure in the Sitka spruce zone. This makes it difficult to accurately determine the fire regime and for these reasons no attempt was made to determine the fire regime in the Sitka spruce zone.

Little work has been done on the fire regime of the Sitka spruce forest type, but it appears that fire events are rare in this zone. Fahnestock and Agee (1983) used age-class data to estimate a fire-return interval of 1,146 years in Sitka spruce forests of western Washington. Agee (1993) quotes studies by Cowlins (1934) and Anonymous (1983) as determining disturbance cycles in the Sitka spruce zone between 200 and 500 years.

In contrast, the western hemlock - Douglas-fir forest type is well adapted to fire. Once mature, Douglas-fir is a fire resister (Rowe, 1981; Agee 1993), adapted to surviving low to medium intensity burns. Douglas-fir has thick bark to protect the cambium, deep roots, and as it matures it drops limbs which prevents fire spread into the crown, and is the most fire-resistant tree species in the Coast Range (Starker, 1934). Due to its characteristics, Douglas-fir can survive the low to medium intensity fires that often kill Sitka spruce, western hemlock and western red cedar (Starker, 1934). These fires will often only scar Douglas-fir by burning off some of the outer bark and the cambium underneath, or by heat transfer through the bark killing the cambium (Gill, 1974). In the Coast Range scars on Douglas-fir are quickly covered by new cambium and bark growth.

The predominance of Douglas-fir trees at sample sites in the study area is an indication of the importance of fire as an ecological process in the study area. Non-fire adapted trees were absent or far less common at sample sites. Sitka spruce was not observed beyond the fog belt. Very little western hemlock was observed at sample sites, especially in the eastern third of the study area. Western red cedar was often found in proximity to riparian areas, and was limited in occurrence. Douglas-fir regenerates well on bare soil associated with moderate and high severity fires (Munger, 1930; Agee, 1993). Isaac and Meagher (1936) found regeneration of Douglas-fire following the Tillamook burn of 1933 to be widespread after two years, apparently due to surviving old growth trees which had mast years (a year of high production of seed, often from a dying tree) before dying from the effects of the fire.

Douglas-fir fire resistance appears strongly linked to its predominance across the study area. Douglas-fir would have been better-adapted to survive the low to moderate severity fires that occurred in the eastern third of the study area than other tree species. Surviving Douglas-fir trees would have been a nearby seed source for gaps that may have developed from a fire.

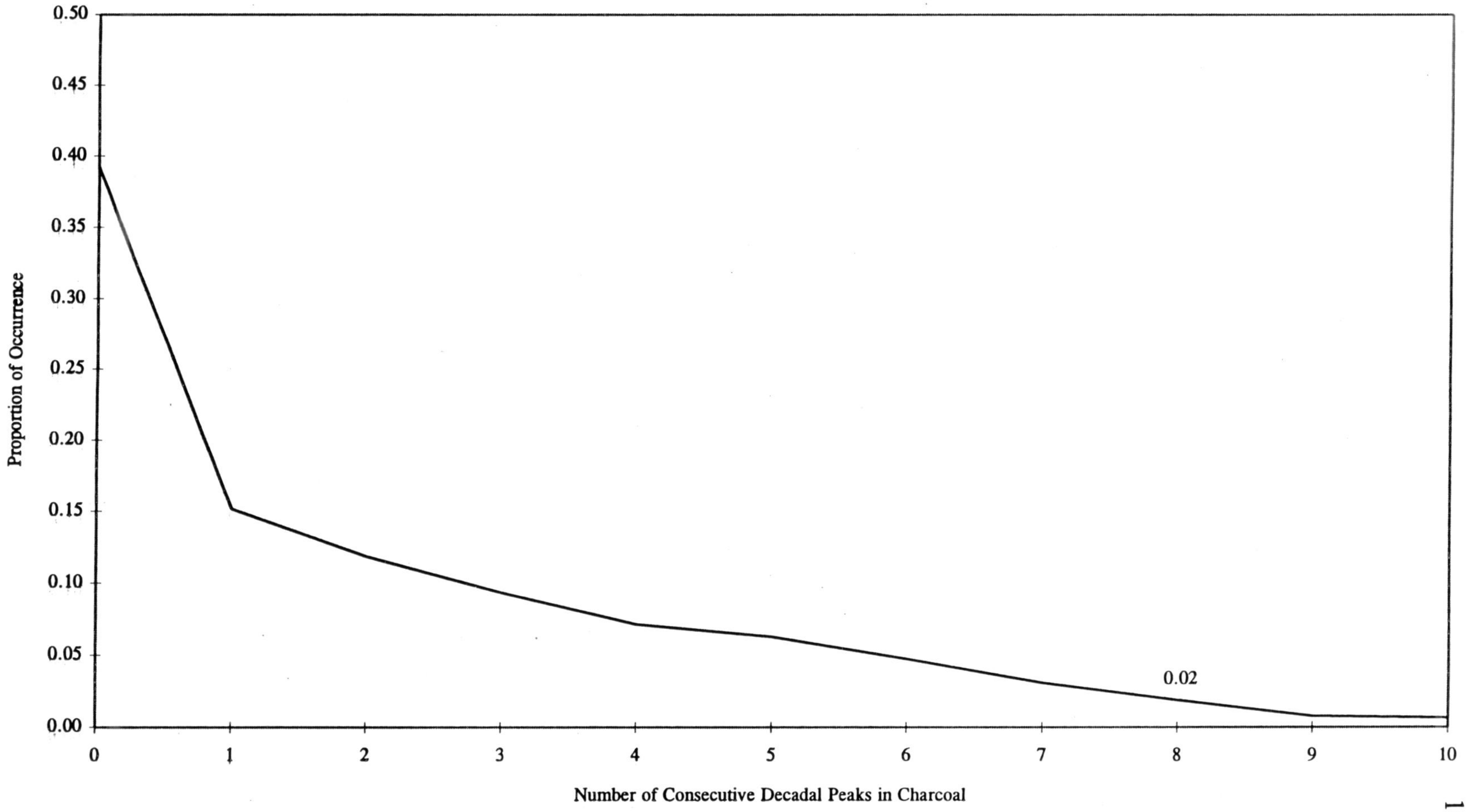
Surviving widespread, high severity fires may be a potent evolutionary adaptation that enables Douglas-fir to predominate in the Coast Range under present and recent conditions. When high severity, widespread fires occurred, there would have been a higher probability of old growth Douglas-fir trees surviving than other tree species. Those trees would have been present to broadcast seeds and capture large areas following fire. This would have been very advantageous in the Coast Range, as shrub and herb growth from species such as salmonberry, thimbleberry (*Rubus parviflorus*), salal, red alder (*Alnus rubra*), bracken fern (*Pteridium aquilinium*), and other plants are aggressive in capturing sites following disturbance (Franklin and Dyrness, 1973; Hemstrom and Logan, 1986). Seed dispersal for Douglas-fir occurs by wind; the seeds will only travel a limited distance (<300 meters; Isaac, 1930). For Douglas-fir to have captured large areas quickly following high severity fires, seed sources would have had to have been relatively well distributed compared to competitors such as salmonberry, for which seeds are widely distributed by birds.

There was a similar maximum length of record and associated age class, approximately 450-500 years, in this study as in other areas previously studied or under study in the Douglas-fir forests west of the Cascades (Hemstrom and Franklin, 1982; Teensma, 1987; Morrison and Swanson, 1990; Teensma and others, 1991). Several of these studies have reported age classes upwards of 700 years, but stands of these ages are rare and limited in extent. The vast majority of the region's dendrochronological record is limited to approximately 500 years or less (Franklin and Dryness, 1973; Agee, 1991). Long (1995) reported eight consecutive decades of fire from the charcoal record that correspond to the years 1430 - 1500, or 490 to 570 years ago. A series of eight consecutive decades recording a fire was very infrequent in Long's record, occurring only approximately 2% of the time in the 9,090-year record (Figure 2.35). This record, as well as the widespread evidence from the studies above, suggests a high degree of fire activity across the region at this time.

Addressing the potential for significant region-wide fire approximately 500 years ago is an important avenue for future research. A large-scale approach to this potential regional phenomenon would address climatic and other long-term influences of fire, and make use of multiple data sources to verify fire occurrence. Additional charcoal and pollen analysis of lake cores would provide a better understanding of the pattern of fire and vegetation change at a Holocene temporal scale over time in the region. Comparing the results from the last 500 years with the entire Holocene record would add greatly to the understanding of the changes forests have undergone in the recent past compared to the last 10,000 years, and be a significant input to ecosystem management approaches and activities.

There are several issues to address when interpreting fire frequency. Only the sites that recorded at least three fires can be included in MFRI calculations; 60 of 178

Figure 2.35 Proportion of Occurrence of Consecutive Decades of Charcoal Peaks Indicating Fire
(compiled from Long, 1995)



sites qualified in this study. By contrast, there were 78 sites with only one fire recorded, and 40 sites with two fires recorded. Sites with one fire recorded were predominantly in the western (I/C) portion of the study area, and the record at these sites initiated primarily from the fire episode of 1852 (Figure 2.36).

Sites which recorded two fires, and had only a single fire return intervals (SRI), showed differences in the fire frequencies of the two zones. There were 15 eastern (VM) sites which recorded only two fires; SRIs ranged from 20 to 240 years. In contrast, there were 29 western (I/C) sites which recorded two fires. The distribution of SRIs of western (I/C) sites which recorded only two fires differed dramatically from eastern (VM) sites, with 13 (45%) of western (I/C) site SRIs between 290 and 330 years, with an average SRI for these 13 sites of 307 years (Figure 2.37a).

Differences in fire interval distributions between zones was also noticeable for sites which recorded three or more fires, and in the distribution of all fire return intervals. Eastern (VM) sites which recorded three or more fire episodes had predominantly short fire return intervals: 71% of these fire return intervals were 70 years or less, and only 2% of fire return intervals at sites with three or more fires were greater than 250 years. In contrast, 26% of the fire return intervals of western (I/C) sites for sites with three or more fires were greater than 290 years (Figure 2.37b). This difference was repeated in the distribution of all fire return intervals: eastern (VM) sites fire return intervals were characterized by a high proportion (69%) of fire return intervals 70 years or less and only 4% of fire return intervals greater than 250 years,

Figure 2.36 Number of Single Fire Episode Sites for each Zone

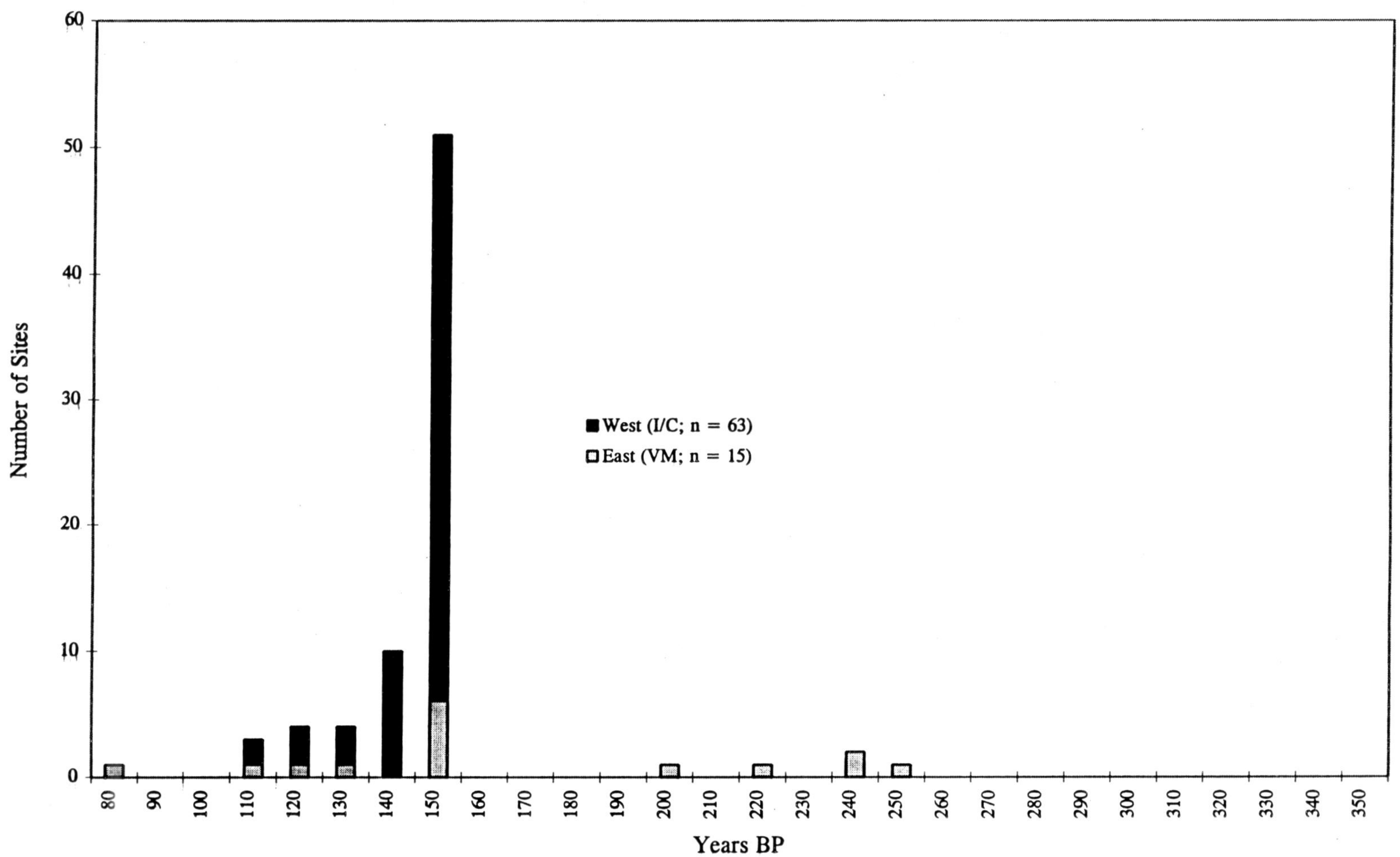
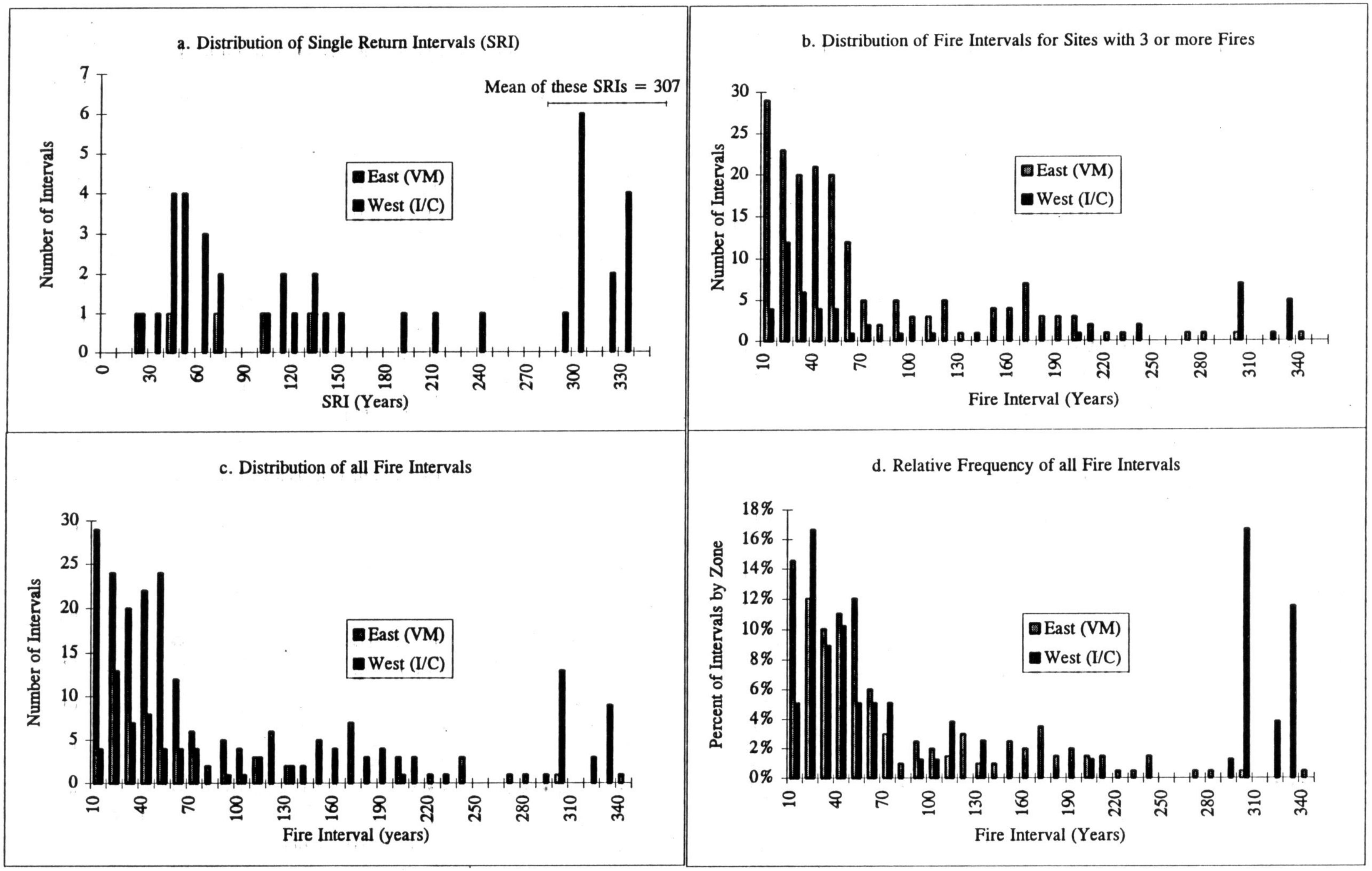


Figure 2.37 Comparison of Fire Frequency Intervals



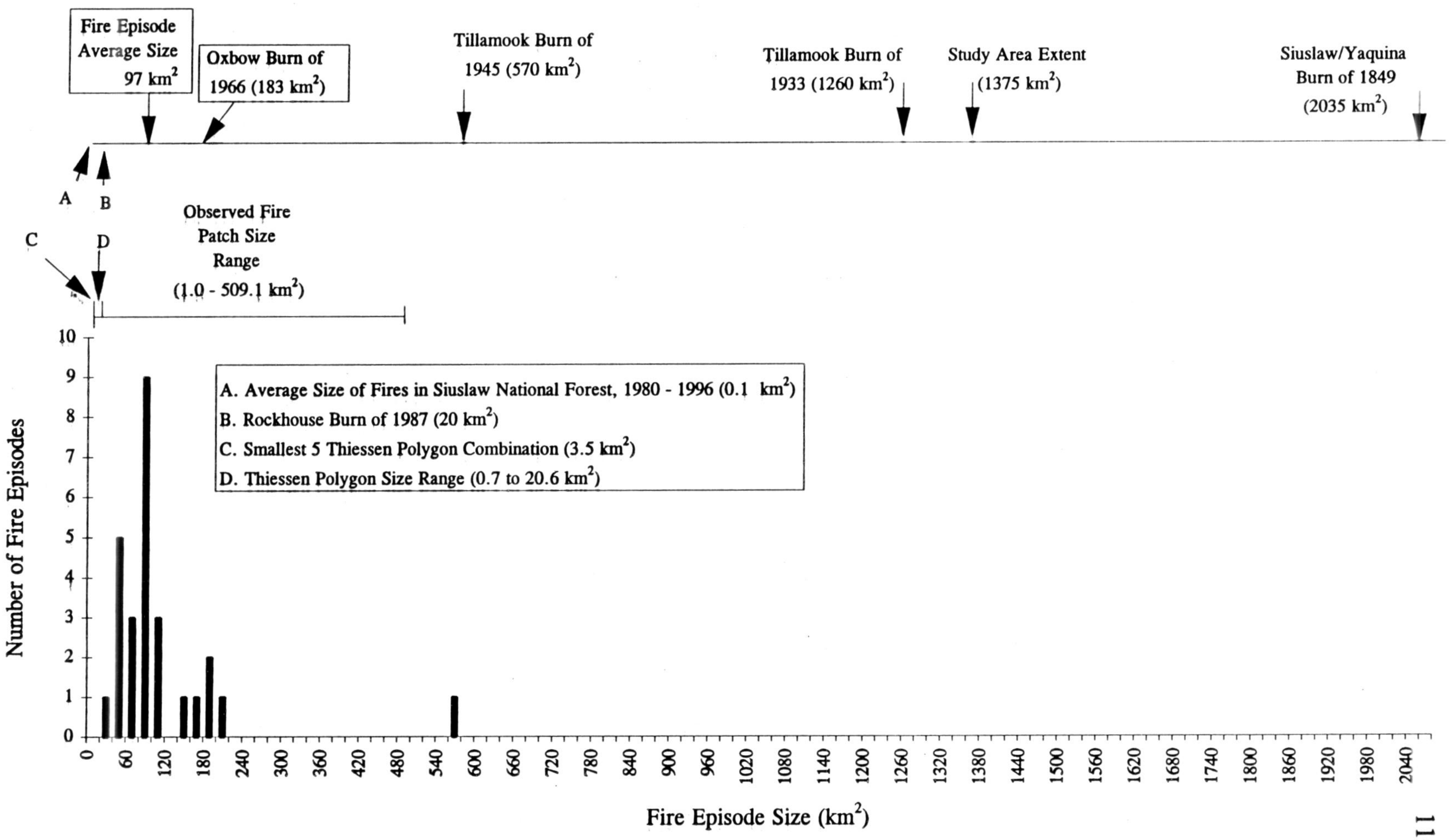
while 34% of all fire return intervals of western (I/C) sites were greater than 290 years (Figure 2.37c and d).

The calculated MFRI of 75 years was a suitable measure of fire frequency for the eastern (VM) portion of the study area, as it was derived from the fire record of 44 (60%) eastern (VM) sites that recorded the three or more fires needed for estimating MFRI. In the western (I/C) portion of the study area, MFRI was less useful as an indicator of fire frequency. Only 16 (16%) of the sites in the western (I/C) zone experienced the three or more fires needed for estimating MFRI, most likely a result of erasure from the fire episode of 1852. An examination of all fire return intervals revealed 15 (15%) of the sites in the western (I/C) zone that recorded only two fires had single fire return intervals over 290 years. Of the 16 western (I/C) sites that did record three or more fires, 14 sites had at least one fire return interval greater than 290 years.

The contrast between the MFRI and single fire return intervals in the western (I/C) zone indicates that other methods of describing fire frequency can be useful in characterizing the fire regime and related forest conditions, especially in forests where fire has erased a large portion of the record, or where fire is relatively infrequent compared to the length of record. For instance, the predominance of long (>290 years) fire return intervals prior to the fire episode of 1852 in the western (I/C) sites indicates there likely was a period of approximately 300 years in this zone when either no fires occurred, or fires that did occur were limited enough in scale that the methods used in this study could not identify them. This has important implications for the forest age class in the western (I/C) portion of the study area prior to the fire episode of 1852. If, as the record suggests, the western (I/C) zone did not experience high severity, large-scale fires between 1555 and 1852, then an age class of approximately 300 years or more could have covered much of the western (I/C) portion of the study area prior to the fire episode of 1852.

The distribution of the estimates of fire episode sizes compared to historic and reported fires indicates that the sample grain was too large to identify small fires, and the extent of the study led to underestimation of the size of very large fires. There is a broad range of reported fire sizes in the Coast Range, from an average of 0.1 km^2 for fires in the Siuslaw National Forest from 1980 - 1996 (John Kwait, pers. comm.) to 2035 km^2 for the Siuslaw/Yaquina burn of 1849 (Morris, 1934) (Figure 2.38). The sampling grain for this study was large (7.7 km^2/site) compared to other similar studies (e.g. Hemstrom and Franklin, 1982; Teensma, 1987; Morrison and Swanson, 1990; see Chapter 4). The method for fire episode identification in this study required five sites recording a fire episode. The area of the smallest five Thiessen polygons combined was 3.5 km^2, but these polygons never associated as a unique set to identify a fire episode. Given the characteristics the sampling grain, rule sets, and requirement of at least five sites and associated Thiessen polygons to identify and size a fire episode, smaller fires, perhaps less than 10 km^2, that occurred over the period of record were likely not identifiable by this study. The size of the smallest fire episode identified was 19 km^2.

Figure 2.38 Size Distribution of Fire Episodes and Reported Fires (km^2)



The size of very large fires was likely underestimated due to the extent of the study and the erasure of the fire record. The fire episodes of 1531, 1555, 1852 and 1871, probably occurred outside the study area, and the actual size of these fires was larger than estimated. As an example, the estimate for the fire episode of 1852 was the largest in this study (544 km^2), yet the Siuslaw/Yaquina Burn of 1849, which is recorded as the fire episode of 1852, was reported to be 2035 km^2 (Morris, 1934). The size of the fire episodes of 1531 and 1555 were likely underestimated because subsequent fires erased the record of occurrence at many sites. Erasure reduced the number of sites retaining a record of these early fire episodes, and thus the size estimate was also reduced.

2.5 CONCLUSIONS

1. The 27 fire episodes of the past 516 years averaged 97 km^2 in size, with a range of 18 to 544 km^2. On average 6.4 km^2, or 0.5% of the study area, burned per year. The NFR for the study area over the entire period of record was 271 years, and the MFRI for the entire study area was 85 years. Site fire severity was mixed within and between fire episodes, reflecting the complex interaction of fire behavior with patterns of wind, fuel loads, vegetation, fog, precipitation, and topography.

2. The MFRI estimate of 75 years for the eastern, Valley Margin Zone was a suitable estimate of fire frequency for this zone. The MFRI estimate of 115 years for the western Interior/Coast Zone was probably a low estimate of fire frequency, given the few sites available to carry out an MFRI calculation, and the occurrence of long (~300 year) fire return intervals at many sites in this zone.

3. This study identified and sized fire episodes in the middle portion of the actual fire size distribution. Smaller fires, perhaps less than 10 km^2, were unlikely to be identified as fire episodes in this study due to the sampling grain and rule sets incorporated to identify fire episodes. Fire episodes larger than the extent of the study area, or occurring outside the study area, were identified but sizes were underestimated. The size of earlier fires, especially the widespread fire episodes of 1531 and 1555, were also probably underestimated due to the subsequent erasure of the record by later fires.

4. Broad-scale spatial patterns of fire are oriented in an east to west direction, and appear to be related to the pattern of precipitation and related fog patterns, vegetation

and fuel load patterns that are coupled to precipitation, and the pattern of ignitions by humans and lightning.

5. Fire episode patterns reflected the influences of spatial and temporal patterns. The occurrence of widespread high severity fire episodes starting in the 1850s may have been related to changes in climate, land use, or some combination of the two. The pattern of severity of these fire episodes may have resulted from the higher fuel loads of the wetter part of the study area. For approximately 300 years prior to climatic and land use changes only Valley Margin fire episodes occurred in the drier, eastern parts of the study area, with mixed severity. Fire episode patterns after 1910 are limited in size and are mostly of low and moderate severity, reflecting the onset of fire control activity in 1910.

6. Smaller-scale spatial patterns such as aspect and hillslope position did not appear to affect fire patterns in the analyses in this chapter. A smaller-scale analysis focusing on these patterns was carried out in Chapter 3 to identify potential influences on the pattern of fire occurrence at these scales.

CHAPTER 3. SPATIAL ANALYSIS OF FIRE PATTERNS

3.1 INTRODUCTION

Several environmental variables may affect the pattern of fire in a landscape (Agee, 1993). At the broadest spatial scale, climate and weather, especially precipitation and relative humidity, influence the conditions for ignition and fire spread by regulating properties of fuel moisture, and vegetation and fuel amounts (Agee and Huff, 1987; Johnson and Larsen, 1991; Agee, 1993; Bessie and Johnson, 1995). Lightning and wind are also important weather influences on fire (Agee, 1993). Lightning is an important ignition source, especially positively charged strikes of long duration (Fukuay, 1980). Wind can dry fuels, drive fire towards additional fuels, and deliver extra oxygen which produces a greater intensity of burn (Rothermel, 1983).

At intermediate spatial scales, landforms influence precipitation, wind, and other factors that affect fire patterns (Swanson and others, 1988). Higher elevations are generally cooler, and can affect the distribution of vegetation types (Zobel and others, 1976) and maintain a snowpack longer, thus reducing both the growing season and the fire season (Agee, 1993).

At finer spatial scales, greater solar radiation exposure due to steeper slope angle or aspect reduces fuel moisture and fuel amounts (Swanson and others, 1990). Fuel preheating on steeper slopes increases the intensity and spread of fire (Agee, 1993). At a smaller spatial scale, lower hillslope positions have been shown to have lower frequency and severity of fire as reflected in age class and forest type than upper hillslope positions; these differences were due to higher fuel moisture content and reduced exposure to flame intensity and lightning strikes (Romme and Knight, 1981). At the finest spatial scale, patches of highly flammable vegetation types may be associated with localized high fuel flammability (Mutch, 1970) and fast growing vegetation types can produce high fuel loads (Agee, 1993).

Complex ecological systems functioning in a landscape, such as the combined processes influencing fire, may be organized within a hierarchy of spatial scales (O'Neill and others, 1992). A hierarchy of spatial scales refers to the interactions that occur across different spatial scales between ecological patterns and processes (O'Neill and others, 1989). Scale interactions may be between patterns that are nested spatially, such as hillslope positions within aspect (Pickett and others, 1989). Ecological processes that influence and produce patterns may operate at specific spatial scales. Outside such a domain of scale (Wiens, 1989) the degree of influence of a process on a pattern can be altered significantly. Scale interactions may occur between processes across domains of scale. Processes operating across domains of scale may produce complex interactions such as those between landforms and precipitation patterns or between landforms and wind patterns.

Hierarchical scale interactions between environmental variables are expected to have influenced fire patterns. Precipitation is influenced by very broad-scale atmospheric phenomena, and is also affected through orographic lifting by landforms.

Vegetation type is strongly associated with precipitation patterns (Zobel and others, 1976). Increased solar radiation exposure due to steeper slope angle or aspect reduces moisture availability (Stage, 1976) and affects vegetation types (Agee and Kertis, 1987) and fuel amounts and thus may also affect fire patterns (Agee, 1993).

Pattern-process interactions are a fundamental component of landscape ecology studies (Turner, 1989). By assessing the influence of the patterns of environmental variables on the pattern of fire, the influence of the processes associated with environmental variables on the process of fire can be interpreted (Turner and others, 1990). Many statistical methods are available and have been used to describe and to test hypotheses about pattern - process interactions, including but not limited to point-pattern analysis (Boots and Getis, 1979), spatial autocorrelation analysis (Legendre and Fortin, 1989; Rossi and others, 1992), logistic regression (Wemple and others, 1996) and neutral models (Gardner and others, 1987; O'Neill and others, 1992).

The objectives of this chapter are to test the influence of the patterns of important environmental variables, namely precipitation, landform, elevation, slope angle, aspect, vegetation type, and hillslope position, on the pattern of fire occurrence as determined from the dendrochronologic record (ca. 500 years).

3.2 METHODS

3.2.1 Relationship of Environmental Variables and Fire: Hypotheses

Each environmental variable tested was expected to have influenced the pattern of fire occurrence as observed in the dendrochronologic record. The influence on the pattern of fire occurrence due to the patterns of precipitation, landforms, elevation, slope angle, aspect, and vegetation type was investigated using logistic regression models (Hosmer and Lemeshow, 1989). The influence on the pattern of fire occurrence by hillslope position was investigated using numerical and graphical comparisons of fire frequency and severity by hillslope position.

I hypothesized that the widespread, severe fire episodes were more likely to occur in the western and central parts of the study area than in the eastern part of the study area. This was because the western and central parts of the study area have higher mean annual precipitation than the eastern part of the study area (Daly and others, 1994). Higher precipitation and the resulting higher fuel moisture content were expected to result in increased primary productivity and produce higher fuel loads in the central and western parts of the study area compared to the eastern parts of the study area. By contrast, the less severe and less widespread fire episodes were expected to have occurred in the drier, eastern part of the study area where fuels would have been drier and more able to ignite and burn, and fuel loads would have been reduced due to less vegetative growth and more frequent occurrence of fire.

It is expected that fire patterns were to some extent affected analogously by landform as by precipitation patterns because they are correlated. Landforms with higher elevations receive greater precipitation due to orographic effects on atmospheric moisture. in Fire was expected to have occurred less frequently at higher elevations than at lower elevations due to the greater precipitation of higher elevations. Fire was expected to have occurred more frequently on steeper slopes than on less steep slopes due to the greater ease of fire spread on steep slopes. Widespread high, severity fire episodes were more likely to occur on north-facing aspects due to increased fuel loads and fuel moisture content that derive from less exposure to the drying effect of solar radiation than other aspects. Widespread, high severity fire episodes were expected to have occurred on sites with wetter vegetation types where fuel loads were greater from higher growth. It was expected that upper hillslope positions experienced more frequent, higher severity fire episodes than lower hillslope positions due to the greater tendency of fire to burn uphill and to burn hotter at higher hillslope positions.

3.2.2 Logistic Regression of Environmental Variables

For the analysis of the influences of environmental variables on fire, logistic regression provides a means to statistically test the differences in effects of different categories of environmental variables such as precipitation and landforms. Logistic regression fits a model of explanatory variables to a binary response variable with value 0 or 1. The distribution of the responses for each category of explanatory variable is converted to proportions to determine the mean of the responses. Proportions of responses of 1 for a given x value are plotted vs. the values of the explanatory variable(s). This procedure produces a curve which approximates the logistic curve based on the scientific constant e ($\simeq$ 2.7081) (Hosmer and Lemeshow, 1989).

The sum of squares of the deviance residuals (the deviance) are used in a drop-in-deviance test to determine whether an explanatory variable produces a significant improvement in the ability of a model to explain the outcome and distribution of the response variable (Ramsey and Schafer, 1997). If the inclusion or removal of a variable in a model is significant, the drop in deviance should have a χ^2 distribution. The drop in deviance is calculated as follows:

$$\text{Drop in Deviance} = (\text{Dev}_{red} - \text{Dev}_{full})$$

where Dev_{red} = the deviance of the reduced model (variable of interest not included); and,

Dev_{full} = the deviance of the full model (variable of interest included)

The degrees of freedom for this test is the drop in degrees of freedom between the reduced and full models and is calculated as follows:

$$(\text{df}_{red} - \text{df}_{full})$$

where df_{red} = the degrees of freedom of the reduced model (variable of interest not included); and,

df_{full} = the degrees of freedom of the full model (variable of interest included)

The drop in deviance is compared to a to χ^2 distribution to determine an associated p-value. For this study a p-value < 0.05 was used to indicate if the explanatory variable (or model tested) was significant.

The β coefficient is the estimate of the slope of the logistic curve. The odds ratio, ψ, is the relative probability of occurrence for each category (or, if continuous, each increase) of explanatory variable compared to the reference category (r), and is $e^{\beta(I)}/e^{\beta(r)}$ for each category (I) (Hosmer and Lemeshow, 1989). The reference category is either the category with the most responses of 1 in the sample, or the category that when assigned as the reference category most often produces odds ratios > 1 for other categories.

Interpretation of the odds ratio gives a comparison of the relative occurrence of different categories of an explanatory variable. The odds ratios are useful in ecological studies where different environmental conditions (e.g. N,S,E,W aspects) can be statistically compared to assess the relative probability of responses of the binary response variable (Trexler and Travis, 1993).

I used logistic regression to determine statistical associations between categories of the explanatory environmental variables precipitation, landform, aspect, vegetation, slope, and elevation and the binary response variable of fire occurrence at a site. These logistic regression models of fire episodes were used to describe the influence of the patterns of the explanatory environmental variables on the pattern of fire occurrence.

3.2.2.1 Initial Data Configuration and Analysis

Preliminary runs were carried out to assess the structure of the data and determine the appropriate data composition for the logistic regression analysis. To carry out a logistic regression requires an adequate number of occurrences for a model to converge (Hosmer and Lemeshow, 1989). Preliminary runs were carried out on the eighteen fire episodes with at least ten sites showing evidence of a fire episode in question. All 178 sites were included in these runs. The fire episodes of 1666 (10 sites recording the fire episode), 1751 (11 sites), 1900 (11 sites) and 1928 (16 sites) failed to converge for any variable and were dropped from analysis, leaving fourteen fire episodes. The output of the initial runs on fourteen fire episodes was examined and the best reference category for each variable was determined. These fourteen fire episodes were tested in a series of preliminary runs and eventually reduced to five fire episodes that were tested. A total of 43 sites were removed from analysis because the categories they represented were not sufficiently well represented and generated infinite values of the parameter estimates. In some cases similar categories were combined to help correct this problem. After the preliminary runs were examined, only fire episodes with at least 15 sites showing evidence of the fire episode in question were used to examine correlations between environmental variables and fire episode occurrence. In summary, for the dataset with 135 sites, the six fire episodes with at least 15 sites showing evidence of a fire were the fire episodes of 1531 (18 sites), 1555 (18 sites), 1852 (78 sites), 1871 (22 sites), 1888 (20 sites), and 1920 (22 sites). These fire episodes were used in the final analysis as response variables.

3.2.2.2 Environmental Variables used in Logistic Regression Models

The variable Zone was a categorical variable which addressed the potential influence of precipitation on the fire regime. Precipitation isolines from the PRISM Model (Daly and others, 1994) were mapped across the study area to identify precipitation patches with differences in precipitation strong enough to delineate distinct areas. Two regions, approximately separated by the 229 cm precipitation isoline, were identified. These areas were identified as the Interior/Coast (IC) and Valley Margin (VM) Zones (Figure 3.1). Sites were assigned to each of these Zones (Figure 3.2).

Aspect was a categorical variable which addressed the potential influence of predominant sun angle on the fire regime. Each site had been assigned an aspect of N (315^0 to 44^0), E(45^0 to 134^0), S(135^0 to 224^0), or W(225^0 to 314^0) based on the compass reading of the prevailing direction the site was facing. Sample sites by aspect were distributed evenly within the study area (Figure 3.3).

Landtype Association (LTA) was a categorical variable derived from the Siuslaw National Forest Land Systems Inventory (Berry and Maxwell, 1981). GIS data files and maps of Landtype Association were obtained from the Siuslaw National Forest and overlaid on site locations to determine their classification. Eight of the original Landtype Associations were not included in the analysis as they covered very small

Figure 3.1 Precipitation Patterns and Derived Zones (from Daly and others, 1994)

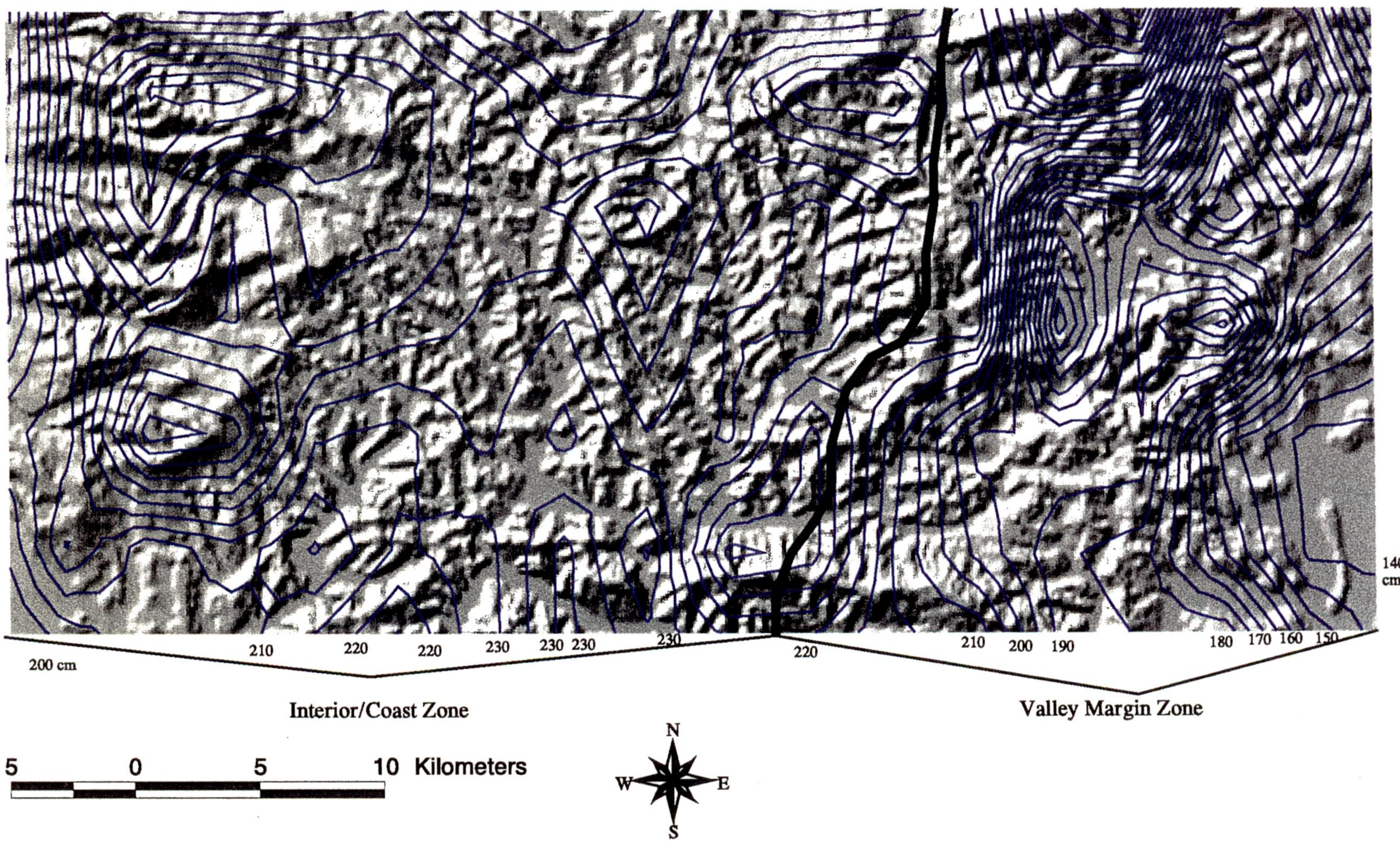


Figure 3.2 Precipitation Classes for Sites. Isolines are 5 cm Contours (from Daly and others, 1994)

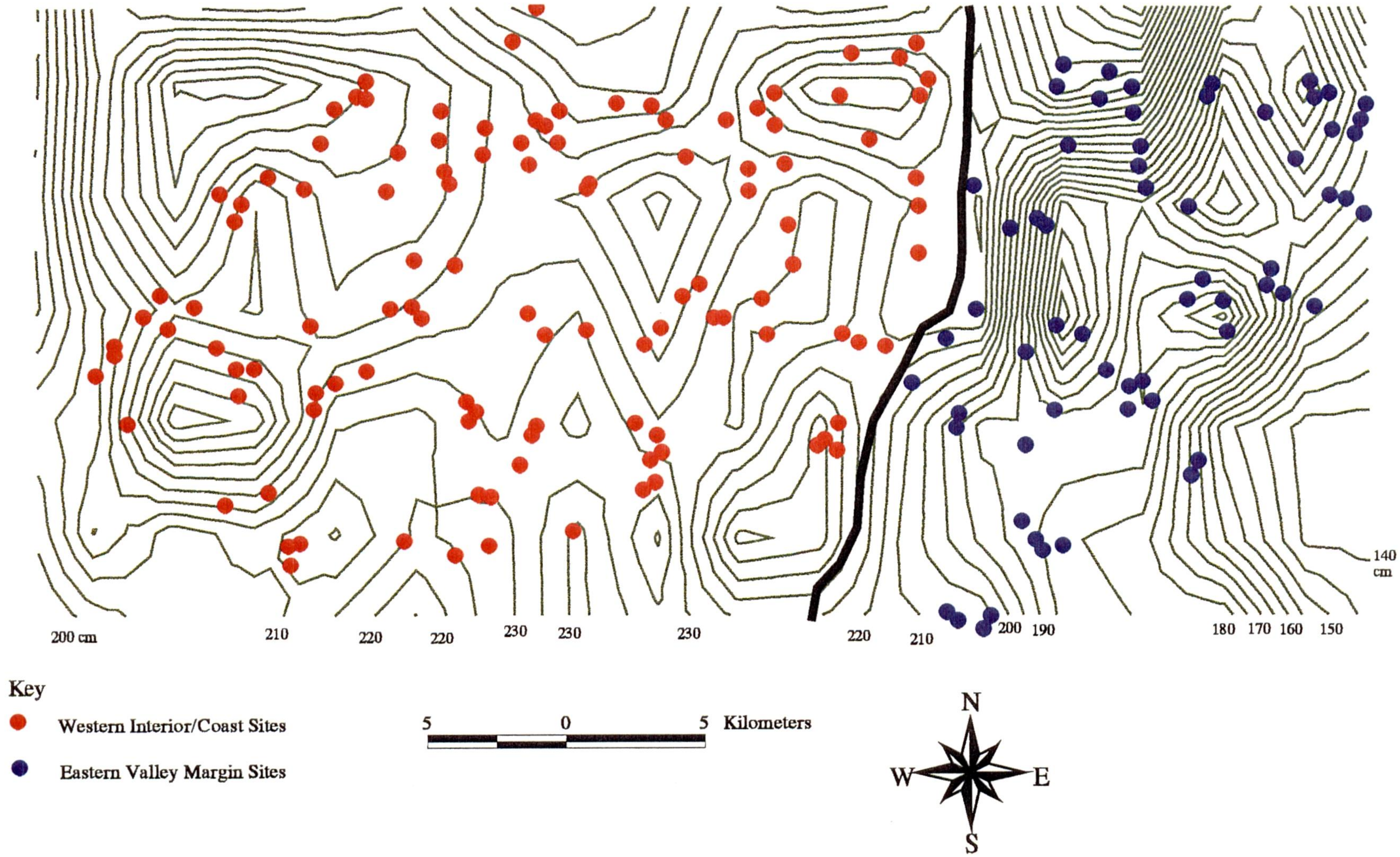
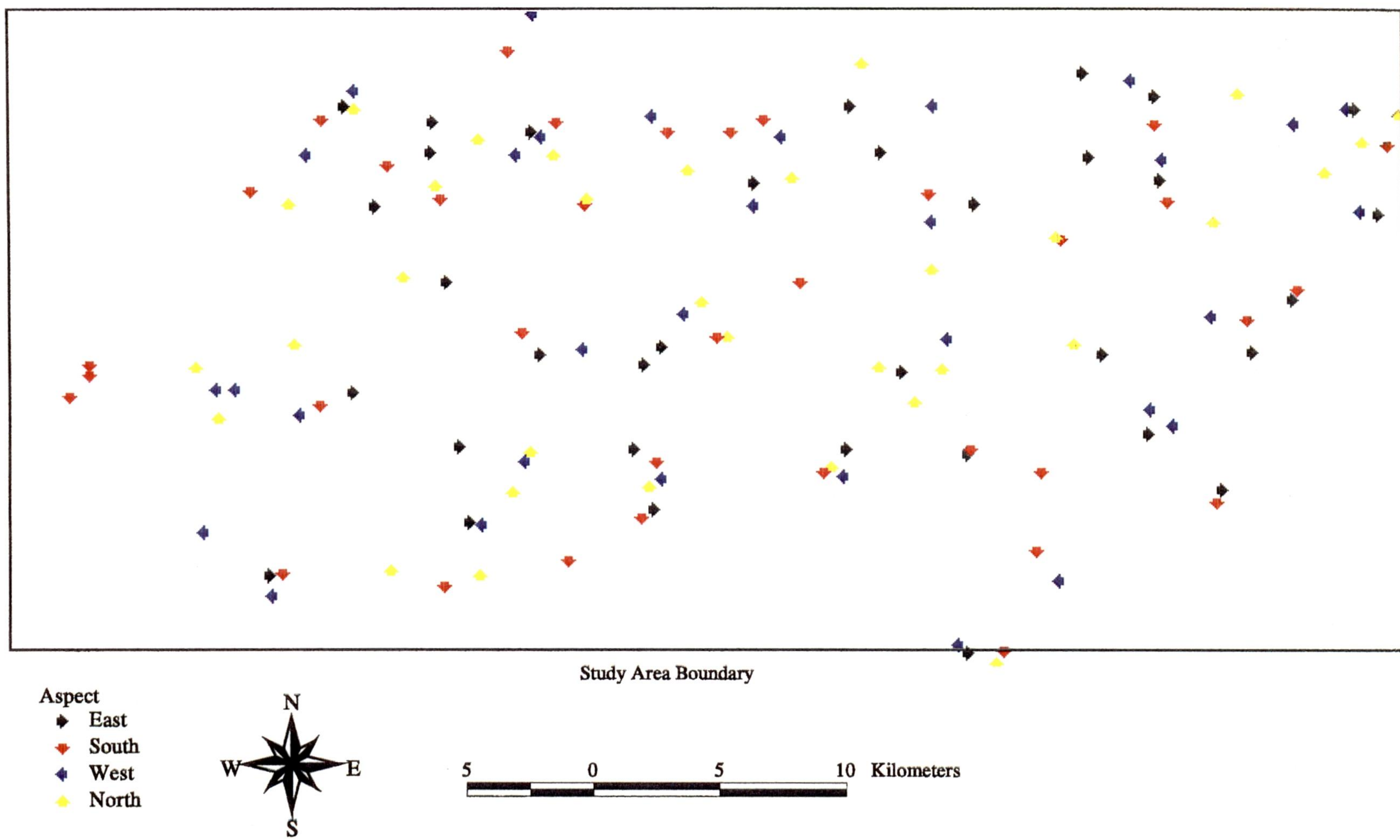


Figure 3.3 Distribution of Sample Sites by Aspect



portions of the study area that lacked sample sites (2Y, 3F1, 3L, and 4J), were representative of mostly non-forested areas (3Z, 3A, and 3H), or were poorly represented in the sample (3M) (Figure 3.4). A total of 27 sites were removed from analysis based on the distribution of site LTAs. The LTA descriptions by Berry and Maxwell (1981) of LTAs 3C, 3C1 and 3C2 were very similar; these categories were combined into the 3C category of the LTA variable. The LTAs included in the analysis were 3B, 3C, 3T, and 3F, representing the Cuestaform Lands (interior mountains with medium relief and drainage texture, 3B), the Interior Fluvial Lands (interior mature topography with medium relief and drainage texture, 3C), the Igneous/Sedimentary Contact Lands (hummocky topography with low relief and medium drainage texture, 3T) and the Fine-Textured Fluvial Lands (interior mature topography with high relief and medium drainage texture, 3F) (Berry and Maxwell, 1981). The sites used in the logistic regression were coded in a GIS, and a map was generated to evaluate the distribution of sample sites based on LTA (Figure 3.5).

Vegetation Association Group (VAG) is a categorical variable that was determined for each site in the field using the Siuslaw National Forest Plant Association and Management Guide (Hemstrom and Logan, 1986). Sixteen specific VAGs in the Western Hemlock series that covers the study area were grouped into 9 general VAGs (Table 3.1) of which only six occurred frequently enough to be included in the analysis. The relevant distinctions were among the understory shrubs and herbs, as all VAGs had western hemlock (designated by TSHE) or Douglas-fir (designated by PSME) in the

Figure 3.4 Distribution of All Site Landtype Associations

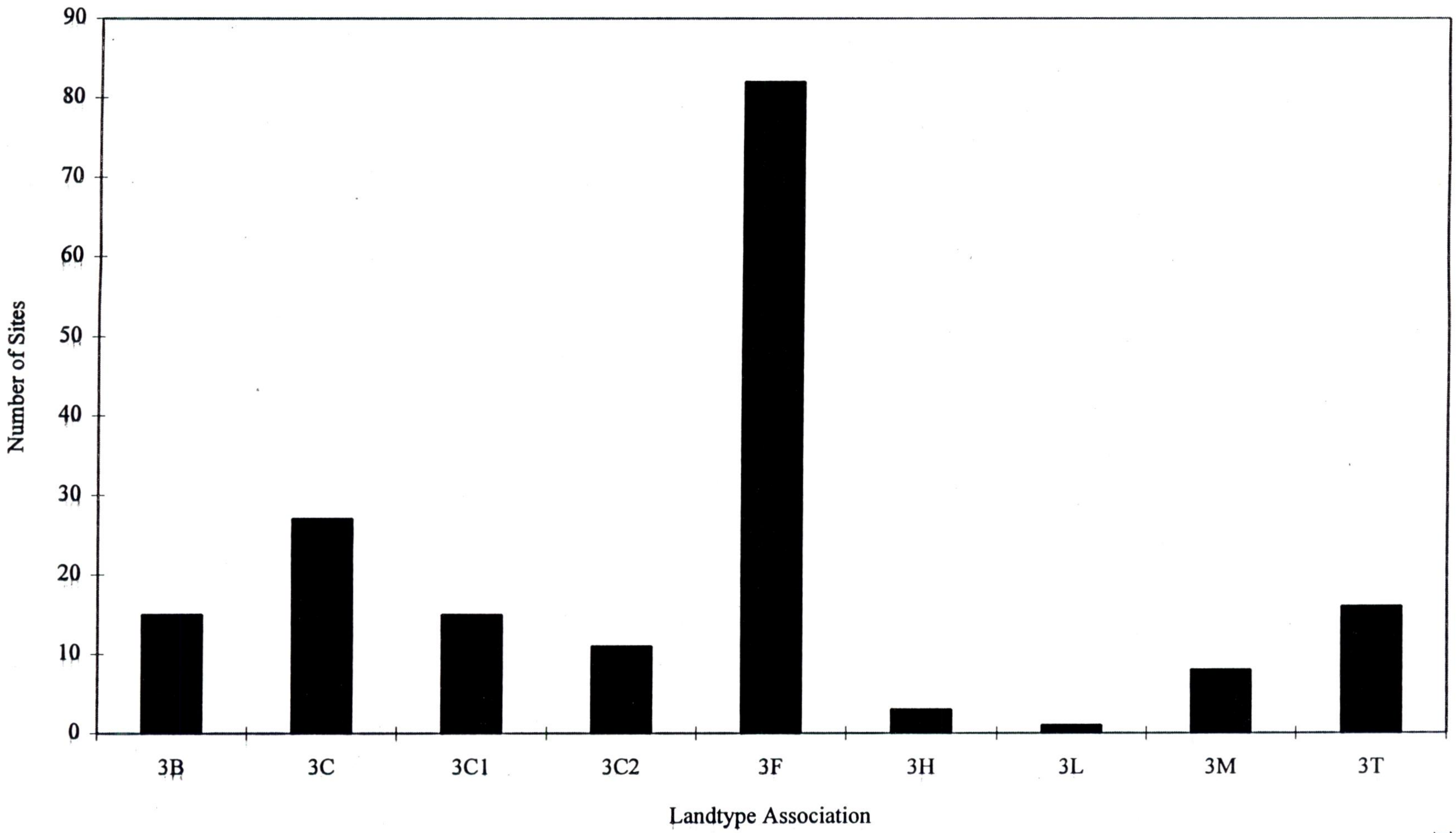


Figure 3.5 Distribution of Site Landtype Associations Used in Logistic Regression Analysis

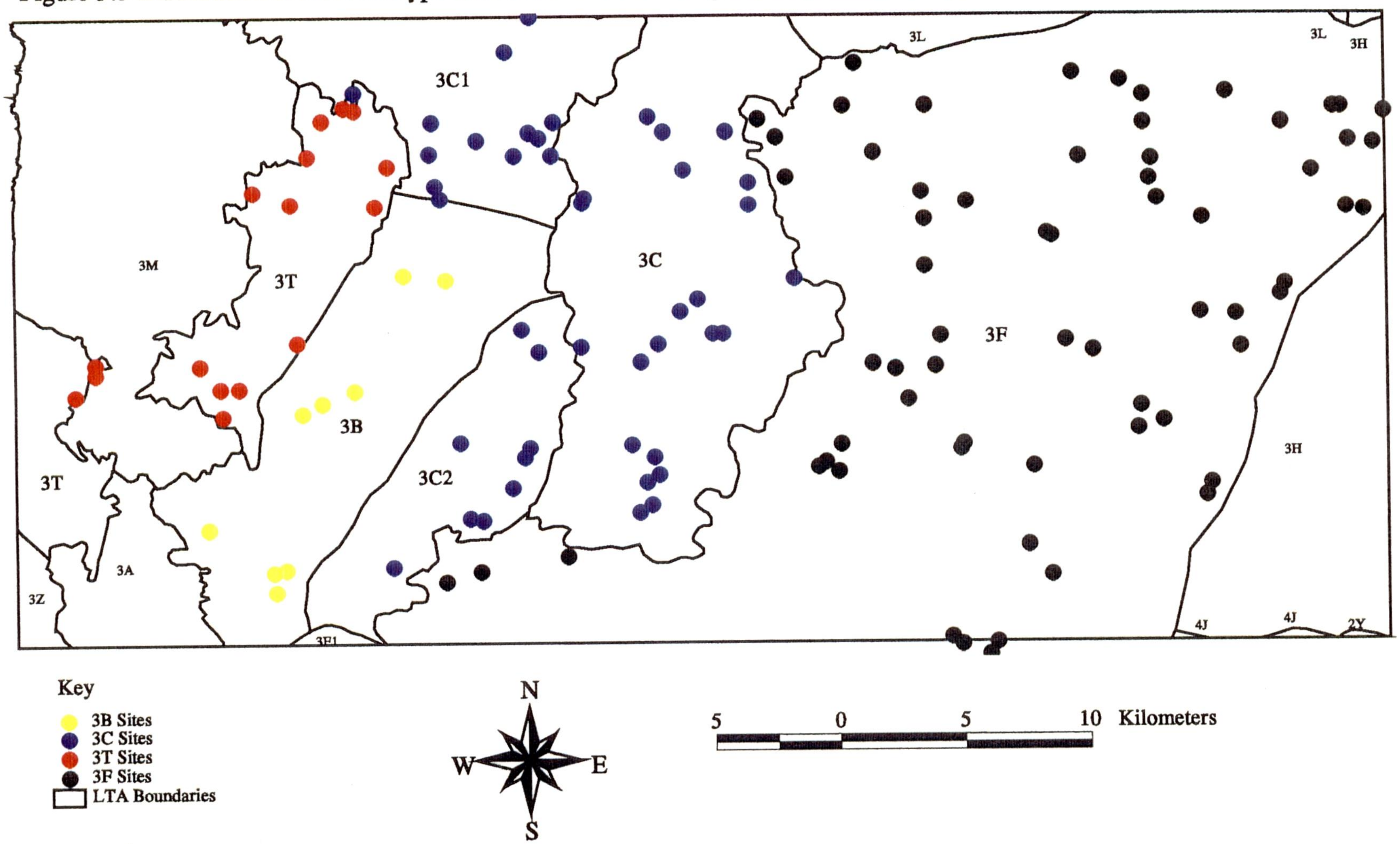


Table 3.1 General and Specific Vegetation Association Groups in the Study Area (from Hemstrom and Logan, 1986).

General VAGs		Specific VAGs	
Species	VAG Code	Species	VAG Code
Rhododendron	RHMA* (driest)	Rhododendron-Evergreen Huckleberry	RHMA/VAOV2
		Rhododendron-Salal	RHMA/GASH
		Rhododendron-Dwarf Oregon Grape	RHMA/BENE
		Rhododendron-Sword Fern	RHMA/POMU
Sword Fern	POMU*	Sword Fern	POMU
Salal	GASH*	Salal	GASH
		Salal-Vine Maple	GASH/ACCI
		Salal-Dwarf Oregon Grape	GASH/BENE
Salmonberry	RUSP* (wettest)	Salmonberry	RUSP
		Salmonberry-Vine Maple	RUSP/ACCI
		Salmonberry-Salal	RUSP/GASH
Dwarf Oregon Grape	BENE	Dwarf Oregon Grape	BENE
Evergreen Huckleberry	VAOV2	Evergreen Huckleberry	VAOV2
Vine Maple-Sword Fern	ACCI/POMU	Vine Maple-Sword Fern	ACCI/POMU
Oregon Oxalis	OXOR	Oregon Oxalis	OXOR
Devils Club	OPHO	Devils Club	OPHO

*used as categories for analysis

canopy. Four of the VAGs were not included in the analysis as they did not occur at any study site or were not the predominant VAG at any site (e.g. devil's club, *Oplopanax horridum*; OPHO and Oregon oxalis, *Oxalis oregana*; OXOR), or only occurred at a few sites (e.g. Oregon grape, *Berberis nervosa*; BENE, and Evergreen Huckleberry *Vaccinium ovatum*; VOAV2). This removed a total of 33 out of 178 sites from the analysis.

The general VAG groups of the Western Hemlock Series used in analyses were RHMA (rhododendron; *Rhododendron macrophyllum*); POMU (sword fern; *Polystichum munitum*); GASH (salal; *Gaultheria shallon*); and RUSP (salmonberry; *Rubus spectabilis*). The site VAG was entered into a GIS database and mapped to evaluate the pattern of VAGs in the study area compared to other variables (Figure 3.6). RHMA VAGs are generally associated with drier sites; RUSP VAGS are generally associated with wetter sites, and both POMU and GASH VAGs are less sensitive to site moisture levels (Hemstrom and Logan, 1986; Zobel and others, 1976).

Slope in degrees was measured at the site with a hand held inclinometer. The average slope of the site was estimated by sighting along the slope angle from the top to the bottom of the site, and is an estimate of the prevailing slope at the site. Slope was tested in preliminary runs as a continuous variable, with a range of 5 to 41 degrees, and as a categorical variable, with 3 categories associated with the distribution of site slopes. The three categories were 0 to 19°; 20 to 31° ; and >32° (Figure 3.7). Based on results from the preliminary runs, there was no advantage to using slope as a categorical

Figure 3.6 Distribution of Sample Site Vegetation Associaiton Groups (VAGs) Used in Logistic Regression Analysis

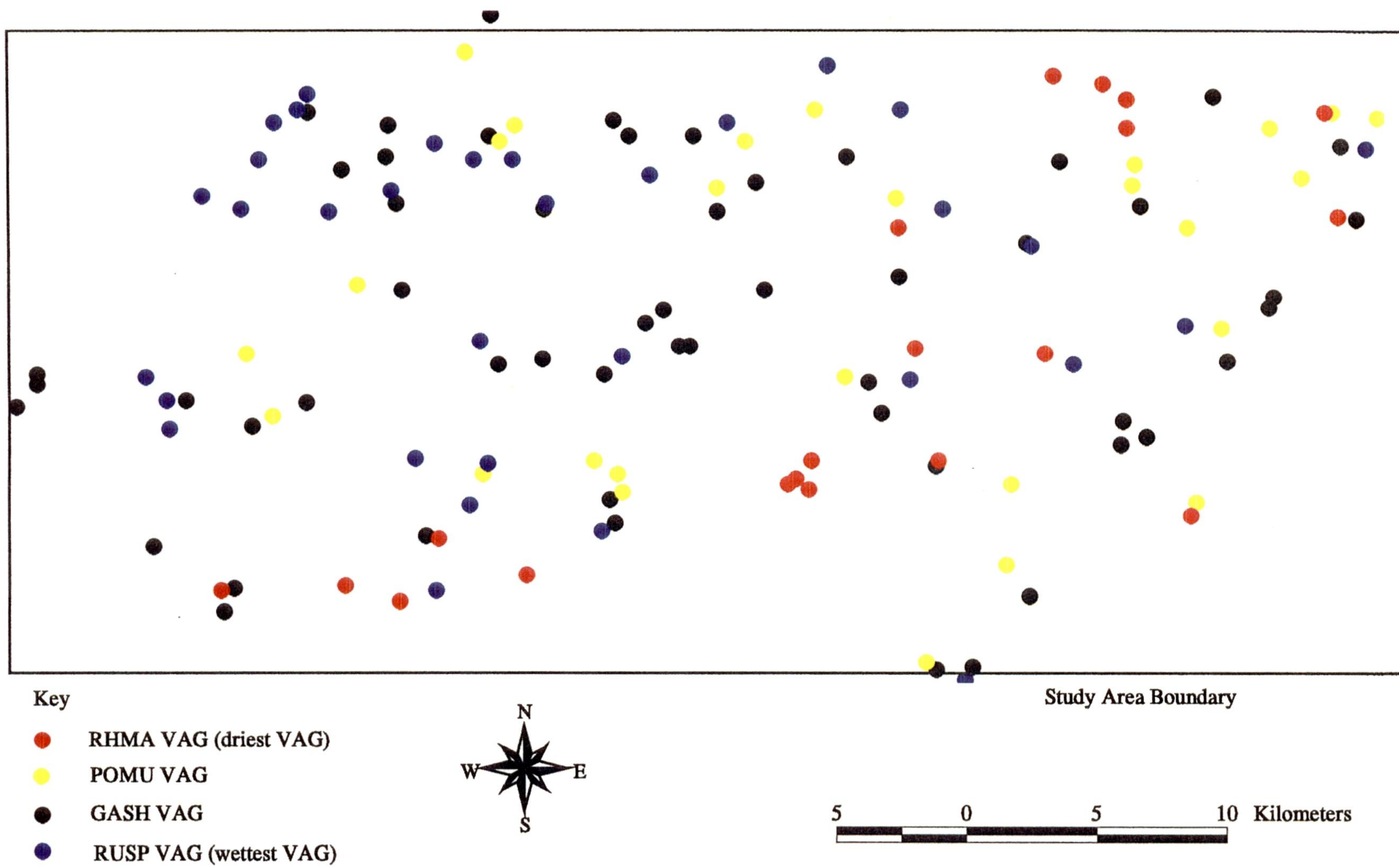
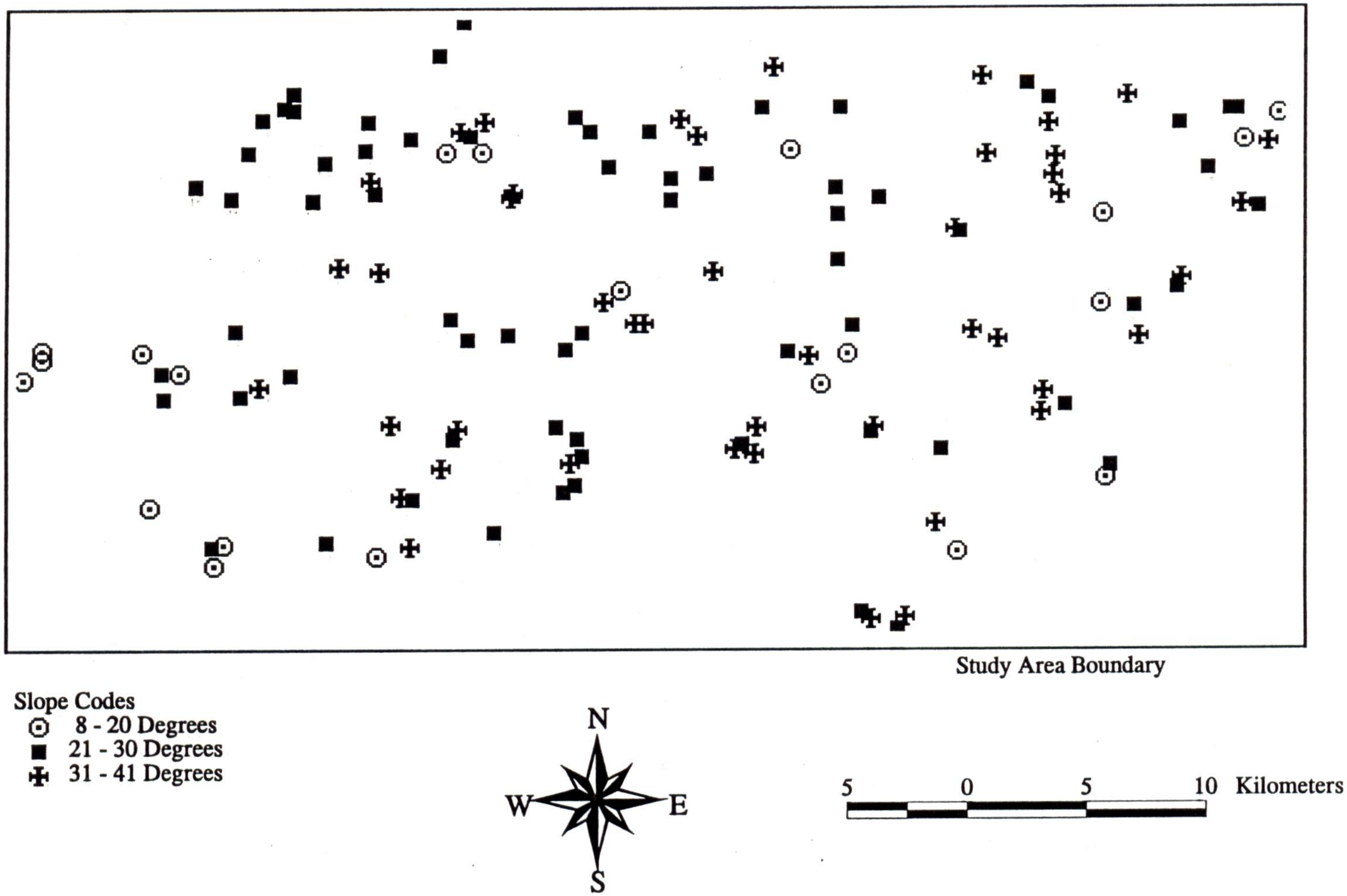


Figure 3.7 Distribution of Site Slope Classes



variable. In subsequent models slope was modeled as a continuous variable to maintain greater degrees of freedom.

To determine site elevation, the sample site was located and its boundaries drawn on a USGS 7.5' topographic map. The contour line that bisected the site was recorded as the site elevation, and converted from feet to meters. The range of site elevations was 30 to 582m. Elevation was tested in preliminary runs as a continuous variable and as a categorical variable, with 3 categories based on the distribution of site elevations. The three categories were 0 to 230m; 231 to 410m ; and >411m (Figure 3.8). As with the slope variable, results from preliminary runs showed no advantage to using elevation as a categorical variable. In the final models elevation was modeled as a continuous variable to maintain greater degrees of freedom.

It was expected that the 78 sites recording the fire episode of 1852 would be a suitable quantity to test interactions between variables. An examination of the *p*-values of individual variables for the fire episode of 1852 showed Zone, LTA, and VAG to be the most significant variables (Table 3.2). Maps of VAG and Zone (Figure 3.9), VAG and LTA (Figure 3.10) and LTA and Zone (Figure 3.11) were generated to evaluate the potential interactions among these variables.

3.2.2.3 Individual and Multiple Variable Tests on Fire Episodes

After data filtering using the results of the preliminary analysis, each variable was tested with each of the six fire episodes with more than 15 sites which recorded the

Figure 3.8 Distribution of Site Elevation Classes

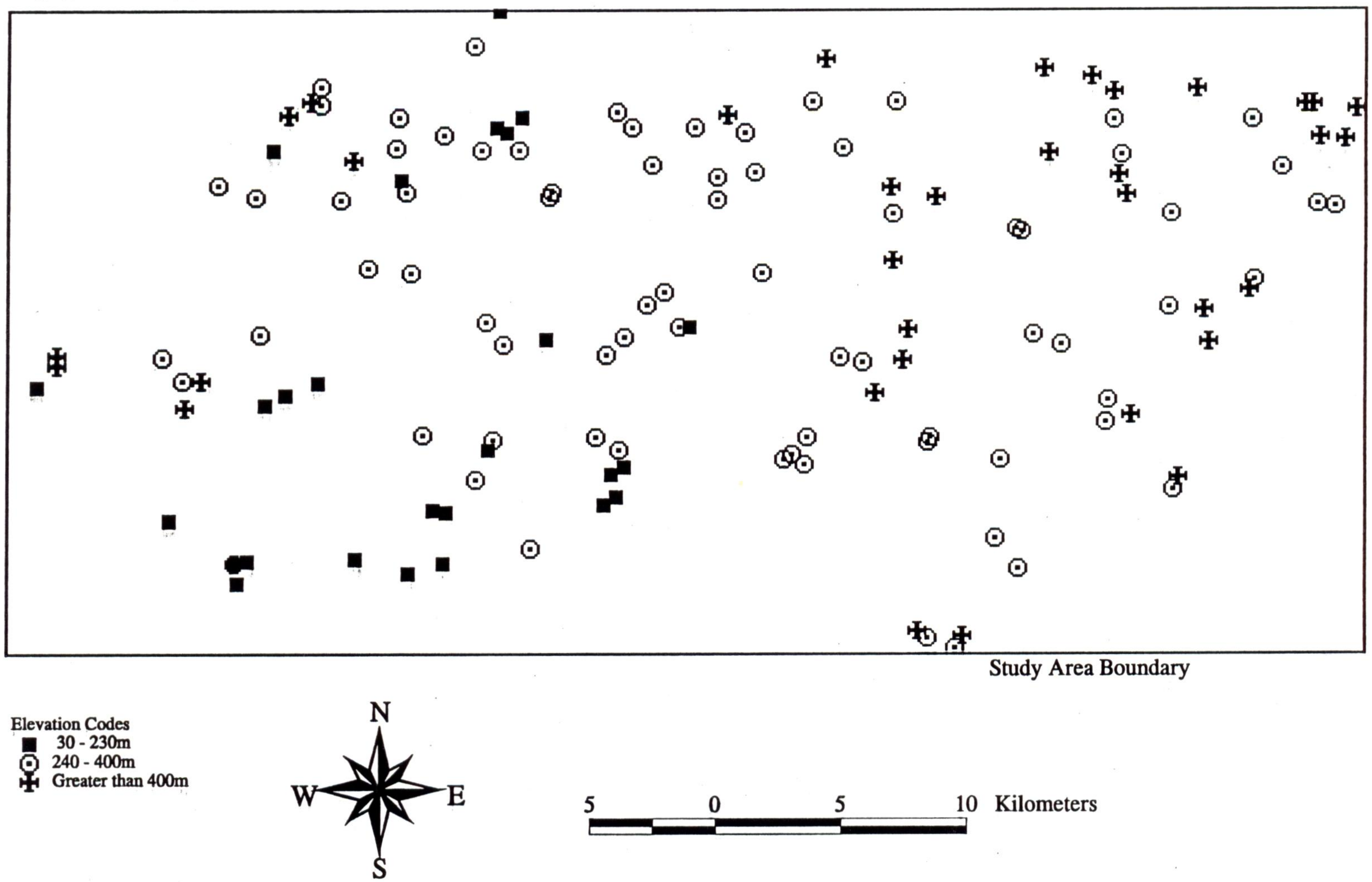


Table 3.2 Summary of p-values and Rank for all Single Variables.
p-values are from logistic regression models of fire occurrence at sites for each fire episode tested. The table shows the p-value for each variable tested for each fire episode, it's rank (in parentheses) based on p-values, and whether it is significant (*; $p < 0.05$) or not significant (x; $p > 0.05$)

Total Sites = 135
variable p-value and (Rank)
* = $p < 0.05$
x = $p > 0.05$

Fire Eisode Year Tested

	1531	1555	1852	1871	1888	1920
Number of Sites Recording Fire Episodes	18	18	78	22	20	22
Variable						
Zone	0.37 (3) x	0.19 (1) x	6.6 E-6 (1) *	0.005 (2) *	0.0001 (1) *	0.002 (1) *
Landtype	0.27 (1) x	0.59 (3) x	0.003 (2) *	0.002 (1) *	0.003 (3) *	0.04 (3) *
Vegetation	0.75 (6) x	0.44 (3) x	0.005 (3) *	0.75 (6) x	0.64 (6) x	0.47 (5) x
Aspect	0.63 (5) x	0.82 (5) x	0.49 (5) x	0.44 (4) x	0.61 (5) x	0.85 (6) x
Elevation	0.58 (4) x	0.37 (2) x	0.11 (4) x	0.32 (3) x	0.001 (2) *	0.27 (4) x
Slope	0.25 (2) x	0.65 (6) x	0.53 (6) x	0.65 (5) x	0.21 (4) x	0.03 (2) *

Figure 3.9 Study Area Vegetation Association Groups and Zones

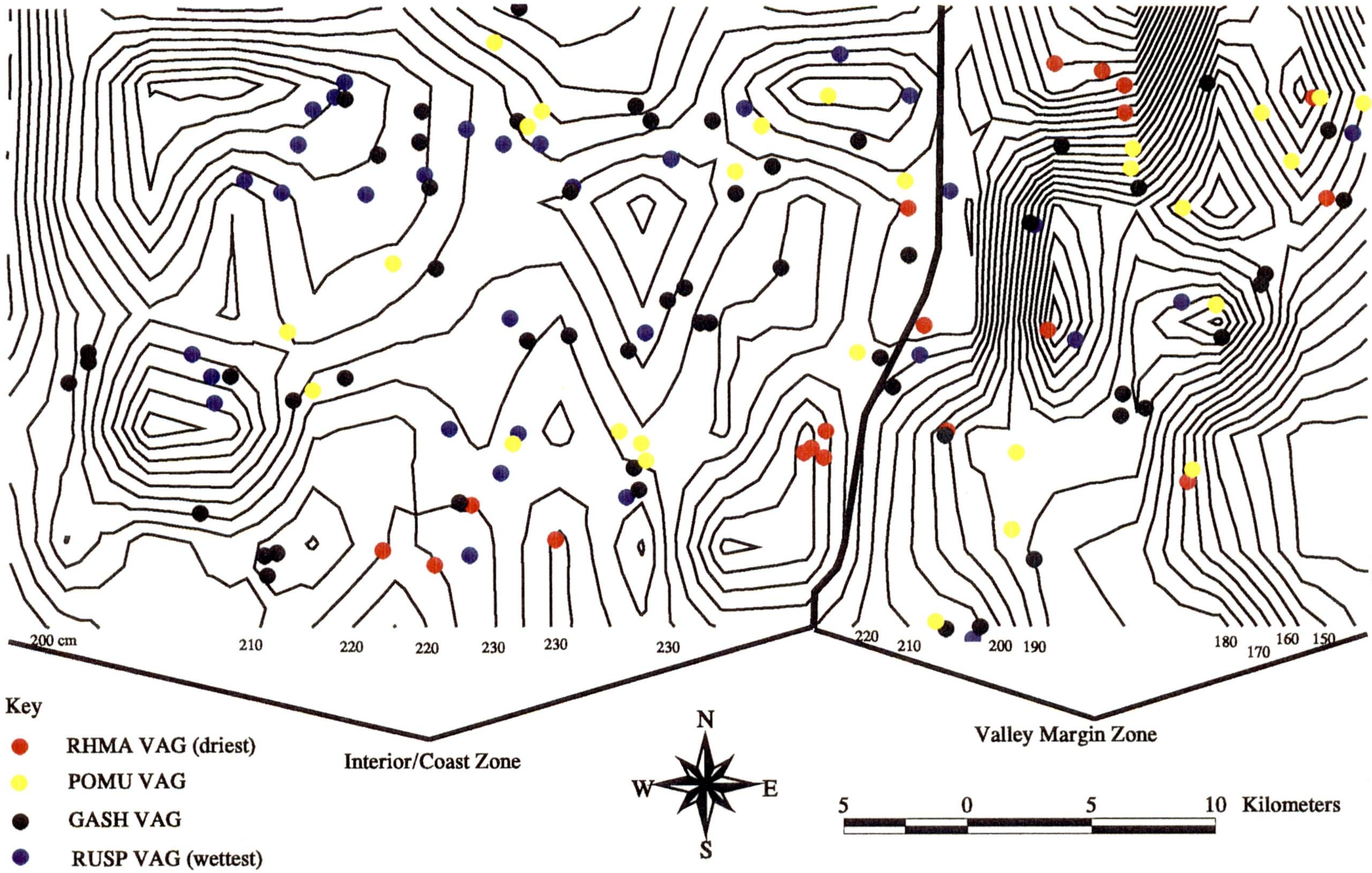


Figure 3.10 Study Area Vegetation Association Groups and Landtype Associations

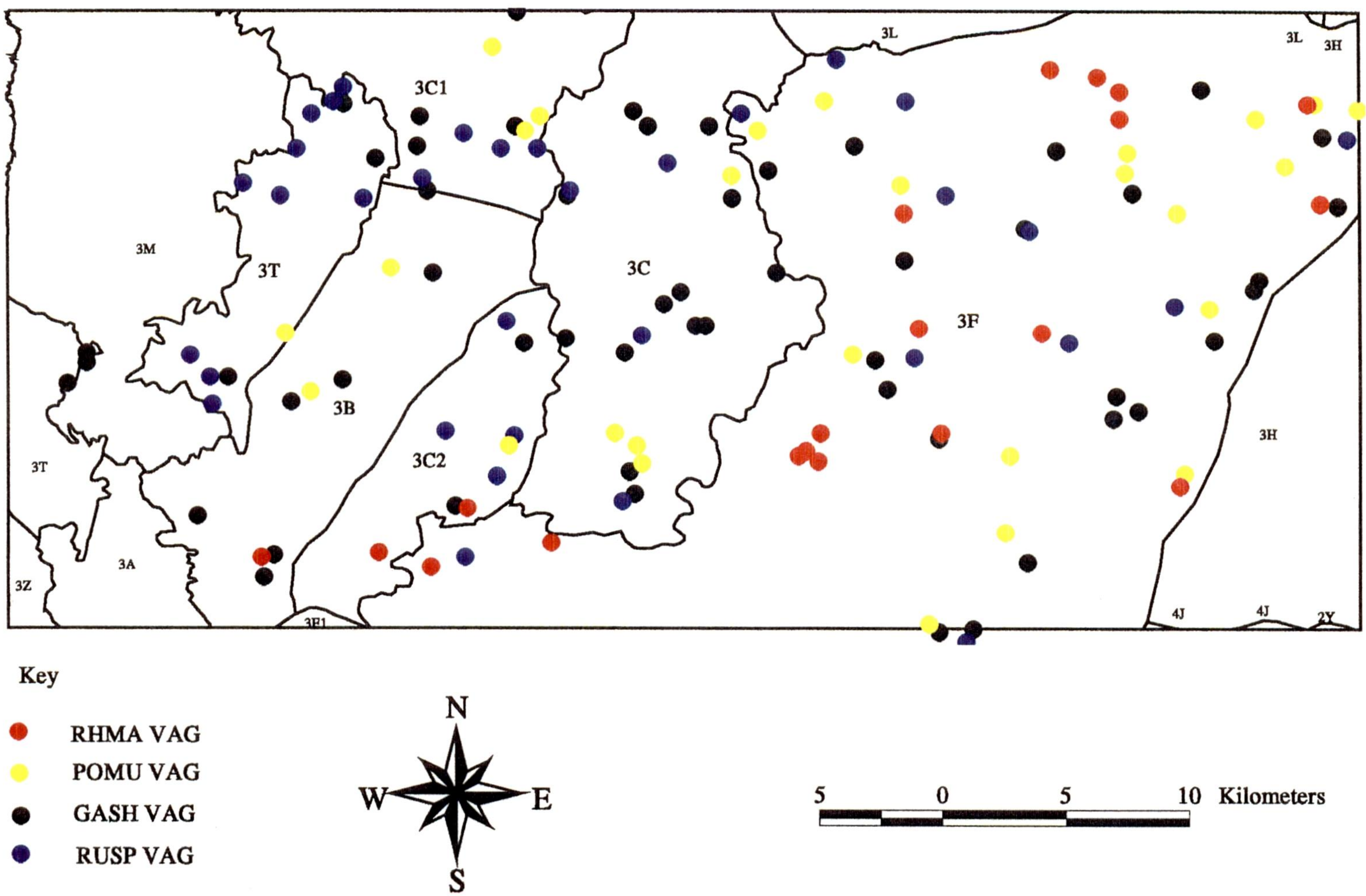
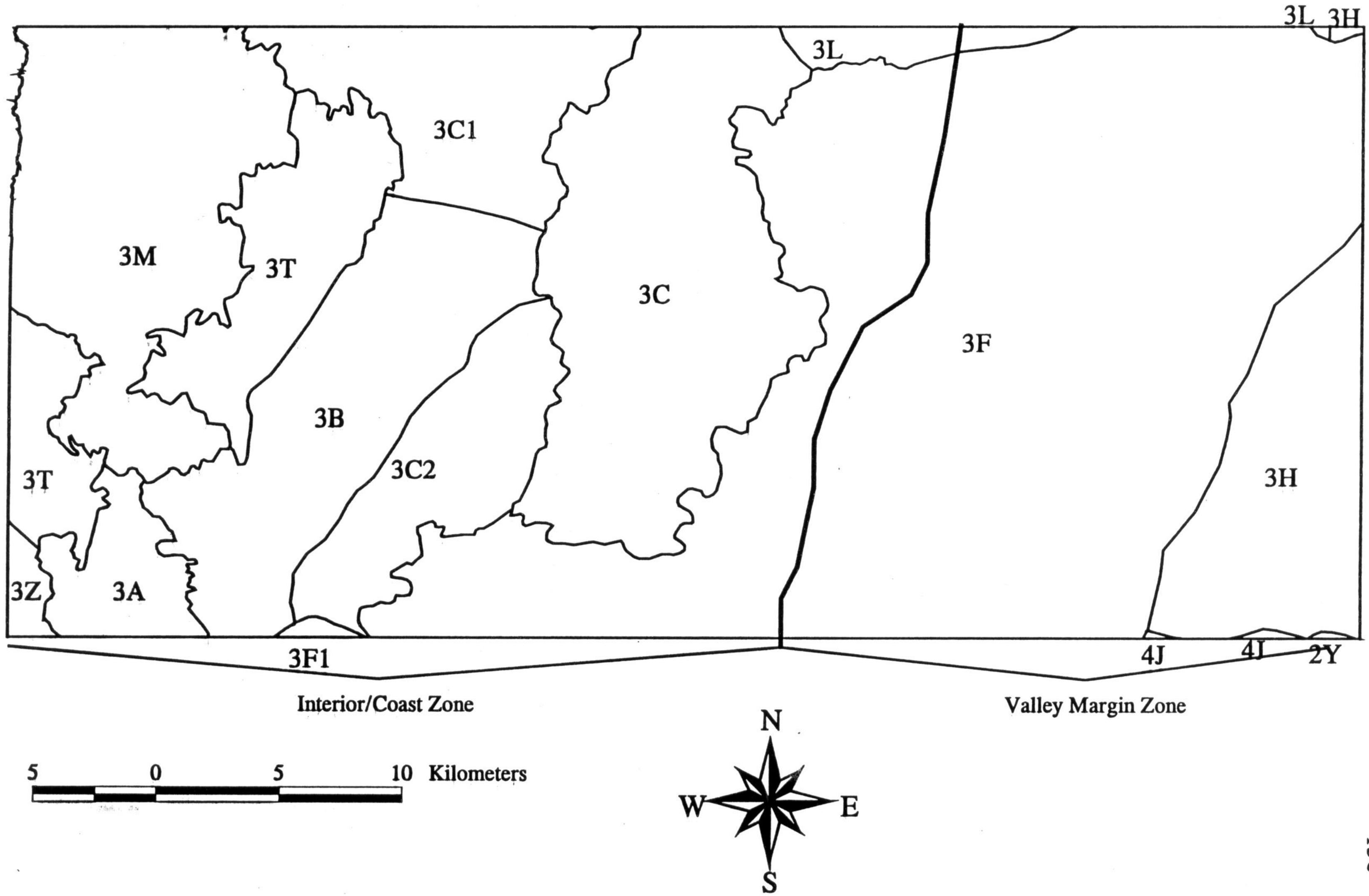


Figure 3.11 Study Area Landtype Associations and Zones



fire episode using the logistic regression function of PROC GENMOD in the statistical software package SAS (Version 6.10). For each fire episode, the null model (no explanatory variable) was also run. The drop in deviance was calculated and compared to a χ^2 distribution to determine if a variable was significant. Variable rank, the relative significance based on *p*-values of a variable for a fire episode compared to other variables, was established from these results. The rank of variables was used to determine the order of variable input for model building with more than one variable. The COVB option was used in SAS logistic regression runs for variables with more than two categories to allow the comparisons of pairs of categories that did not include the reference category.

A forward stepwise logistic regression was carried out to assess multiple variable models for each of the six fire episodes. The variable with the lowest p value was the first variable included in the model and was paired with all other variables by p value (Table 3.2). For the six variables this produced five pairs. The pair with the lowest p value from a drop in deviance test was then combined with all remaining individual variables to test the four possible combinations of triplets. This process was continued until all six variables were included in the model. A final model was determined by selecting the largest combination of variables that were still significant compared to the prior combination of variables.

A backwards stepwise logistic regression was carried out to develop a model for the fire episode of 1852. The fire episode of 1852 was the only fire episode with enough sites showing evidence of fire to permit an analysis with all single variables and all 15 possible two-variable interactions in the initial model. The inclusion of all variables and their combinations at the start of a backwards stepwise logistic regression allows for the evaluation of multiple variables that is not available in forward stepwise logistic regression.

At the start the backwards stepwise logistic regression included the full model of all six individual variables and all 15 two-variable interactions possible. The variable with the highest p value was removed and a new p value associated with the change in deviance from the full to the reduced model was calculated. A new p value > 0.05 indicated that the addition of the dropped variable to the reduced model was not significant, and the variable being tested should be removed. New p values were calculated for all variables following the removal of a variable. The process of testing variables was continued until all remaining variables were significant.

3.2.3 Hillslope Position Analysis

Patterns of fire occurrence due to hillslope position were investigated using aggregated regeneration and scar data to generate estimates of the fire frequency and severity for upper, mid and lower hillslope positions. Scar and regeneration data were aggregated and analyzed at both the stump and site level.

3.2.3.1 Scar and Regeneration Data Analysis at the Hillslope Scale

For each fire episode the number of trees regenerated following a specific fire episode and the number of scars associated with that fire episode were tabulated by reviewing the data sheets for each site. These counts were then converted to proportions. The counts and proportions of regenerated trees and scars associated with a given fire episode were graphed showing total and relative amounts for each fire episode, and temporal trends in proportions.

A similar data analysis was carried out for site counts of fire occurrence by hillslope position. The analysis by site was used for hillslope position frequency and severity comparisons, and allowed the comparison of results from the occurrence of fire episode at a site with numbers of scar and/or regeneration trees associated with a fire episode.

3.2.3.2 Frequency Analysis at the Hillslope Scale

A frequency analysis was carried out at the hillslope scale on the 60 sites in the study area that showed evidence of three or more fire episodes. The MFRI was determined for separate site hillslope positions with evidence of at least three or more fire episodes.

3.2.3.3 Severity Analysis at the Hillslope Scale

The severity of a fire episode was determined at each hillslope position. When only scars occurred at a hillslope position for a fire episode, the severity was classified as low. When regeneration with no older age classes occurred at a hillslope position for a fire episode, the severity was classified as high. When regeneration with older, surviving age classes occurred at a hillslope position for a fire episode, the severity was classified as moderate.

3.3 RESULTS

3.3.1 Results of Logistic Regression Models

Of six fire episodes modeled, four (1852, 1871, 1888, and 1920) had variables that were significant; Zone, Landtype Association, Vegetation Association Group, and Slope were the most significant (lowest p values) predictors of the spatial patterns of these fires (Table 3.3). Zone was significant in three out of four models, Landtype Association was significant in half of the models, and Vegetation Association Group and Slope were significant in one out of four models. No variables were significant for the fire episodes of 1531 and 1555.

When multiple variables could be tested (the fire episode of 1852), Zone, Landtype Association, and Vegetation Association Group were all significant predictors

Table 3.3
Summary of Final Logistic Regression Models for Six Fire Episodes
Total Sites = 135

Fire Episode Year	Number of Sites with Fire Episode	Variable(s) Included in Model	Final Model *p*-value	Variable Categories
1531	18	None Significant	0.08	
1555	18	None Significant	0.19	
1852	78	ZLV	0.008	IC VM* 3B 3C 3T 3F* RHMA RUSP POMU GASH*
1871	22	L	0.002	3B 3C 3T 3F*
1888	20	ZS	0.01	IC VM*
1920	22	Z	0.002	IC VM*

Variable Key:
Z Zone
L Landtype
V Vegetation
A Aspect
S Slope
E Elevation

* Reference Category

of the pattern of this fire. This model was significant for both the forward stepwise and backward stepwise procedures. There are ten categories with related odds ratios and confidence intervals (Table 3.4), with 32 possible combinations of categories using three variables. With this quantity of variables and associated categories, it was possible to compare different combinations of variables to address differences in fire occurrence. To examine a difference in the range of combinations, I compared the combination of the "wettest" categories of the variables (the area represented by the category that receives the most precipitation, or the category associated with the wettest environment; e.g. Interior/Coast Zone, LTA 3T and VAG RUSP) with the "driest" categories (Valley Margin Zone, LTA 3F, VAG RHMA) for the occurrence of fire. The fire episode of 1852 was 11 times more likely to occur on the wettest combination of categories than on the driest combination of categories (95% CI = 4.54 to 33.33).

The final model for the fire episode of 1852 also was used to test the difference between wet and dry VAGs with VAG as a separate variable. In the final model of the fire episode of 1852, the VAG RUSP is 15 times more likely to have experienced the fire episode of 1852 than the VAG RHMA (95% CI = 2.56 to 88.23).

The fire episode of 1871 was 2 times more likely to occur on LTA 3B than LTA 3F (95% CI = 0.4 to 14.3), 1.5 times more likely to occur on LTA 3C than LTA 3F (95% CI = 0.5 to 5.1), and 10 times more likely to occur on LTA 3T than LTA 3F (95% CI = 2.7 to 35.9) (Table 3.4). An additional comparison was made between the LTAs 3B and 3C and LTA 3T as the odds ratio for LTA 3T was much greater than for

Table 3.4
Final Logistic Regression Models for Four Fire Episodes

<u>Fire Episode of 1852</u>

Variables	n	df	Chi Sq.	*p*-value
Zone	135	1	23.5	0.0001
Land	135	3	21.6	0.0001
Vegetation	135	3	12.2	0.007

Odds Ratios

Zone	Categories IC	VM
estimate	3.35	0.0
Std. error	1.19	
odds ratio	28.5	1.0
95% CI	2.78 to 293.6	

Land	Categories 3B	3C	3T	3F
estimate	-3.19	-0.54	-3.63	0.0
Std. error	1.35	1.26	1.31	
odds ratio	0.04	0.58	0.03	1.0
95% CI	0.003 to 0.58	0.05 to 6.9	0.002 to 0.35	

Vegetation	Categories RHMA	POMU	GASH	RUSP
estimate	-2.11	-0.7	0.0	0.6
Std. error	0.8	0.6		0.62
odds ratio	0.12	0.5	1.0	1.82
95% CI	0.02 to 0.58	0.16 to 1.58		0.5 to 6.2
	(driest VAG)			(wettest VAG)

<u>Fire Episode of 1871</u>

Variable	n	df	Chi Sq.	*p*-value
Land	135	3	12.8	0.002

Odds Ratios

Land	Categories 3B	3C	3T	3F
estimate	0.9	0.44	2.24	0.0
Std. error	0.9	0.61	0.61	
odds ratio	2.45	1.55	9.87	1.0
95% CI	0.4 to 14.3	0.5 to 5.1	2.7 to 35.9	

Table 3.4 cont.

Fire Episode of 1888

Variables	n	df	Chi Square	*p*-value
Zone	135	1	5.9	0.01
Slope	135	1	3.8	0.05

Odds Ratios

Zone	Categories	
	IC	VM
estimate	-2.02	0.0
Std. error	0.58	
odds ratio	0.13	1.0
95% CI	0.04 to 0.41	

Slope	Continuous
estimate	-0.08
Std. error	0.04
odds ratio	0.92
95% CI	0.86 to 0.99

Fire Episode of 1920

Variable	n	df	Chi Sq.	*p*-value
Zone	135	1	7.9	0.002

Zone	Categories	
	IC	VM
estimate	-1.4	0.0
Std. error	0.5	
odds ratio	0.25	1.0
95% CI	0.65 to 0.09	

LTAs 3B and 3C. The fire episode of 1871 was 0.3 times as likely to occur on 3B than on 3T (95% CI = 0.04 to 1.56) and 0.2 times as likely to occur on 3C than on 3T (95% CI = 0.04 to 0.58).

The fire episode of 1888 was 0.1 times as likely to occur in the Interior/Coast Zone than in the Valley Margin Zone (95% CI = 0.04 to 0.41) (Table 3.4). The odds ratio for Slope was 0.9 (95% CI = 0.86 to 0.99) (Table 3.4), indicating steeper slopes had a slightly lower chance of fire occurrence than less steep slopes.

The fire episode of 1920 was 0.3 times as likely to occur in the Interior/Coast Zone than in the Valley Margin Zone (95% CI = 0.09 to 0.65) (Table 3.4).

3.3.2 Results of Hillslope Position Analysis

3.3.2.1 Hillslope Position Scar and Regeneration Data Analysis

Hillslope position site counts based on fire scar evidence do not show the same trend as hillslope position site counts based on regeneration data. Fire scar evidence for early fire episodes (1478, 1531 and 1555) is inconclusive, due to the absence or low numbers of older surviving trees to record scars for these fire episodes (Tables 3.5 and 3.6). Fire episodes from 1689 to 1794 show high proportions of scars at the mid slope position, as do fire episodes from 1844 to 1909. Fire episodes from 1909 to 1974 show the middle and upper hillslope positions with the greatest occurrence of scars at site (Figures 3.12 and 3.13).

Table 3.5
Fire Occurrence Comparison by Slope Position
Site Counts of Fire Occurrence by Hillslope
Position based on Scar Data

Fire Year	Upper Slope	Mid Slope	Lower Slope	Total
1478	0	0	0	0
1531	0	0	0	0
1555	0	0	0	0
1585	0	0	1	1
1629	1	3	2	6
1637	1	1	0	2
1655	0	0	0	0
1666	3	1	0	4
1689	2	2	1	5
1699	2	3	2	7
1737	1	2	1	4
1751	1	5	0	6
1763	1	3	1	5
1794	1	1	0	2
1815	3	2	1	6
1831	2	1	3	6
1844	4	5	2	11
1852	5	13	12	30
1871	1	7	4	12
1881	2	4	3	9
1888	5	12	2	19
1900	3	8	1	12
1909	5	8	4	17
1920	12	8	6	26
1928	5	5	1	11
1934	4	4	0	8
1974	5	4	1	10
Totals	69	102	48	219

Table 3.6
Fire Occurrence Comparison by Slope Position
Site Proportions of Fire Occurrence by Hillslope
Position based on Scar Data

Fire Year	Upper Slope	Mid Slope	Lower Slope	Total
1478	--	--	--	--
1531	--	--	--	--
1555	--	--	--	--
1585	--	--	1.00	1.00
1629	0.17	0.50	0.33	1.00
1637	0.50	0.50	0.00	1.00
1655	--	--	--	--
1666	0.75	0.25	0.00	1.00
1689	0.40	0.40	0.20	1.00
1699	0.29	0.43	0.29	1.00
1737	0.25	0.50	0.25	1.00
1751	0.17	0.83	0.00	1.00
1763	0.20	0.60	0.20	1.00
1794	0.50	0.50	0.00	1.00
1815	0.50	0.33	0.17	1.00
1831	0.33	0.17	0.50	1.00
1844	0.36	0.45	0.18	1.00
1852	0.17	0.43	0.40	1.00
1871	0.08	0.58	0.33	1.00
1881	0.22	0.44	0.33	1.00
1888	0.26	0.63	0.11	1.00
1900	0.25	0.67	0.08	1.00
1909	0.29	0.47	0.24	1.00
1920	0.46	0.31	0.23	1.00
1928	0.45	0.45	0.09	1.00
1934	0.50	0.50	0.00	1.00
1974	0.50	0.40	0.10	1.00

Figure 3.12
Site Counts of Fire Occurrence by Hillslope Position
Scar Data

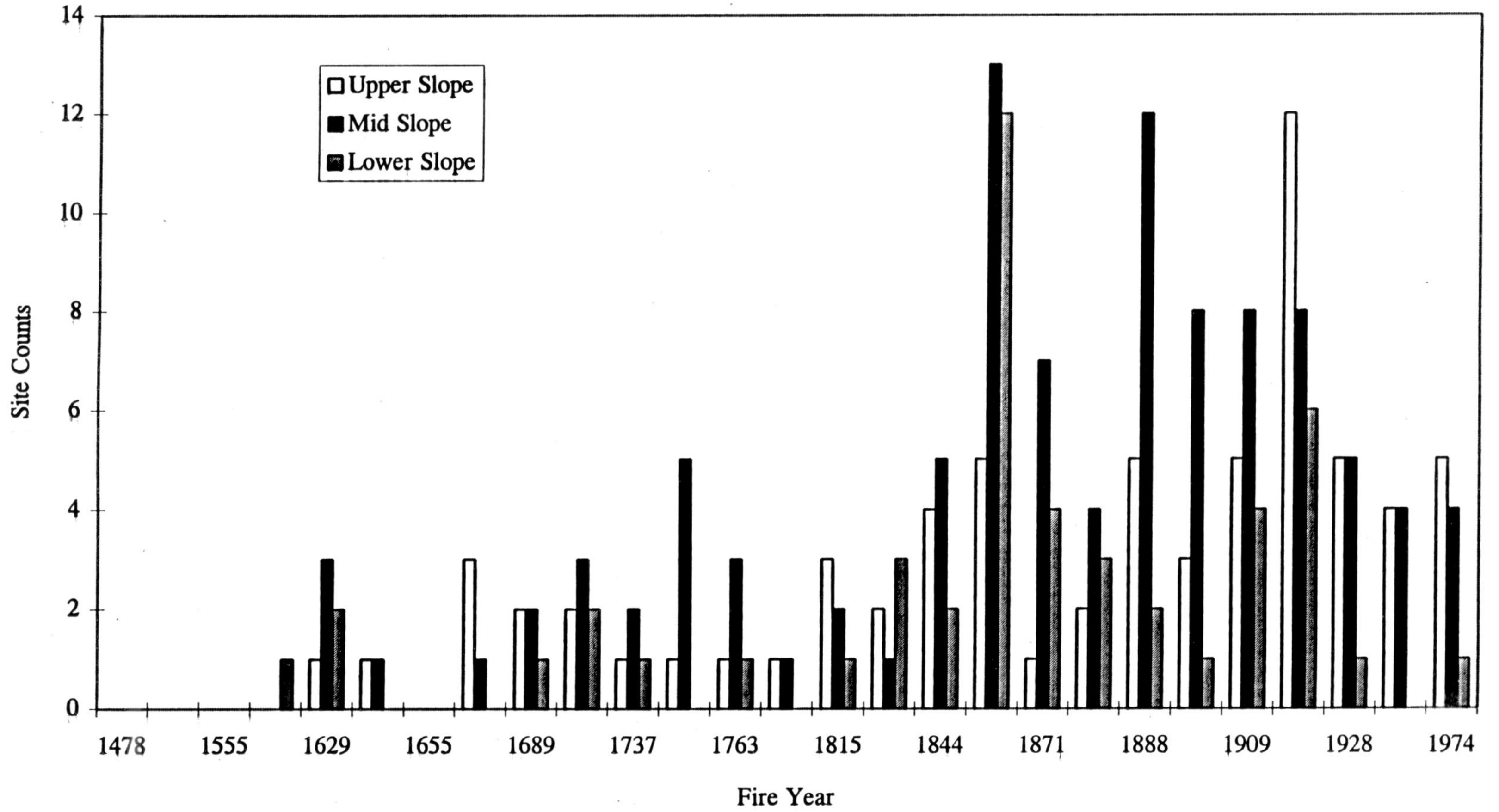
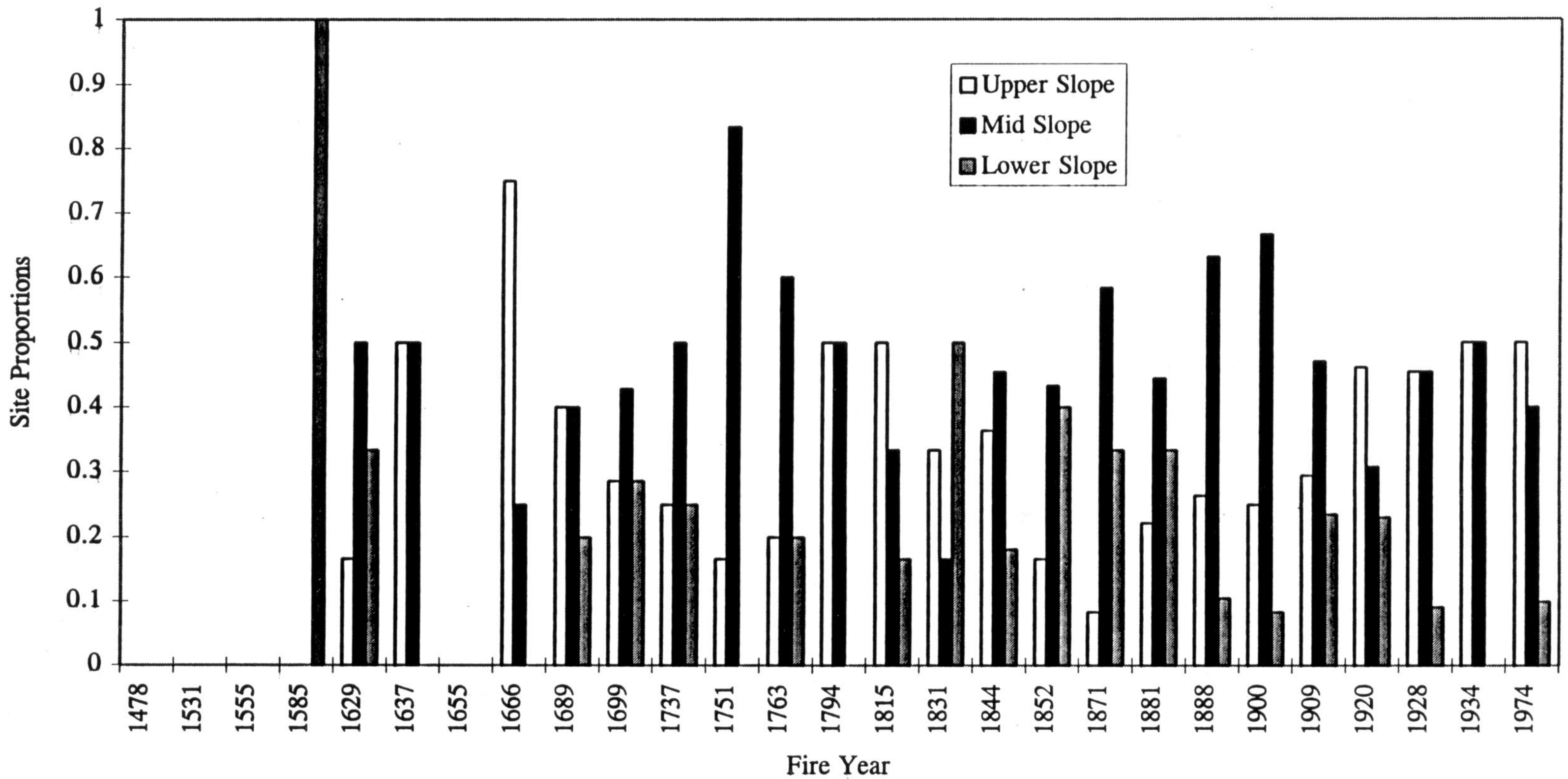


Figure 3.13
Site Proportions for Fire Occurrence by Hillslope Position
Scar Data



There was some indications of differences in hillslope position frequency and severity from direct counts of regeneration trees and fire scars. Raw tree regeneration count data indicated little discernible differences in fire occurrence by hillslope position, but raw scar count data indicated potential differences, especially in fire episodes after 1888 where mid and upper slope positions have greater numbers of scars (Table 3.7 and Figures 3.14 and 3.15).

A comparison of proportions of tree regeneration fire evidence by hillslope position better showed differences in hillslope frequency and severity. The proportions of tree regeneration counts show a temporal trend in regeneration, with high numbers of regeneration trees at lower slope positions for early fire episodes (1478 - 1666), high numbers of regeneration trees at mid slope positions for intermediate date fire episodes (1689 - 1763) and high numbers of regeneration trees at upper slope positions for later fire episodes (1881 - present) (Table 3.8 and Figures 3.16 and 3.17).

The same temporal trends are not as apparent for fire scars, although there are some time periods where certain slope positions have relatively more fire scars (Figures 3.18 and 3.19). For instance, later fire episodes seem to have more scars at upper and to some extent mid slope positions, and there is a period from 1844 to 1871 where lower slope positions have more fire scars. For other fire episodes, either upper or mid slope positions contain the most fire scar evidence.

Counts of sites showing regeneration evidence of fire episodes indicate little difference in fire occurrence by hillslope position (Table 3.9 and Figure 3.20). Site

Table 3.7

Counts of Regeneration Trees and Scars by Hillslope Position

	Upper		Middle		Lower		Totals	
	Trees	Scars	Trees	Scars	Trees	Scars	Trees	Scars
1478	0	0	2	0	5	0	7	0
1531	26	0	42	0	48	1	116	1
1555	19	0	33	0	68	0	120	0
1585	5	1	3	2	3	1	11	4
1629	0	1	0	3	1	3	1	7
1637	23	1	26	3	35	0	84	4
1655	56	0	67	0	75	0	198	0
1666	16	2	16	1	23	0	55	3
1689	4	4	11	3	4	2	19	9
Fire 1699	15	6	27	5	23	1	65	12
Year 1737	27	2	48	3	33	2	108	7
1751	16	2	18	4	16	0	50	6
1763	29	1	46	2	28	0	103	3
1794	27	1	32	0	32	0	91	1
1815	7	2	4	3	14	2	25	7
1831	5	7	5	1	1	2	11	10
1844	24	6	26	6	20	7	70	19
1852	597	3	612	7	550	13	1759	23
1871	248	0	307	4	203	5	758	9
1881	94	2	61	6	43	4	198	12
1888	89	6	34	21	35	4	158	31
1900	48	3	5	16	5	2	58	21
1909	0	10	0	6	0	5	0	21
1920	25	20	22	12	32	4	79	36
1928	6	7	0	8	0	1	6	16
1934	5	8	6	6	5	2	16	16
1974	0	9	0	15	0	4	0	28
Totals	1411	104	1453	137	1302	65	4166	306

Figure 3.14
Count of Trees Recording Fires for Each Slope Position

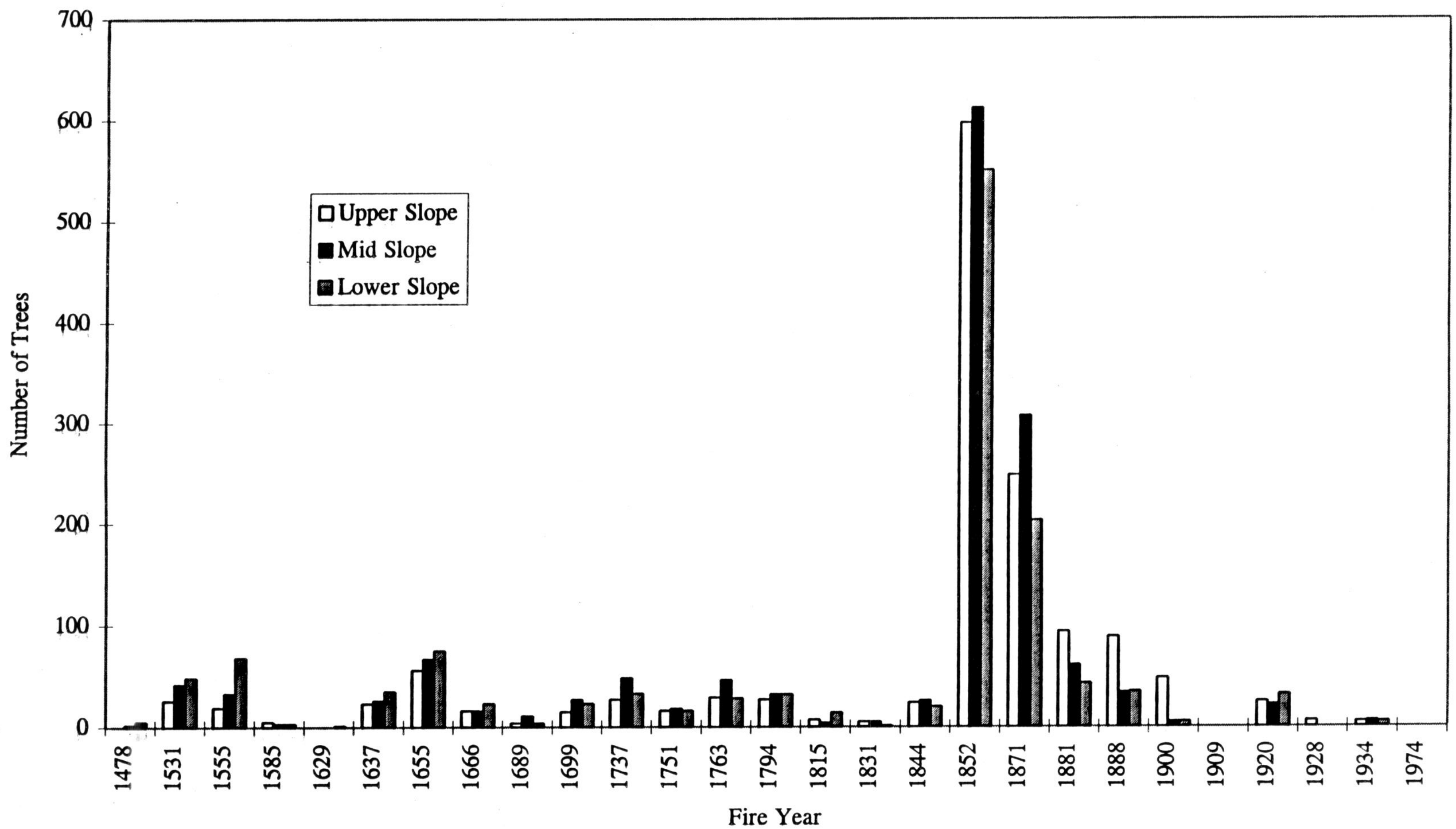


Figure 3.15
Count of Scars Recording Fires for Each Slope Position

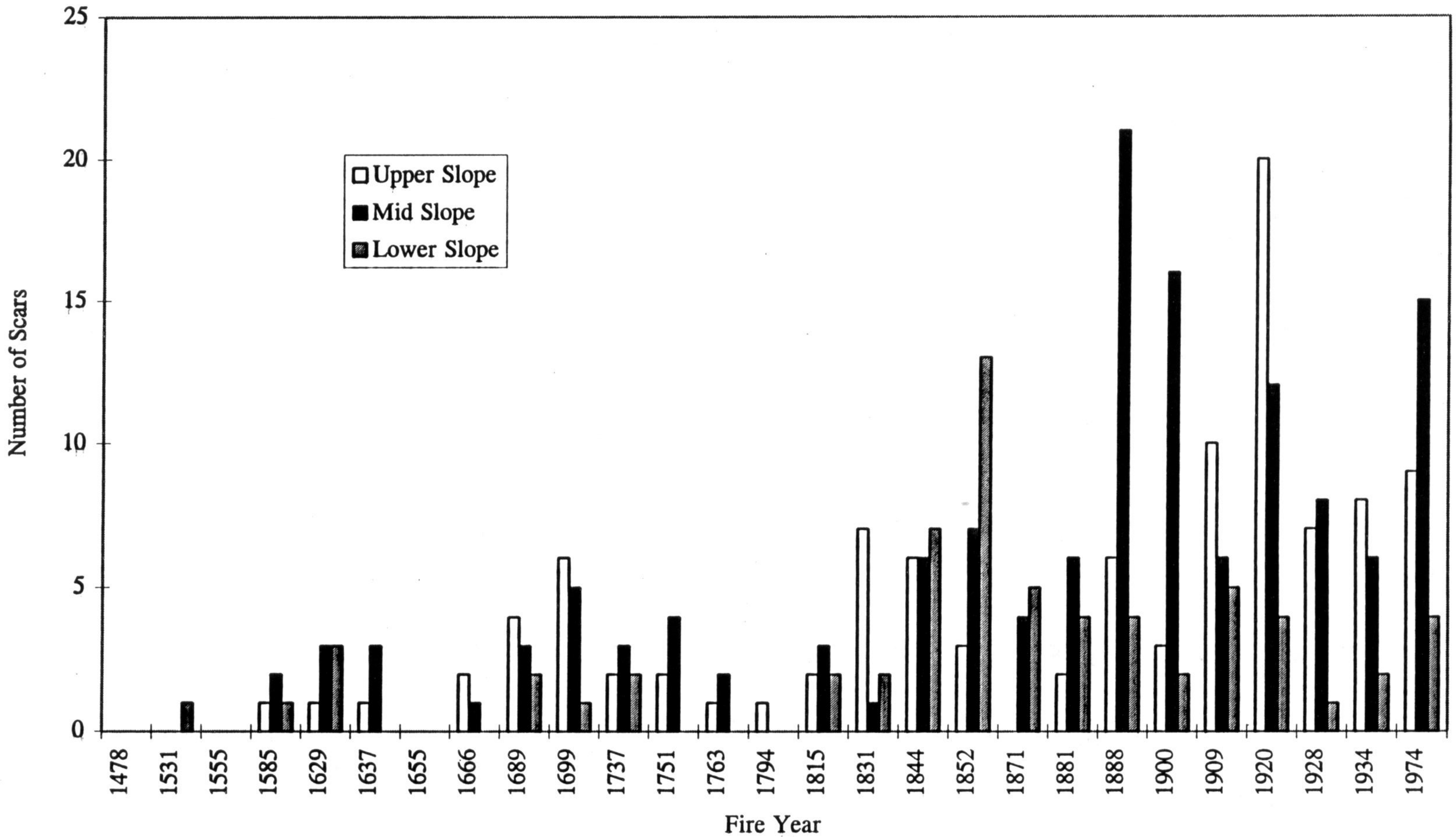


Table 3.8

Proportions of Regeneration Trees and Scars by Hillslope Position

		Upper		Middle		Lower		Counts	
		Trees (%)	Scars (%)	Trees (%)	Scars (%)	Trees (%)	Scars (%)	Trees	Scars
	1478	0		29	--	71	--	7	0
	1531	22	0	36	0	41	100	116	1
	1555	16	--	28	--	57	--	120	0
	1585	45	25	27	50	27	25	11	4
	1629	0	14	0	43	100	43	1	7
	1637	27	25	31	75	42	0	84	4
	1655	28	--	34	--	38	--	198	0
	1666	29	67	29	33	42	0	55	3
Fire	1689	21	44	58	33	21	22	19	9
Year	1699	23	50	42	42	35	8	65	12
	1737	25	29	44	43	31	29	108	7
	1751	32	33	36	67	32	0	50	6
	1763	28	33	45	67	27	0	103	3
	1794	30	100	35	0	35	0	91	1
	1815	28	29	16	43	56	29	25	7
	1831	45	70	45	10	9	20	11	10
	1844	34	32	37	32	29	37	70	19
	1852	34	13	35	30	31	57	1759	23
	1871	33	0	41	44	27	56	758	9
	1881	47	17	31	50	22	33	198	12
	1888	56	19	22	68	22	13	158	31
	1900	83	14	9	76	9	10	58	21
	1909	--	48	--	29	--	24	0	21
	1920	32	56	28	33	41	11	79	36
	1928	100	44	0	50	0	6	6	16
	1934	31	50	38	38	31	13	16	16
	1974	--	32	--	54	--	14	0	28

Figure 3.16
Proportion of Trees Recording Fires for Each Slope Position

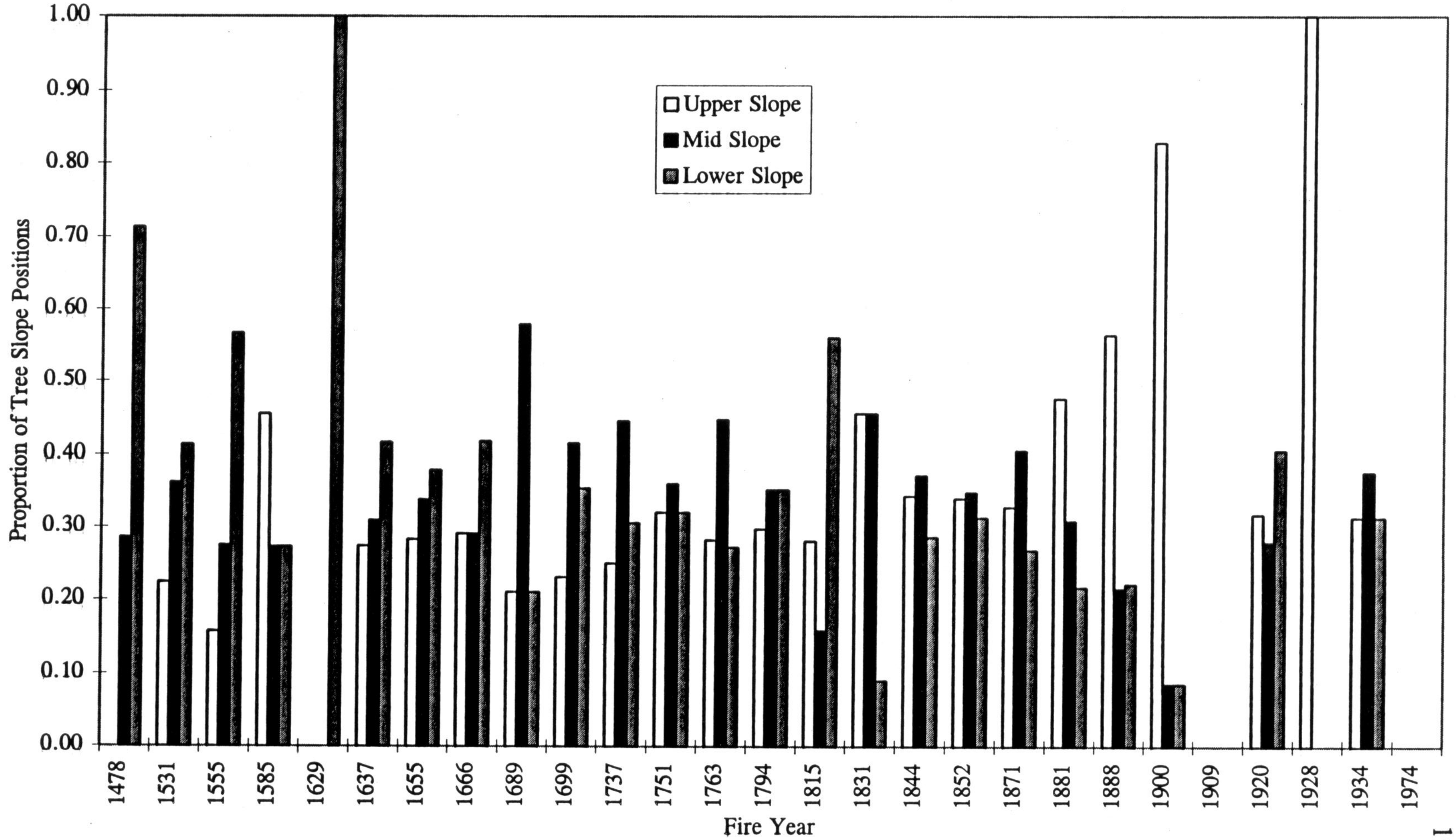


Figure 3.17 Trend in Tree Regeneration Proportions by Hillslope Position Over Time

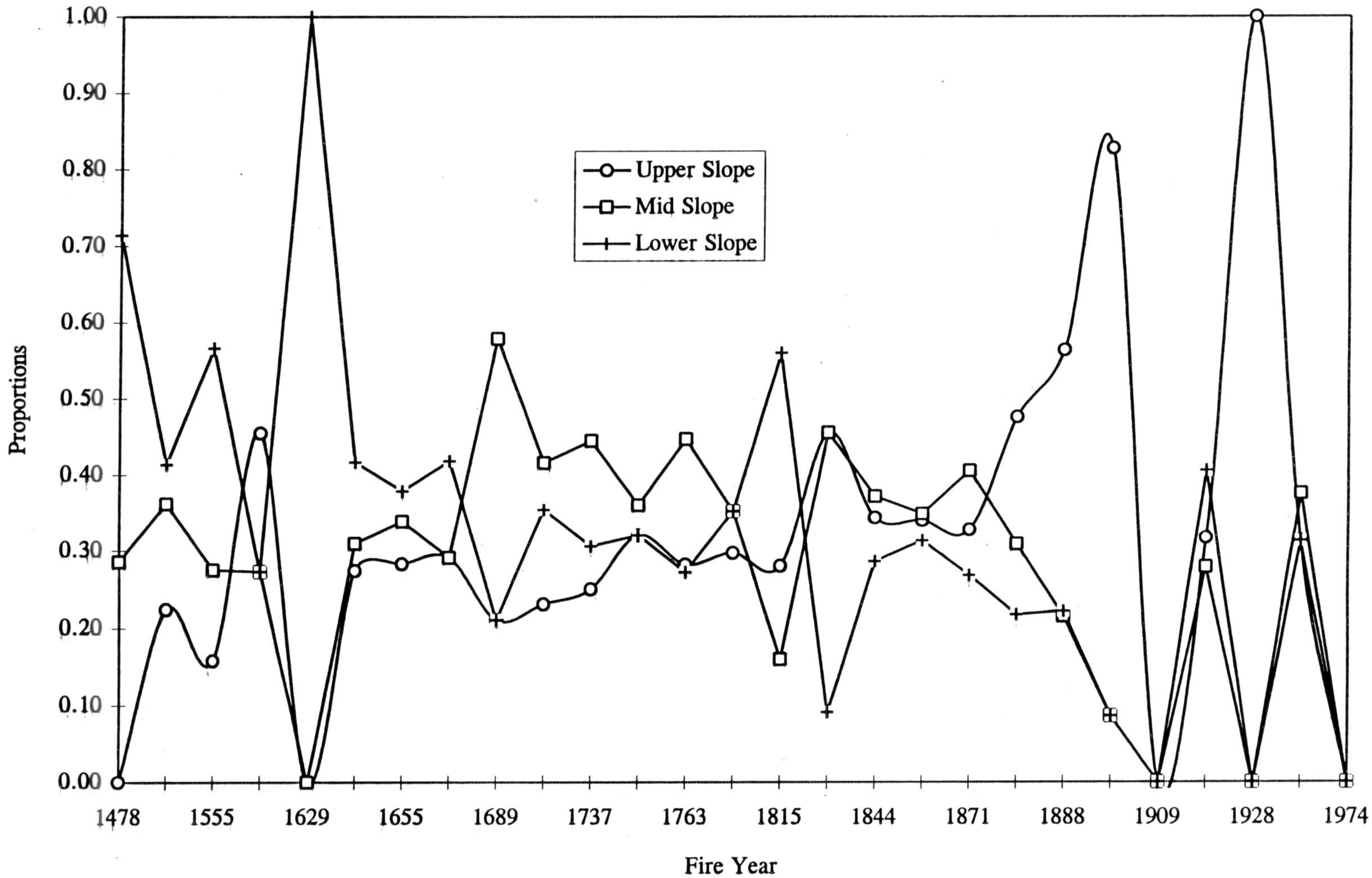


Figure 3.18 Proportion of Scars Recording Fires for Each Slope Position

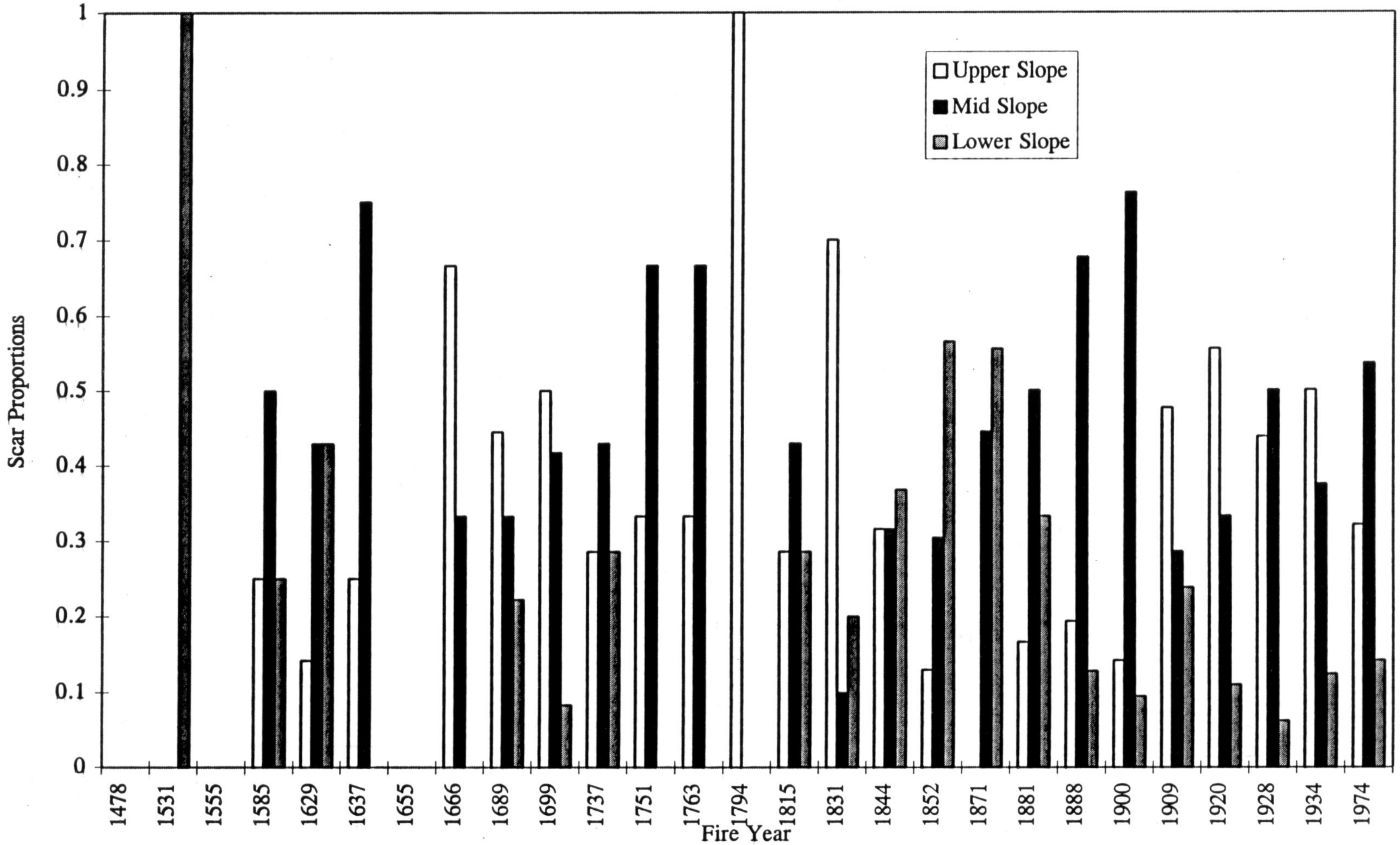


Figure 3.19 Trend in Scar Proportions by Hillslope Position Over TIme

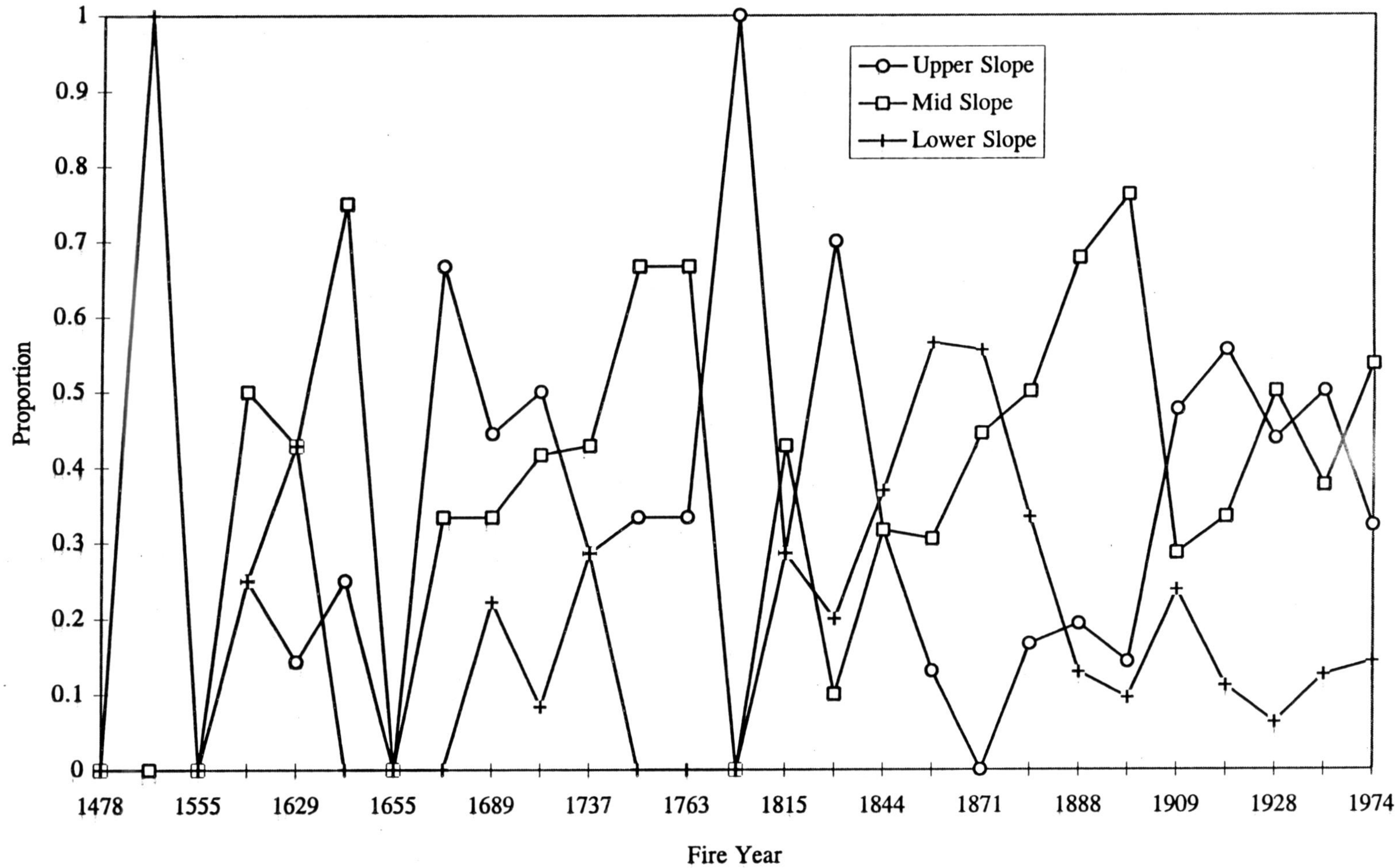
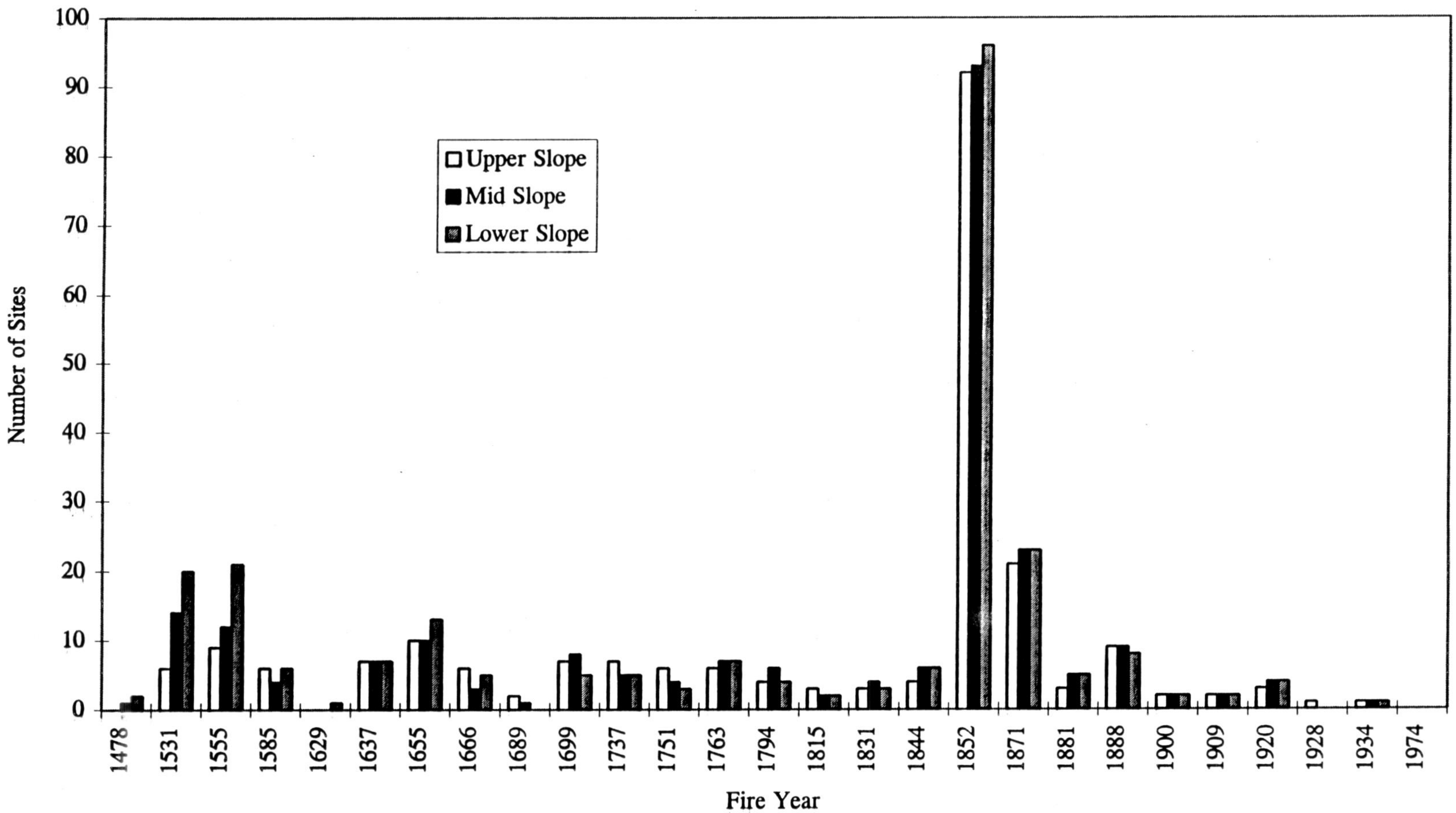


Table 3.9
Fire Occurrence Comparison by Slope Position
Site Counts of Fire Occurrence by Hillslope
Position based on Regeneration Data

Fire Year	Upper Slope	Mid Slope	Lower Slope	Totals
1478	0	1	2	3
1531	6	14	20	40
1555	9	12	21	42
1585	6	4	6	16
1629	0	0	1	1
1637	7	7	7	21
1655	10	10	13	33
1666	6	3	5	14
1689	2	1	0	3
1699	7	8	5	20
1737	7	5	5	17
1751	6	4	3	13
1763	6	7	7	20
1794	4	6	4	14
1815	3	2	2	7
1831	3	4	3	10
1844	4	6	6	16
1852	92	93	96	281
1871	21	23	23	67
1881	3	5	5	13
1888	9	9	8	26
1900	2	2	2	6
1909	2	2	2	6
1920	3	4	4	11
1928	1	0	0	1
1934	1	1	1	3
1974	0	0	0	0
Totals	220	233	251	704

Figure 3.20
Site Counts for Fire Occurence by Hillslope Position
Tree Regeneration Data



proportions of regeneration evidence of fire episodes indicate more sites recording fire episodes between 1478 and 1629 at lower hillslope positions, but no clear trends after then (Table 3.10 and Figure 3.21).

3.3.2.2 Hillslope Position Frequency Analysis

Results show greater fire frequency at upper hillslope positions than at lower hillslope positions (Table 3.11a), but these differences are less than within-hillslope position differences (Table 3.11b). Upper hillslope positions had greater frequency of fire episodes, with an MFRI of 75.4 years. Lower hillslope positions had the lowest frequency of fire episodes, with an MFRI of 115.9 years. Middle hillslope positions had an MFRI of 93.7 years.

3.3.2.3 Hillslope Position Severity Analysis

Fire episodes of the early 1500s were high severity at lower and mid hillslope positions, the fire episodes of 1852 and 1871 were high severity at all hillslope positions, and other fire episodes (1585 - 1844 and after 1881) were of similar severity at all hillslope positions (Table 3.12 and Figure 3.22). Early fire episodes (1531 and 1555) show regeneration evidence only, indicating high severity. Regeneration from these fire episodes are primarily at middle and lower hillslope positions. Mid-date fire episodes (1585 - 1844) are evenly distributed in terms of severity class occurrence by

Table 3.10
Fire Occurrence Comparison by Slope Position
Site Proportions of Fire Occurrence by Hillslope
Position based on Regeneration Data

Fire Year	Upper Slope	Mid Slope	Lower Slope	Totals
1478	0.00	0.33	0.67	1.00
1531	0.15	0.35	0.50	1.00
1555	0.21	0.29	0.50	1.00
1585	0.38	0.25	0.38	1.00
1629	0.00	0.00	1.00	1.00
1637	0.33	0.33	0.33	1.00
1655	0.30	0.30	0.39	1.00
1666	0.43	0.21	0.36	1.00
1689	0.67	0.33	0.00	1.00
1699	0.35	0.40	0.25	1.00
1737	0.41	0.29	0.29	1.00
1751	0.46	0.31	0.23	1.00
1763	0.30	0.35	0.35	1.00
1794	0.29	0.43	0.29	1.00
1815	0.43	0.29	0.29	1.00
1831	0.30	0.40	0.30	1.00
1844	0.25	0.38	0.38	1.00
1852	0.33	0.33	0.34	1.00
1871	0.31	0.34	0.34	1.00
1881	0.23	0.38	0.38	1.00
1888	0.35	0.35	0.31	1.00
1900	0.33	0.33	0.33	1.00
1909	0.33	0.33	0.33	1.00
1920	0.27	0.36	0.36	1.00
1928	1.00	0.00	0.00	1.00
1934	0.33	0.33	0.33	1.00
1974	--	--	--	--

Figure 3.21
Site Proportions for Fire Occurrence by Hillslope Position
Tree Regeneration Data

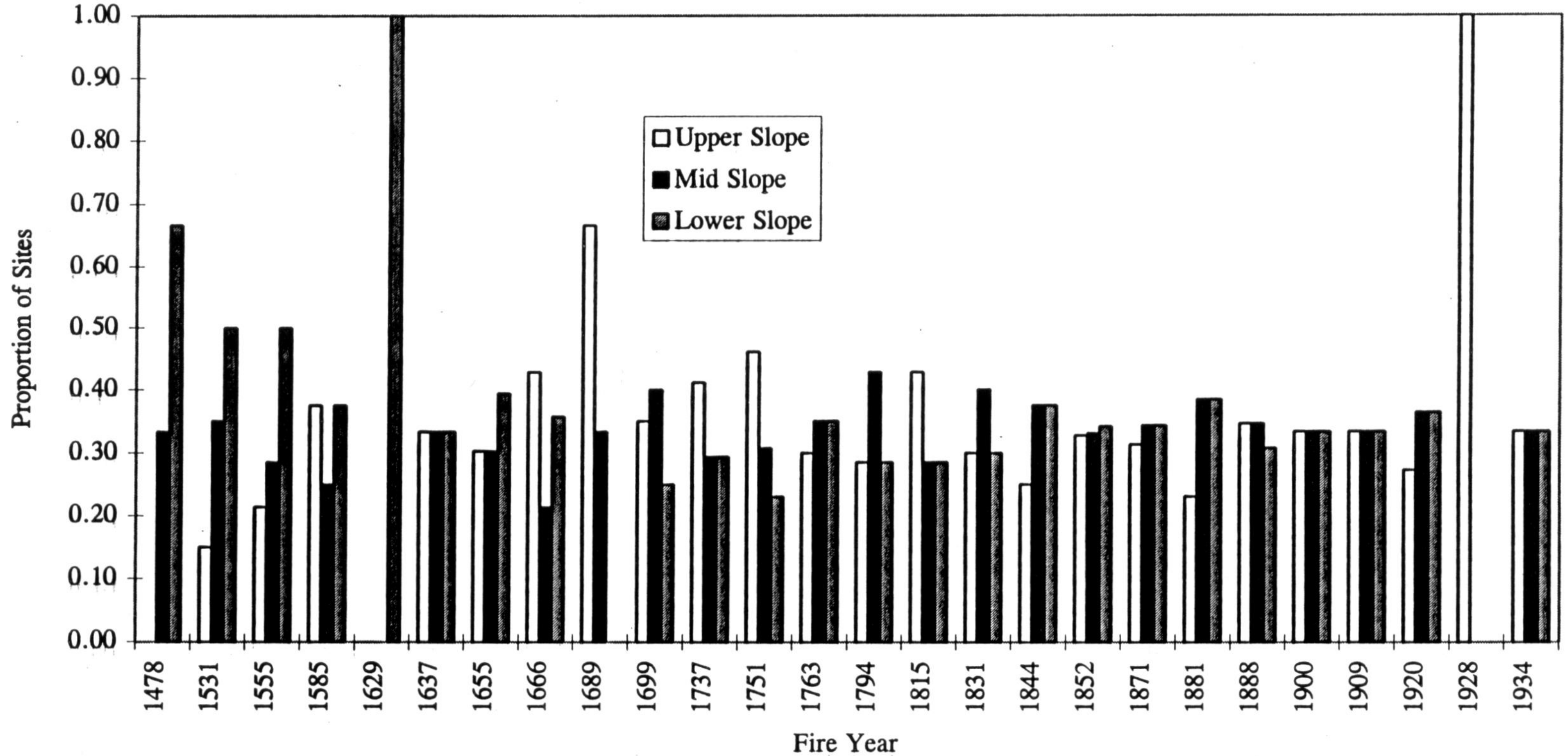


Table 3.11a Mean Fire Return Intervals for Hillslope Positions

	Upper MFRI	Mid MFRI	wer MFRI
Number of Sites	36	33	19
MFRI	75.4	93.7	115.9
Std. Dev.	42.1	52.1	47.2

Table 3.11b Site Mean Fire Return Intervals for Hillslope Positions

Site	Upper MFRI	Mid MFRI	Lower MFRI
9301	52.7		
9303	94.7		94.7
9309	35.3	156.5	
9401		209	
9402	51.5	51.5	170
9403		182.5	158
9404	61	25.3	108.7
9405		178.5	
9406	93.3		
9407	46.5	166.5	170
9408	69.9	73.7	94.5
9409	98.5		
9410	76.7	93.3	140.7
9411	22.7	68.6	
9412	20.5	55.7	87.7
9413		46.7	
9503	63.5	63	35.3
9504	71.4	80.2	52.2
9507	112.3		
9516		107	160.5
9522	139.5	116.5	118
9523		81	
9525	99.25		
9528		123	
9529	23.5		
9530	23.5		
9531	26.8		
9534	71.7	36.5	
9535			98.5
9539	13.5	19	107.5
9541	53.5	28.5	53.5
9546	25		

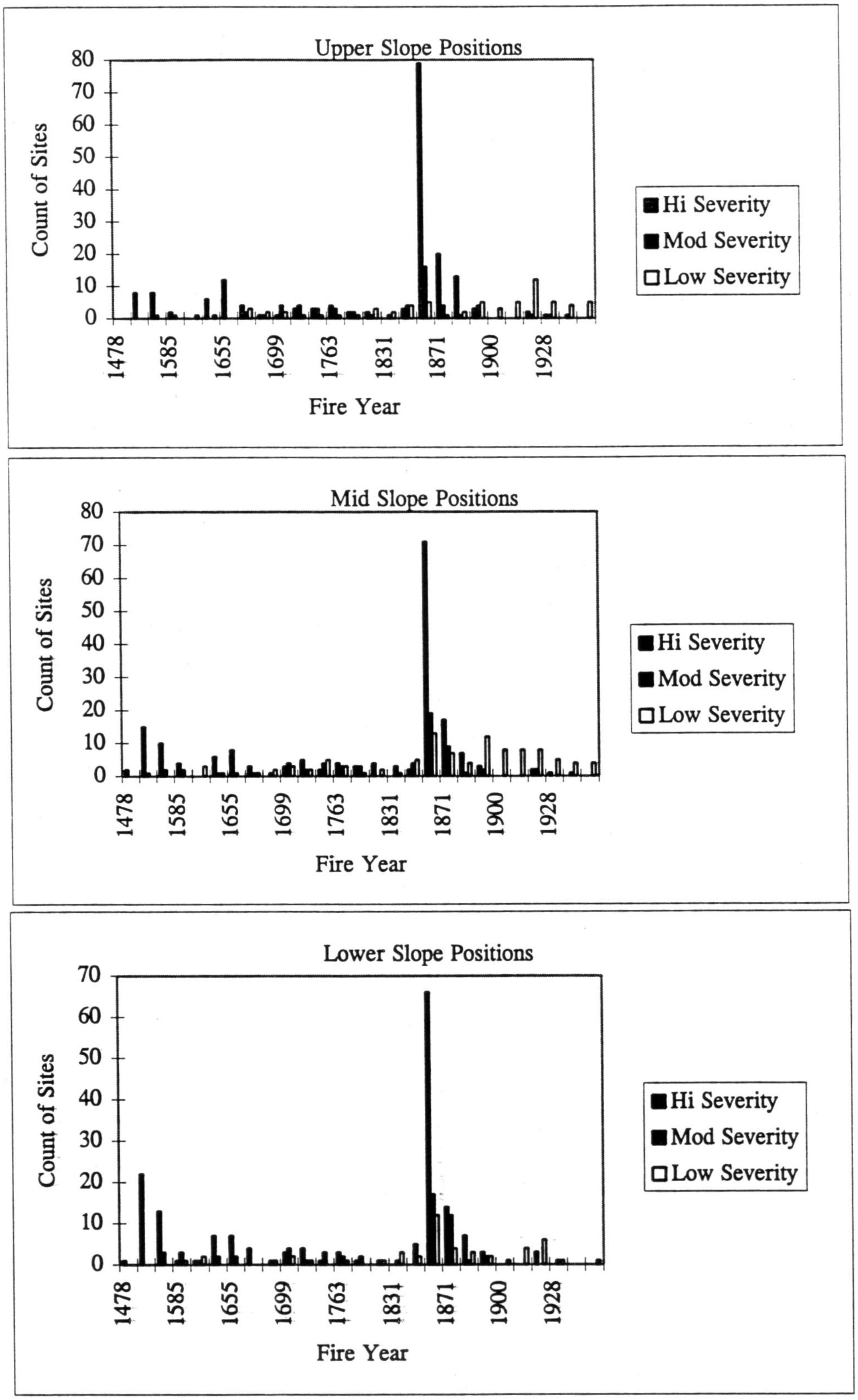
Table 3.11b (continued)

Site	Upper MFRI	Mid MFRI	Lower MFRI
9548	132.5		
9549	116.5		
9550	117		
9551		87.25	
9553		125.5	
9554	136	97	97
9555	107		
9556	43	81.5	
9558	55		
9559	50.3	57.5	
9560	108.7		
9561	107	52.5	
9564		71.8	187
9565		67.5	73.8
9568	100		
9573		170	
9585	194.5		194.5
9592		171.5	
9597		28	
95129		119	

Table 3.12
Site Counts of Fire Severity by Hillslope Position

Fire	Upper Slope Severity Class			Mid Slope Severity Class			Lower Slope Severity Class		
Year	H	M	L	H	M	L	H	M	L
1478	0	0	0	2	0	0	1	0	0
1531	8	0	0	15	1	0	22	0	0
1555	8	1	0	10	2	0	13	3	0
1585	2	1	0	4	2	0	1	3	1
1629	0	0	1	0	0	3	1	1	2
1637	6	0	1	6	1	1	7	2	0
1655	12	0	0	8	1	0	7	2	0
1666	4	2	3	3	1	1	4	0	0
1689	1	1	2	0	1	2	0	1	1
1699	1	4	2	3	4	3	3	4	2
1737	3	4	1	5	2	2	4	1	1
1751	3	3	1	2	4	5	1	3	0
1763	4	3	1	4	3	3	3	2	1
1794	2	2	1	3	3	1	1	2	0
1815	2	1	3	4	0	2	0	1	1
1831	0	1	2	0	3	1	0	1	3
1844	3	4	4	2	4	5	0	5	2
1852	79	16	5	71	19	13	66	17	12
1871	20	4	1	17	9	7	14	12	4
1881	13	1	2	7	1	4	7	1	3
1888	3	4	5	3	2	12	3	2	2
1900	0	0	3	0	0	8	0	0	1
1909	0	0	5	0	0	8	0	0	4
1920	2	1	12	2	2	8	3	0	6
1928	1	1	5	1	0	5	0	1	1
1934	0	1	4	0	1	4	0	0	0
1974	0	0	5	0	0	4	0	0	1
Totals	177	55	69	172	66	102	161	64	48

Figure 3.22 Count of Severity Occurrence for Slope Positions



hillslope position. High severity for these fire episodes does not occur at sites that have established age classes from the 1531 and 1555 fire episodes. Later fire episodes show more regeneration at upper hillslope positions.

The 1852 fire episode is a unique case. Counts of high severity at hillslope positions for the 1852 fire episode are greatest for upper hillslope positions (79 sites), followed by mid hillslope positions (71 sites) and lower hillslope positions (66 sites). This result is a further indication of the very severe, widespread nature of this fire episode. The fire episode of 1871 is similar in site proportions, but not overall counts, of severity occurrence by hillslope position (Table 3.10).

Fire episodes after the fire episode of 1871 are predominantly of low to moderate severity. The occurrence of these severity classes is close to even between hillslope positions, with the 1920 fire episode showing a relatively high number of upper hillslope positions registering the fire episode, and the 1888 fire episode showing a relatively high number of mid hillslope positions registering the fire episode.

3.3.2.4 Summary of Hillslope Position Analysis Results

For the fire episodes in this study area, frequency was greater at upper hillslope positions. The frequency results for the MFRI support the hypothesis that upper hillslope positions have higher frequency of fire episodes. Additionally, upper hillslope positions had the most sites with at least three fire episodes, followed by middle and finally lower hillslope positions, which also supports higher frequency for upper hillslope positions.

Proportions of sites with regeneration trees and fire scars varied over time by hillslope position, with a higher proportion of sites with evidence of early fires at lower hillslope positions. Regenerated trees are a higher proportion of total regeneration at lower hillslope positions for early fire episodes and at upper hillslope positions for later fire episodes. In other words, more trees regenerated from early fire episodes at lower hillslope positions survived later fire episodes. This supports the hypothesis that lower hillslope positions have lower severity than upper hillslope positions.

3.4 DISCUSSION

3.4.1 Outcome of Hypotheses Tested

Hypotheses tested to evaluate the influences of environmental variables on the pattern of fire in the study area were: 1) widespread, severe fire episodes were related to precipitation, landform and vegetation patterns and were more likely to occur in the wetter western and central parts of the study area than in the drier eastern part of the study area; 2) fire occurred less frequently at higher elevations than at lower elevations; 3) fire occurred more frequently on steeper slopes than on less steep slopes; 4) widespread, high severity fire episodes occurred more frequently on northern aspects; 5) widespread, high severity fire episodes occurred more frequently on sites with wetter vegetation types than on sites with drier vegetation types; and, 7) upper hillslope positions experienced more frequent, higher severity fire episodes than lower hillslope positions.

The results of the logistic regression supported hypotheses 1, 6: widespread fire episodes were more likely to occur in the wetter western and central part of the study area than in the drier eastern part of the study area, in the wetter landforms of the study area, and on sites with the wetter vegetation type RUSP. An analysis of scar and regeneration data supported hypothesis 7: upper hillslope positions experienced more frequent, higher severity fire episodes than lower hillslope positions.

Logistic regression results did not support hypotheses 3, 4, and 5. As individual variables, elevation and slope were each significant in only one logistic regression model of a fire episode. Elevation was significant as an individual variable in the fire episode of 1888, however the odds ratio (1.01) indicated that as elevation increased the chance of fire occurrence increased. Slope was significant with Zone in the model of the fire episode of 1888, however the odds ratio (0.9) for slope supported the converse to the hypothesis proposed: as slope increased, fire was less likely to occur. Aspect was not significant in any logistic regression model of widespread, high severity fire episodes.

3.4.2 Logistic Regression Models of Fire Episodes

Record erasure may explain why no variable was significant for the fire episodes of 1531 and 1555. The fire episodes of 1531 and 1555 were widespread like the fire episodes of 1852 and 1871, but few sites retained evidence of these fires (Figures 3.23 and 3.24), since the fire episodes of 1852 and 1871 erased much of the record.

The results from the logistic regression model of the fire episode of 1852 suggest that the response of fire from Zone, LTA, and VAG are similar. For each individual variable the wettest category was more likely to experience the widespread, high severity fire episode of 1852 than the driest category. Sites with the wettest combination of characteristics were 11 times more likely to show evidence of the fire episode of 1852 than sites with the driest characteristics. Sites of RUSP VAG, indicative of the wettest sites, were 15 times more likely to experience the fire episode of 1852 than sites of RHMA VAG, indicative of the driest sites. Wet conditions increase vegetation growth and reduce occurrence of fire. Both of these factors contribute to relatively high fuel loads. High fuel loads increase fire severity and may facilitate fire spread through fuel continuity. These factors add to the explanation of the large size and pattern of severity of the fire episode. The fire episode of 1852 has a high proportion of sites in the wetter IC Zone with high severity, while the drier VM Zone has a high proportion of mid and low severity sites (Figure 3.25).

The logistic regression model for the fire episode of 1871 reflects the spatial occurrence of the fire episode (Figure 3.26). Landtype Association was the most

Figure 3.23 Occurrence of the 1531 Fire Episode

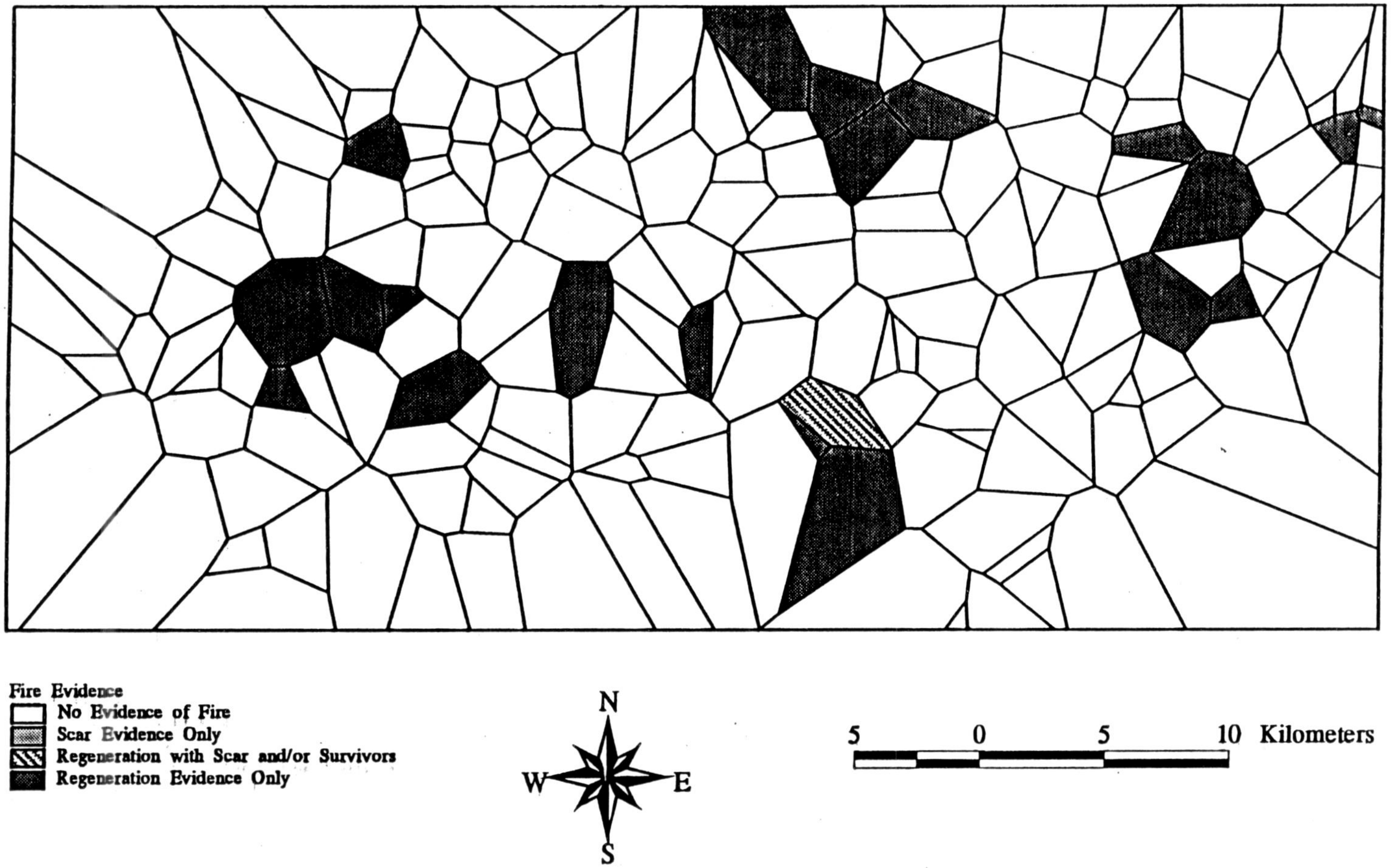


Figure 3.24 Occurrence of the 1555 Fire Episode

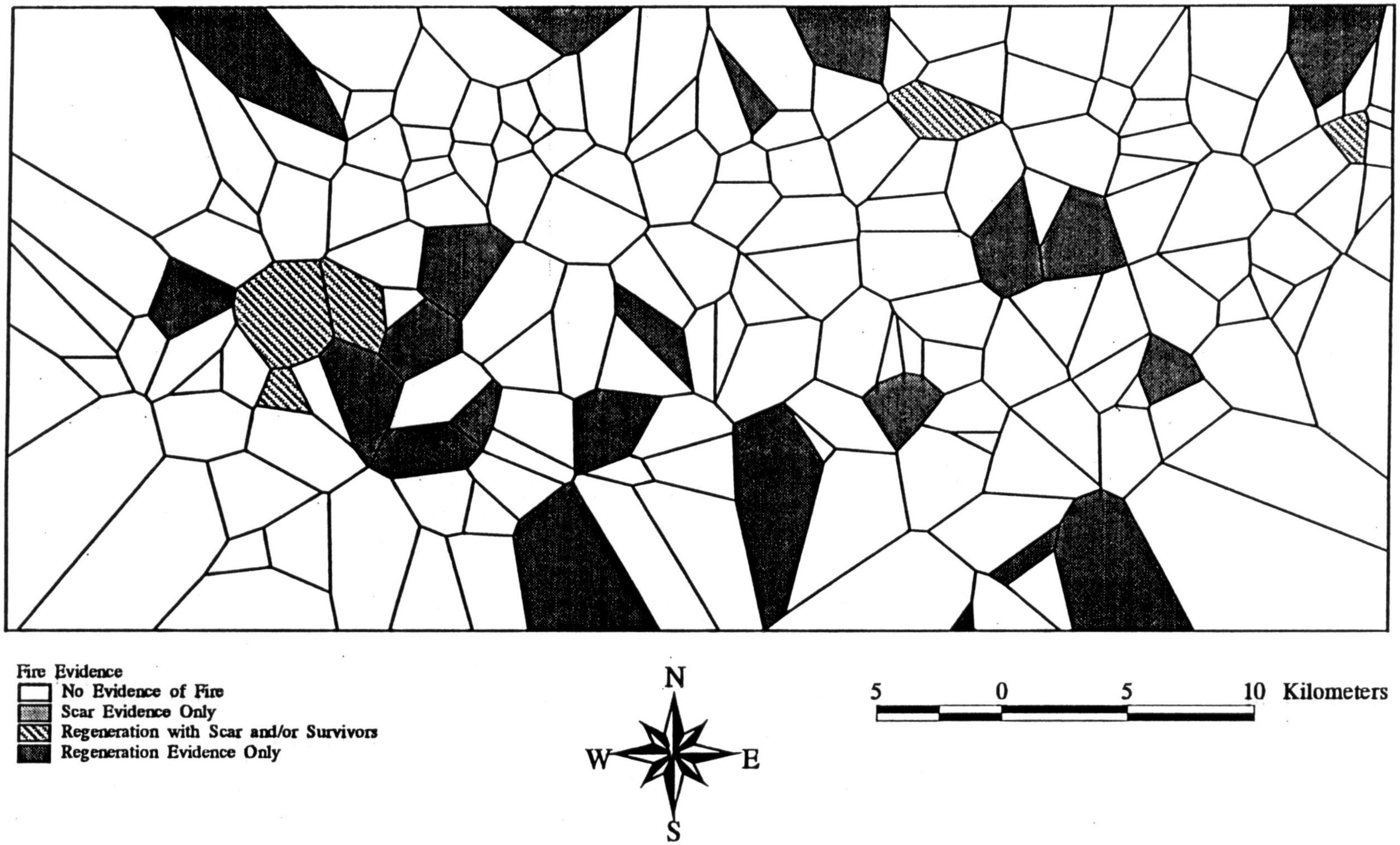


Figure 3.25 Occurrence of the 1852 Fire Episode

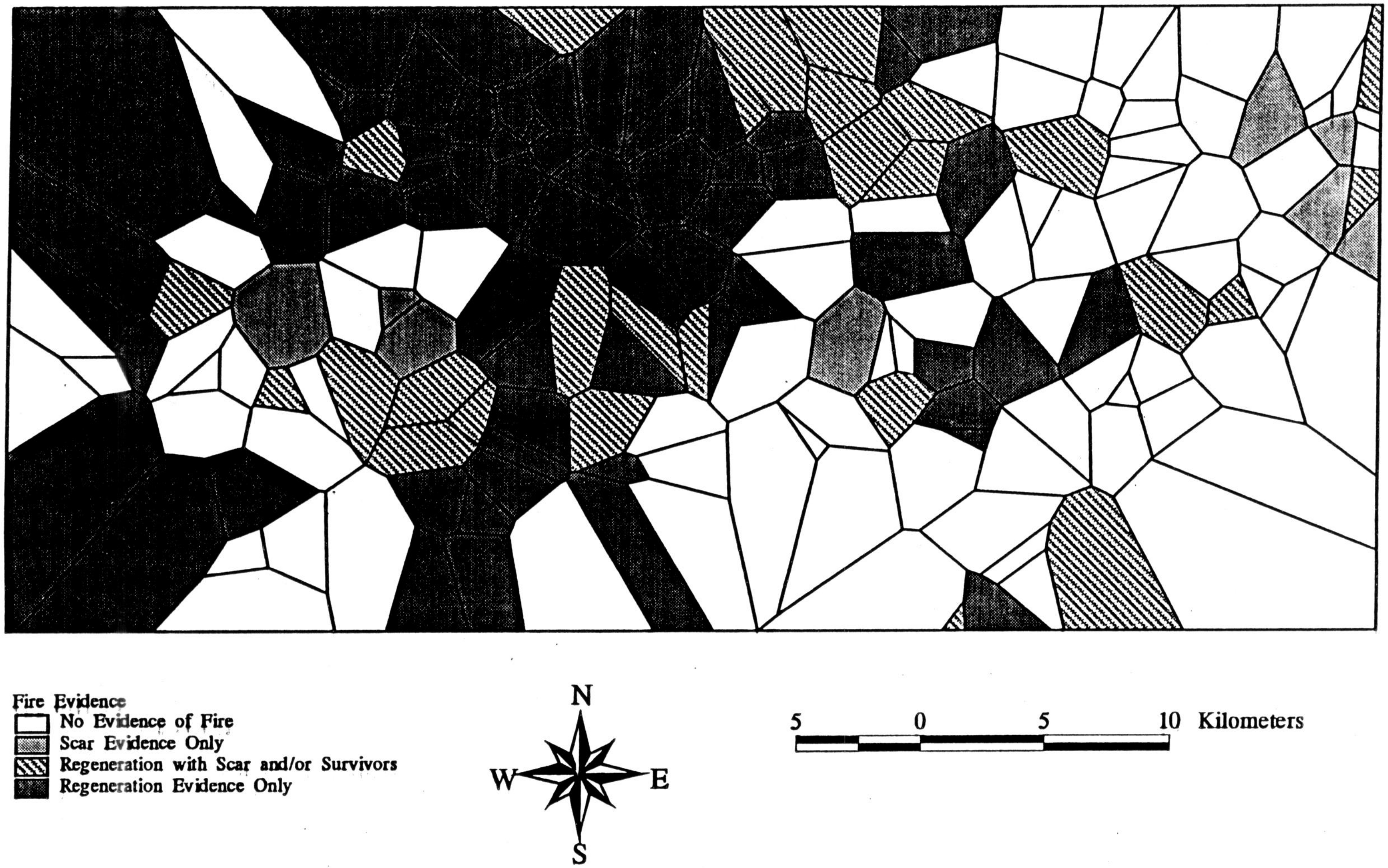
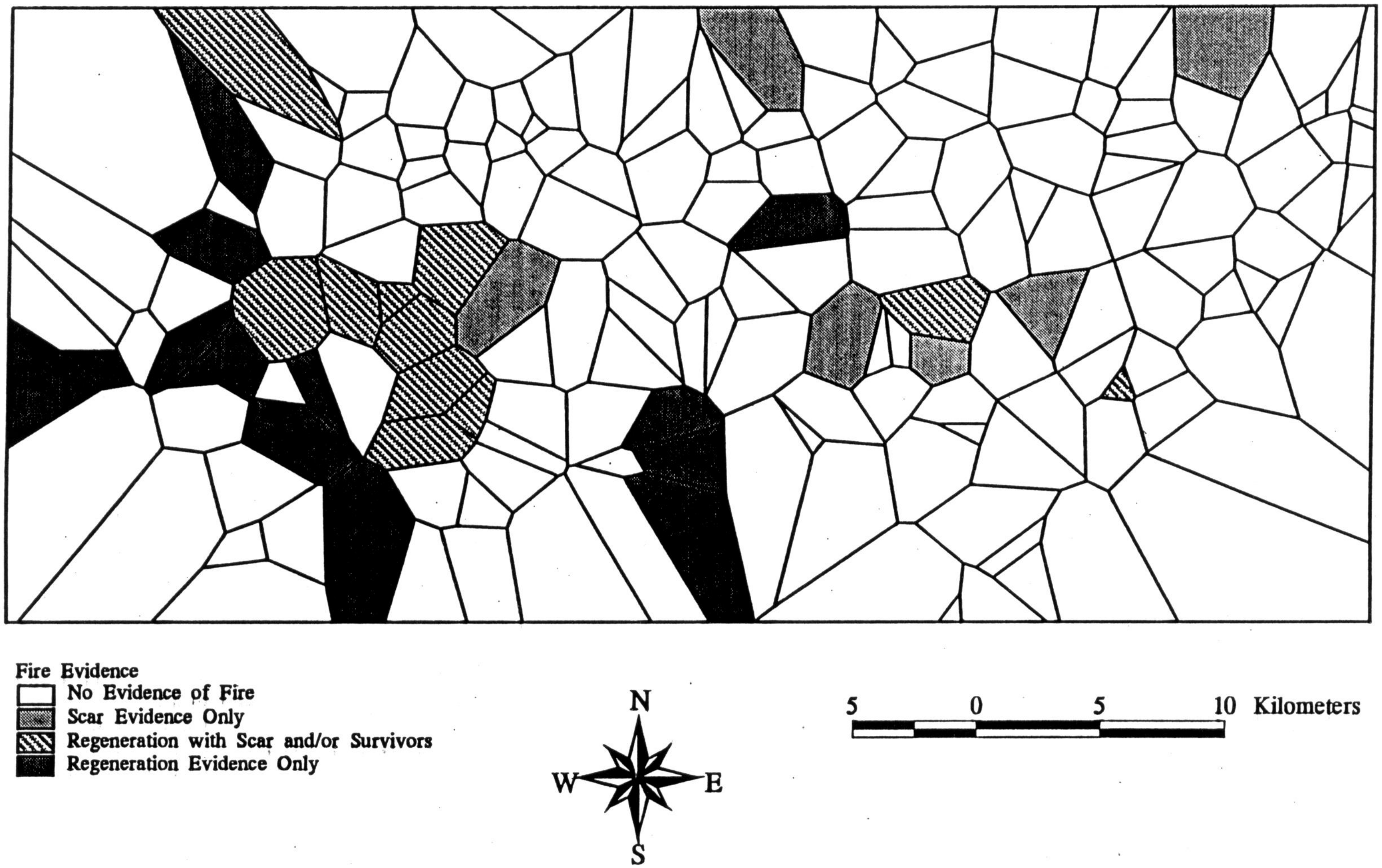


Figure 3.26 Occurrence of the 1871 Fire Episode



significant variable in this model; no variable combinations were significant. The results of the model show the fire episode of 1871 was most likely to occur in the LTA 3T. The fire episode of 1871 also was more likely to occur in LTAs 3B and 3C than in LTA 3F, and in LTA 3B than in LTA 3C.

There was little indication from the description for LTAs (Berry and Maxwell, 1981) of why the fire episode of 1871 was more likely to occur in the certain LTAs and not others. Historical records indicate the Coos Bay fire of 1868, which was identified in this study using scar analysis as the fire episode of 1871, burned extensively along or close to the coast (Morris, 1934; Zybach, 1988). The Coos Bay fire was predominantly located to the south of the study area, and may have moved northward along the coast into the study area. The moderate relief of LTAs 3B and 3C described by Berry and Maxwell (1981) may have permitted east winds to reach the fire while it was in LTA 3T and to some extent contain the fire there.

The results of logistic regression models support the hypothesis that widespread, severe fire episodes were more likely to occur in the wetter LTAs. Fire occurrence, and related odds ratios, for the widespread, high severity fire episode of 1871 was greater for western and central LTAs than for the drier LTA 3F. These results are analogous to the results for Zone, and also reflect the importance of moisture availability and related fuel conditions to fire occurrence and severity.

The fire episode of 1888 was the only fire episode in which slope was significant. As slope increased, the probability of fire decreased very slightly (odds ratio = 0.92). The fire episode of 1888 may have been caused by the use of fire for land clearing activities related to homesteading (Steinhauer, 1974; Rust, 1984). It is possible that steeper slopes were somewhat less likely to be burned due to lower demand for steep slopes for agriculture.

Zone was the most significant variable for the fire episode of 1920, which occurred primarily in the eastern part of the study area. The fire episode of 1920 was of low severity over most of its occurrence. Low severity fire episodes were expected to be more likely to occur in the eastern portion of the study area, where drier conditions permit easier fire initiation and spread. If the fire episode started in the eastern part of the study area its spread into the western part of the study area may have been prevented by fire control efforts initiated in 1910.

3.4.3 Individual Variables in Logistic Regression Models

The variable aspect was not consistently significant in logistic regression models. Aspect was only significant in the preliminary runs of the fire episodes of 1637, 1699 and 1844 (Table 3.13). For these fire episodes fire occurrence was significantly more likely on south and west aspects than on north and east aspects, as reflected by the odds ratios. Aspect was not significant in the other eleven fire episodes and fire occurrence was evenly distributed by aspect.

Two potential hypotheses were developed about the influence of aspect on fire occurrence in the Coast Range. The first hypothesis was that exposure to drying east

Table 3.13 Summary of Logistic Regression Results for Aspect as an Individual Variable

(North as reference; total number of sites = 178)

Fire Episode Year (t = Tested)	Number of Fire Episode Sites	Aspects							Aspect p-value
		East		South		West		North	
		Site Counts	Odds Ratio	Site Counts	Odds Ratio	Site Counts	Odds Ratio	Site Counts	
1478	3	1		0		1		1	
1531(t)	23	4	0.1	4	0.7	10	2.1	5	0.169
1555(t)	27	7	1.3	7	1.2	7	1.1	6	1.00
1585	8	0		2		3		3	
1629	5	0		2		3		0	
1637(t)	12	1	1.0	3	3.1	7	7.5	1	**0.002**
1655(t)	15	4	2.2	6	3.3	3	1.4	2	0.216
1666	10	0		2		5		3	
1689	6	1		1		1		3	
1699(t)	13	2	2.2	4	4.2	6	6.3	1	**0.032**
1737(t)	12	2	0.7	2	0.6	5	1.6	3	0.351
1751	9	1		4		2		2	
1763(t)	12	4	2.2	2	1.0	4	1.9	2	0.394
1794	8	2		2		2		2	
1815	8	1		2		2		3	
1831	7	1		3		2		1	
1844(t)	14	1	0.5	6	3.2	5	2.5	2	**0.025**
1852(t)	101	28	1.7	22	0.8	27	1.1	24	0.553
1871(t)	31	3	0.3	9	1.0	10	1.0	9	0.169
1881(t)	16	4	1.0	4	1.0	4	0.9	4	1.0
1888(t)	29	4	0.5	10	1.3	7	0.8	8	0.394
1900	12	0		4		4		4	
1909(t)	13	4	2.2	4	2.0	3	1.4	2	0.553
1920(t)	28	5	0.5	6	0.6	8	0.8	9	0.683
1928	16	2		5		4		5	
1934	9	4		1		2		2	
1974	9	3		1		4		1	
Totals	456	89		118		141		108	

winds would cause east aspects to experience higher frequency and severity of fire episode. The second hypothesis was that the dryer fuels of southern aspects made ignition easier, increasing fire frequency. The converse was that northern aspects experienced lower frequency, higher severity fire episodes.

Climate, fire severity and topography may explain the lack of significance of aspect as a predictor of fire occurrence. The Coast Range has a wet, temperate climate that may reduce fuel drying differences between aspects during the dry season.

Fires in the Coast Range can be very severe and widespread, such as the Tillamook fire of 1933 and possibly historical fires (Clark, 1905; Morris 1934). These fires may have reduced or eliminated the influence of aspect. These fires may create their own weather and be insensitive to fuel or other conditions that vary with aspect. Large scale severe fire episodes such as that of 1852 show a very even distribution of fire occurrence by aspect (Table 3.13) which may have eliminated any record of differences in fire occurrence by aspect for previous lower severity fire episodes.

Short slope lengths may account for a limited influence of aspect on fire occurrence. The study area has a highly dissected topography. Hillslope lengths are less than in other regions where fire studies have examined the influence of aspect on fire, such as the Cascades and Rocky Mountains (Teensma, 1987; Morrison and Swanson, 1990; Arno, 1976; Arno, 1980). Swanson and others (1990) have hypothesized that if hillslope lengths are less than several tree heights, topography can have a reduced effect on fire and other disturbance agents such as wind. In this case the aspect of a stand does not produce a difference in the pattern of occurrence of fires associated with high or severe wind events, while the pattern of occurrence may still be different at other scales (e.g zone, Landtype, or hillslope position).

It is impossible to know if earlier fire episodes would show a significant influence from aspect if record erasure had not occurred. The lack of significance of aspect in later fire episodes, such as those occurring after 1871, would indicate that aspect is not important in fire occurrence. The proportion of sites by aspect recording fire episodes does not change substantially before and after the fire episode of 1871 (Table 3.14).

The results reflect the difference in fire regimes for the Valley Margin (VM) and Interior/Coast (IC) Zones. The VM zone has more frequent fire episodes that are smaller and less severe than the IC zone. Many of these fire episodes are exclusively within the VM zone (Table 3.15), heavily influencing the odds ratios.

Zone is not significant for the 1531 and 1555 fire episodes. Both of these fire episodes are more widespread than the fire episodes with extreme odds ratios; both of these fire episodes also have odds ratios near 1, indicating even distribution within zones. Fire episode maps (Figure 3.23 and 3.24) show the widespread, high severity nature of these fire episodes. It is possible that these two fire episodes were more widespread but that much of the record of their occurrence has been erased.

Other widespread fire episodes such as those of 1852 and 1871 (Figures 3.25 and 3.26) have odds ratios reflective of the higher occurrence in the IC zone (Table

Table 3.14 Summary of Recorded Fire Occurrence by Aspect

Number of Sites Recording Fires	Total	East Sites		South Sites		West Sites		North Sites	
		Count	Percent	Count	Percent	Count	Percent	Count	Percent
Before 1871	324	63	19%	83	26%	105	32%	73	23%
After 1871	132	26	20%	35	27%	36	27%	35	27%
Total	456	89	20%	118	26%	141	31%	108	24%

3.15). Large-scale fires are more likely to have a greater percent of sites with higher severity, and occur less frequently than smaller fires (Agee, 1993). These results support the hypothesis that the IC zone experienced the high severity, widespread fire episodes of lower frequency, while the VM zone experienced the more frequent, less severe fire episodes. If Zone adequately reflects the influence of precipitation on fire occurrence, these results indicate that differences in precipitation influence the pattern of fire through the related factors of fuel loads and fuel moisture content.

It is unclear if Zone adequately reflects the influence of precipitation on fire occurrence. Precipitation patterns used in the analysis were developed in a model using precipitation records from 1961 - 1990 (Daly and others, 1994). The pattern of precipitation and its influence on fire may have changed over the 500 year period of record. Because precipitation is affected by landforms, the significance of Zone is likely due in part to the pattern of Landtype Associations.

It is difficult to determine conclusively whether Landtype Association plays a significant role in the occurrence of fire. Landtype Association was significant for the fire episodes of 1852, 1871, 1888 and 1920 (Table 3.16). Landtype Association was the most significant variable for only the fire episode of 1871. The Landtype Association 3F and the Valley Margin Zone overlap each to a high degree (Figure 3.11). The Landtype Associations 3B, 3C and 3T delineate the IC Zone but it is unclear if this delineation can be used to acquire a better understanding of fire. Zone more closely reflects precipitation patterns than Landtype Association, so is more useful in

Table 3.15 Summary of Logistic Regression for Zone as an Individual Variable

Number of Sites = 135

Fire Episode Year	Number of Fire Episod Sites	Zone: IC Site Counts	IC Odds Ratio	VM* Site Counts	VM* Reversed Odds Ratio	Zone p-value
1478	3					
1531(t)	18	9	0.6	9	1.6	0.32
1555(t)	17	8	1.9	9	0.5	0.19
1585	7					
1629	5					
1637	11					
1655	11					
1666	7					
1689	4					
1699	9					
1737	10					
1751	8					
1763	9					
1794	6					
1815	5					
1831	6					
1844	11					
1852(t)	78	61	6.6	17	0.2	**6.6 E-6**
1871(t)	22	16	2.0	6	0.5	**0.005**
1881	14					
1888(t)	20	5	0.2	15	5.9	**0.0001**
1900	10					
1909	12					
1920(t)	22	7	0.3	15	4.0	**0.002**
1928	12					
1934	6					
1974	2					

*Reference Category

(t = Tested)

Table 3.16 Summary of Logistic Regression for Landtype Association as an Individual Variable

Number of Sites = 135

Fire Episode Year	Number of Fire Episod Sites	Landtype Association 3B Site Counts	3B Odds Ratio	3C Site Counts	3C Odds Ratio	3T Site Counts	3T Odds Ratio	3F Site Counts	LTA p-value
1478	3								
1531(t)	18	2	1.09	2	0.21	2	0.63	12	0.27
1555(t)	17	3	2.66	4	0.62	2	0.89	9	0.59
1585	7								
1629	5								
1637	11								
1655	11								
1666	7								
1699	9								
1737	10								
1751	8								
1831	6								
1844	11								
1852(t)	78	4	0.94	40	13.46	7	1.09	27	**0.003**
1871(t)	22	2	2.46	6	1.55	8	9.87	6	**0.002**
1881	14								
1888(t)	20	1	0.37	1	8.00E-02	3	0.77	15	**0.003**
1900	10								
1909	12								
1920(t)	22	1	0.37	6	0.38	0	1.13 E-13	15	**0.040**
1928	12								
1934	6								
1974	2								

*Reference Category

(t = Tested)

identifying possible precipitation effects on the fire regime than Landtype Association. However, the landforms on which Landtype Association are based affect precipitation patterns through the action of orographic lifting. Landtype Association was developed from multiple variables, including climate, lithology (bedrock formations), landscape structure/morphology, age (within the erosion cycle), landforms, soil and vegetation (Berry and Maxwell, 1981). Climate is not as distinct or as important a descriptor of Landtype Association as precipitation is for Zone. It is unclear if lithology had a significant effect on fire, rather it likely played a role through its influence on landforms and general structure (e.g slope steepness). Landscape structure was derived from morphology, including aspect. Landform ratings were derived from slope steepness and drainage texture. Soil and vegetation were derived from datasets existing at the time the document was prepared.

Some of the variables used by Berry and Maxwell to develop Landtype Association, such as vegetation, aspect, and precipitation, are tested in this study as separate variables. The mixing of these variables makes it difficult to interpret results in which LTA is significant. This significance may be due to a variable inside the construct of LTA, or due to interactions occurring between variables which cannot be identified.

VAG was only significant as an individual variable in the fire episode of 1852. The difference in response of the wet (RUSP) VAG to the dry (RHMA) VAG sites in the final model for the fire episode of 1852 was additional evidence that large, high severity fire episodes are more likely to occur on sites where fuel loads can accumulate and wet conditions reduce the occurrence of fire for long periods.

Slope was significant as an individual variable for the fire episode of 1920, and was significant in a multiple variable model with Zone for the fire episode of 1888. Slope angle may represent too small a scale of measure to be significant in large-scale, high severity fire episodes. The severity of fire episodes in the Coast Range may have overcome the effect of slope on the other fire episodes that occurred in the study area. Very severe fire episodes may have developed high enough intensities that the severity of a fire episode was the same for all slope angles, and erased the record to a degree that a smaller-scale variable such as slope was not significant. The broad scale of the variables that are most commonly significant for (large-scale) high severity fire episodes (e.g Zone and Landtype Association) may better match the scale of these fire episodes.

In an investigation of pattern-process interactions such as this one, the influence of an environmental process such as precipitation on the process of fire is evaluated by testing the pattern of precipitation on the pattern of fire. Consequently, spatial patterns are used as proxy variables in understanding how an environmental process affects the process of fire. The significance of Zone, Landtype Associations, and Vegetation Association Groups in the logistic regression model of the fire episode of 1852, and of Zone and Landtype Association as separate variables in other models of fire episodes, has been used to evaluate the difference in the pattern of the response of fire to patterns that reflect conditions of moisture availability and related fuel loads and fuel moisture content. The association of these patterns with the pattern of fire occurrence indicated that processes related to fuel loads and fuel moisture content have affected the process of fire.

3.4.3 Potential Scale Interactions of Variables

Whether there is a hierarchy of spatial factors that contribute to the process of fire is an important consideration when describing the environmental influences on fire. Due to the importance of moisture availability and soils on vegetation and associated fuel conditions, spatial interactions of interest included those between precipitation and vegetation, landform and vegetation, and aspect and vegetation. Results from the logistic regression model of the fire episode of 1852 failed to show any significant interaction terms in models that converged. Significance of an interaction term indicates that a change in one explanatory variable influences the other explanatory variable's effects on the response variable (Hosmer and Lemeshow, 1989). The interaction of Zone and Vegetation, and Aspect and Vegetation, were significant in backwards stepwise logistic regression models, but those models failed to converge. The significance of these interaction terms is an initial indication that these variables may be affecting each other.

The lack of statistical significance of interactions among environmental variables does not preclude the possibility that spatial hierarchies of these variables exist. The influence of aspect on vegetation, soils on vegetation, and precipitation on vegetation has been shown in the western hemlock - Douglas-fir forests of the Pacific Northwest (Zobel and others, 1976). The influence of landforms on precipitation is an important input into the modeling of precipitation patterns in the study area (Daly and others, 1994).

Statistical results from this study were inconclusive as to whether patterns of environmental influences on fire operate within a hierarchy of spatial scales. To evaluate the existence of spatial hierarchies using logistic regression may require datasets with fire episodes having more site occurrences to adequately test interactions between variables. Additional study is warranted as there are strong empirical observations that interactions of environmental variables influencing fire occur across spatial scales. The most significant variables for the fire episode of 1852 were Zone (precipitation), Landtype Association, and Vegetation Association Group. The interaction of landforms influencing precipitation patterns which influence vegetation type and fuel loads is strong indications of a hierarchy among these variables.

3.4.4 The Influence of Hillslope Position on Fire Patterns

Examinations of the interaction of fire frequency and severity have indicated that when severity is high, frequency is low (Agee, 1993). Results from the hillslope position analysis in this study contradict this notion for the Coast Range. Upper hillslope positions were found to both have higher frequency and severity than lower hillslope positions. It appears that the MFRIs, both at the site and at the hillslope position, were long enough to allow for a significant buildup of fuels so that upper hillslope positions have both higher frequency and severity of fire. This is possible given the high rates of growth in the Coast Range (Fujimora, 1971), as well as potentially rapid regeneration following disturbance (Isaac and Meagher, 1936).

Several factors may influence the lower severity of fire and the related higher incidence of long-term tree survival at lower hillslope positions than at upper hillslope positions. The water table is closer to the upper soil layers and related soil moisture content is higher at lower hillslope positions. Higher soil moisture content will increase the time needed for live fuels to dry out sufficiently to reach combustible levels (Agee, 1993). Lower hillslope positions are also closer to riparian areas, where higher relative humidities (Perry, 1994) can reduce or delay fuel drying as well as fire spread. Lower hillslope positions are less exposed to the preheating and increased drying of fuels that occurs due to the nature of heat from fire to move up slope. Topography may provide lower hillslope positions greater protection from winds that drive fires, which would increase the chances of surviving a moderate to high severity fire.

Higher tree survival from fire at lower hillslope positions and the resulting age class distribution has implications for the study of fire patterns and related stand structure and management. Following a high severity fire episode, old growth trees may be distributed along valley bottoms and near riparian areas, as opposed to arranged in a large stand. If this is the case the pattern of old growth may resemble networks more than patches, and better approaches to studying old growth patterns might use network analysis. Implications of the result of differential tree survival due to hillslope position include the effects of old growth patterns on old growth dependent species. The transitional stages of old growth dependent species may in some part be controlled by these patterns if old growth patterns resemble networks more than patches.

3.5 CONCLUSIONS

1. The patterns of environmental variables, precipitation, landform, and vegetation, were significant (p-value < 0.05) in a multiple-variable model explaining the occurrence of the widespread, high severity fire episode of 1852. The wettest sites, those within the higher precipitation Interior/Coast Zone, within Landtype Association 3T, and with vegetation association type RUSP, were 11 times more likely to experience the widespread, high severity fire episode of 1852 than the driest sites within the lower precipitation Valley Margin Zone, within Landtype Association 3F, and with vegetation association type RHMA. The association of these variables with the pattern of fire occurrence indicated that processes related to fuel loads and fuel moisture content affected the process of fire.

2. Zone, a variable developed to reflect precipitation patterns, was significant (p-value < 0.05) in three out of six fire episodes modeled, and had the lowest p-values of any individual explanatory variable for four of the six fire episodes modeled. This significance is an indication that precipitation patterns influence fire patterns in the

Coast Range. However, Zone may be limited in representing precipitation patterns as it is a construct based on a model of precipitation.

3. Landtype Association was significant in two of the six fire episodes modeled, and was the most significant variable for the fire episode of 1871. LTA was significant as an individual variable for four of the six fire episodes modeled. These results indicate that fire patterns are sensitive to the influences of the patterns of landforms in the study area. The complex of factors used in defining a Landtype Association complicates determining its influence on fire patterns.

4. Other environmental variables were less often significant as individual variables or included in final logistic regression models. For the fire episode of 1852 Vegetation Association Group was significant as an individual variable and was included in the final model. The wettest VAG (RUSP) were 15.03 times more likely to experience the widespread, high severity fire episode of 1852 than the driest VAG (RHMA). Vegetation Association Group was not significant in any other fire episode. Slope was significant as an individual variable in the fire episode of 1920, and was included in the final logistic regression model for the fire episode of 1888. However, the odds ratio for Slope (0.92) indicated a limited effect on fire occurrence due to change in slope angle. Neither Elevation nor Aspect were significant in any final logistic regression models.

5. Logistic regression models did not support the hypothesis that there is an interaction across spatial scales between the significant variables Zone, Landtype Association, and Vegetation Association Groups, for the fire episode of 1852. However, an evaluation of

the results of the models which included interaction terms but that did not converge gives an initial indication that a spatial hierarchy may exist that is not discernible with the data available and methods used. Future researchers using logistic regression to generate explanations of pattern - process interactions and controls of fire should be aware of the limits of the logistic regression method when low numbers of sites record a fire episode.

6. Upper hillslope positions had higher frequency and severity of fire than lower hillslope positions. An important feature of this result is that old growth trees are more common at lower hillslope positions than at upper hillslope positions. This pattern of old growth occurrence should be considered in studies of forest patterns and related management approaches to old growth forests.

CHAPTER 4. A COMPARISON OF FIRE REGIME DETERMINATION METHODS AND STUDIES

4.1 INTRODUCTION

4.1.1 Background

Fire and other disturbance regime information is increasingly being considered in designing long-term land-use strategies for landscapes (Christensen and others, 1996), especially in the Pacific Northwest, where the status, both biological and legal, of endangered species such as the Northern spotted owl and marbled murrelet have required new approaches to resource management (FEMAT, 1993). Ecosystem management addresses the range of natural variability of ecosystem processes relative to present day conditions (Swanson and others, 1993). Understanding the forest disturbance regime is necessary in this context to establish a baseline of knowledge about stand initiation, succession, structure, and composition.

Different methods are available to characterize the important measures of fire regime determination; size, frequency and severity. Different methods may alter results of a fire regime study. Studies in the Douglas-fir forests of the Pacific Northwest have approached fire regime determination in different ways. Fire size, frequency and severity have been addressed with different methodologies, although some similarity between studies were also present. Additionally, these studies were carried out at different scales, each with unique extent and grain for each study. Other unique factors were determination of study boundaries, sampling density, and the data available and collected.

The possibility exists for resource managers to use a study from one area, carried out at a specific scale, to address management issues for a different area of different scale. This possibility is increased in the Pacific Northwest, where several studies of fire regimes in Douglas-fir west of the Cascades forests are available for comparison and possibly for use as inputs to management plans in such areas as coastal Douglas-fir forests..

In this chapter I evaluate the sensitivity of derived fire regime characteristics to different evaluation methods. Specifically, I evaluated the results of this study and compared them to several studies carried out in Douglas-fir forests west of the Cascades, with special emphasis on the sensitivity of methods to scale- and sample-dependent constraints.

4.1.2 Approach

This chapter contains two analyses. The first analysis is a within-study comparisons of results of different fire regime methods. The sensitivity of the fire regime determination results in Chapter 2 was tested by using different methods to estimate size, frequency and severity.

In the second analysis, between-study results were compared to examine methodologies and potential region-wide fire regimes. The methods used and results reported were reviewed for comparisons of fire regime studies of Douglas-fir forests west of the Cascades.

4.2 METHODS

4.2.1 Within Study Comparison

4.2.1.1 Fire Size

To investigate possible bias in the Thiessen fire episode size determination method, three other methods were used to calculate fire episode size and compare results. The other three fire episode size methods were interpolation methods 1 and 2 which used the site Thiessen polygons (Chapter 2) to generate additional fire episode size estimates, and the ratio method (Teensma, 1987; Morrison and Swanson, 1990).

Interpolation methods 1 and 2 were secondary landscape level analyses, for which rule sets were developed to address the potential occurrence of a fire episode at sites where the record was erased by subsequent fire episodes. Both interpolation methods were based on proximity to sites where the record had not been erased, but that recorded earlier fire episodes.

The rule set for adding a polygon to the initial fire episode dataset for Interpolation method 1 was:

1. A polygon under consideration must have an initial (oldest) age class younger than the fire episode being interpolated.

2. The polygon under consideration must be bounded on two sides by polygons that show evidence of the fire episode

OR

3. The polygon under consideration must be bounded by one polygon that shows evidence of the fire episode and 2 polygons generated in (1) above.

Interpolation method 2 was more restrictive. The rule set for adding a polygon to the initial fire episode dataset for interpolation method 2 was:

1. A polygon under consideration must have an initial (oldest) age class younger than the fire episode being interpolated.

2. The polygon under consideration must be bounded on three sides by polygons that show evidence of the fire episode

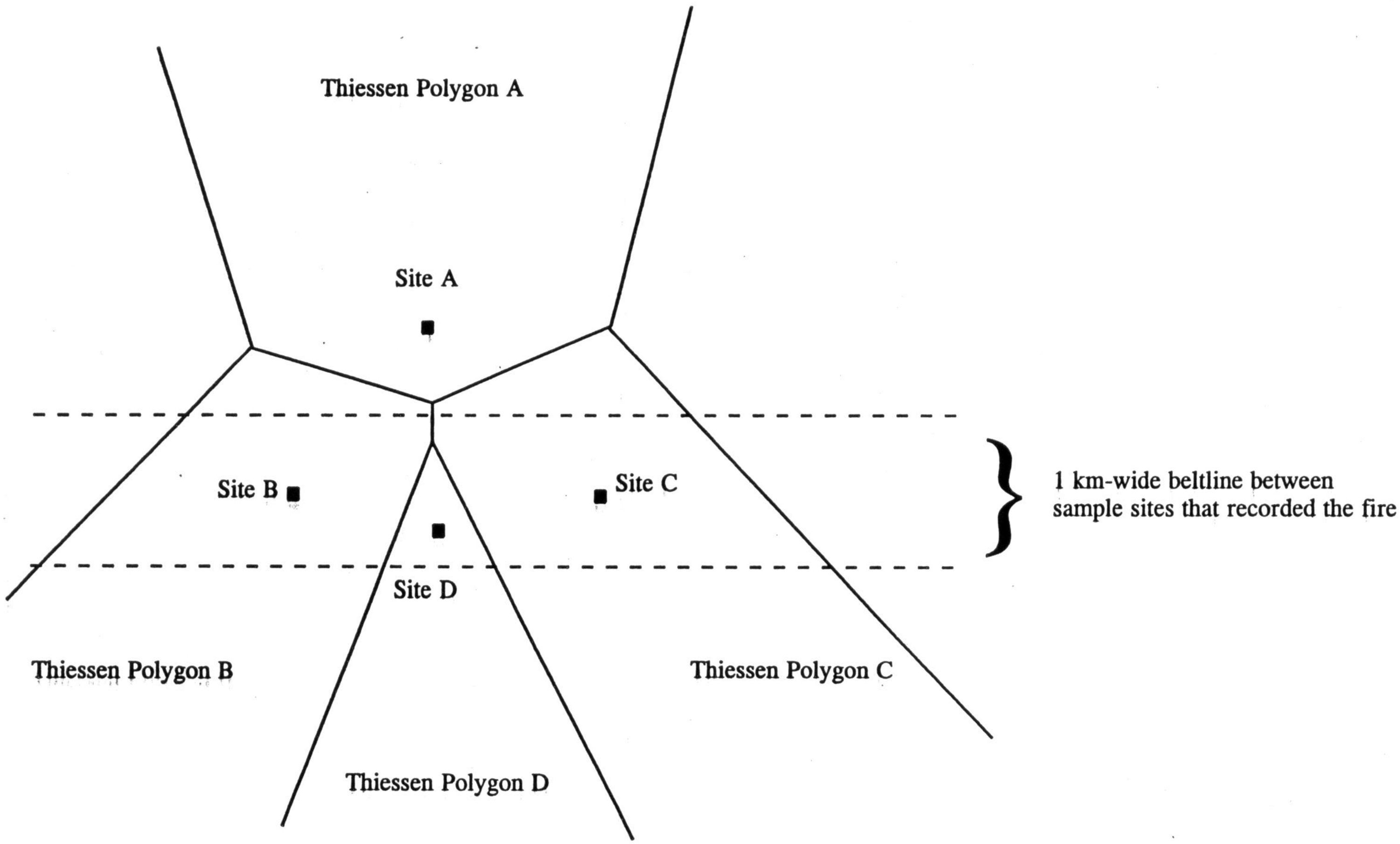
OR

3. The polygon under consideration must be bounded on two sides by polygons that show evidence of the fire episode being interpolated.

AND

The sample *site* of the polygon under consideration must be within a beltline 1 km wide between the two sample *sites* of the polygons that show evidence of the fire episode being interpolated (Figure 4.1).

Figure 4.1 Schematic Diagram of Rule Set for Fire Size Interpolation Method 2. Sites B and C recorded a fire episode; at sites A and D the record was erased by a more recent fire. The Thiessen polygons for both sites A and D are bounded by at least two Thiessen polygons that recorded the fire, but only site D falls within a beltline 1 km wide between sites B and C. Only site D would be included as a site for fire size determination based on interpolation method 2.



Fire episode size was also calculated using the ratio method (Teensma, 1987; Morrison and Swanson, 1990). In the ratio method fire episode size is determined by multiplying the total study area by the number of sites showing evidence of a fire episode divided by the total number of sites, after accounting for erasure, which could show evidence of the fire episode, or:

$$FA(e) = (SA) * NS(e)/(NST-NRE);$$

where

FA(e)	=	estimated area burned during a given episode e,
SA	=	total study area (1375 km^2),
NS(e)	=	number of sites with a record of the episode e,
NST	=	total number of sample sites in the study area (178), and
NRE	=	number of sites where the record was erased by later fires.

The number of sites where the record was erased was determined for each fire episode by determining the initiation age of the stand at each site, based on oldest stump, and comparing that age to the date of the fire episode. If the fire episode occurred before the initiation age of a site stand, then the record had been erased at that site after the fire episode in question. For a fire episode this site would be included in the total for NRE above.

4.2.1.2 Fire Frequency

The MFRI was calculated at several scales to investigate sensitivity of the MFRI calculation to scale. For each scale considered the scale in question served as the grain of measure. For instance, for the study area scale the entire study area was considered as one site and all fire episodes were used for MFRI calculations. The scales calculated were the entire study area; zones; 5 x 5 km^2 grid cells; aspects; and individual sites.

The natural fire rotation (NFR) is a measure of frequency that is related to size of fire by the proportion of the area in question burned over the study period (Heinselman, 1973). The NFR was calculated for each of the fire episode size determination methods and compared between the cultural fire periods identified in Chapter 2.

4.2.1.3 Fire Severity

The original severity determination method relied on the combination of scar and regeneration data found at sites, as outlined in Chapter 2. The original severity tree mortality percentages (method 1) that defined severity classes were:

Low severity: 0% mortality from a fire (scar evidence only)

Moderate severity: 1 - 99% mortality (some tree survivors of fire)

High severity: 100% mortality (regeneration evidence only)

To address possible percent differences in survival from fire, an additional severity measure was generated to compare to the original method. Using the sampled tree/stumps as a representation of the stand and the relative survivorship of age classes prior to the fire episode in question, the following rule set (method 2) was used for severity determination at a site:

Low Severity: >70-100% of stumps sampled age older than the fire

Moderate Severity: >30-70% of stumps sampled age older than the fire

High Severity: 0-30% of stumps sampled age older than the fire

The severity determination method 2 applied a more discriminating rule set on moderate severity fire episodes than severity determination method 1. High and low severity as determined by severity determination method 1 was more constrained: high severity fire episodes had no survivors, low severity fire episodes were only recorded in scars and had no mortality.

4.2.2 Between Study Comparison

There are numerous ways to approach a fire regime study to generate the general measures of interest: fire size, frequency and severity. A statistical measure of these components of the fire regime was described in the other fire studies examined. The studies examined in this section for comparison to this study were all primarily dendrochronological fire studies. A statistical measure of fire frequency was described in all studies, and size and/or severity of fire episodes were also addressed. An attempt was made in all studies to identify fires as landscape-level episodes by comparing sites across the study area to generate a degree of certainty regarding the occurrence and date of a fire. Some studies (Teensma, 1987; Morrison and Swanson, 1990, this study) used iterative approaches to refine estimates of the most likely date and location of a fire episode, using subjective rule sets rigorously applied. Differences in these rule sets reflected the different availability and accuracy of data.

Data collection and analysis protocols were not discernable from the reports of other studies. Most of the data collected were used to address the MFRI and/or the NFR, which are standardized measurements (Romme, 1980), as well as size and severity analyses. Methods of data collection were often outlined in the research reports and articles, but specifics were limited.

Five studies were selected to compare with this study. The primary criterion for selection was the location of the fire study in the western hemlock - Douglas-fir forest zone west of the Cascades. The fire study of the Boundary Waters Canoe Area, located in the boreal forests of northern Minnesota (Heinselman, 1973), was included in the comparison because the extent of that study (4050 km^2) was similar to this study.
The studies compared with this one are:

1) Heinselman (1973): "Fire in the Virgin Forests of the Boundary Waters Canoe Area, Minnesota;"

2) Hemstrom and Franklin (1982): "Fire and Other Disturbance of the Forests in Mount Rainier National Park;"

3)Teensma (1987): "Fire History and Fire Regimes of the Central Western Cascades of Oregon;"

4) Morrison and Swanson (1990): "Fire History and Pattern in a Cascade Range Landscape;" and,

5) Krusemark and others (1996) : "The History of Fire in the Bull Run Watershed, Oregon."

Each study had similar approaches to estimating fire size, frequency and severity. Heinselman (1973) used interpretations of stand boundaries from air photos to estimate extent of fires. Age class and scar data were used to determine fire dates and compare stand ages; the areas of similarly aged stands were combined into a single fire. Hemstrom and Franklin (1982) also used age class data and air photo interpretation to generate an initial fire size estimate. A fire size model was then applied to the initial fire boundaries to incorporate influences of topography, and a final fire size was generated. Both Teensma (1987) and Morrison and Swanson (1990) used an iterative examination of data to generate fire size. Interpretations of stand boundaries from air photos were used in conjunction with site dendrochronological information to determine fire extent. Fire episodes were mapped by drawing lines between sites with and without evidence of a fire. If a site was near to or between sites with evidence of a fire episode it could be added to the fire episode in question by a "best-fit" interpolation method. The ratio method described above was used to generate a different measure of fire episode size. Krusemark and others (1996) used age class and air photo interpretation of stands to generate fire size estimates.

The measures of the natural fire rotation (NFR) and/or the mean fire return interval (MFRI) were used to describe the fire frequency in these studies. All studies determined the NFR; fire studies in Douglas-fir forests determined the NFR for several historical periods that can be generalized as the pre-European settlement period, a post-settlement period, and the fire suppression period after 1910. Teensma (1987) and

Morrison and Swanson (1990) determined the MFRI for their respective studies.

Severity of fires was not reported by Heinselman (1973) or Hemstrom and Franklin (1982). Teensma (1987) categorized fires as underburns (scars only) or regular fires (scars and regeneration). Morrison and Swanson (1990) categorized fire severity as patches of high, medium and low severity. These patches were mapped and analyzed for a fire that occurred in 1893 in their study area. Krusemark and others (1996) determined fire severity using three datasets: Forest Service Ecology Plots, age class information from stand dendrochronological work, and air photo interpretation of percent canopy cover of stands. For the Forest Service Ecology Plots mixed age classes in plots implied moderate fire severity, single age classes implied high severity. Air photo interpretation was used to assess the proportion of younger to older forest to determine fire severity for three large fires in the Bull Run study area between 1850 and 1915. The low severity fires were those fires (at the site level) in which <20% of the overstory (previously existing) trees were killed; moderate severity fires had 20-70% of the overstory killed, and high severity fires had >70% of the overstory killed.

4.3 RESULTS

4.3.1 Within Study Comparison

4.3.1.1 Fire Size

Interpolation method 1 increased average estimated fire episode size over the Thiessen fire episode size estimation by 40% to 136 km^2. The range of fire episode size increased from 526 to 683 km^2 (Table 4.1). For interpolation method 1 the fire episode of 1852 remained the largest fire episode (708 km^2) and the fire episode of 1478 remained the smallest fire episode (25 km^2). The greatest percent increase was for the fire episode of 1555 (146%), followed by the fire episode of 1531 (144%).

Interpolation method 2 was more restrictive, and generated smaller fire episode size estimates than interpolation method 1 (Table 4.1). The average fire episode size estimate for interpolation method 2 was 107 km^2, an 11% increase in the average size estimate over the Thiessen fire episode size estimation method. As with interpolation method 1 the largest fire episode was the 1852 fire episode (628 km^2) and the smallest fire episode was the 1478 fire episode (18 km^2). The range of fire episode size estimates for interpolation method 2 was 610 km^2. The greatest percent increase was for the fire episode of 1637 (35%), followed by the fire episode of 1666 (32%).

Neither interpolation method increased the size estimates of the fire episodes of 1815, 1900, 1909, 1920, 1928, 1934 or 1974. Additionally, interpolation method 2 had

Table 4.1 Estimated Size of Fires and Percent Change for Four Size Determination Methods

Fire Date	Number of Sites	Thiessen Polygon		Interpolation Method 1			Interpolation Method 2			Ratio Method		
		Size (km^2)	Proportion of Area	Size (km^2)	Percent Change	Proportion of Area	Size (km^2)	Percent Change	Proportion of Area	Size (km^2)	Percent Change	Proportion of Area
1478	3	17.6	0.01	24.8	41	0.02	17.6	0	0.01	n/a	n/a	n/a
1531	21	133.0	0.10	325.1	144	0.24	152.1	14	0.11	1210.0	809.7	0.88
1555	27	171.2	0.12	421.8	146	0.31	205.3	20	0.15	1325.9	674.6	0.96
1585	7	57.1	0.04	109.0	91	0.08	60.1	5	0.04	220.0	285.5	0.16
1629	5	35.2	0.03	53.4	52	0.04	35.2	0	0.03	134.8	282.5	0.10
1637	12	67.6	0.05	143.8	113	0.10	91.3	35	0.07	279.7	313.9	0.20
1655	15	90.3	0.07	136.7	51	0.10	99.5	10	0.07	290.5	221.8	0.21
1666	10	64.9	0.05	90.0	39	0.07	85.7	32	0.06	183.3	182.5	0.13
1689	6	28.9	0.02	49.5	71	0.04	28.9	0	0.02	90.5	213.5	0.07
1699	13	61.9	0.04	85.0	37	0.06	71.8	16	0.05	232.1	275.2	0.17
1737	11	57.7	0.04	77.1	34	0.06	75.0	30	0.05	203.7	253.2	0.15
1751	11	97.3	0.07	132.0	36	0.10	117.7	21	0.09	184.5	89.6	0.13
1763	12	65.4	0.05	76.3	17	0.06	76.3	17	0.06	194.1	196.8	0.14
1794	8	35.4	0.03	48.6	37	0.04	35.4	0	0.03	126.4	257.1	0.09
1815	5	33.5	0.02	33.5	0	0.02	33.5	0	0.02	126.4	277.2	0.09
1831	6	36.4	0.03	54.6	50	0.04	36.4	0	0.03	110.6	203.6	0.08
1844	14	66.3	0.05	84.4	27	0.06	78.9	19	0.06	221.3	233.8	0.16
1852	100	543.7	0.40	707.7	30	0.51	627.9	15	0.46	910.6	67.5	0.66
1871	32	198.9	0.14	245.9	24	0.18	209.7	5	0.15	258.3	29.9	0.19
1881	16	93.6	0.07	98.4	5	0.07	98.4	5	0.07	127.9	36.6	0.09
1888	29	172.0	0.13	185.2	8	0.13	172.0	0	0.13	227.9	32.4	0.17
1900	11	66.2	0.05	66.2	0	0.05	66.2	0	0.05	94.3	42.4	0.07
1909	13	77.1	0.06	77.1	0	0.06	77.1	0	0.06	101.6	31.7	0.07
1920	27	148.5	0.11	148.5	0	0.11	148.5	0	0.11	216.3	45.7	0.16
1928	16	80.3	0.06	80.3	0	0.06	80.3	0	0.06	123.6	54.0	0.09
1934	9	61.3	0.04	61.3	0	0.04	61.3	0	0.04	69.5	13.5	0.05
1974	9	55.2	0.04	55.2	0	0.04	55.2	0	0.04	69.5	26.0	0.05

no effect on the size estimates of the fire episodes of 1478, 1629, 1689, 1794, 1831 and 1888.

All fire episode estimates increased in size based on the ratio method, and early fire episode size estimates increased substantially in size (Table 4.1). The ratio method is biased when considering early fire episodes, as subsequent record erasure minimizes sites available have trees old enough to record a fire episode. Consequently, the 1478 fire episode would "cover" 100% of the study area, and was not included in the analysis. Due to record erasure the size estimates of the fire episodes of 1531 and 1555 based on the ratio method were very large compared to the other fire episode size determination methods, increasing 8.1 and 6.7 times, respectively. All fire episode size estimates derived from the ratio method for fire episodes between 1531 and 1871 were significantly larger than from the other calculation methods, increasing from 2.3 to 8.1 times in size (Table 4.1). The 1852 fire episode increased by 67% with the ratio size determination method. Later fire episodes were less affected by record erasure and increased in size from 13% to 54% (Table 4.1)

4.3.1.2 Fire Frequency

MFRI

The MFRI was 19.1 years at the scale of the entire study area, the weighted MFRI at the scale of Zone (scale: 536 - 839 km^2) was 23.0 years, the MFRI for 5 km^2 grids (scale: 25 km^2) was 63.2 years, the weighted average for aspect (variable scale) was 85.5 years, and the MFRI calculated in the standard manner at the scale of sites was also 85.5 years (Table 4.2a). As the scale at which MFRI is calculated increases, the MFRI decreases (Figure 4.2).

NFR

Both interpolation methods lower the NFR estimate for the entire study period and the Pre-settlement and Settlement periods, but neither lower the NFR for the Suppression period (Table 4.2b). The ratio method decreases the NFR estimate substantially from 271 years for the Thiessen polygon method to 92 years, a reflection of the significant increase in calculated size of fire episodes based on the ratio method. Unlike interpretation methods 1 and 2, the ratio method decreases the NFR estimate for the Suppression period from 335 to 246 years.

4.3.1.3 Fire Severity

The severity classes recorded at site did not change significantly (Table 4.3). Out of a total of 456 site recordings of fire episodes, only 32 site recordings (7%), changed. Of the site recordings that changed, 18 sites recording fire episode changed from moderate to high severity, and 14 sites changed from moderate to low severity (Table 4.3).

Table 4.2a Mean Fire Return Interval for Different Scales

Scale	Area (km^2)	Number of Sites	MFRI (years)
Entire Study Area	(1375 km^2)	60	19.1
Zone (Weighted Average)	(1375 km^2)	60	23
Zones			
Valley Margin	(536 km^2)	44	18.2
Interior/Coast	(839 km^2)	16	34.1
5 km^2 Grid	(25 km^2 each)	60	63.2
Aspects			85.5
North		14	81.2
South		15	75.4
East		10	102.3
West		21	87.2
Sites		60	85.5

Table 4.2b Natural Fire Rotation for Different Fire Size Determination Methods

	NFR (Years) Size Estimation Method			
Period	Thiessen Polygons	Interpolation Method 1	Interpolation Method 2	Ratio Method
Total Record 1478 - 1994	271	193	245	92
Pre-Settlement 1478 - 1845	452	259	388	92
Settlement 1846 - 1909	78	65	71	50
Fire Suppression 1909 - 1994	335	335	335	246

Figure 4.2 MFRI at Different Scales

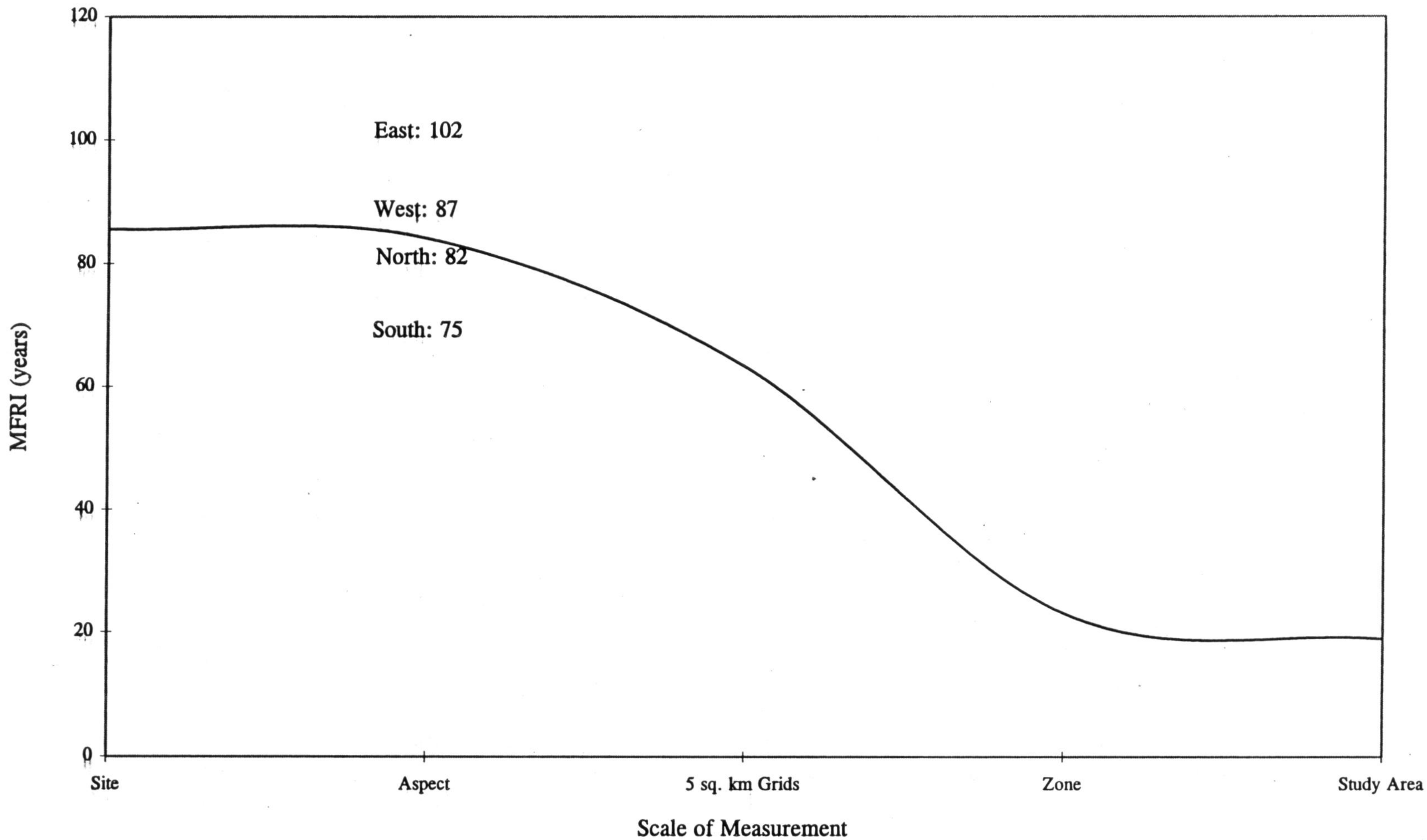


Table 4.3 Number of Sites in Severity Classes for Each Fire, Determined with Severity Methods 1 and 2

Fire Date	Sites with High Sever. Method 1	Percent of Sites	Sites with High Sever Method 2	Percent of Sites	Sites with Mod. Sever. Method 1	Percent of Sites	Sites with Mod. Sever. Method 2	Percent of Sites	Sites with Low Sever. Method 1	Percent of Sites	Sites with Low Sever. Method 2	Percent of Sites
1478	3	100.0	3	100.0	0	0.0	0	0.0	0	0.0	0	0.0
1531	23	95.8	24	100.0	1	4.2	0	0.0	0	0.0	0	0.0
1555	22	81.5	25	93.0	5	18.5	2	7.0	0	0.0	0	0.0
1585	1	16.7	1	16.7	4	66.7	1	16.7	1	16.7	4	66.7
1629	1	20.0	1	20.0	1	20.0	0	0.0	3	60.0	4	80.0
1637	8	66.7	8	66.7	2	16.7	2	16.7	2	16.7	2	16.7
1655	12	80.0	12	80.0	3	20.0	3	20.0	0	0.0	0	0.0
1666	4	40.0	5	50.0	3	30.0	2	20.0	3	30.0	3	30.0
1689	1	16.7	1	16.7	2	33.3	2	33.3	3	50.0	3	50.0
1699	1	7.7	1	7.7	7	53.8	7	53.8	5	38.5	5	38.5
1737	4	33.3	4	33.3	5	41.7	3	8.3	3	25.0	5	58.3
1751	1	9.1	2	18.2	5	45.5	3	27.3	5	45.5	6	54.6
1763	3	25.0	5	41.7	6	50.0	3	25.0	3	25.0	4	33.3
1794	2	25.0	2	25.0	5	62.5	3	37.5	1	12.5	3	37.5
1815	0	0.0	0	0.0	4	50.0	4	100.0	4	50.0	4	100.0
1831	0	0.0	0	0.0	3	42.9	3	100.0	4	57.1	4	100.0
1844	0	0.0	0	0.0	7	50.0	7	100.0	7	50.0	7	100.0
1852	64	64.0	72	72.0	28	28.0	20	20.0	8	8.0	8	8.0
1871	14	45.2	17	54.8	11	35.5	8	25.8	6	19.4	6	19.4
1881	7	43.8	7	43.8	1	6.3	0	0.0	8	50.0	9	56.3
1888	4	13.8	4	13.8	5	17.2	5	17.2	20	69.0	20	69.0
1900	0	0.0	0	0.0	1	8.3	0	0.0	11	91.7	12	100.0
1909	0	0.0	0	0.0	0	0.0	0	0.0	13	100.0	13	100.0
1920	2	7.1	2	7.1	1	3.6	0	0.0	25	89.3	26	92.9
1928	0	0.0	0	0.0	1	6.3	0	0.0	15	93.8	16	100.0
1934	0	0.0	0	0.0	2	22.2	2	22.2	7	77.8	7	77.8
1974	0	0.0	0	0.0	0	0.0	0	0.0	9	100.0	9	100.0

4.3.2 Between Study Comparison

4.3.2.1 Extent, Sampling, and Fire Regime Methods

The range of spatial extent between studies was wide, ranging from 38.8 km^2 for Morrison and Swanson (1990) to 4050 km^2 for the Boundary Waters Canoe Area (Heinselman, 1973), with an average extent of 1061 km^2. Temporal scale ranged from over 1000 years at Mt. Rainier to approximately 400 in the Boundary Waters Canoe Area study, with an average of 708 years. The number of fires recorded in the studies (including low severity and/or "underbrush" fires, those recorded as scars only) ranged from 71 in the Boundary Waters Canoe Area study to 12 in the Bull Run Watershed study, with an average of 31.3 fires recorded (Table 4.4).

This study recorded the lowest sample density of sites and trees per km^2, although it is possible that a lower stump/tree sample density was used in the Boundary Waters Canoe Area. The site sample density for this study was 0.13 sites/km^2; the tree/stump density was 3.1 per km^2. The highest density of sites was in the Bull Run Watershed, with 7.9 sites per km^2. The highest density of trees/stumps was in the Teensma (1987) study at 21.0 trees/stumps per km^2. Number of sites was not reported in the Mt. Rainier study; number of sampled trees was not reported in the Boundary Waters Canoe Area and Bull Run Watershed studies (Table 4.4).

Most studies used one or two techniques for determining size, frequency and severity of fire events. No severity determination was made in the Mt. Rainier and

Table 4.4 Summary of Extent, Sampling Density, and Techniques of Several Fire Studies

Study	Extent (km^2)	Number of Sites	Density of sites (per km^2)	Number of Sampled Trees	Density of Trees (per km^2)	Number of Fires	Approx. Dendro. Limit (yrs)	Number of Techniques Used		
								Size	Frequency	Severity
Heinselman, 1973	4050	923	0.23	---	---	71	400	1	1	---
Hemstrom and Franklin, 1982	532	---	---	1000	1.9	14	>1000	2	3	---
Teensma 1987	110	359	3.3	2305	21.0	35	800	2	2	1
Morrison and Swanson, 1990	38.8	161	4.1	570	14.7	29	800	2	2	1
Cook Quentin	19.4	86	4.4			18				
Deer Creek	19.4	75	3.9			11				
Krusemark and others, 1996	264	208	0.8	---		12	750	1	1	1
This Study	1375	178	0.13	4320	3.1	27	500	4	3	2

Boundary Waters studies. In the Mt Rainier study, three frequency techniques (the MFRI, NFR and negative exponential) were attempted, but only results from the NFR were reported (Table 4.4).

4.3.2.4 Mean Fire Size Estimates

Fire size estimates between studies ranged from 17 to 265 km^2 (Table 4.5). The overlap between size techniques used in other studies and the techniques used in this study was restricted to the ratio method, which gave very large fire size estimates for this study. However, the ratio method of fire size determination generated similar results to the air photo/planimeter fire size results for Teensma (1987) and Morrison and Swanson (1990).

4.3.2.5 Fire Frequency Results

NFR

The NFR results of the studies in the Douglas-fir forests west of the Cascades were similar for periods prior to 1910. All studies had higher NFR for the fire suppression period after 1910, with the reported NFR at Mt. Rainier National Park increasing to over 2500 years after 1900 (Hemstrom and Franklin, 1982) (Table 4.6). The NFR reported in Teensma (1987) and Morrison and Swanson (1990) changed slightly due to fire size determination methods. As outlined above, in this study the

Table 4.5 Comparison of Mean Fire Size (km^2) for Several Fire Studies

Study	Thiessen Polygons	Interpolation #1	Interpolation #2	Ratio	Planimeter/ Air Photo	Fire Model
	Size Method					
Heinselman, 1973	---	---	---	---	28.9	---
Hemstrom and Franklin, 1982	---	---	---	---	34.0	69.8
Teensma 1987	---	---	---	17.4	19.3	---
Morrison and Swanson, 1990						
Cook Quentin	---	---	---	7.5	6.5	---
Deer Creek	---	---	---	7.0	5.9	---
Krusemark and others, 1996	---	---	---	31.4	---	---
This Study	96.9	135.9	107.3	265.2	---	---

Table 4.6 Comparison of NFR and MFRI for Several Fire Studies

Study	NFR (years) Size Method						MFRI
	Thiessen Polygons	Int. #1	Int. #2	Ratio	Planimeter/ Air Photo	Fire Model	
Heinselman, 1973	---	---	---	---	100	---	6.1 (all sites aggregated)
Hemstrom and Franklin, 1982							---
1200-1850	---	---	---	---	---	465 (405)	
1850-1900	---	---	---	---	---	226 (227)	
1900-1978	---	---	---	---	---	583 (2600)	
Teensma 1987							114
1435-1986	---	---	---	108	91	---	
1435-1830	---	---	---	102	89	---	
1831-1850	---	---	---	36	30	---	
1851-1909	---	---	---	102	71	---	
1910-1986	---	---	---	768	587	---	
1435-1909	---	---	---	95	80	---	
1772-1830	---	---	---	86	69	---	
Morrison and Swanson, 1990	---	---	---	119	---	---	
Cook Quentin	---	---	---	95	---	---	96
Deer Creek	---	---	---	149	---	---	241
Krusemark and others, 1996							---
1493-1992	---	---	---	---	350	---	
1493-1800	---	---	---	---	267	---	
1493-1900	---	---	---	---	299	---	
This Study							85.5
1478-1994	271	193	245	92	---	---	
1478-1845	452	259	388	92	---	---	
1846-1910	78	65	71	50	---	---	
1911-1994	335	335	335	246	---	---	

NFR differed slightly due to calculations of fire episode size from fire size interpolation methods 1 and 2 and changed substantially from calculations of fire size from the ratio method (Table 4.6).

MFRI

The MFRI was calculated in this study, Morrison and Swanson (1990), and Teensma (1987). The MFRI calculation in the Boundary Waters Canoe Area considered the study area as a single unit, and all fires recorded in the study area were used in the calculation, giving a very low figure (6.1 years). This is not the standard method for the MFRI determination.

MFRI was similar for studies in the Douglas-fir forests west of the Cascades. This study has a MFRI of 85.5 years; Teensma (1987) reported an MFRI of 114 years. Morrison and Swanson (1990) had two separate areas in which they determined the MFRI. There was a considerable difference in the reported MFRIs of 96 years for the Cook-Quentin area and 241 years for the Deer Creek Area (Table 4.6).

4.4 DISCUSSION

The comparison of methods to determine the fire regime within this study showed significant differences in results for size and frequency, but severity class determinations changed little. Comparison between studies showed a large difference in size and frequency, possibly due to differences in extent, grain, and sampling densities.

The greater size of fires in the Coast Range than in the Cascades, as estimated in this study and reported in the historic record, may arise from the characteristics of the fire regimes or the greater extent of this study compared to Cascade fire studies.

4.4.1 Within Study

4.4.1.1 Size

Fire size estimates of widespread, early fires increased the most with interpolation method 1. The large percent increase in size of the fire episodes of 1531 (144%) and 1555 (146%) from interpolation method 1 is related to the widespread pattern of fire episode occurrence and the erasure of the record of these two fire episodes. This erasure appears to be predominantly from the fire episode of 1852. Both interpolation methods 1 and 2 connected polygons showing fire episodes that were separated by only one or two polygons not showing evidence of the fire episode; however, interpolation method 1 tended to create a more continuous series of polygons due to less rigid rules for adding polygons (Figures 4.3 and 4.4). The greatest percent increase in size of the fire episodes from interpolation method 2 was for the fire episodes of 1637 (35%) and 1666 (32%); however, the patterns of these fire episodes based on interpolation method 2 reflect the reduced influence of interpolation method 2 in increasing fire episode size (Figures 4.5 and 4.6). It is unclear if either of these interpolation methods provides a better estimation of fire episode size than the initial

Figure 4.3 Fire Occurrence of the Fire Episode of 1531 based on Interpolation Method 1

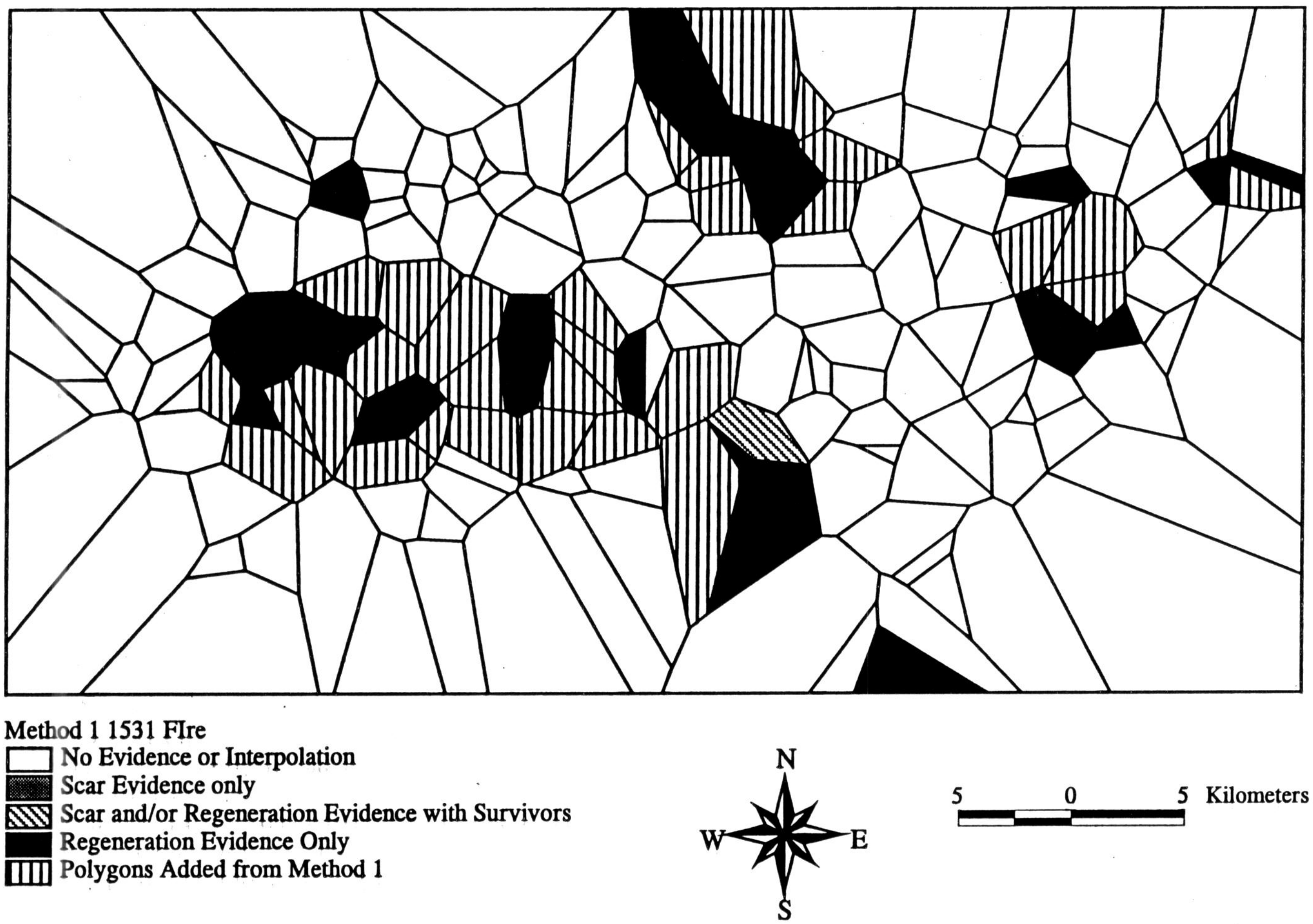


Figure 4.4 Fire Occurrence of the Fire Episode of 1555 based on Interpolation Method 1

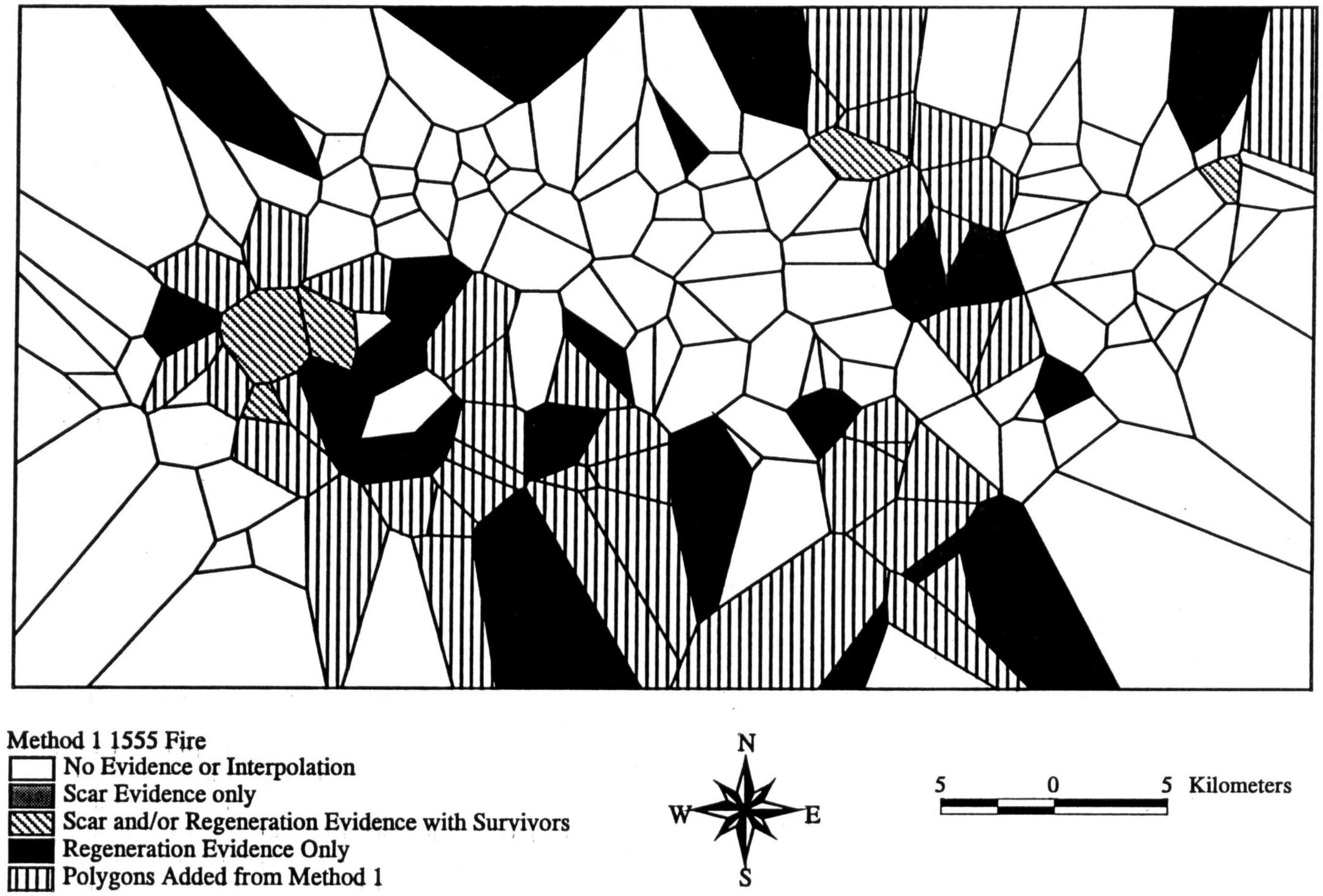


Figure 4.5 Fire Occurrence of the 1637 Fire Episode based on Interpolation Method 2

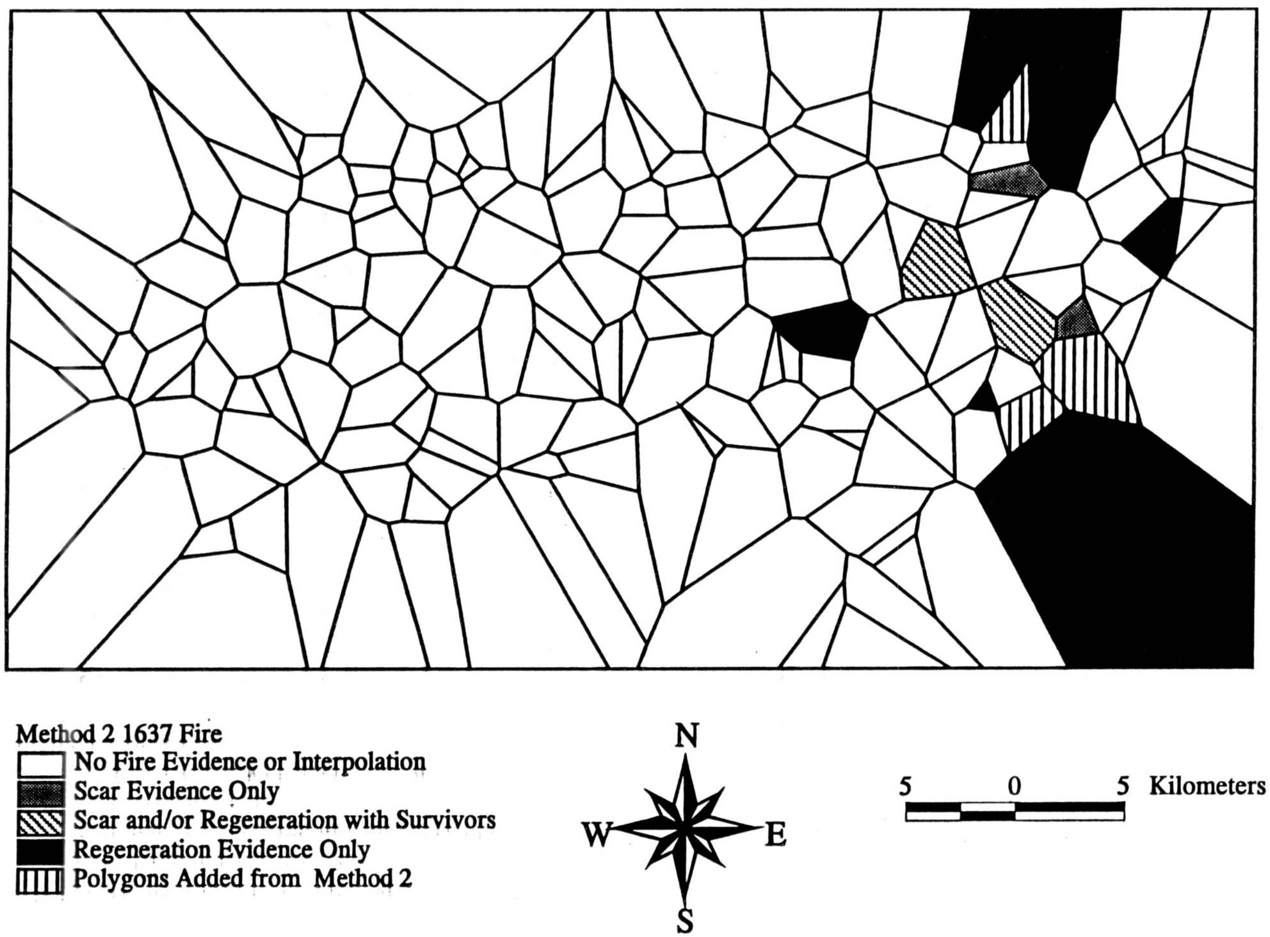
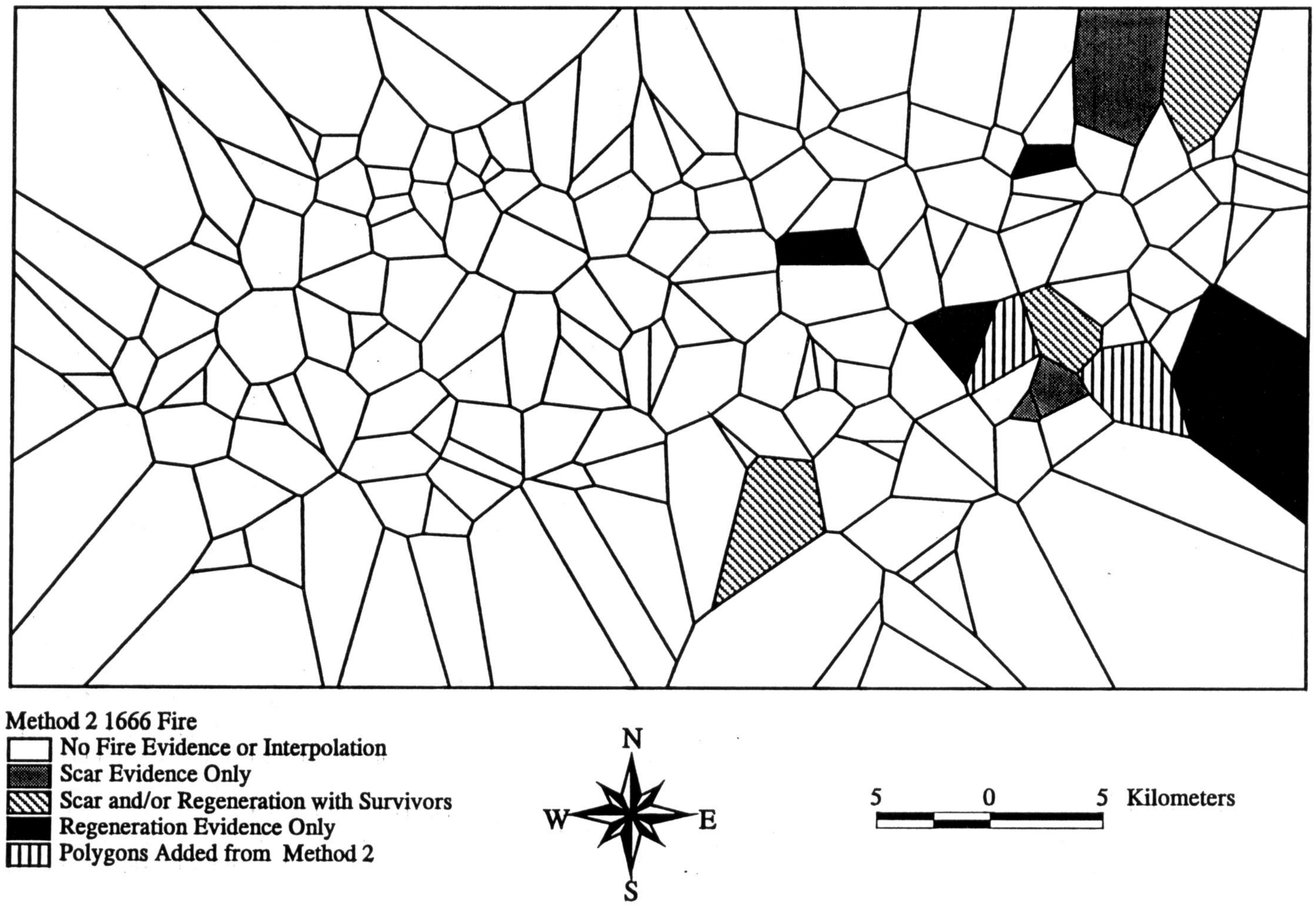


Figure 4.6 Fire Occurrence of the Fire Episode of 1666 based on Interpolation Method 2



Thiessen polygon method. Interpolation method 1 was useful in illuminating the possible contiguity of early, widespread fire episodes for which much of the record had been removed by later fires.

The ratio method dramatically increased size of fire episodes compared to initial estimates and other interpolation methods. This increase was especially pronounced for early fire episodes. The maximum increase in fire episode size for all fire episodes from the ratio method was substantial, reaching up to eight times the fire episode of 1531. The size of the fire episode of 1555 based on the ratio method was 1325 km^2, which would have covered 96% of the study area. Morrison and Swanson (1990) indicated that the ratio method should have dense, random sampling to be suitably applied. It is possible that when the ratio method was used for fire size estimation in this study the relatively extensive sampling increased fire episode size to such a high degree, and that the ratio method was less meaningful for this study than other fire size estimation methods.

Size estimate accuracy may have been limited by the grain and extent of the study. The grain of this study was 7.7 km^2/site, which likely limited the possibility of detection of medium to small fires on the order of 1 ha to 5 km^2. The extent of the study area, 1375 km^2, was smaller than the ~2020 km^2 size of the 1849 Siletz-Siuslaw fire reported in Morris (1934), which corresponds to the fire episode of 1852. The early fire episodes of 1531 and 1555, as well as the fire episode of 1871, may have also occurred in areas outside of the study area, and thus may have been larger than estimated by any of the above methods. Other fire episodes may have also occurred beyond the study area.

4.4.1.2 Frequency

Change in NFR follows the increase in fire episode size from the interpolation methods and the ratio method. As the fire episode size estimates increase, more area is considered to have burned and the NFR is reduced as less time is taken to burn an area equal to the study area. The NFR was lower when interpolation methods 1 and 2 were used for fire episode size estimates, but the ratio method decreased the NFR substantially. The NFR decreased for the post-suppression fire period only when the ratio method was used.

In general, as the MFRI scale being considered increased, the MFRI decreased. Change in the MFRI as the scale considered for the MFRI calculation changed was an expected occurrence. More fire episodes were included in MFRI calculations as a greater area was considered as one unit. This sensitivity of the MFRI to the scale considered for the MFRI calculation requires that the scale of calculation be identified in a fire regime study to allow the comparison of results with other studies.

4.4.1.4 Severity

Proportions of fire severity classes for fire episodes changed little due to differences in severity determination methods. Both the initial and second severity determination method were based on tree mortality. One limitation to these methods was the difficulty in determining, at sites with multiple fire episodes, which fire episode caused mortality. As an example, if a site experienced the 1531, 1629 and 1852 fire episodes and the age class distribution was 25% from the 1531 fire episode, 25% from the 1629 fire episode and 50% from the 1852 fire episode, it could be concluded that the 1852 fire episode was severe, based on age class comparisons to the 1629 and the 1531 fire episode. However, whether the mortality suffered by the age class associated with the 1531 fire episode was from the 1852 fire episode, the 1629 fire episode, or a combination of both would be difficult to determine. Using the initial severity determination method both the 1629 and 1852 fire episodes would have been identified as moderate at this site, as there were survivors from both fire episodes.

The high severity nature of the fires and the subsequent data erasure in the central Coast Range may explain the lack of change in the proportions of fire severity classes for fire episodes due to differences in severity determination measures. Six of the fire episodes had more than half of the sites recording the fire episode with 100% mortality and would thus not change severity classes due to changes in severity class definitions. Other regions with more mixed severity fire episodes, such as the drier

Ponderosa Pine and Douglas-fir forests, may be more suitable for a comparison of severity determination methods.

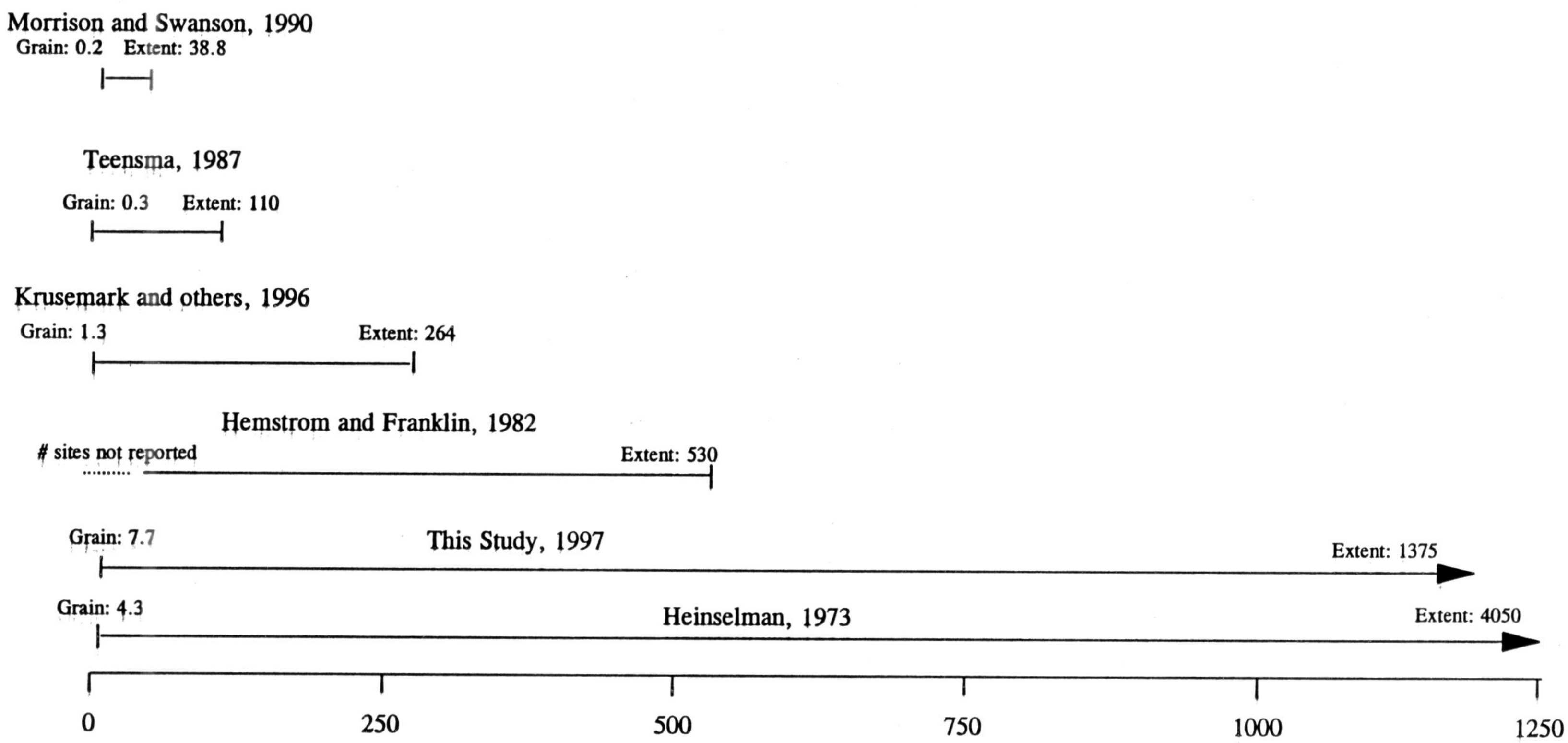
4.4.2 Between Study Comparisons

4.4.2.1 Extent, Grain and Sampling

There is a substantial range of extent of study areas compared (Figures 4.7 and 4.8). The range of the grains of the studies compared was also broad, but seems to have affected fire size estimates to a lesser degree. All studies have somewhat arbitrary (i.e. not delineated by ecological criteria) study area boundaries, be they based on edges of wilderness/park areas (Heinselman, 1973; Hemstrom and Franklin, 1982); research and/or specific land-use areas (Teensma, 1987; Krusemark and others, 1996); or boxes drawn around areas of interest (Morrison and Swanson, 1990; this study). Consequently the extent of these studies may or may not cover ecologically-distinct fire regimes, or may overlap between two such regimes.

Sampling densities were also variable. In general, the larger the extent, the lower the density of sites and trees per km^2. The only exception was the Boundary Waters Canoe Area study, which has a higher density of sites per km^2 and a larger study extent than this study. However, only 2-5 trees were sampled at each site in Heinselman's study (the actual total was not reported), compared to an average of 24 trees per site in this study.

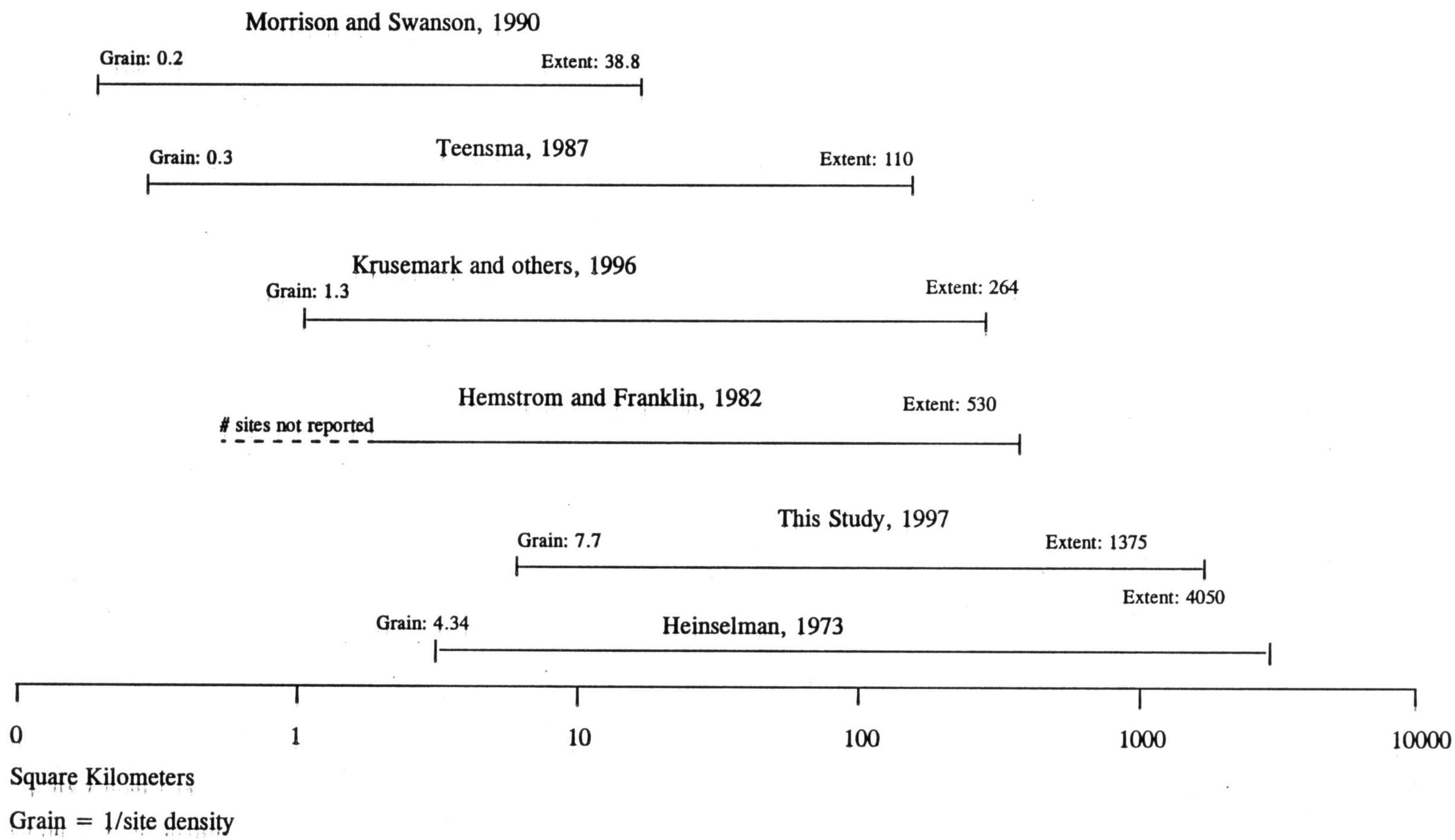
Figure 4.7 Grain and Extent of Compared Studies (Normal Scale)



Square Kilometers

Grain = 1/site density (sq. km/site)

Figure 4.8 Grain and Extent of Compared Studies (Approximate Logarithmic Scale)



4.4.2.2 Fire Size Estimates

Average fire size estimates appear to be linked to the extent of the study area, especially for the studies in the Douglas-fir forests west of the Cascades. The ratio of the average fire size/extent is similar for these studies, even though the extent of these studies varies considerably (Table 4.7). This has implications for the interpretation of fire size estimates, and indicates studies with small extents may underestimate fire size. Heinselman (1973), Teensma (1987), and Krusemark and others (1996) estimated fires that were substantially smaller than the extent of their respective study areas; some fires reported were also smaller than the grain of study (Table 4.8). The air photo interpretation size method used in these three studies may allow the size estimation of fires smaller than the grain, however, Morrison and Swanson (1990) used air photo interpretation and did not report such relatively small fires.

The substantially larger fire sizes found in this study compared to other studies of Douglas-fir forests west of the Cascades may be due to several factors: (1) fires in the Coast Range were much larger than fires in the Cascades; (2) the Thiessen polygon method overestimates fire size; or (3) small study areas underestimate the extent of large fires.

The historic fires in the Coast Range that have been reported (e.g. Morris, 1934; Munger, 1944; Teensma and others, 1991) have been very large compared to historic fires reported in the Cascades (Burke, 1979). The exception to this may be the Yacolt

Table 4.7

Study	Grain (km2/site)	Extent (km2)	Average Size (km2)	Avg. Size/ Grain	Avg. Size/ Extent
Morrison and Swanson	0.2	38.8	7.5	37.5	0.19
Teensma	0.3	110	17.4	58	0.16
Krusemark and others	1.3	264	32.6*	25.1	0.12
Hemstrom and Franklin	--	530	70	--	0.13
This Study	7.7	1375	97	12.6	0.07
Heinselman	4.3	4050	28.9	6.7	0.01

*rough estimate from description in study

Table 4.8

Study	Grain (km2/site)	Extent (km2)	Smallest Fire (km2)	Ratio of Smallest Fire/ Grain	Ratio of Smallest Fire/ Extent
Morrison and Swanson	0.2	39	1	5	0.03
Teensma	0.3	110	0.1	0.33	0.001
Krusemark and others	1.3	264	0.1*	0.08	0.0004
Hemstrom and Franklin	--	530	6	--	0.01
This Study	7.7	1375	19	2.5	0.01
Heinselman	4.3	4050	2.6	0.6	0.001

*rough estimate from description in study burn of 1902; however this fire may not have been representative of Cascade fires as an east wind event through the nearby Columbia River Gorge strongly affected this fire.

Whether Thiessen polygons overestimate fire sizes is unclear. The Thiessen polygon method for fire size estimation has not been used as a primary fire size estimation method before this study. Thiessen polygons have been used for comparison as a secondary fire size estimation (Heyerdahl and Agee, 1996), but sample sites were comparably more evenly spaced and relatively close together.

To date no large-scale study of fire regimes has been done in the Cascades. With an extent of 530 km^2, Hemstrom and Franklin (1982) was the Cascade study with an extent closest in size to this study; it also has the closest average fire size (although average size was based on a modeling method). The similarity between the (average size/grain) and the (average size/extent) ratios for this study and the Cascade studies indicates that if larger fire studies in the Cascades were undertaken, they might reveal larger fires than reported to date. By comparison, Heinselman's study has similar average fire size estimates but different (average size/grain) and (average size/extent) ratios than all other studies, with the (average size/extent) ratio different by an order of magnitude than all other studies.

As an indication of the potential for much larger fires in the Cascades, all Cascade Douglas-fir forest fire studies summarized have shown a similar age class at approximately 450 - 500 years of age, indicating widespread fire activity about that time. Such activity would correspond to fire activity 450 - 500 years ago in the central

Coast Range, and to charcoal indications of fire as reported by Long (1996) that occurred 570 - 490 years ago. This was possibly a region-wide fire event, or perhaps a fire period. If the similar age-class was shown to be related to a region-wide fire event, this would be an initial indication that larger fires than reported occurred in the Cascades.

4.4.2.3 Frequency

The NFR for this study was less than the NFR for the Teensma (1987) and Morrison and Swanson (1990) studies. However, NFR for this study was similar to the NFR observed in both the Hemstrom and Franklin (1982) and Krusemark and others (1996) studies. All four Cascade study areas have similarities in elevation and other physical factors. Neither Hemstrom and Franklin (1982) nor Krusemark and others (1996) used the ratio method for fire size determination and NFR calculations, whereas Teensma (1987) and Morrison and Swanson (1990) used both the air photo/planimeter and the ratio method for NFR calculation. Hemstrom and Franklin (1982) and Krusemark and others (1996) cored trees for stand age determination, whereas Teensma (1987) and Morrison and Swanson (1990) collected data primarily from stumps.

The differences in data collection and analysis are potential reasons for the difference in the NFR between these Cascade studies. The ratio method may overestimate fire size, thus lowering NFR estimates. While it is unclear if the ratio method overestimates fire size; in this study it produced the largest fire estimates of the four fire size methods used.

Another reason for differences in the NFR may be that there are significant differences in the fire regime of these two groups of studies. Higher severity fire regimes are hypothesized to experience lower frequency of fire (Agee, 1993). According to Hemstrom and Franklin (1982), the Mt. Rainier area is colder and wetter than the areas Teensma (1987) and Morrison and Swanson (1990) studied, and the precipitation difference between west and east slopes is less pronounced than in the southern Oregon Cascades. The Bull Run Watershed is very close to the Columbia River Gorge, which experiences strong east winds. Both the wetter, colder environment and greater exposure to east winds could create a higher likelihood of high severity fires than in the southern Oregon Cascades, making for less frequent, higher severity fires that would be expressed in a lower NFR.

The MFRI for this study was lower than the Cascade studies. The MFRI result of this study is disproportionally weighted by the few sites (60, only 34%) recording more than two fires. Of those sites, 75% were in the Valley Margin Zone, which experiences more frequent fires than the Interior/Coast Zone. The Valley Margin Zone may have a MFRI more similar to the western Cascade Douglas-fir region than the Interior/Coast Zone, due to the drier nature of the Valley Margin Zone.

4.5 CONCLUSIONS

1. Changing the rule sets for fire size determination by interpolating between sites where fire episodes occurred but the record may have been subsequently erased produced an increase in fire size estimates up to 150% over the Thiessen polygon method, while the ratio method estimated fire sizes up to 800% over the Thiessen polygon method. Fire episode occurrence at a site and subsequent size determination methods requires a certain degree of subjective analysis. This is especially the case where interpolation and/or extrapolation of fire episode occurrence due to suspected record erasure is carried out. This is not necessarily limiting: rather the rules applied and the justification for assumptions must be spelled out in fire regime studies to clarify how results were obtained.

2. The estimate of MFRI is sensitive to the number of sites available for calculations and the scale of calculation. MFRI estimates in this study were limited by the low number of sites which experienced enough fires to calculate MFRI. As the scale of measurement increased, MFRI decreased, indicating that the scale of measurement should be specified when reporting MFRI.

3. In this study the NFR of 271 years without accounting for erasure versus 92 years using the ratio method indicates that NFR estimates were very sensitive to assumptions of and changes in rule sets for fire episode determination. Reported NFR values could be expected to vary among studies either due to differences in the fire regimes or according to assumptions about record erasure.

4. Differences in fire size estimates between studies in the Douglas-fir forests west of the Cascades appear to be related to the extent of the studies considered: larger extent studies had larger fire size estimates than smaller extent studies, but similar ratios of average estimated fire size to extent. This comparison of ratios of average estimated fire size to extent, and the region-wide occurrence of an age class of approximately 450 - 500 years of age, indicate that a much larger-scale study of fire in the Oregon Cascades than has been carried out to date may reveal large fires such as those that have occurred in the Coast Range.

CHAPTER 5. THE EFFECTS OF FIRE IN THE CENTRAL OREGON COAST RANGE

5.1. INTRODUCTION

Disturbance regime information is an important input to ecosystem management plans. An important goal of ecosystem management is to maintain ecosystem properties at sustainable levels. One way to do this is to restore ecosystem processes and patterns within the range of natural variability (Swanson and others, 1993). It is hypothesized that by maintaining ecosystems within the range of natural variability, flora and fauna dependent on these ecological patterns and processes will be less likely to face extirpation or extinction (Christensen and others, 1996). In addition, disturbance regime information can shed light on ecologically important areas such as past and present stand conditions.

In forests, high severity disturbances initiate predominantly even-aged stands, whereas low and mixed severity disturbances create stands of diverse age, structure and composition (Runkle, 1985). The long-lived forests of the Pacific Northwest contain a record of the history of disturbances of various sizes, frequencies and severities that can be evaluated to determine the range of natural variability for a given disturbance regime (Pickett and White, 1985; Swanson and others, 1993; Agee, 1993).

Recent ecosystem management initiatives in the Pacific Northwest (e.g. FEMAT, 1993) have underscored the need for additional information on the historic conditions of ecosystems as an input into the determination of the range of natural variability of present day ecosystems from which potentially useful management strategies can be derived. To address this issue in this study the past conditions of forests in the study area were investigated using the age class and fire information described in previous chapters.

Perceptions of past conditions of Coast Range forests have varied over time and between authors. The work of Clark (1905), Morris (1934) and Zybach (1988) used explorer's accounts to describe historic, large-scale, high severity fires in the Oregon Coast Range attributed primarily to Native American burning, most notably by the Kalapuya of the Willamette Valley (e.g. Boyd, 1986), and to early European settlers. Based on these accounts it has been inferred that stands of old growth occurred in low densities and covered limited areas in the Oregon Coast Range (Zybach, 1988; Zybach 1993).

Teensma and others (1991) and Ripple (1994) used General Land Survey Notes and Federal and private timber cruise reports to generate estimates of past age class structure and amounts of old growth in the Oregon Coast Range. These studies suggest that old growth over the last several hundred years was not uncommon in Coast Range forests.

From the variety of perceptions about past (and present) Coast Range forest conditions, and the need for ecological information to address ecosystem management issues, several key questions emerge:

1) How much old-growth forest exists in the study area, and where is old growth located?

2) Over the past 500 years, what was the structure and composition of forests in the study area? What proportion of the study area was in old-growth stands over the period of record, and how did this change over time?

3) Is the recent (ca. 500 years) fire history representative of a longer fire record? If so, what can be inferred about the occurrence of old growth in the central Oregon Coast Range from the Holocene (ca. 10,000 year) fire record?

In this chapter dendrochronologic data from sample sites, field observations of present natural stands, and databases from federal land management agencies were used to construct a map of old-growth stands in the study area in the mid-1980s to early 1990s. The results from previous chapters of this study of the fire regime in the central Oregon Coast Range were used to reconstruct previous stand characteristics over the period of record. The results from fire episode determination also were compared with the paleoecological charcoal fire record from Long (1995) to describe the link between dendrochronological and paleoecological data within the study area.

5.2 METHODS

5.2.1 Mapping the Occurrence of Old Growth Stands

The occurrence of old growth in the study area was mapped using four data sources: 1) map databases containing old-growth stand information from the Siuslaw National Forest; 2) map databases containing old-growth stand information from the Eugene Office of the Bureau of Land Management, 3) field observations of stands with old-growth trees; and, 4) sampled sites with stumps of old-growth trees.

The old growth map databases of the Siuslaw National Forest and the Eugene office of the Bureau of Land Management were developed from air photo interpretations of uncut stands on federal lands. Lands in the study area managed by these agencies have undergone extensive cutting of natural stands and the natural stands are fragmented to a high degree (*sensu* Franklin and Forman, 1987). Lands managed by the Siuslaw National Forest are contiguous, and the area analyzed for old-growth stands was primarily connected. In the Siuslaw National Forest analysis "remnant old-growth stands" were identified as having at least one old-growth tree (>200 years of age) in the stand (Kertis, pers. comm.).

In contrast to the Siuslaw National Forest, the Bureau of Land Management ownership patterns are "checkerboard," with alternating square mile sections of private and Bureau of Land Management lands. This pattern is a historical remnant of lands ceded by the U.S. Government to the Oregon and California Railroad Corporation (hence the customary term "O&C lands") that were reclaimed by the U.S. Government when the railroad failed due to fraud. The significance of this ownership pattern to the analysis of old growth is that the Bureau of Land Management mapping only covered federal lands. Consequently, the old-growth stand mapping done by the Bureau of Land Management has sharp edges defined by ownership boundaries that may or may not correspond to old-growth stand boundaries.

Old-growth stands identified in the field were those observed while carrying out surveys for suitable clearcuts for sample sites. These surveys were conducted along Bureau of Land Management and Forest Service roads within the study area, at times using 10X binoculars to identify old-growth trees within a stand. An early comparison of stand maps from both the Siuslaw National Forest and the Bureau of Land Management and the field observations indicated that there were more natural stands with old-growth trees in the study area than air photo interpretations had identified. Therefore, all old-growth trees and associated stands identified in the field were mapped and added to a map database for the study area. The large number of these additional stands not identified in air photo surveys is likely due to a combination of the limited resolution of air photos used and the similarity in appearance in aerial photos of the structure of mature and old-growth trees in terms of tree heights and crown size.

Sample sites with old-growth stumps were included and identified on the old-growth map. All sample sites in the study area were clearcuts that had been harvested within 15 years prior to data collection; most were harvested within five years prior to data collection (Chapter 2). The sample sites with old-growth stumps are indicative of where old-growth trees were located up to at least 1980, and are included in the old growth map to further illustrate the pattern of old growth occurrence over the period of record.

5.2.2 Retrospective Characterization of Forest Conditions

Old-growth Douglas-fir stands in the Pacific Northwest west of the Cascades are predominantly characterized by trees over 200 years of age, with other characteristics, including mixed age classes, varied composition, high gross productivity but low net productivity, large accumulations of woody debris and other organic matter, and high diversity of invertebrate and other faunal species (Franklin and others, 1981; Old Growth Definition Task Group, 1986; Franklin and Spies, 1991a and 1991b).

Three methods were used to evaluate previous stand conditions, with an emphasis on estimating the quantity of old-growth forest that existed in the study area over the past 500 years: the oldest-tree-at-site method; the density of old-growth stems method; and the percent of sampled stumps method. The number of sites in the study area that were classified as old-growth sites based on these definitions were graphed over time.

For the oldest-tree-at-site method the initiation date of the stand at a site was identified based on the oldest tree sampled. A site was labeled old growth when the oldest tree at a site reached 200 years of age. To determine the density of old-growth stems at a site, the area of each sample transect was estimated and the density of old-growth stems within the transect was calculated. The results were compared to the Old Growth Definition Task Group (1986) minimum of 20 old-growth stems/hectare to assign old-growth classification for a site. The percent of sampled stumps reaching old-growth status over time was calculated for each site. A site was classified as old growth based on when a percent of stumps sampled (e.g. 30%, 50% and 70%) exceeded 200 years of age.

Sampling at sites (see Chapter 2) was carried out with the primary objective of determining the fire history of sites; old-growth stumps were sampled opportunistically to maximize the available fire record. Each of the old growth determination methods should be interpreted as an estimate of historic old growth in the study area with this proviso, and others mentioned in Chapter 2.

5.2.3 Linking Dendrochronological and Paleoecological Data

Decades identified as having charcoal peaks attributed to fire (hereafter referred to as "peaks") by Long (1995) were compared to the age class distribution and fire episodes identified by this study (Chapter 2). Five classes of proximity of a site recording a fire to Little Lake were identified (adapted from Millspaugh and Whitlock, 1995; Whitlock, pers. comm.): 1) local fires were recorded at the local sample site within the watershed of Little Lake, where the lake core was extracted; 2) extra-local fires were recorded at a site associated with a Thiessen polygon adjacent to the Thiessen polygon of the local (Little Lake) site; 3) extra-local upwind fires were recorded at a site associated with a Thiessen polygon within 5 km and upwind to the Thiessen polygon of the local site; 4) extra-local downwind fires were recorded at a site associated with a Thiessen polygon adjacent to and downwind of the Thiessen polygon of the local site; and, 5) regional fires were recorded only at other sites that were not local or extra-local sites (Figure 5.1). The extra-local sites to the northeast, east, or southeast of the local site were defined as "upwind sites" since fires require hot, dry conditions associated with east wind events to initiate and spread. Weather associated with east wind has been considered the predominant weather pattern for fires in the Coast Range (Morris, 1934; Cramer, 1957).

5.3 RESULTS

5.3.1 Recent Forest Stand Conditions

A total of 192 locations with at least one old-growth tree at cutting or with one old-growth tree in a stand were identified from sample sites, field observations, and map databases (Figure 5.2). This equaled a location with at least one old-growth tree at cutting or with one old-growth tree in a stand for every 7.2 km^2 in the study area. In the Valley Margin Zone, 92 locations (1 location/5.8 km^2) with at least one old-growth tree at cutting or with one old-growth tree in a stand were identified; in the Interior/Coast

Figure 5.1 Local, Extra-Local and Regional Sites

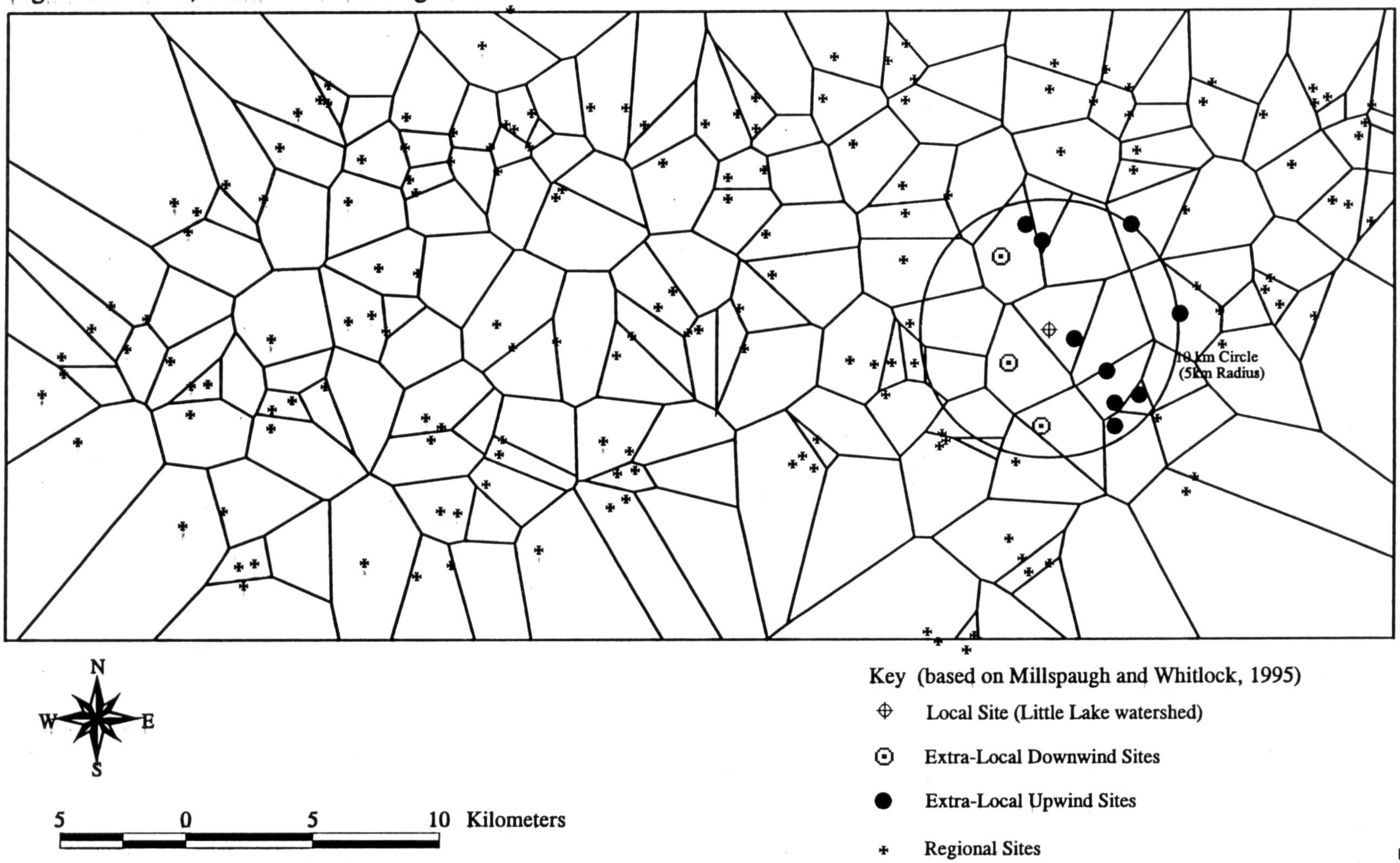
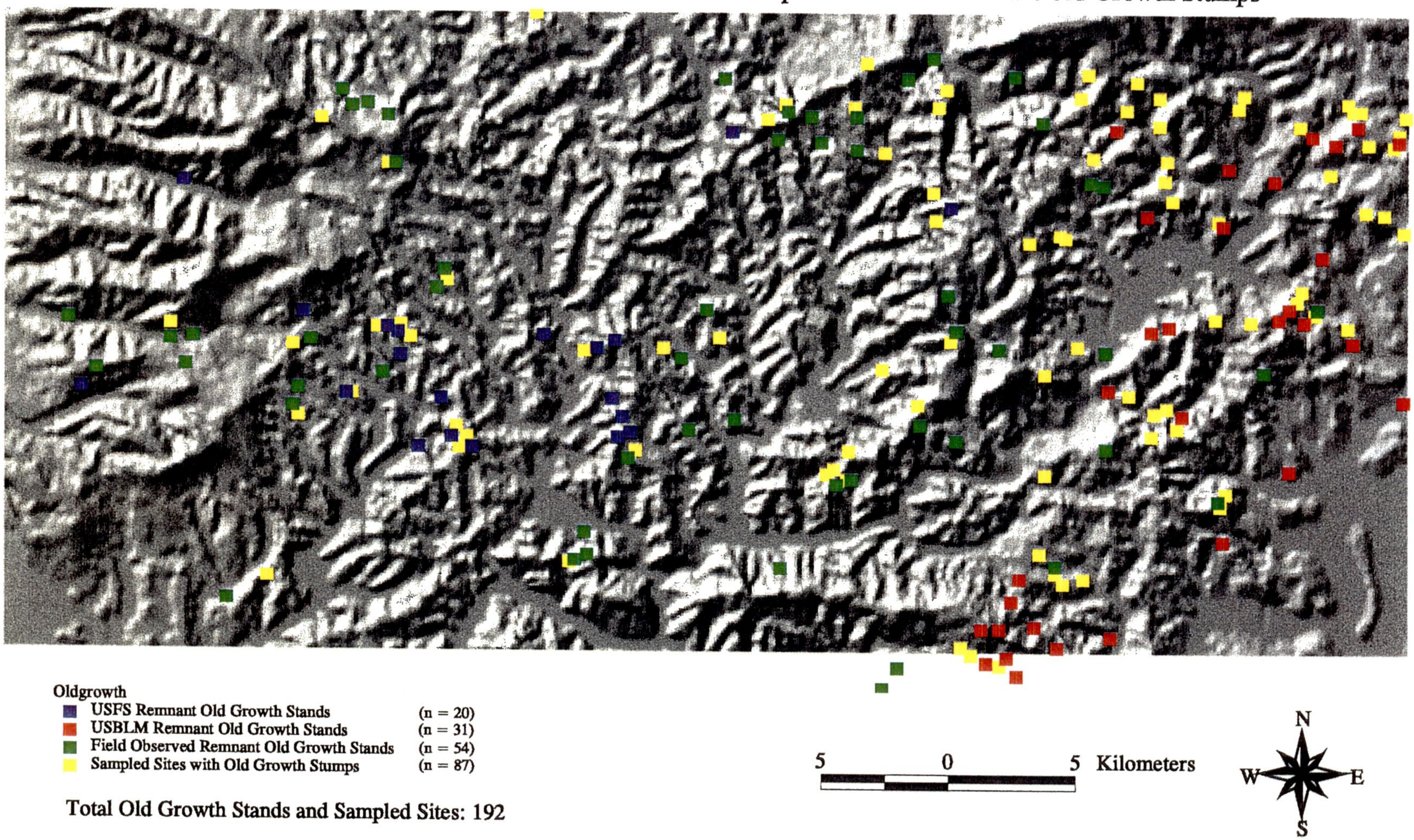


Figure 5.2 Location of Stands with Remnant Old Growth Trees and Sampled Sites with Remnant Old Growth Stumps



Zone 100 locations (1 location/8.3 km^2) with at least one old-growth tree at cutting or with one old-growth tree in a stand were identified.

A total of 87 of the 178 sites sampled in this study (49%) had at least one old-growth tree at cutting. The Siuslaw National Forest map database identified 20 remnant old-growth stands, the Bureau of Land Management map database identified 31 remnant old-growth stands, and field observations identified 54 additional remnant old-growth stands.

There were 51 study area sample sites that were old growth before cutting based on the 20 old-growth stems/ha criteria of the Old Growth Definition Task Group (1986) (Figure 5.3). By comparison, 47 sample sites were old growth before cutting based on the 30% of sampled stumps criteria, 36 sample sites were old growth before cutting based on the 50% of sampled stumps criteria, and 26 sample sites were old growth before cutting based on the 70% of sampled stumps criteria (Figure 5.4).

5.3.2 Retrospective Characterization of Forest Conditions

The oldest-tree-at-site method showed distinct differences between the Interior/Coast Zone and the Valley Margin Zone. Valley Margin sites had a slow increase in age class over time, reflective of the mixed age class of the Zone (Figure 5.5). In the Valley Margin Zone the first site having at least one tree >200 years of age occurred in the 1670s. The most dramatic increases in extent of old-growth sites over time, based on the oldest-tree-at-site method, occur in the 1730s and 1830 - 1860 for

Figure 5.3 Cumulative Number of Old Growth (>200 years) Sites Over Time based on the 20 Stems/ha Criterion

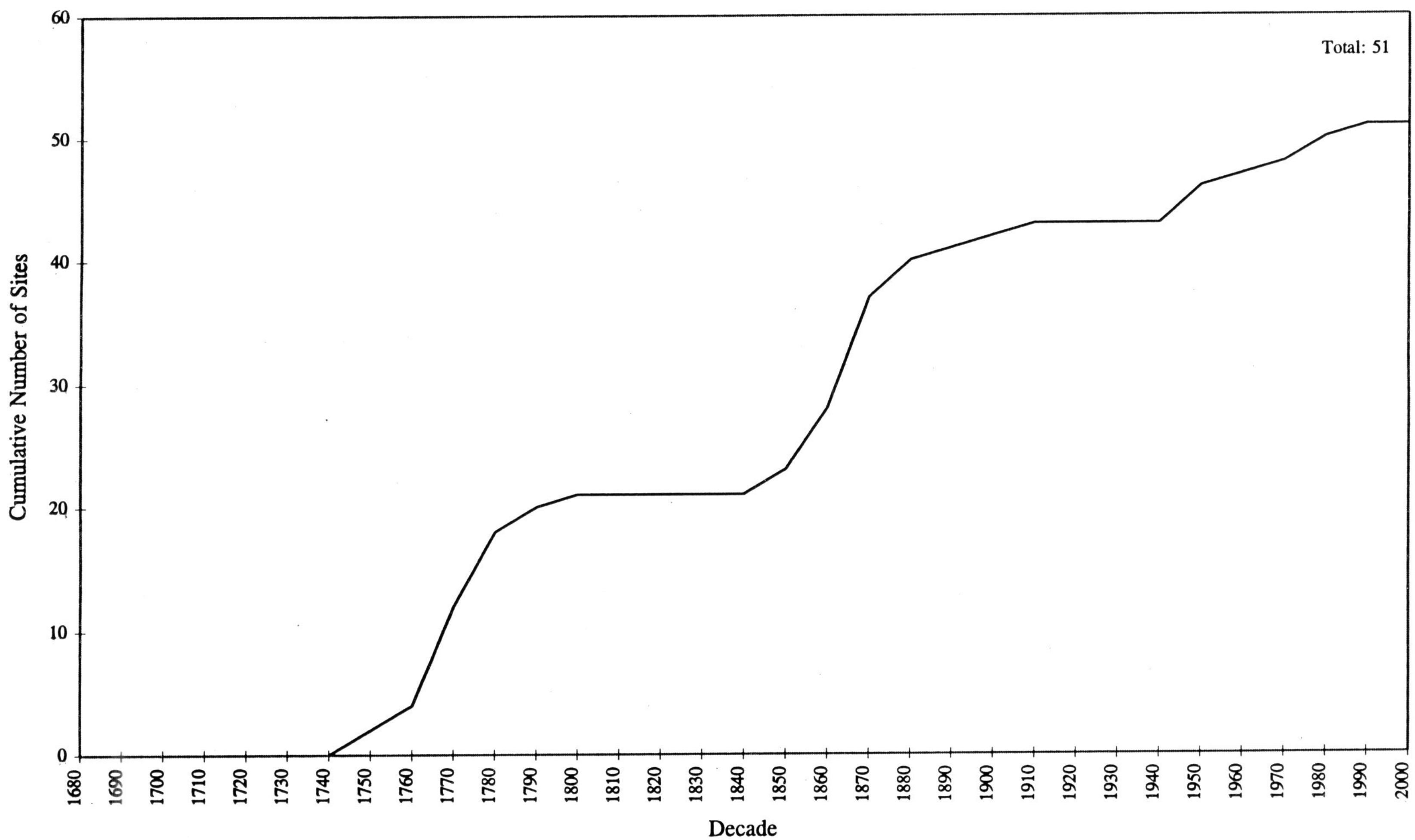


Figure 5.4 Cumulative Sites with Percent of Sampled Stumps >200 Years, by Decade (all Sites)

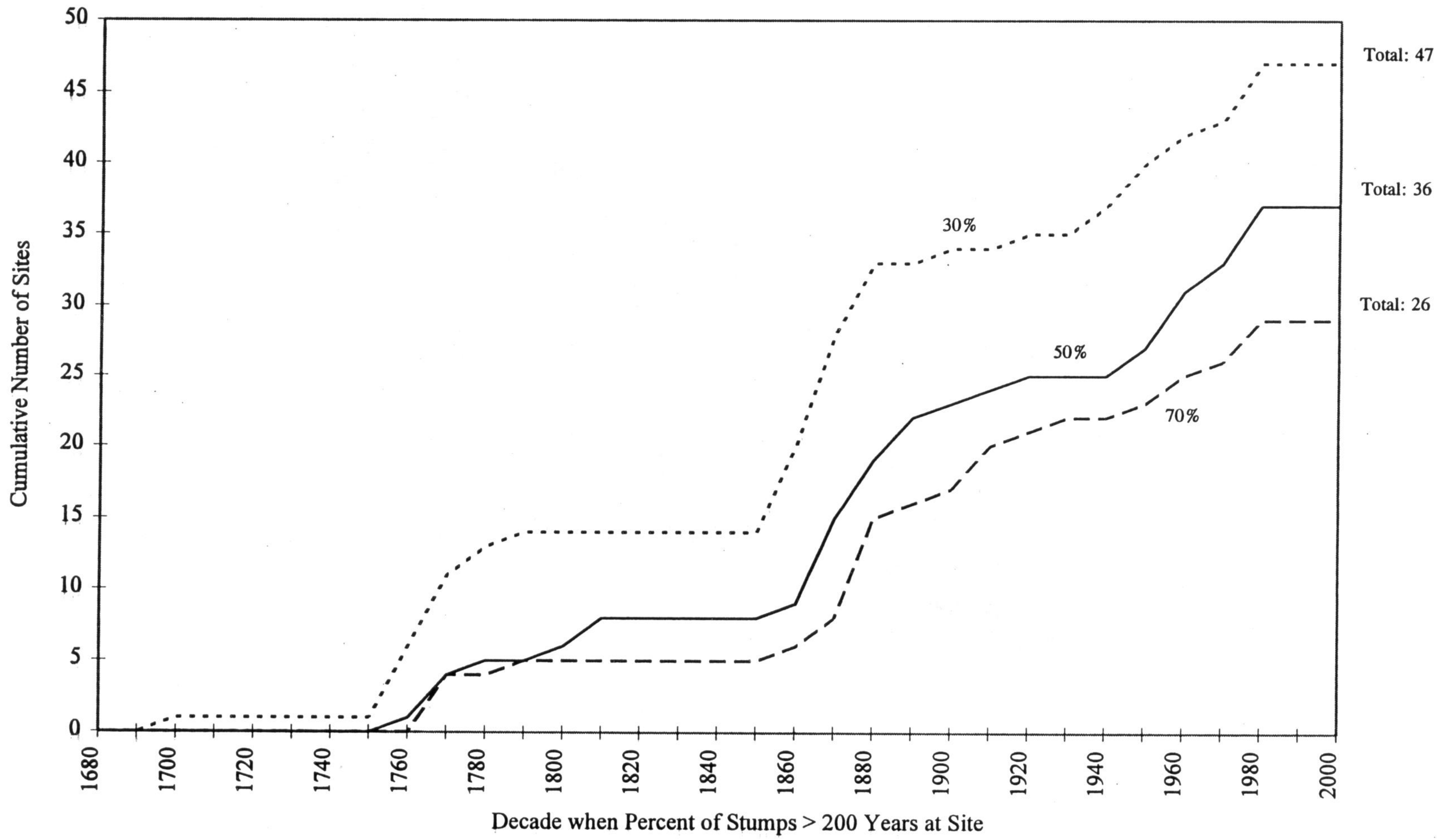
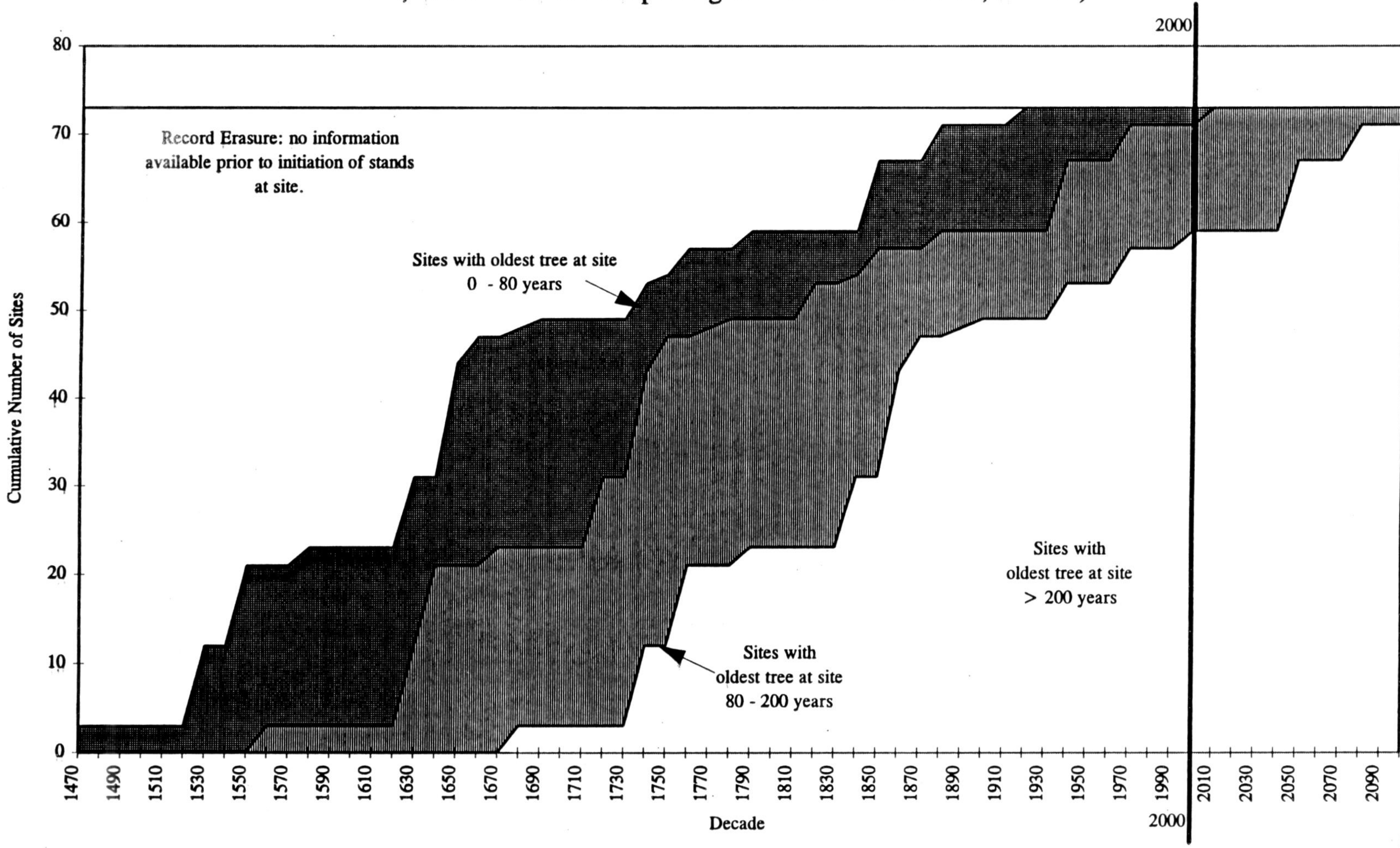


Figure 5.5 Cumulative Number of Valley Margin Sites with Oldest Tree at Site (by Decade 1470 - 2100; assumes no stand-replacing disturbance after 2000; n = 73)

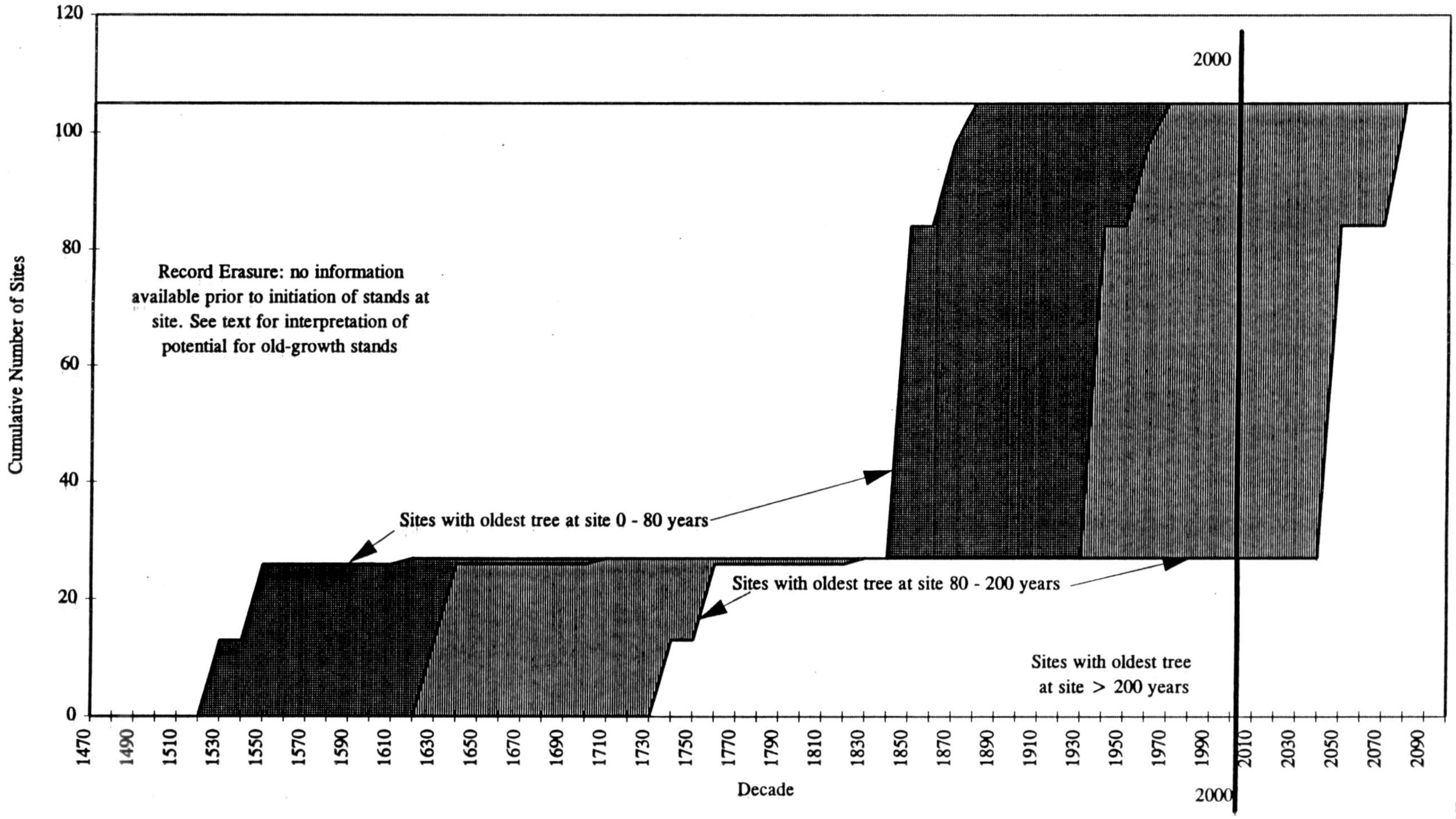


Valley Margin sites. A total of 61 sites (83%) in the Valley Margin Zone had at least one old growth tree before cutting. Projecting to the year 2100, 71 of 73 (97%) Valley Margin sites sampled would have been 200 years of age if they had not been cut or experienced stand-replacing disturbance.

In contrast, the more even-age distribution of Interior/Coast Zone sites implies dramatic changes in age class and stand structure over time, reflective of the associated higher-severity, stand-initiation fires that occurred in the Zone (Figure 5.6). The majority of sites were initiated by the high severity fire episode of 1852, and thus only 26 of 105 sites (25%) had old-growth trees when the sites were cut (~1985 - 1994). The first site with at least one tree >200 years of age occurred in the 1730s. The most dramatic increases in old-growth sites over time, based on the oldest-tree-at-site method, occur at 1730 - 1760 for Interior/Coast sites. At the time of cutting a high proportion of sites sampled were approaching old-growth status based on the oldest-tree-at-site method. All 105 Interior/Coast sites sampled would have old-growth trees by the year 2080 if they had not been cut or experienced stand-replacing disturbance.

The density of old-growth stems criterion showed increases in sites becoming old growth over time, especially between 1760 - 1780 and 1850 - 1870 (Figure 5.3). The first site with at least 20 old-growth stems/ha occurred in the 1740s. At the period of harvesting (1970 - 1990), 51 sites (49%) had an old-growth stem density greater than or equal to 20 stems/ha.

Figure 5.6 Cumulative Number of Interior/Coast Sites with Oldest Tree at Site (by Decade 1470 - 2100; assumes no stand-replacing disturbance after 2000; n = 105)

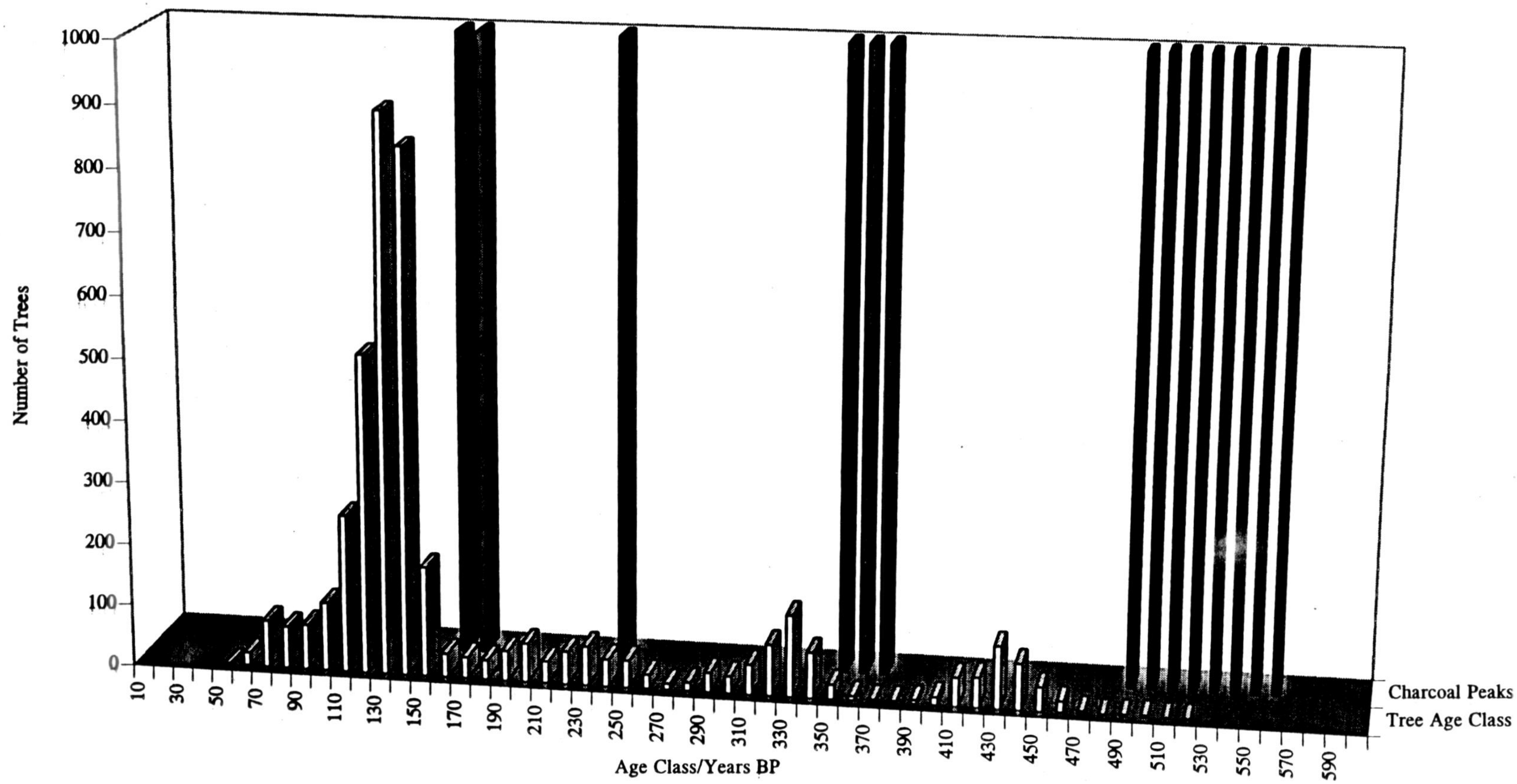


Old-growth sites also increased over time, based on the percent of sampled stumps method, with sharp increases between 1750 - 1770 and 1850 - 1880 (Figure 5.4). Based on the 30% of sampled stumps criterion, 47 of 178 sites (26%) would have been classed as old growth by the year 2000. By contrast, 37 out of 178 sites (21%) and 28 out of 178 sites (16%) would have been classed as old growth based on the 50% and 70% of sampled stumps criteria, respectively. The first sites classified as old growth based on percent sampled criteria occur in the 1690s based on the 30% of stumps sampled criterion, in the 1750s based on the 50% of stumps sampled criterion, and in the 1760s based on the 70% of stumps sampled criterion. The number of sites meeting old-growth standards by the year 2000 for all thresholds of the percent of stumps sampled method were lower than both the oldest tree at site method (176 sites) and the stem density method (51 sites).

5.3.3 Dendrochronological and Paleoecological Data

Charcoal peaks at Little Lake determined by Long (1995) coincide somewhat with study area-wide age class information and nearby fire episodes. The four major peaks of regeneration in the past 500 years coincided with and lagged behind four series of charcoal peaks by approximately 10 - 50 years, with the longest lag (~ 40 - 50 years) following the 8 decade-long charcoal peak ending 490 years ago (Figure 5.7). Peaks of regeneration occurred within ~10 years of the charcoal peaks of 350 - 370 and 150 - 170 years ago, but the relationship is less clear for the charcoal peak 230 years ago.

Figure 5.7 Comparison of Age Class and Charcoal Data



Local fire episodes recorded in the tree ring and archival records at or near the site in the Little Lake watershed were not clearly associated with charcoal peaks. Only one of six locally recorded fire episodes (17%) matched a charcoal peak within 10 - 20 years (Figure 5.8). This peak most likely corresponds to the fire of 1852. Only four of the 17 fire episodes (24%) recorded at extra-local sites occur within 20 years of a charcoal peak (Figure 5.9). Fire episodes recorded at extra-local upwind sites are slightly more closely associated with charcoal peaks; four of the 14 fire episodes (29%) recorded at extra-local upwind occur within 20 years of a charcoal peak (Figure 5.10). The fire episodes recorded at extra-local downwind sites showed a similar association with charcoal peaks as extra-local upwind sites; two of the seven fire episodes (29%) recorded at extra-local downwind sites occur within 20 years of a charcoal peak (Figure 5.11). Two of the four fire episodes (50%) recorded only at regional sites occurred within 10 - 20 years of a charcoal peak (Figure 5.12).

5.4 DISCUSSION

5.4.1 Spatial and Historic Characteristics of Fire

Four spatial patterns of fire episode were determined in this study; Widespread, Valley Margin, Mixed, and Modern fires (Chapter 2). Each pattern type has a distinct range of size, severity, contiguity, and potential to have spread beyond the study area.

Figure 5.8 Comparison of Fires Recorded at Local Site (Watershed) and Charcoal Data

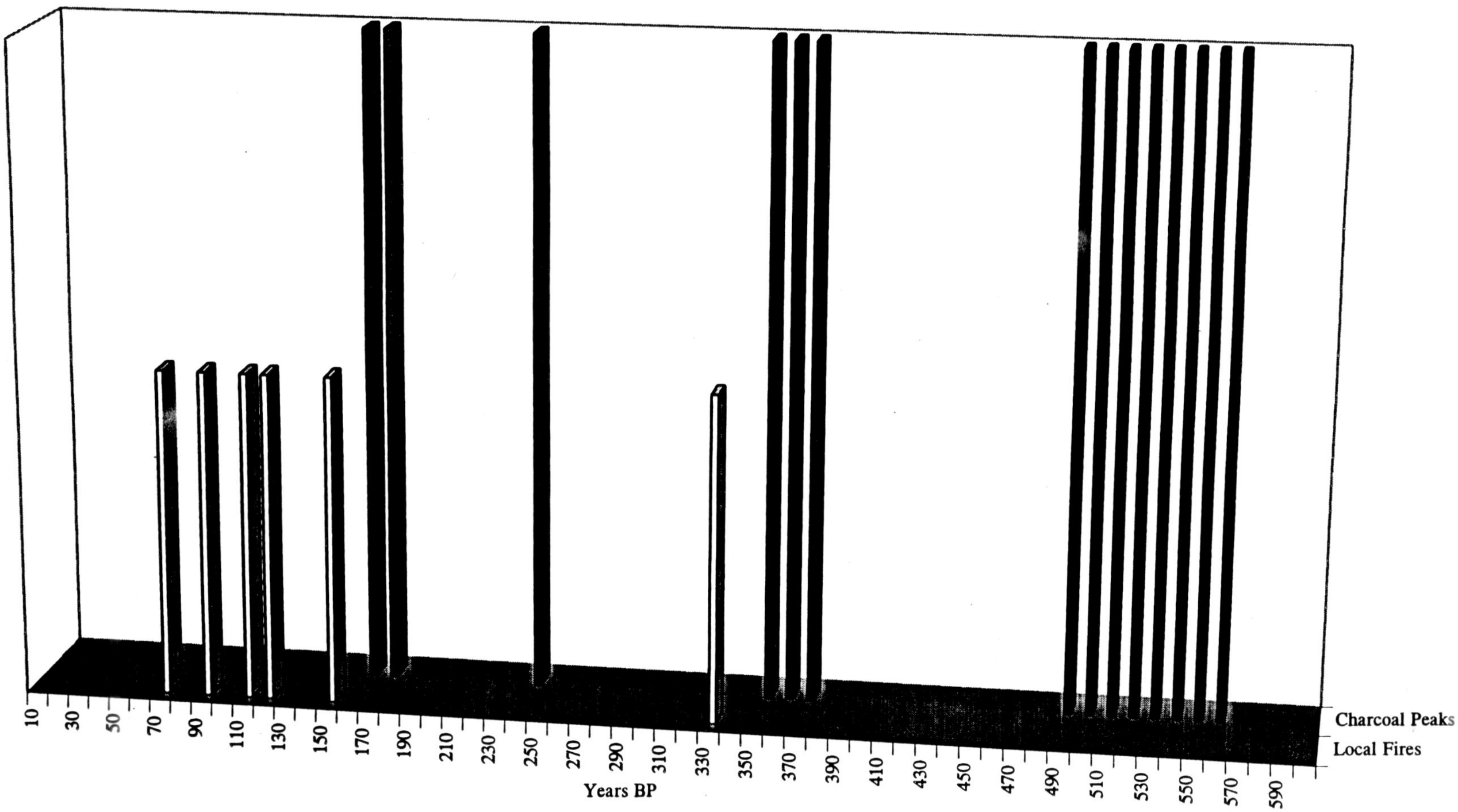


Figure 5.9 Comparison of Fires Recorded at All Extra-Local Sites and Charcoal Data

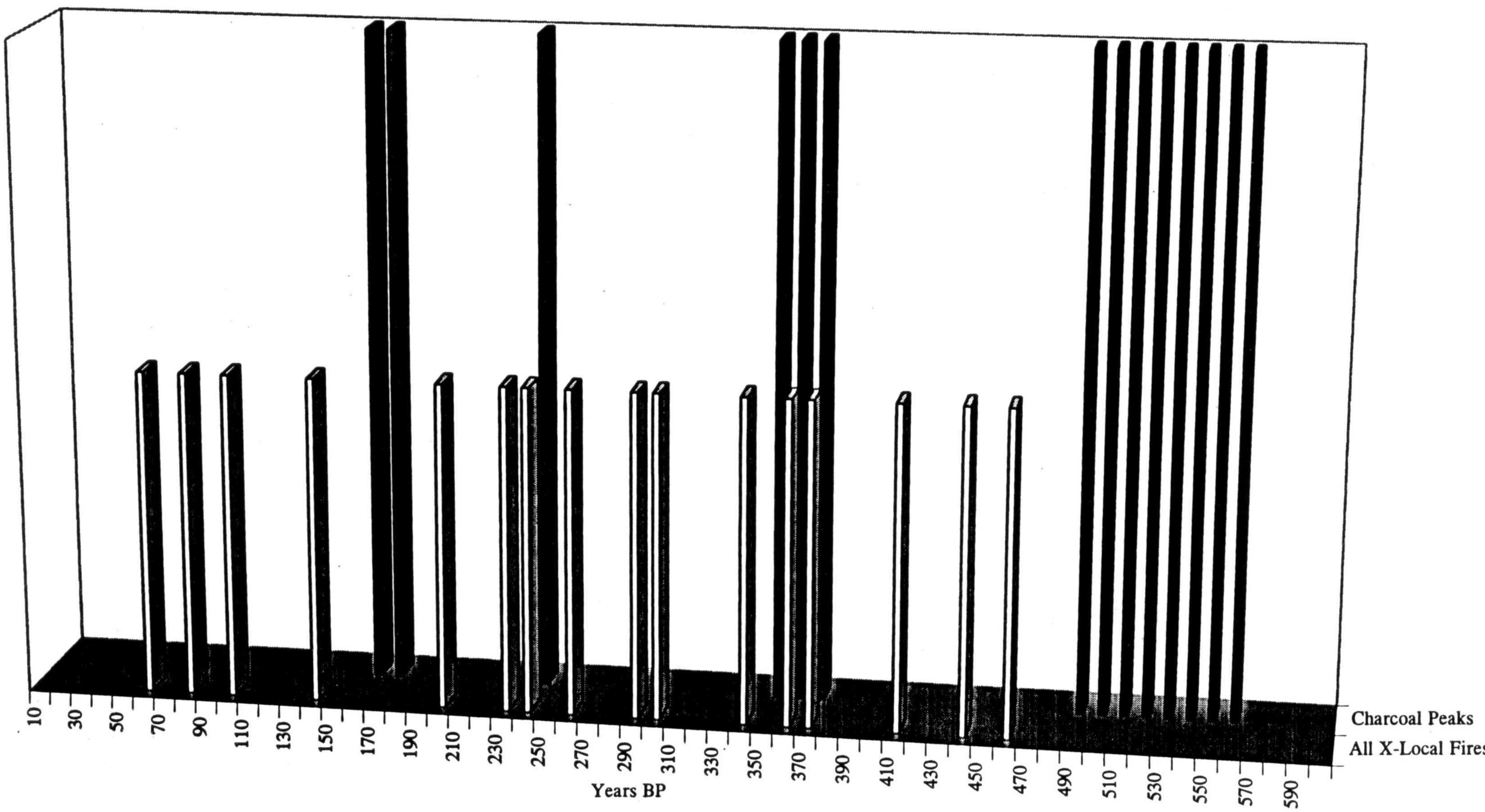


Figure 5.10 Comparison of Fires Recorded at Extra-Local Upwind Sites and Charcoal Data

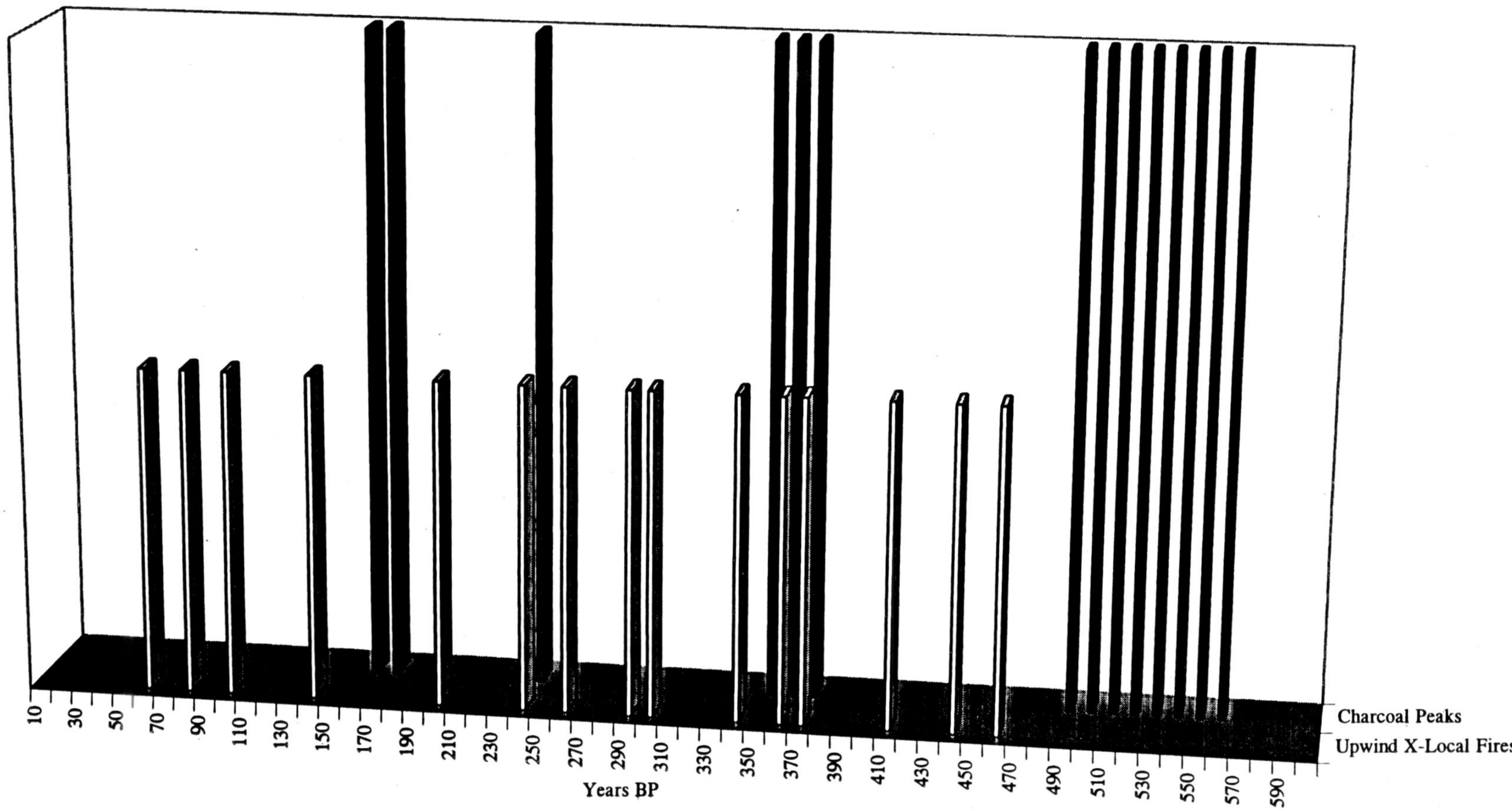


Figure 5.11 Comparison of Fires Recorded at Extra-Local Downwind Sites and Charcoal Peaks

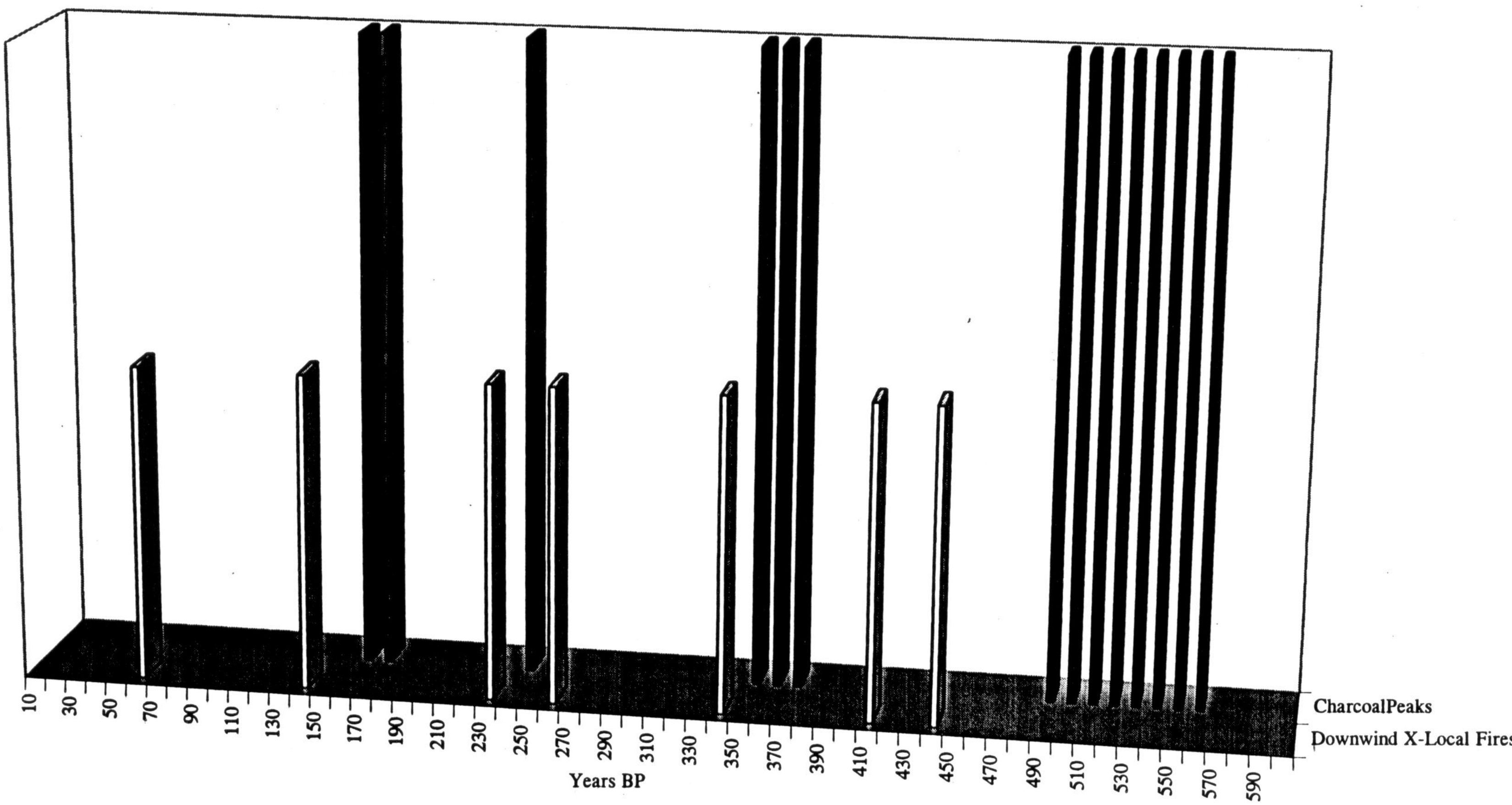
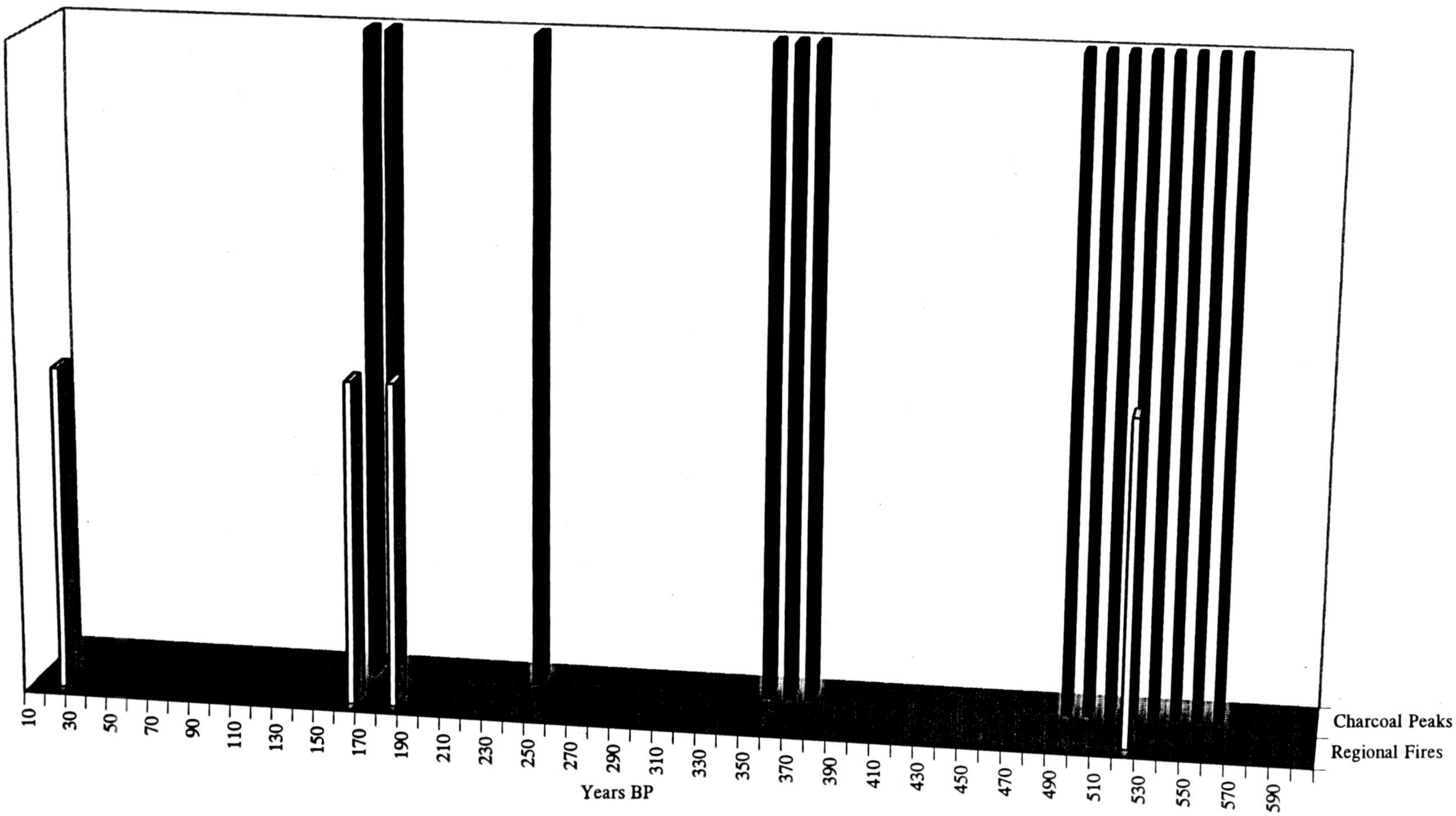


Figure 5.12 Comparison of Regional Fires and Charcoal Data



According to this reconstruction of old growth, widespread fire episodes had the greatest impact in the study area over the last 500 years on forest age class and composition, especially in the Interior/Coast Zone. These fire episodes were large and destructive, and established extensive, near even-aged stands. They corresponded to many popular perceptions and depictions of fire in the Coast Range (e.g. Morris, 1934; Munger, 1944; Zybach 1988), and are similar to historically known fires, such as the Tillamook fire of 1933, in terms of severity, extent, and degree of stand initiation.

The fire episode of 1852 had the greatest effect on present-day forests, as it covered the largest amount of the study area, and burned at a high severity over much of the study area. This fire episode initiated the most number of stands of any identified. The fire episode of 1871 was second to the fire episode of 1852 in area burned and number of stands initiated. The characteristics of the fire episodes of 1531 and 1555 are indicative of widespread, severe fires, which appear to have altered forest age class, structure and composition. Due to record erasure it is less conclusive, but likely, that these fires had a similar impact on the forest ecosystem as the fires of 1852 and 1871.

Fires in the Coast Range are capable of burning large areas at high severities. The past occurrence of these fires appears to have been greatest in the Interior/Coast Zone, where it appears that fuel loading reach high levels as a result of rapid plant growth and long intervals between fires. Fuel buildup in the Interior/Coast Zone may be augmented by the mild, relatively moist summers and the rarity of drying east winds and ignition sources. If prolonged drying east winds and lightning and/or human ignitions coincide in the future, the potential for a widespread fire will be enhanced. A fire such as the Tillamook fire of 1933 does not appear to be abnormal, and it is possible, if not likely, that similar fires will visit Coast Range forests again.

A common perception of Coast Range fires is all were widespread and very severe. In contrast to the large-scale severe fires described above, the Coast Range also experienced smaller, less severe fires, especially in the Valley Margin Zone. These fires also affected forest age class, structure and composition. Understory vegetation may have been altered by fire at a relatively frequent rate, producing conditions for a diverse mosaic of vegetation types. The lower severity, smaller fires left parts of stands intact, and over time mixed age class stands developed. The variable canopy age class and understory forest composition was enhanced by the fact that Valley Margin fires burned at low, moderate and high severities and generated some areas with even age classes.

A second perception of fires in the Coast Range is that east-facing portions of the landscape might have been more severely affected by fires that were spread by east winds. However, little difference with respect to aspect was found in the fire regime. The analysis in Chapter 2 of age-class histograms comparing aspects was inconclusive, as was a comparison of mean fire return interval by aspect. The logistic regression analysis in Chapter 3 indicated that aspect was significant in only four out of 12 fires initially tested; in later tests aspect was not significant for any fires with greater than 15 sites recording a fire. These results are interesting in light of perceptions and observations that aspect affects the fire regime (e.g. Swanson and others, 1988; Turner and Romme, 1994). Swanson and others (1990) hypothesized that landforms and topography may not influence fire patterns when slope length is less than several tree heights. It is possible that slope length in the study area is too short to affect other influences of fire, such as east winds. Thus the influence of aspect may not be a significant factor in Coast Range fires.

The fire regime did appear to be influenced by hillslope position (Chapter 3), with upper hillslope positions experiencing higher fire severities and frequencies than lower hillslope positions. Greater occurrence of old-growth trees at lower hillslope positions indicated a relatively higher degree of tree survival from moderate severity fires at lower hillslope positions than at upper hillslope positions . Old-growth trees were also found at mid and upper hillslope positions, but to a lesser extent than in lower hillslope positions.

5.4.2 Retrospective Stand Characteristics in the Central Oregon Coast Range: How Much Old Growth is There Presently and How Much Has There Been in the Study Area Over Time?

A third common perception is that the central Oregon Coast Range has had limited old growth. However, this study indicates that the past, present and future potential for old growth in the central Oregon Coast Range is quite high. Given the variability of fire severity, especially due to hillslope position, it is likely that there were many stands with single or few old-growth trees, even following high severity fires. As an example, Isaac and Meagher (1936) observed many old-growth survivors of the Tillamook burn that were important in subsequent Douglas-fir regeneration.

Old-growth trees are important ecologically to many forest processes, even in dispersed or low numbers (Franklin and others, 1981). Individual old-growth trees and snags act as wildlife nesting sites (Mannon and others, 1980; Carey and others, 1991), food larders for invertebrate predators (Carey and others, 1991) and fungal predators, nutrient stores (Grier and Logan, 1977; Harmon and others, 1986), vertebrate and invertebrate habitat (Maser and others, 1979; Corn and Bury, 1991), inputs to streams of nitrogen and coarse woody debris (Harmon and others, 1986; Maser and others, 1988), and as a platform for nitrogen-fixing epiphytes, such as lichens in living old-growth trees (Pike and others, 1977) and for nitrogen-fixing bacteria in snags and downed logs (Franklin and others, 1981; Harmon and others, 1986). These characteristics of individual old-growth trees make it important to understand the pattern of individual old-growth trees in the landscape.

The dendrochronologic record indicates that old growth was more extensive in the study area in the recent past than the present, especially prior to the fire of 1852. If, as the record indicates, there was no fire of major extent between 1555 and 1852 in the Interior/Coast Zone, there would have been widespread tracts of natural stands covering most of the Interior/Coast Zone of approximately 300 years of age when the fire of 1852 occurred. This may account for the widespread and severe character of the fire, as fuel continuity and fuel loads would have been high. If the widespread, high severity fires had not occurred in the 1850s - 1880s in the Interior/Coast Zone, it is possible that the majority of remaining natural stands in the Zone would have been in an age class of 400 - 450 years of age today.

This study revealed the existence of 192 sites or stands containing old-growth trees in the 1375 km^2 study area. This result contradicts the speculation that the Oregon Coast Range rarely had extensive tracts of old growth, and that the old growth that did occur was as limited and sporadic in occurrence as described (Zybach, 1988; Zybach, 1993). In contrast, other studies, using size class information from the 1933 timber survey to generate fire probabilities and associated age-class distributions from the negative exponential model (Van Wagner, 1978), have estimated large areas of old growth in the Coast Range and in the Pacific Northwest. Ripple (1994) estimated that 43.6% of the Northern Oregon Coast Range and 42.9% of the Southern Oregon Coast Range were old growth prior to logging by Europeans. Booth (1991) estimated that 62% of pre-logging forests were old growth in the Pacific Northwest, which would be a substantial amount compared to estimates of present-day old-growth occurrence.

Prior to the onset of large-scale timber harvesting in the 1950s, the central Oregon Coast Range had the potential to develop into stands that would be predominantly old growth by 2080 - 2100 due to the even aged-nature of forests in the study area, especially in the Interior/Coast Zone (Figures 5.5 and 5.6). This scenario is unlikely if a widespread, high severity fire recurs in the near future.

5.4.3 Comparing the Long-term (ca. 500 years) Dendrochronologic Fire Record with the Holocene Fire Record.

The clearest relationship between the dendrochronologic and paleoecological fire record is between the regional-scale tree age-class distribution and charcoal peaks, but the charcoal record is not consistently related to fires within 10 km of the coring site. Regional sites recorded the highest percentage (50%) of fires most closely associated with charcoal peaks, but associated fires were limited to two. The association between the paleoecological fire record and the fire record at extra-local upwind sites, while limited, is suggestive of the importance of east winds on fire in the study area.

The association between the paleoecological fire record and the study area tree age-class distribution has implications for interpretations of the historic occurrence of old growth in the Oregon Coast Range. There is a lag period between widespread (e.g. across the Valley Margin Zone, or across the entire study area) regeneration dates and charcoal peaks (Figure 5.7). If the ability of the charcoal record to distinguish individual fire episodes is limited, multiple fire episodes identified in this study may have been combined in the charcoal record. However, the outcome of those combined fires, a widespread, similar age class, seems associated with the charcoal data.

This association of the recent charcoal record and the existing age class can be used to investigate possible age-class structure of the forest over the charcoal period of record, approximately 10,000 years. The charcoal record derived by Long (1995) shows periods of several decades of charcoal peaks, interspersed with periods with relatively few charcoal decades (Figure 5.13). For example, long fire periods (>6 decades within a hundred year period) ended 490, 1080, 2950, 4310, 4660, 5440, 5790, 7110, 8340 and 8740 years before present (YBP). In the last 3500 years, when Douglas-fir was the predominant tree species (Worona and Whitlock, 1995), there was a 1500 year period between 1450 YBP and 2950 YBP in which only four charcoal decades were recorded (Figure 5.14). If during this period the fires recorded as charcoal peaks have had a similar effect on the age class distribution as appears to have occurred in the past 500 years, and other mortality agents, such as windthrow and disease, were limited, the possibility exists that there may have been extensive, very old stands on the order of 700 to 1400 years of age in the study area. A prehistoric forest 700 to 1400 years of age would have had age classes, composition, and structure very different than the present day forests of the central Oregon Coast Range, which are predominantly limited to ~500 years of age. Stands of this age would be expected to have greater quantities of later seral species, such as western hemlock and western red cedar, as well as a complex canopy and varied size and age classes (Franklin and others, 1981).

Figure 5.13 Charcoal Decade Peaks at Little Lake, Oregon ca. 9090 years BP to Present (from Long, 1995)

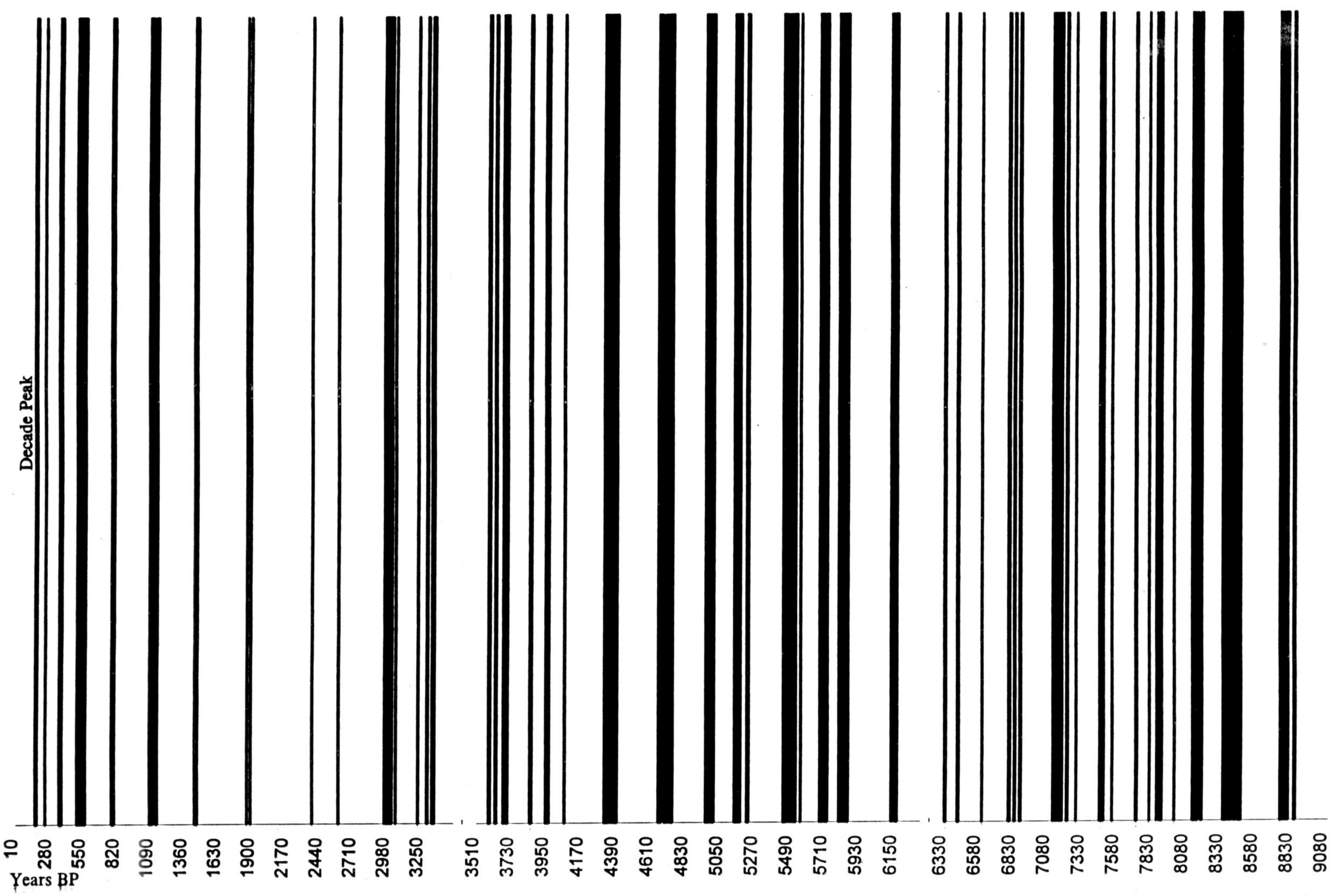
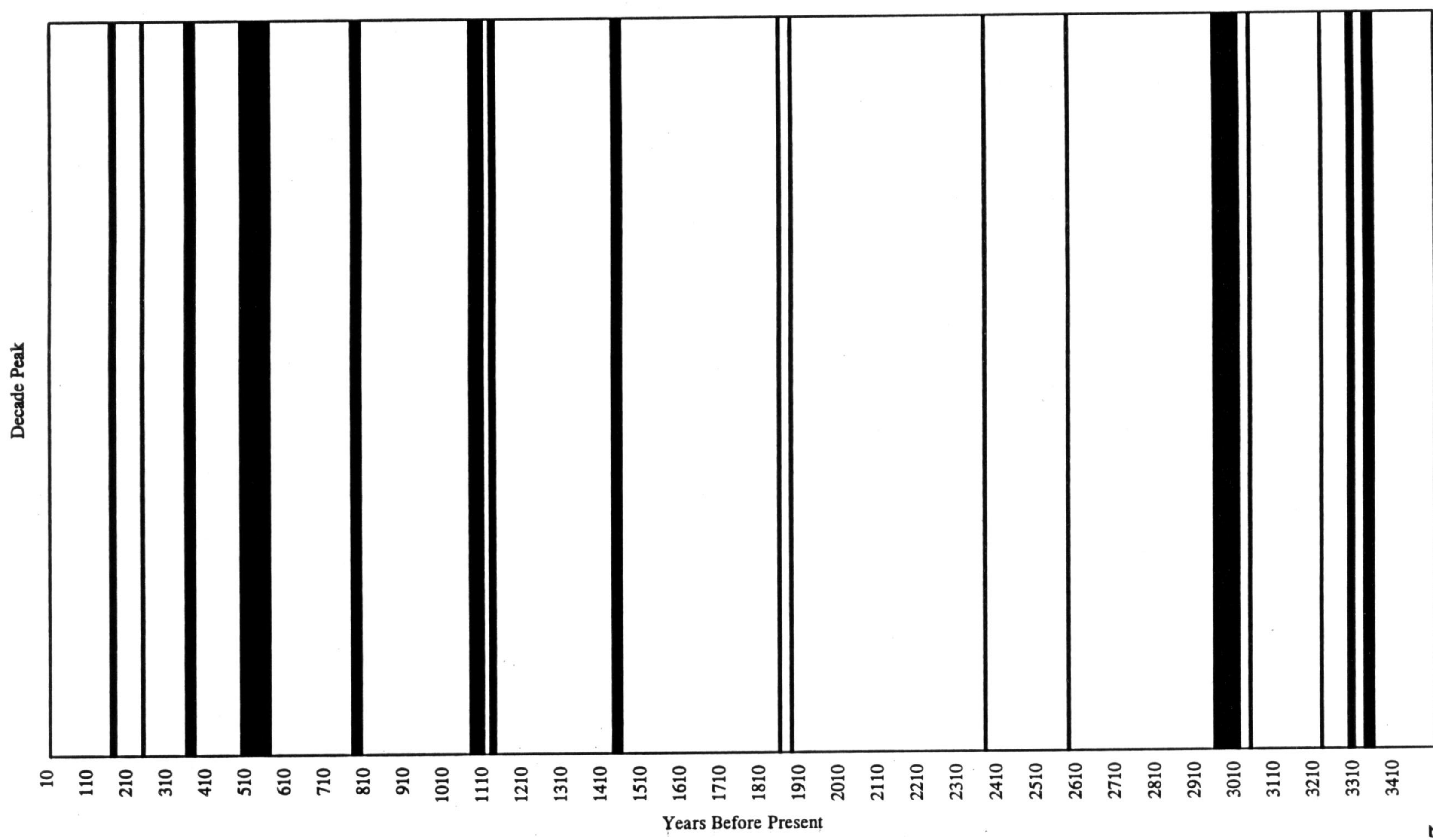


Figure 5.14 Charcoal Peaks from the Little Lake Core ca. 3500 YBP to Present (from Long, 1995)



5.5 CONCLUSIONS

1. Dating of trees from tree rings on stumps and field observations show recent widespread, but patchy, old growth in the central Oregon Coast Range. This old growth seems to be a remnant of a geographically broader age class erased by subsequent fire.
2. The fire evidence and existing natural stand age classes suggest that prior to the fire of 1852, perhaps 50 - 70% of the study area was old growth of approximately 300 years of age, primarily in the Interior/Coast Zone of the study area. Remnants of this age class (now 400 - 450 years old) are present throughout the study area. Additional mixed age class old-growth stands were present in the Valley Margin Zone.
3. Due to large scale stand initiation from the major fire episodes after the 1850s, most of the remaining natural stands in the study area will exceed 200 years of age in 2050. If harvesting of natural stands had not occurred, and without large-scale stand-replacing natural disturbances, much of the study area could have become old growth by 2050.
4. The strongest association between the paleoecological and the dendrochronological fire record is the from fires recorded at regional sites (*sensu* Millspaugh and Whitlock, 1995). The study area age class does correspond with charcoal peaks identified in the lake core. The charcoal record suggests that over the period of record (ca. 10,000 years) periods of fires were common, indicating mixed age classes, and reduced extent of old growth. These periods were interspersed with centuries-long periods when fires were less common, indicating less mixed age classes, and the potential for large areas of old-growth forests.

CHAPTER 6. CONCLUSIONS

1. The 27 fire episodes of the past 516 years averaged 97 km^2 in size, with a range of 18 to 544 km^2. On average 6.4 km^2 , or 0.5% of the study area, burned per year. The NFR for the study area over the entire period of record was 271 years, and the MFRI for the entire study area was 85 years. Site fire severity was mixed within and between fire episodes, reflecting the complex interaction of fire behavior with patterns of wind, fuel loads, vegetation, fog, precipitation, and topography.

2. The MFRI estimate of 75 years for the eastern, Valley Margin Zone was a suitable estimate of fire frequency for this zone. The MFRI estimate of 115 years for the western Interior/Coast Zone was probably a low estimate of fire frequency, given the few sites available to carry out an MFRI calculation, and the occurrence of long (~300 year) fire return intervals at many sites in this zone.

3. This study identified and sized fire episodes in the middle portion of the actual fire size distribution. Smaller fires, perhaps less than 10 km^2, were unlikely to be identified as fire episodes in this study due to the sampling grain and rule sets incorporated to identify fire episodes. Fire episodes larger than the extent of the study area, or occurring outside the study area, were identified but sizes were underestimated. The size of earlier fires, especially the widespread fire episodes of 1531 and 1555, were also probably underestimated due to the subsequent erasure of the record by later fires.

4. Broad-scale spatial patterns of fire are oriented in an east to west direction, and appear to be related to the pattern of precipitation and related fog patterns, vegetation and fuel load patterns that are coupled to precipitation, and the pattern of ignitions by humans and lightning.

5. Fire episode patterns reflected the influences of spatial and temporal patterns. The occurrence of widespread high severity fire episodes starting in the 1850s may have been related to changes in climate, land use, or some combination of the two. The pattern of severity of these fire episodes may have resulted from the higher fuel loads of the wetter part of the study area. For approximately 300 years prior to climatic and land use changes only Valley Margin fire episodes occurred in the drier, eastern parts of the study area, with mixed severity. Fire episode patterns after 1910 are limited in size and are mostly of low and moderate severity, reflecting the onset of fire control activity in 1910.

6. The patterns of environmental variables, precipitation, landform, and vegetation, were significant (p-value < 0.05) in a multiple-variable logistic regression model explaining the occurrence of the widespread, high severity fire episode of 1852. The wettest sites, those within the higher precipitation Interior/Coast Zone, within Landtype Association 3T, and with vegetation association type RUSP, were 11 times more likely to experience the widespread, high severity fire episode of 1852 than the driest sites within the lower precipitation Valley Margin Zone, within Landtype Association 3F, and with vegetation association type RHMA. The association of these variables with the

pattern of fire occurrence indicated that processes related to fuel loads and fuel moisture content affected the process of fire.

7. Zone, a variable developed to reflect precipitation patterns, was significant (p-value < 0.05) in three out of six fire episodes modeled, and had the lowest p-values of any individual explanatory variable for four of the six fire episodes modeled. This significance is an indication that precipitation patterns influence fire patterns in the Coast Range. However, Zone may be limited in representing precipitation patterns as it is a construct based on a model of precipitation.

8. Landtype Association was significant in two of the six fire episodes modeled, and was the most significant variable for the fire episode of 1871. LTA was significant as an individual variable for four of the six fire episodes modeled. These results indicate that fire patterns are sensitive to the influences of the patterns of landforms in the study area. The complex of factors used in defining a Landtype Association complicates determining its influence on fire patterns.

9. Logistic regression models did not support the hypothesis that there is an interaction across spatial scales between the significant variables Zone, Landtype Association, and Vegetation Association Groups, for the fire episode of 1852. However, an evaluation of the results of the models which included interaction terms but that did not converge gives an initial indication that a spatial hierarchy may exist that is not discernible with the data available and methods used. Future researchers using logistic regression to generate explanations of pattern - process interactions and controls of fire should be

aware of the limits of the logistic regression method when low numbers of sites record a fire episode.

10. Upper hillslope positions had higher frequency and severity of fire than lower hillslope positions. An important feature of this result is that old growth trees are more common at lower hillslope positions than at upper hillslope positions. This pattern of old growth occurrence should be considered in studies of forest patterns and related management approaches to old growth forests.

11. Changing the rule sets for fire size determination by interpolating between sites where fire episodes occurred but the record may have been subsequently erased produced an increase in fire size estimates up to 150% over the Thiessen polygon method, while the ratio method estimated fire sizes up to 800% over the Thiessen polygon method. Fire episode occurrence at a site and subsequent size determination methods requires a certain degree of subjective analysis. This is especially the case where interpolation and/or extrapolation of fire episode occurrence due to suspected record erasure is carried out. This is not necessarily limiting: rather the rules applied and the justification for assumptions must be spelled out in fire regime studies to clarify how results were obtained.

12. The estimate of MFRI is sensitive to the number of sites available for calculations and the scale of calculation. MFRI estimates in this study were limited by the low number of sites which experienced enough fires to calculate MFRI. As the scale of

measurement increased, MFRI decreased, indicating that the scale of measurement should be specified when reporting MFRI.

13. In this study the NFR of 271 years without accounting for erasure versus 92 years using the ratio method indicates that NFR estimates were very sensitive to assumptions of and changes in rule sets for fire episode determination. Reported NFR values could be expected to vary among studies either due to differences in the fire regimes or according to assumptions about record erasure.

14. Differences in fire size estimates between studies in the Douglas-fir forests west of the Cascades appear to be related to the extent of the studies considered: larger extent studies had larger fire size estimates than smaller extent studies, but similar ratios of average estimated fire size to extent. This comparison of ratios of average estimated fire size to extent, and the region-wide occurrence of an age class of approximately 450 - 500 years of age, indicate that a much larger-scale study of fire in the Oregon Cascades than has been carried out to date may reveal large fires such as those that have occurred in the Coast Range.

15. Dating of trees from tree rings on stumps and field observations show recent widespread, but patchy, old growth in the central Oregon Coast Range. This old growth seems to be a remnant of a geographically broader age class erased by subsequent fire.

16. The fire evidence and existing natural stand age classes suggest that prior to the fire of 1852, perhaps 50 - 70% of the study area was old growth of approximately 300 years of age, primarily in the Interior/Coast Zone of the study area. Remnants of this age

class (now 400 - 450 years old) are present throughout the study area. Additional mixed age class old-growth stands were present in the Valley Margin Zone.

17. Due to large scale stand initiation from the major fire episodes after the 1850s, most of the remaining natural stands in the study area will exceed 200 years of age in 2050. If harvesting of natural stands had not occurred, and without large-scale stand-replacing natural disturbances, much of the study area could have become old growth by 2050.

18. The strongest association between the paleoecological and the dendrochronological fire record is the from fires recorded at regional sites (*sensu* Millspaugh and Whitlock, 1995). The study area age class does correspond with charcoal peaks identified in the lake core. The charcoal record suggests that over the period of record (ca. 10,000 years) periods of fires were common, indicating mixed age classes, and reduced extent of old growth. These periods were interspersed with centuries-long periods when fires were less common, indicating less mixed age classes, and the potential for large areas of old-growth forests.

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APPENDICES

Appendix A. Fire Chronology

Appendix A. Fire Chronology

Data for Fire Chronology							Dates of Identified FIres										
Zone	Utmeast	Utmnorth	Clearcut	#Events	Area	Aspect	1478	1531	1555	1585	1629	1637	1655	1666	1689	1699	1737
VM	448900	4877900	9560	4	529315	E	0	0	3	0	0	0	0	0	0	0	2
IC	432100	4898200	95103	1	659710	W	0	0	0	0	0	0	0	0	0	0	0
VM	465700	4898400	9309	6	690802	W	0	3	0	0	0	0	0	0	0	1	0
VM	450000	4877500	9561	4	747703	N	0	3	0	0	0	0	0	0	0	0	2
VM	449000	4885900	9533	1	884769	S	0	0	0	0	0	0	0	0	0	0	0
VM	443500	4885200	9566	3	966876	N	0	3	0	2	0	0	0	0	0	0	0
VM	463900	4899300	9410	10	978841	W	3	0	0	0	1	0	0	0	0	1	1
VM	456100	4887400	9550	3	1012989	W	0	0	0	0	0	3	0	1	0	0	0
IC	424300	4899400	95133	1	1156500	E	0	0	0	0	0	0	0	0	0	0	0
VM	447000	4889000	9302	1	1540917	S	0	0	0	0	0	0	0	0	0	0	0
IC	431100	4897500	95100	1	1622577	W	0	0	0	0	0	0	0	0	0	0	0
VM	446300	4888900	9530	3	1635323	E	0	0	0	0	0	0	0	0	0	0	0
IC	426500	4890800	9402	6	1689898	W	0	3	0	0	0	0	0	0	0	0	0
IC	419200	4888200	9418	1	1725245	W	0	0	0	0	0	0	0	0	0	0	0
VM	465500	4897900	9408	10	1750067	S	0	0	0	0	0	0	3	0	0	2	0
VM	461700	4891800	9545	2	1854192	E	0	0	0	0	0	0	0	0	0	0	0
IC	427900	4896300	95114	1	1870298	N	0	0	0	0	0	0	0	0	0	0	0
IC	422500	4887200	95129	4	1895391	W	0	3	2	0	0	0	0	0	0	0	0
IC	436300	4884400	9590	1	1929273	N	0	0	0	0	0	0	0	0	0	0	0
VM	464200	4899300	9505	2	2113194	E	0	0	0	0	0	0	0	0	0	0	0
IC	419500	4895000	95139	2	2147263	E	0	0	0	0	0	0	0	0	0	0	0
VM	452200	4881100	9557	2	2221811	N	0	0	3	0	0	0	0	0	0	0	0
VM	465100	4895200	9536	2	2291100	E	0	0	0	0	0	0	0	0	0	0	3
IC	427700	4897600	95112	1	2328509	E	0	0	0	0	0	0	0	0	0	0	0
VM	459900	4891000	9504	10	2442098	S	0	3	0	1	1	1	0	0	1	2	0
VM	464500	4898000	9412	8	2505474	N	0	3	2	0	0	0	0	0	2	0	1

IC	431700	4898400	95105	1	2545922	E	0	0	0	0	0	0	0	0	0	0	0
IC	423300	4887600	95128	2	2584253	S	0	0	0	0	0	0	0	0	0	0	0
IC	429100	4886400	9404	7	2667589	W	0	0	3	0	0	0	0	0	0	0	0
IC	440900	4898900	9574	2	2690782	S	0	0	3	0	0	0	0	0	0	0	0
IC	424700	4899300	95132	1	2722185	N	0	0	0	0	0	0	0	0	0	0	0
VM	455000	4899300	9512	2	2725115	S	0	0	0	0	0	0	3	0	0	2	0
VM	456500	4896500	9526	1	2813086	E	0	0	0	0	0	0	0	0	0	0	0
IC	414200	4888800	9414	1	2836169	S	0	0	0	0	0	0	0	0	0	0	0
IC	432600	4897500	95106	1	2864056	N	0	0	0	0	0	0	0	0	0	0	0
IC	440500	4896400	9582	1	2879899	E	0	0	0	0	0	0	0	0	0	0	0
VM	465950	4899100	9411	6	2938441	N	0	0	0	3	0	0	0	0	0	0	0
IC	421300	4880900	95125	1	2943375	E	0	0	0	0	0	0	0	0	0	0	0
VM	456300	4898700	9509	2	2995025	S	0	0	0	0	0	0	0	3	0	0	0
IC	439400	4890300	9576	2	2996891	N	0	0	0	0	0	0	0	0	0	0	0
IC	429700	4882900	95118	1	2999726	W	0	0	0	0	0	0	0	0	0	0	0
VM	452400	4894300	9524	3	3062342	N	0	0	0	0	0	0	3	0	0	0	0
IC	421300	4880900	95126	2	3085007	E	0	3	0	0	0	0	0	0	0	0	0
IC	446800	4900900	9515	1	3086432	S	0	0	0	0	0	0	0	0	0	0	0
IC	441600	4898200	9570	1	3102784	W	0	0	0	0	0	0	0	0	0	0	0
IC	431400	4885400	9593	1	3118220	W	0	0	0	0	0	0	0	0	0	0	0
IC	429500	4897000	9308	2	3132973	N	0	0	0	0	0	0	0	0	0	0	0
VM	462400	4891300	9544	2	3314596	N	0	0	0	0	0	0	0	0	0	0	0
VM	465900	4894500	9535	3	3419591	S	0	0	0	0	0	0	3	0	0	0	0
IC	439000	4890300	9585	3	3808052	S	0	3	0	0	0	0	0	0	0	0	0
IC	429600	4898100	95110	1	3892527	N	0	0	0	0	0	0	0	0	0	0	0
IC	416400	4889900	95144	1	3945057	E	0	0	0	0	0	0	0	0	0	0	0
VM	447900	4889000	9529	5	3980705	N	0	0	0	0	0	0	0	0	0	0	0
VM	456600	4897300	9525	6	4023402	W	0	3	0	0	0	1	0	0	0	1	0
IC	437100	4898400	9577	2	4118319	S	0	0	0	0	0	0	0	0	0	0	0
IC	419950	4888200	9420	1	4123264	W	0	0	0	0	0	0	0	0	0	0	0
VM	452500	4880700	9556	6	4183118	W	0	0	0	0	0	0	0	0	0	0	3

VM	456600	4887600	9551	6	4246184	N	0	0	3	0	0	0	0	1	2	0	0
VM	455100	4888100	9541	4	4322105	S	0	0	0	0	0	0	0	0	0	0	3
IC	426000	4897100	95135	2	4542775	S	0	3	0	0	0	0	0	0	0	0	0
IC	441000	4891100	9305	2	4575836	E	0	0	0	0	0	0	0	0	0	0	0
IC	436800	4889900	9586	4	4722252	E	0	0	3	0	0	0	0	0	0	0	0
VM	450300	4878000	9562	1	4723633	S	0	0	0	0	0	0	0	0	0	0	0
VM	449000	4886100	9532	3	4825931	W	0	0	0	0	0	0	0	0	0	0	0
IC	432700	4898800	95104	1	4927344	S	0	0	0	0	0	0	0	0	0	0	0
VM	456300	4899800	9508	2	4973369	E	0	0	0	0	0	0	3	0	0	2	0
VM	459100	4891900	9502	2	4982781	N	0	0	0	0	0	0	0	0	0	0	0
IC	447400	4896000	9520	3	5132429	S	0	0	0	0	3	0	2	0	0	0	0
IC	430900	4884200	95117	1	5207303	N	0	0	0	0	0	0	0	0	0	0	0
IC	428100	4895800	95113	1	5289987	S	0	0	0	0	0	0	0	0	0	0	0
VM	447500	4894900	9521	1	5331777	W	0	0	0	0	0	0	0	3	0	0	0
IC	433900	4895800	95102	1	5362444	N	0	0	0	0	0	0	0	0	0	0	0
VM	464400	4895300	9534	5	5404150	W	0	0	0	0	0	3	0	0	0	0	0
VM	457000	4886800	9552	2	5576577	W	0	0	0	0	0	0	3	0	0	0	0
IC	418400	4889100	9417	2	5588876	N	0	0	0	0	0	0	0	0	0	0	0
VM	446800	4887700	9538	3	5623158	N	0	0	3	0	0	0	0	0	0	0	0
IC	431800	4903000	95108	2	5642782	W	0	0	3	0	0	0	0	0	0	0	0
IC	442000	4896600	9569	1	5648778	N	0	0	0	0	0	0	0	0	0	0	0
IC	444300	4899400	9575	3	5716125	E	0	3	0	0	0	0	0	0	0	0	0
IC	440500	4895500	9583	1	5925866	W	0	0	0	0	0	0	0	0	0	0	0
IC	437700	4891200	9587	2	5951210	W	0	0	0	0	0	0	0	0	0	0	0
VM	459400	4899400	9506	2	5951899	W	0	0	0	0	0	3	0	0	0	1	0
IC	432000	4889600	9598	1	6013496	E	0	0	0	0	0	0	0	0	0	0	0
IC	429200	4883000	95121	1	6037568	E	0	0	0	0	0	0	0	0	0	0	0
VM	447900	4900100	9517	1	6230440	N	0	0	0	0	0	0	0	0	3	0	0
IC	436800	4884700	9589	1	6250891	W	0	0	0	0	0	0	0	0	0	0	0
IC	431400	4896600	9599	1	6298294	E	0	0	0	0	0	0	0	0	0	0	0
IC	436600	4885400	9588	1	6310156	S	0	0	0	0	0	0	0	0	0	0	0

IC	447600	4899400	9516	4	6363604	W	0	3	2	0	0	0	0	0	1	0	0
IC	417500	4890800	95143	2	6378175	S	0	0	3	0	0	0	0	0	0	0	0
IC	425600	4890700	9401	4	6437499	W	0	3	2	0	0	0	0	0	0	0	0
IC	439600	4898400	9580	2	6487351	S	0	0	0	0	0	0	0	0	0	0	0
IC	422800	4897500	95137	1	6555881	W	0	0	0	0	0	0	0	0	0	0	0
IC	436100	4889200	9579	2	6560026	E	0	0	0	0	0	0	0	0	0	0	0
VM	455400	4900400	9510	3	6664163	W	0	0	0	0	0	3	0	0	0	0	0
VM	461900	4892200	9546	3	6699250	S	0	0	0	0	0	0	0	0	0	0	0
IC	426600	4892700	95115	2	6797328	N	0	0	0	0	0	0	0	0	0	0	0
IC	426900	4890300	9403	4	6803548	W	0	0	3	0	0	0	0	0	0	0	0
VM	453100	4890000	9539	6	6928603	N	0	0	0	0	0	0	0	3	0	0	0
IC	428800	4886000	9406	5	7056123	E	0	0	3	0	0	0	0	0	0	0	0
VM	456000	4886500	9549	3	7069197	E	0	0	0	0	0	0	3	0	1	0	0
VM	444100	4885900	9568	5	7177866	E	3	2	0	0	0	0	0	0	0	1	0
VM	461800	4898700	9409	4	7213966	W	0	0	0	0	0	0	3	0	0	2	0
IC	431600	4885800	9595	1	7260035	N	0	0	0	0	0	0	0	0	0	0	0
IC	421800	4881000	95124	1	7267047	S	0	0	0	0	0	0	0	0	0	0	0
VM	453000	4886400	9547	1	7451209	N	0	0	0	0	0	0	0	0	0	0	0
IC	428700	4886800	9405	4	7525370	S	0	3	0	0	0	0	0	0	0	0	0
VM	456800	4895700	9527	2	7566346	S	0	0	0	0	0	0	0	0	0	3	0
IC	438400	4891700	9584	1	7582059	N	0	0	0	0	0	0	0	0	0	0	0
VM	463000	4896800	9413	5	7597754	N	0	0	0	3	0	0	0	0	0	0	0
VM	454200	4889600	9540	1	7612705	E	0	0	0	0	0	0	0	0	0	0	0
IC	447500	4901500	9514	1	7738543	E	0	0	0	0	0	0	0	0	0	0	0
IC	425500	4895500	95136	1	7810486	E	0	0	0	0	0	0	0	0	0	0	0
VM	453200	4899800	9513	2	7812184	N	0	0	0	0	0	0	3	0	0	2	0
VM	448100	4890200	9531	4	7874796	W	0	0	0	0	0	3	0	0	0	0	0
IC	442100	4894100	9306	2	7888720	S	0	0	0	0	0	0	0	0	0	0	0
IC	435700	4885900	9594	2	8016711	E	0	0	3	0	0	0	0	0	0	0	0
IC	427800	4898800	95111	1	8080592	E	0	0	0	0	0	0	0	0	0	0	0
IC	445500	4897600	9571	2	8254076	E	0	3	0	0	0	0	0	0	0	0	0

VM	451200	4894000	9303	6	8370759	W	0	0	3	2	0	0	2	0	0	0	1
VM	458500	4891100	9503	13	8565059	W	0	3	0	2	1	2	0	2	0	2	2
IC	419200	4894300	95141	2	8577309	N	0	0	0	0	0	0	0	0	0	0	0
VM	452600	4894200	9523	7	8705633	S	0	0	3	2	0	2	2	0	0	0	2
IC	428200	4880500	95120	1	8728658	S	0	0	0	0	0	0	0	0	0	0	0
IC	442300	4892500	9563	1	8744632	S	0	0	0	0	0	0	0	0	0	0	0
IC	414200	4889200	9415	1	8903764	S	0	0	0	0	0	0	0	0	0	0	0
VM	451800	4888900	9542	1	8909301	W	0	0	0	0	0	0	0	0	0	0	0
IC	419300	4887100	9419	1	8930301	N	0	0	0	0	0	0	0	0	0	0	0
IC	444800	4901100	9572	2	9017386	N	0	0	3	0	0	0	0	0	0	0	0
VM	451800	4885000	9548	3	9047296	S	0	0	0	0	0	0	3	0	0	0	0
IC	437900	4896900	9581	1	9135404	N	0	0	0	0	0	0	0	0	0	0	0
IC	420500	4883100	95148	2	9159675	S	0	0	0	0	0	0	0	0	0	0	0
IC	422100	4895600	95138	1	9166653	N	0	0	0	0	0	0	0	0	0	0	0
IC	424600	4888100	95127	2	9177301	E	0	0	3	0	0	0	0	0	0	0	0
VM	449200	4895600	9518	1	9207847	E	0	0	0	0	0	0	0	0	0	0	0
VM	445400	4889100	9564	6	9405505	N	3	0	0	0	0	0	0	0	0	0	0
IC	429600	4880900	95119	1	9466830	N	0	0	0	0	0	0	0	0	0	0	0
IC	428300	4892500	95116	2	9477500	E	0	0	3	0	0	0	0	0	0	0	0
VM	453700	4897400	9522	5	9517429	E	0	0	0	0	0	0	3	0	0	0	0
IC	435050	4899100	9307	2	9826576	N	0	0	0	0	0	0	0	0	0	0	0
VM	453500	4900700	9511	1	9871156	E	0	0	0	0	0	0	3	0	0	0	0
IC	422400	4886500	95130	1	10111354	N	0	0	0	0	0	0	0	0	0	0	0
IC	433700	4889800	9596	2	10427267	W	0	3	0	0	0	0	0	0	0	0	0
IC	413400	4887950	9416	1	10474073	S	0	0	0	0	0	0	0	0	0	0	0
IC	436500	4899000	9578	1	10591898	W	0	0	0	0	0	0	0	0	0	0	0
VM	463700	4899600	9301	8	10771505	S	0	0	3	0	0	0	0	2	0	0	0
IC	433800	4895600	95101	1	10799292	S	0	0	0	0	0	0	0	0	0	0	0
IC	420600	4896100	95142	1	10811094	S	0	0	0	0	0	0	0	0	0	0	0
VM	447500	4893000	9519	1	10811390	N	0	0	0	0	0	0	0	0	0	0	0
VM	448900	4885700	9537	1	10935554	E	0	0	0	0	0	0	0	0	0	0	0

VM	451600	4881900	9558	6	11065151	S	0	0	0	0	0	0	0	0	0	0	0
IC	431300	4890500	9597	4	11217238	S	0	0	0	0	0	0	0	0	0	0	0
VM	458600	4894900	9528	4	11320186	N	0	3	0	0	0	0	0	0	0	0	2
IC	430800	4901600	95109	1	11331190	S	0	0	0	0	0	0	0	0	0	0	0
IC	422300	4890000	9407	6	11546095	N	0	3	2	0	0	0	0	0	0	0	0
IC	441200	4889600	9304	2	11642259	W	0	0	0	0	0	0	0	0	0	0	0
IC	441600	4899500	9573	3	11664985	W	0	3	0	0	0	0	0	0	0	0	0
VM	459600	4899900	9507	5	12167497	N	0	0	0	0	0	3	0	1	0	0	0
VM	460100	4889700	9501	2	13184989	E	0	0	0	0	0	0	0	0	0	0	0
IC	421400	4880100	95123	1	13487468	W	0	0	0	0	0	0	0	0	0	0	0
IC	436000	4883200	9592	3	14220720	S	0	0	0	0	0	0	0	0	0	0	0
IC	424700	4900000	95134	1	14642124	W	0	0	0	0	0	0	0	0	0	0	0
IC	436500	4883500	9591	1	16378854	E	0	0	0	0	0	0	0	0	0	0	0
VM	444000	4884800	9565	7	18123819	W	0	3	0	2	2	0	0	2	0	0	0
IC	423400	4898900	95131	2	18179518	S	0	0	3	0	0	0	0	0	0	0	0
IC	426100	4881100	95122	1	18391729	N	0	0	0	0	0	0	0	0	0	0	0
IC	416100	4891300	95145	1	18828567	E	0	0	0	0	0	0	0	0	0	0	0
VM	448500	4878200	9559	3	20103296	W	0	0	0	0	0	0	0	0	0	0	3
VM	453300	4880900	9555	4	20353852	E	0	0	3	0	0	0	0	0	0	0	0
VM	443200	4885000	9567	2	20594076	S	0	0	3	0	0	0	0	0	0	0	0
IC	433100	4881500	95107	2	21364147	S	0	0	3	0	0	0	0	0	0	0	0
VM	463700	4890800	9543	1	23156872	W	0	0	0	0	0	0	0	3	0	0	0
VM	458900	4884300	9554	4	26371913	E	0	0	0	0	0	3	0	0	0	0	0
IC	418700	4882600	95147	1	31874265	W	0	0	0	0	0	0	0	0	0	0	0
IC	414700	4885900	95149	1	33807241	W	0	0	0	0	0	0	0	0	0	0	0
VM	458700	4883800	9553	3	46315941	S	0	0	0	0	0	3	0	0	0	0	0
IC	418600	4895400	95140	1	57568494	W	0	0	0	0	0	0	0	0	0	0	0
IC	415400	4890400	95146	1	69445881	W	0	0	0	0	0	0	0	0	0	0	0

1751	1763	1794	1815	1831	1844	1852	1871	1881	1888	1900	1909	1920	1928	1934	1974	SITE MFR
0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	107
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	73
0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	128
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	114
0	2	0	2	0	1	0	0	0	0	1	1	1	0	0	0	49.1
0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	117
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	3	0	0	0	1	1	0	0	23.5
0	0	0	0	0	0	1	2	0	0	0	1	0	1	0	1	87.4
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	2	0	0	0	2	0	0	1	2	1	0	1	1	2	0	31
0	3	0	0	0	0	0	0	0	2	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	118
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	N/A
0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	N/A
0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	1	1	2	0	0	1	0	0	0	0	0	0	39.2
0	0	2	1	0	2	1	0	0	0	0	0	0	0	0	0	45.3

0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	N/A
0	0	0	0	0	0	2	2	1	0	0	0	1	1	0	1	69.8
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	1	1	1	0	1	1	0	0	15.2
0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	140
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	N/A
3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	N/A
0	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	98.5
0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	192
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	1	1	0	0	0	1	2	0	0	19
2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	78.6
0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	2	0	0	0	1	0	0	0	1	1	1	0	0	0	0	34.4

0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	75
1	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0	35.7
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	1	N/A
0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	0	122
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	1	0	0	1	0	0	0	34
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	0	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	112
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	2	1	0	1	0	0	1	0	0	0	0	0	0	62.8
0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	N/A
0	0	0	0	0	0	2	0	0	1	0	0	0	0	0	0	165
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	186
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	1	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A

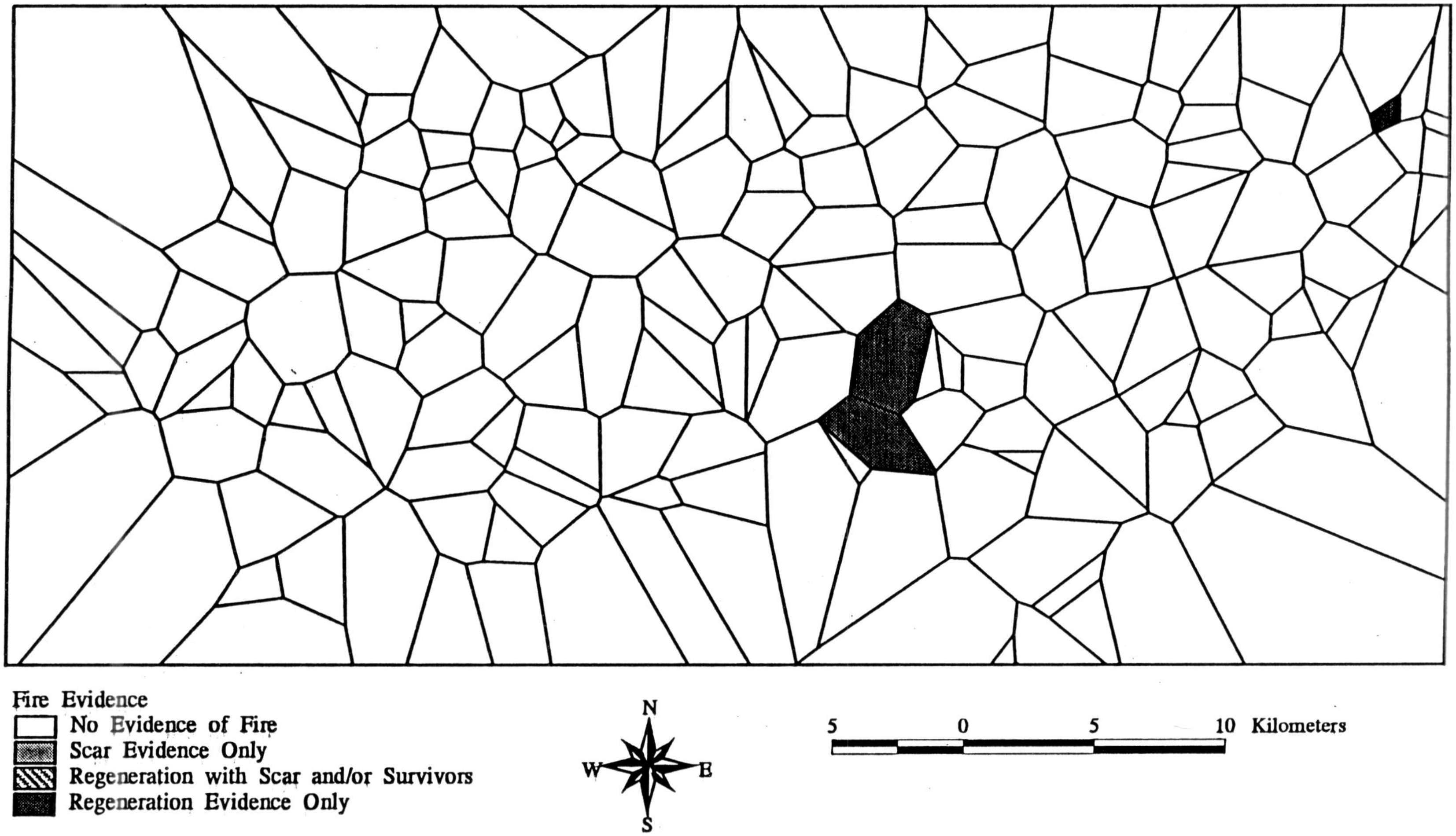
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	158
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	146
0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	1	0	0	0	0	N/A
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	107
0	0	3	0	1	1	0	0	0	2	0	0	0	0	0	0	28.5
0	0	0	0	0	0	0	0	3	0	0	0	1	0	0	0	N/A
0	0	0	0	0	0	1	2	0	0	0	0	1	0	0	0	122
0	0	0	0	0	2	0	1	1	0	1	0	1	0	0	0	50.8
0	0	0	0	0	0	2	2	0	0	0	0	1	1	0	0	93.3
0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	117
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71.3
0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	77.7
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	N/A
0	0	0	0	0	0	2	2	0	1	0	0	0	0	0	0	118
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	2	0	0	0	0	0	0	1	0	1	0	0	1	0	20.5
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	2	0	0	0	0	1	1	0	0	97
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A

0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	62.5
0	0	0	0	0	1	2	0	1	1	0	0	1	0	1	0	33.3
0	0	0	0	0	0	0	3	0	2	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	70
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	133
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	1	2	0	1	1	0	0	0	1	0	0	0	0	90
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	1	2	0	0	1	0	0	0	0	1	0	69.8
0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
1	0	0	2	0	2	0	0	0	1	0	0	1	1	0	0	52.7
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	N/A

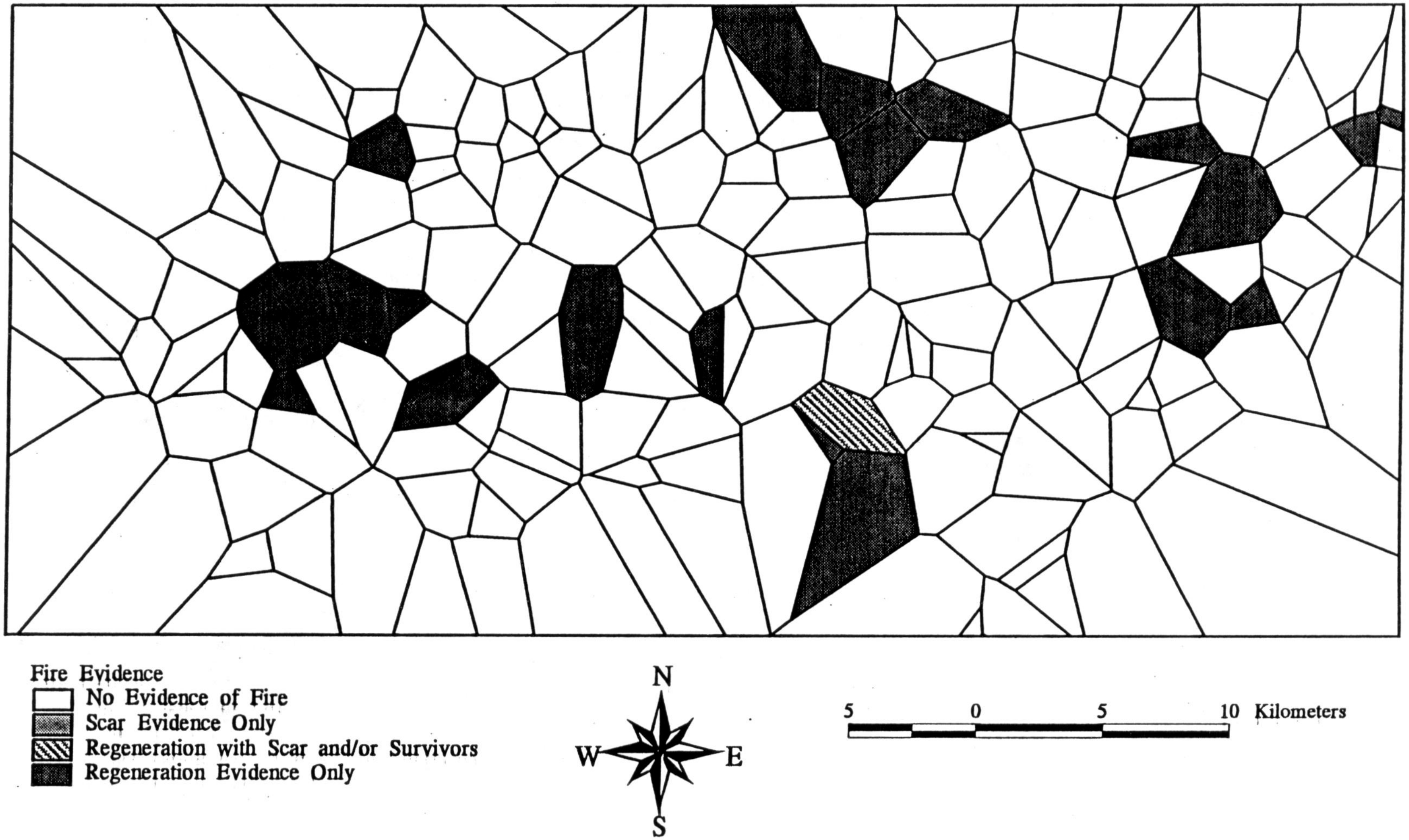
0	3	0	0	0	0	0	0	2	0	1	1	1	1	0	0	33
0	0	0	0	0	0	3	1	0	1	0	0	0	1	0	0	25.3
2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	122
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	1	2	0	1	0	0	0	0	0	1	87.4
0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	1	N/A
0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	167
0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	72.8
0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	N/A
0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	1	1	0	0	38
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	61.3
0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	75.5
0	2	0	1	0	0	2	0	0	0	0	0	0	0	0	0	97.7
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	N/A
0	0	2	0	2	0	0	0	0	0	0	1	0	0	0	0	136
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	126
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A
0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	N/A

Appendix B. Thiessen Polygon Fire Maps

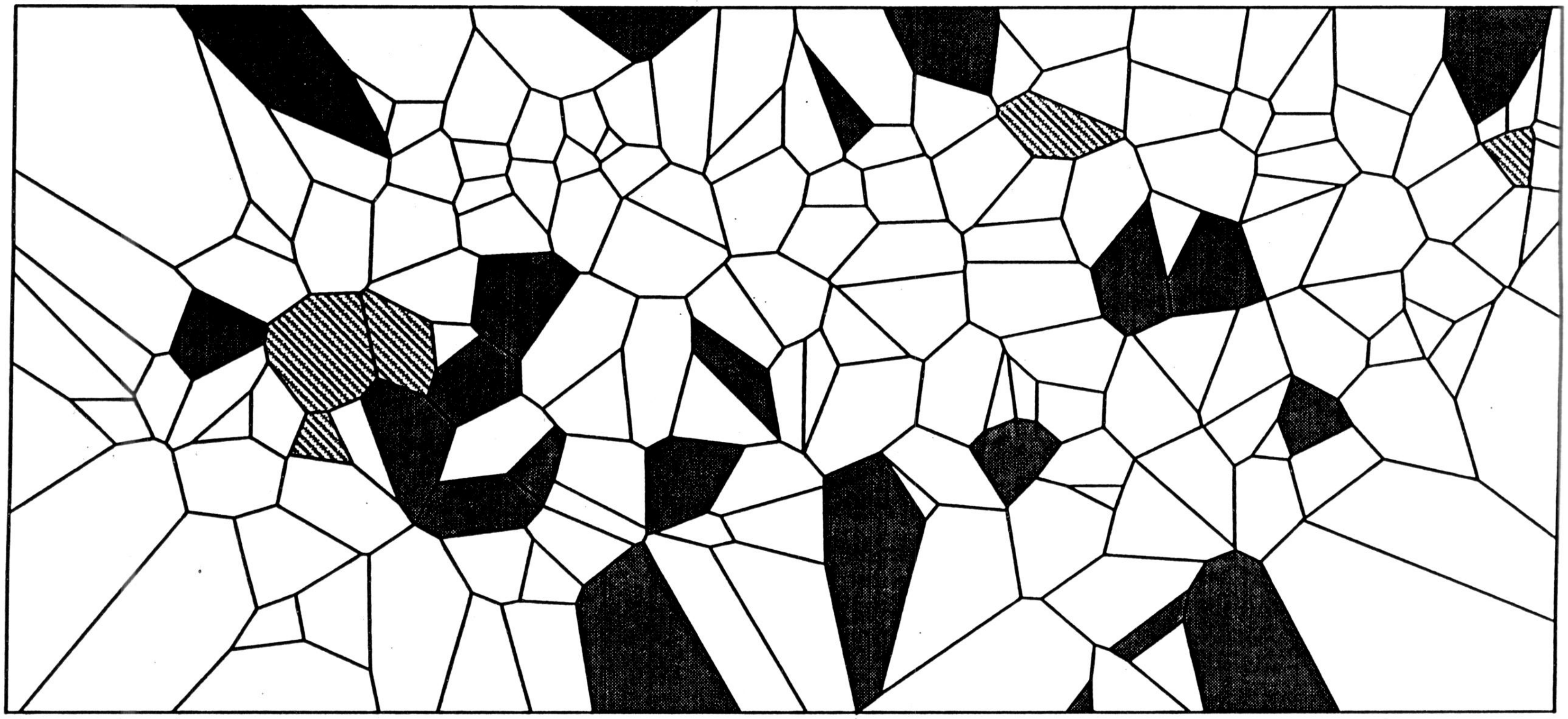
Map B.1 Thiessen Polygons for the Fire Episode of 1478



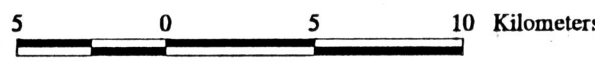
Map B.2 Thiessen Polygons for the Fire Episode of 1531



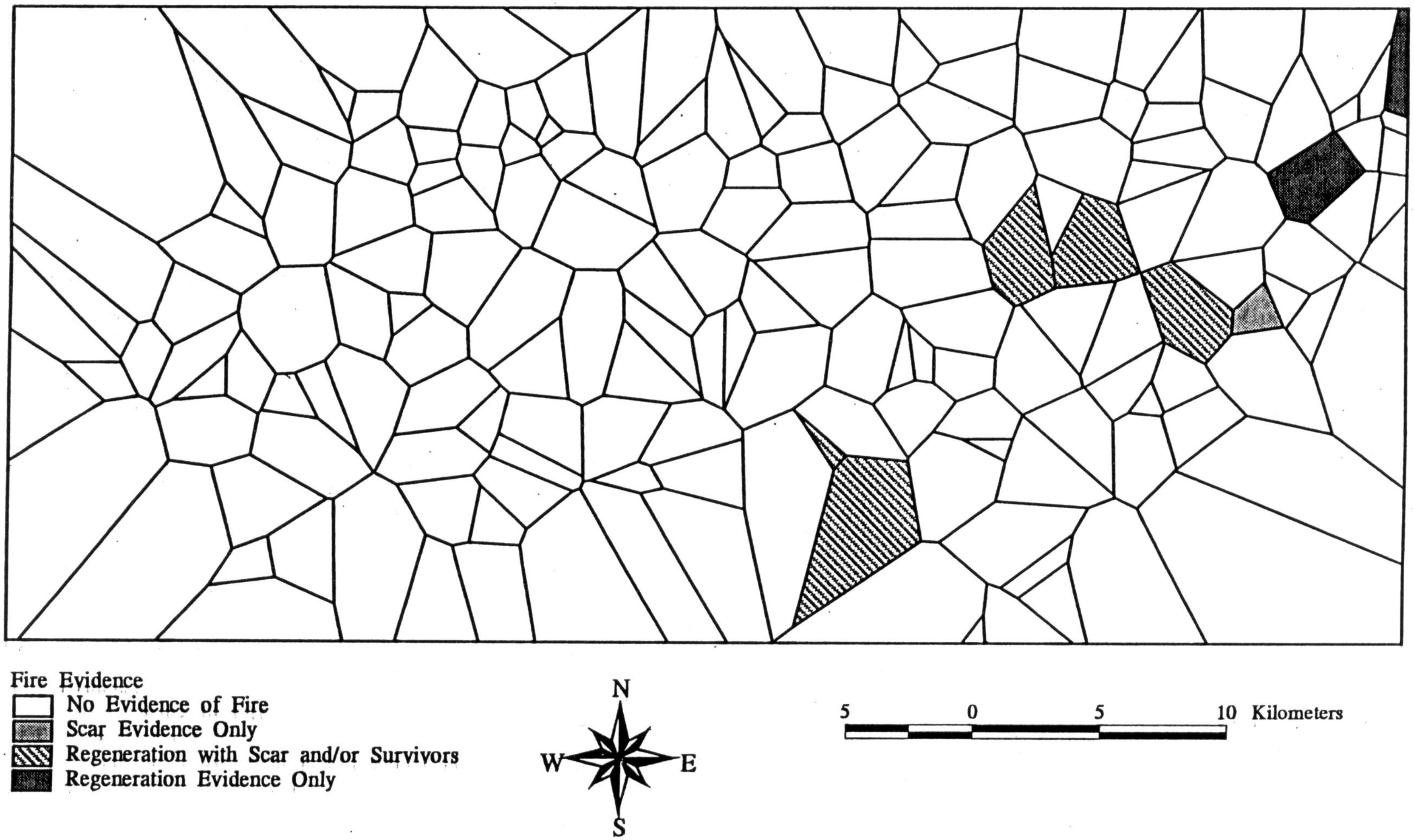
Map B.3 Thiessen Polygons for the Fire Episode of 1555



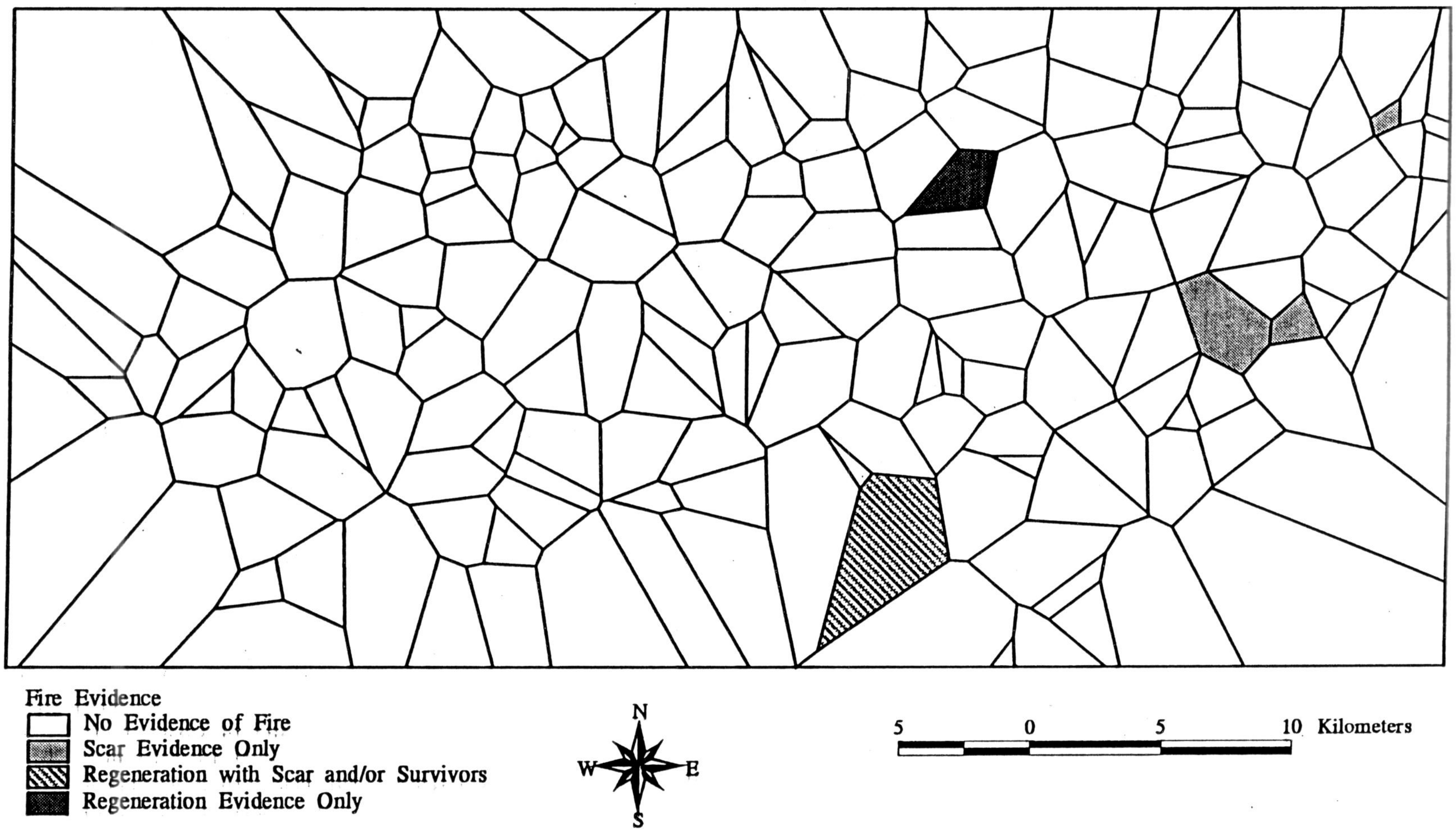
Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Regeneration with Scar and/or Survivors
- Regeneration Evidence Only



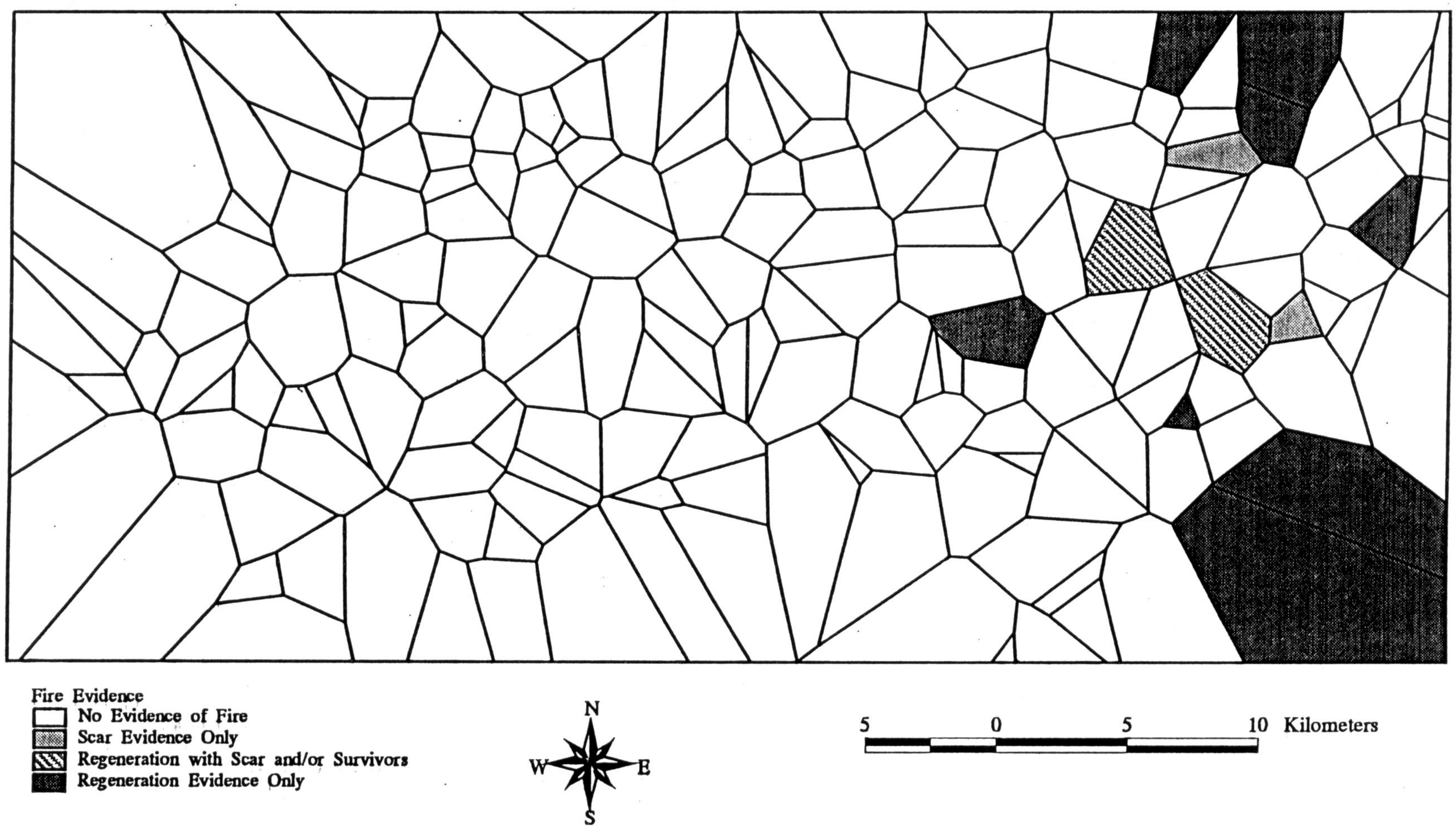
Map B.4 Thiessen Polygons for the Fire Episode of 1585



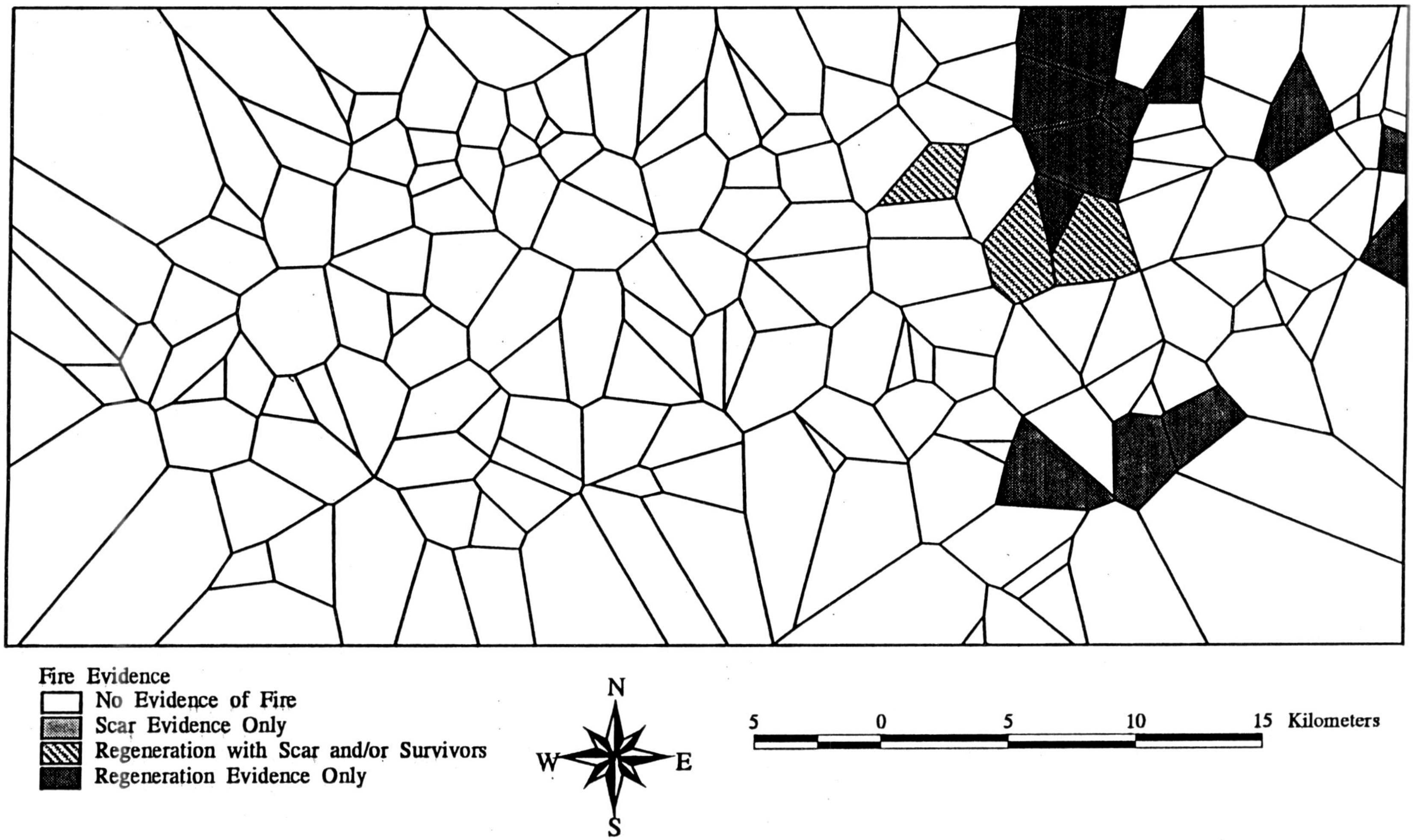
Map B.5 Thiessen Polygons for the Fire Episode of 1629



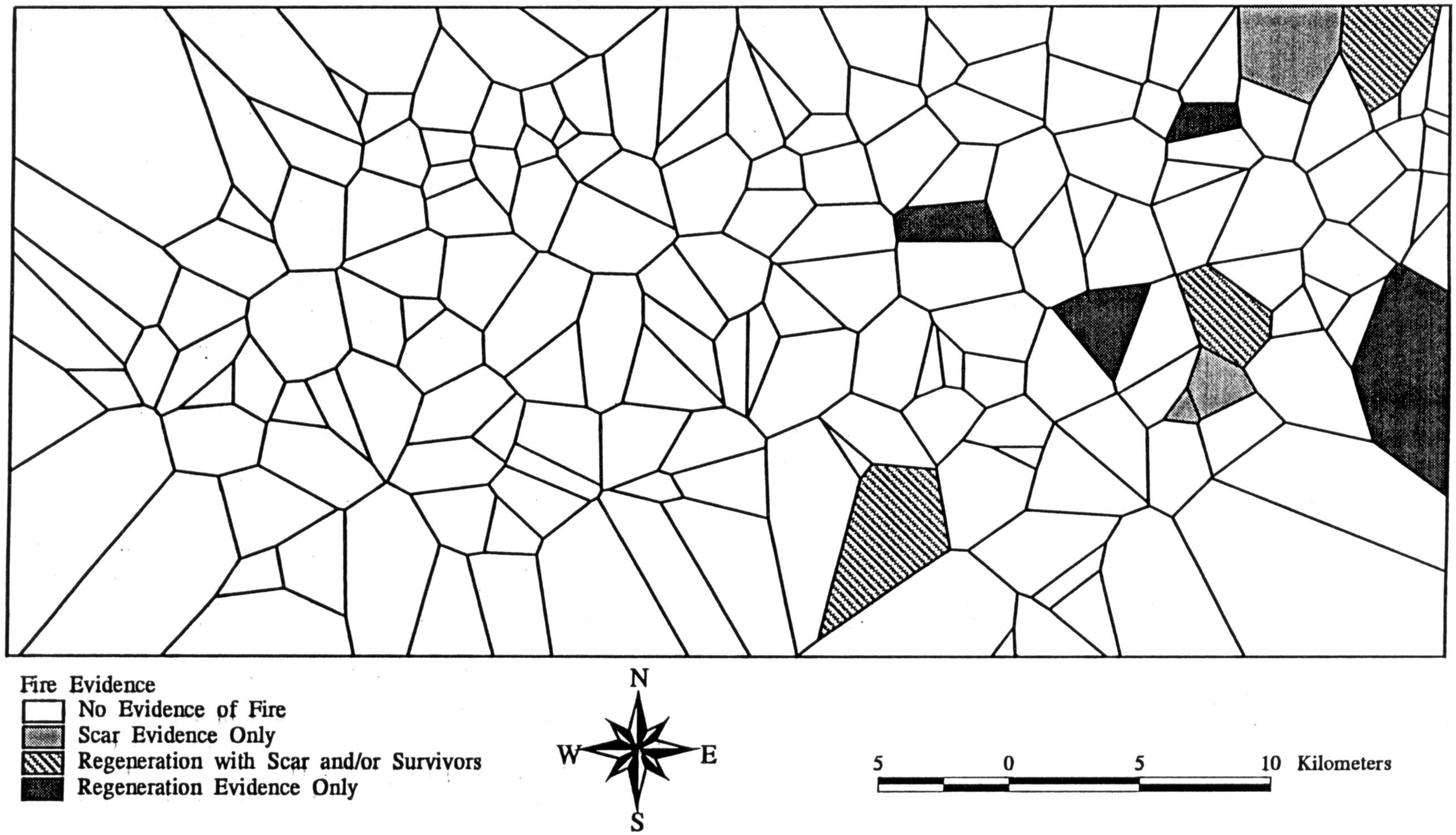
Map B.6 Thiessen Polygons for the Fire Episode of 1637



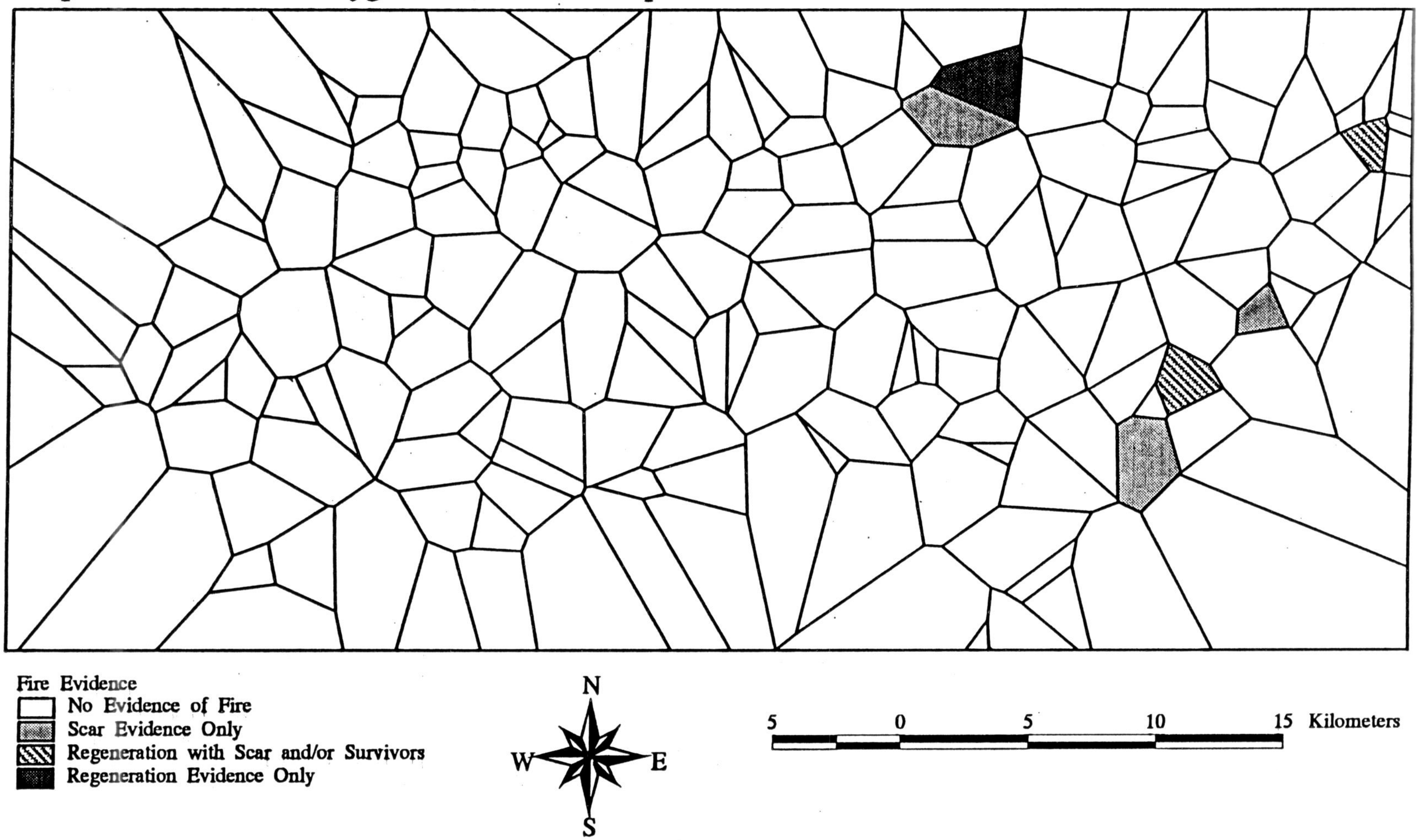
Map B.7 Thiessen Polygons for the Fire Episode of 1655



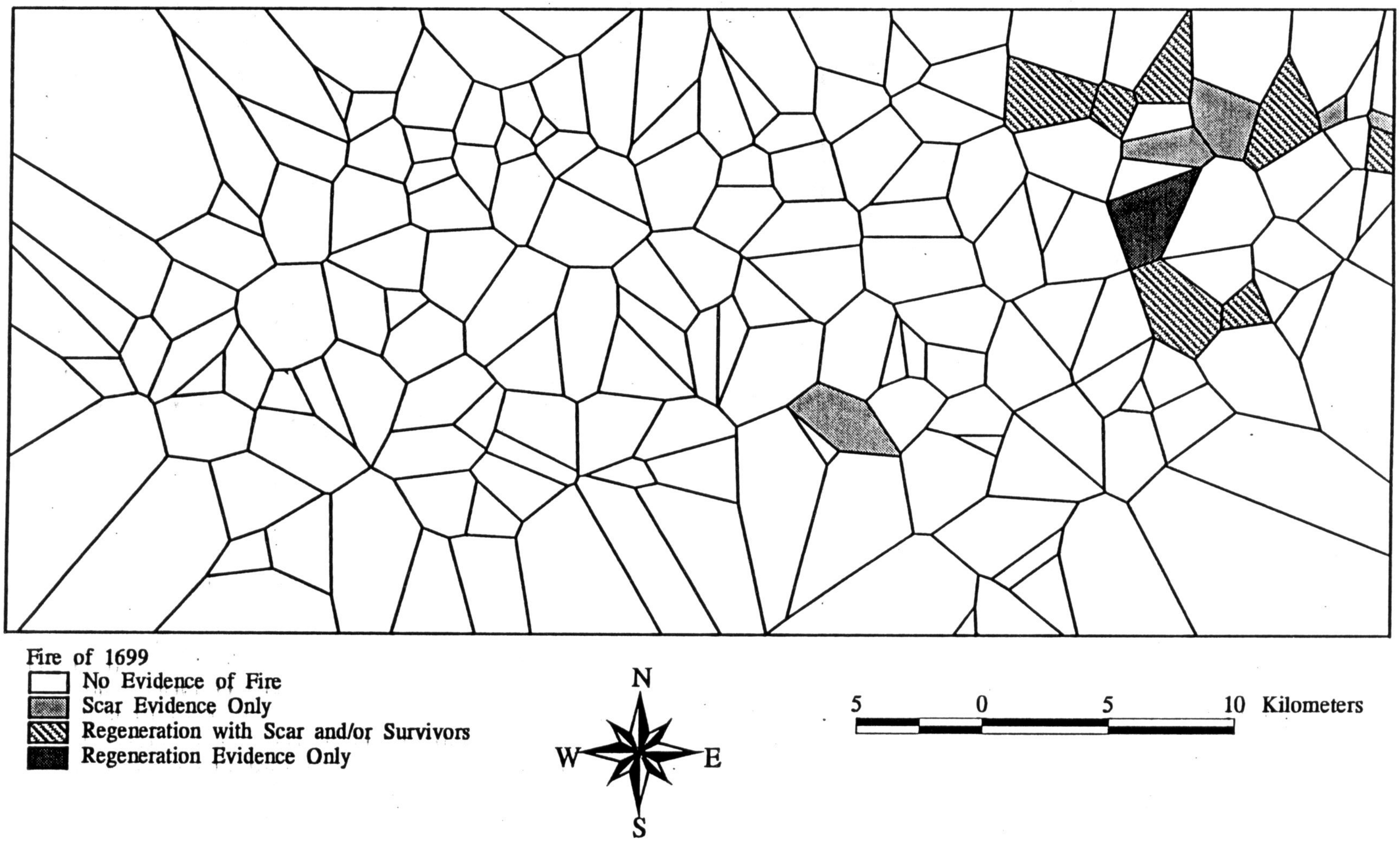
Map B.8 Thiessen Polygons for the Fire Episode of 1666



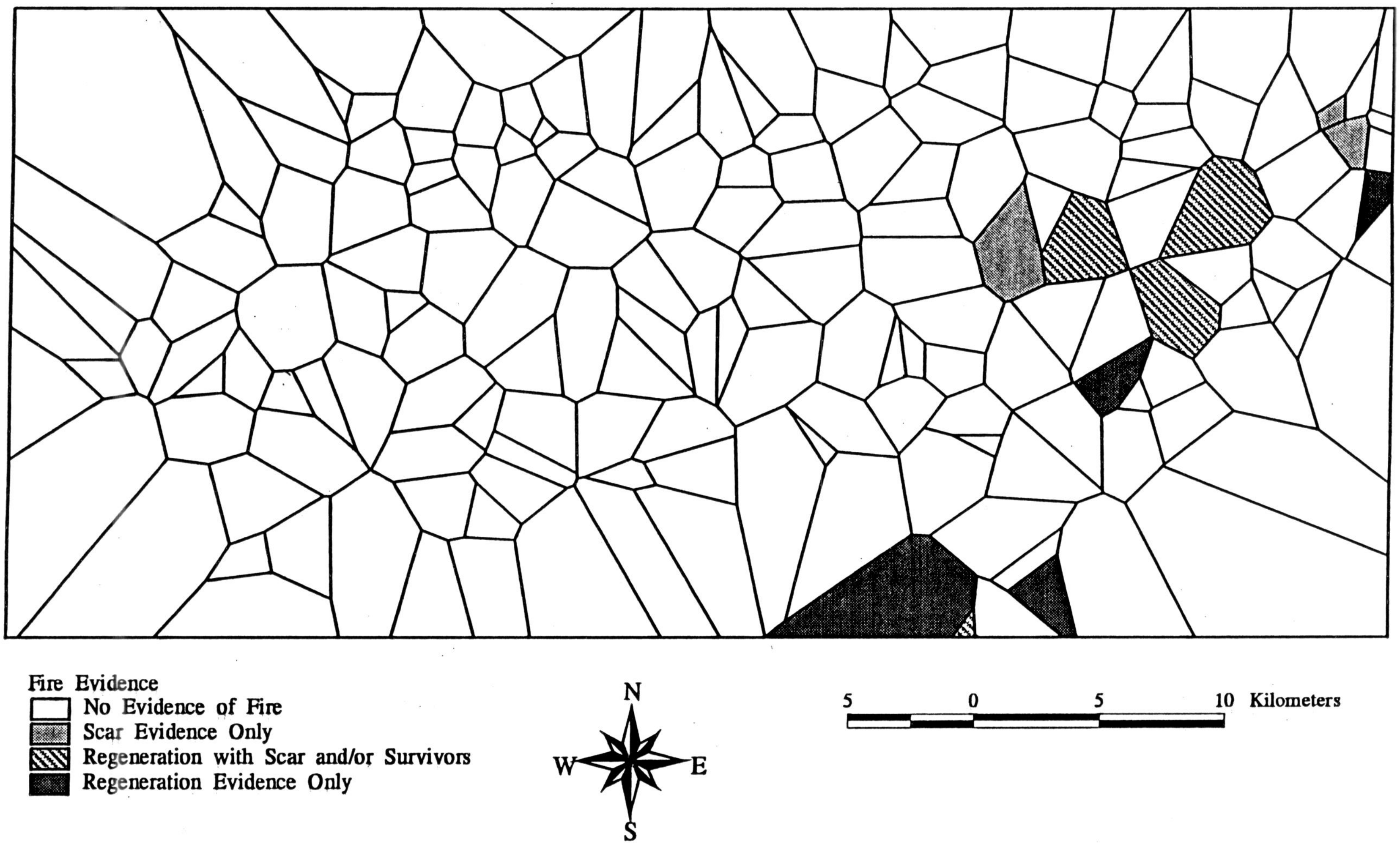
Map B.9 Thiessen Polygons for the Fire Episode of 1689



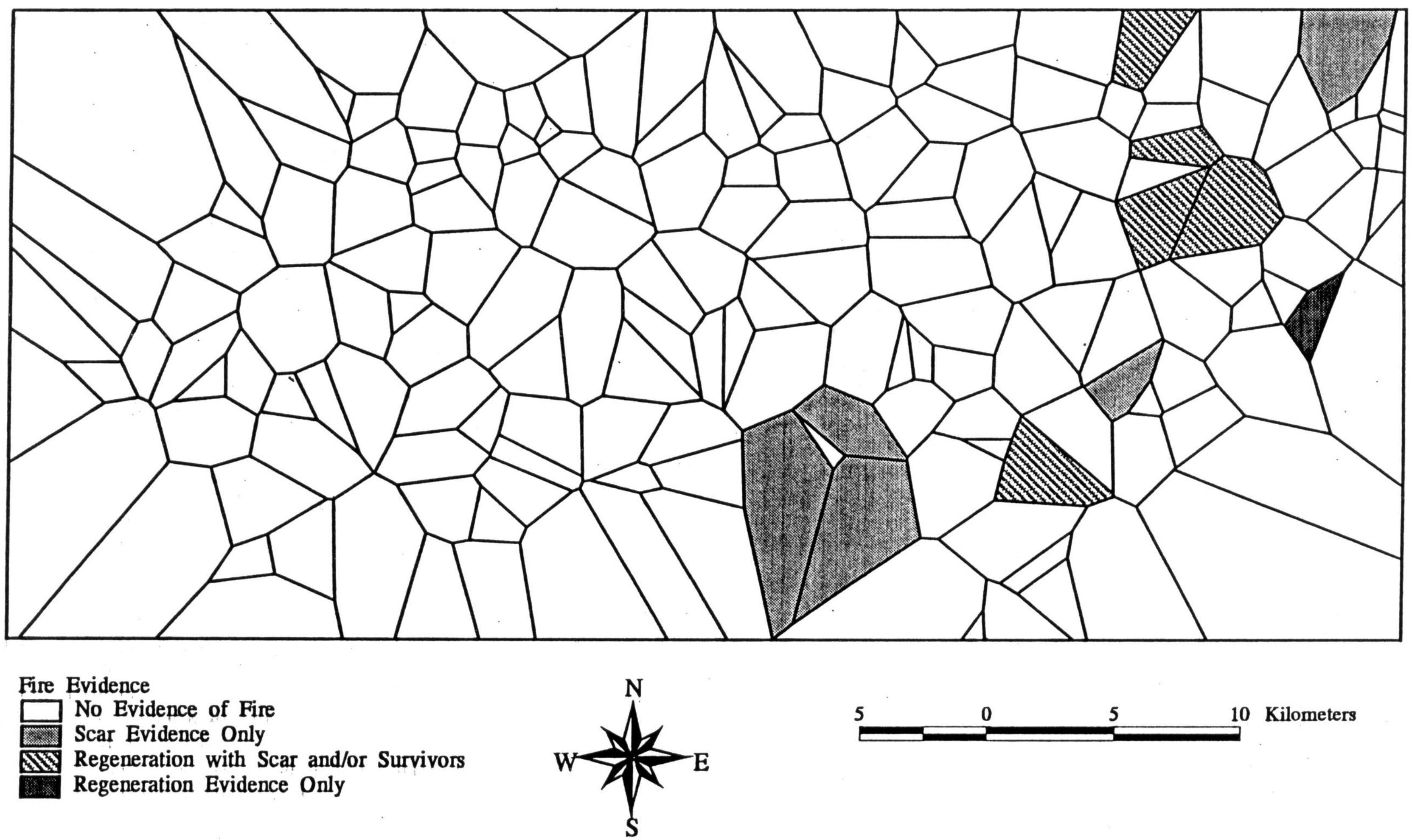
Map B. 10 Thiessen Polygons for the Fire Episode of 1699



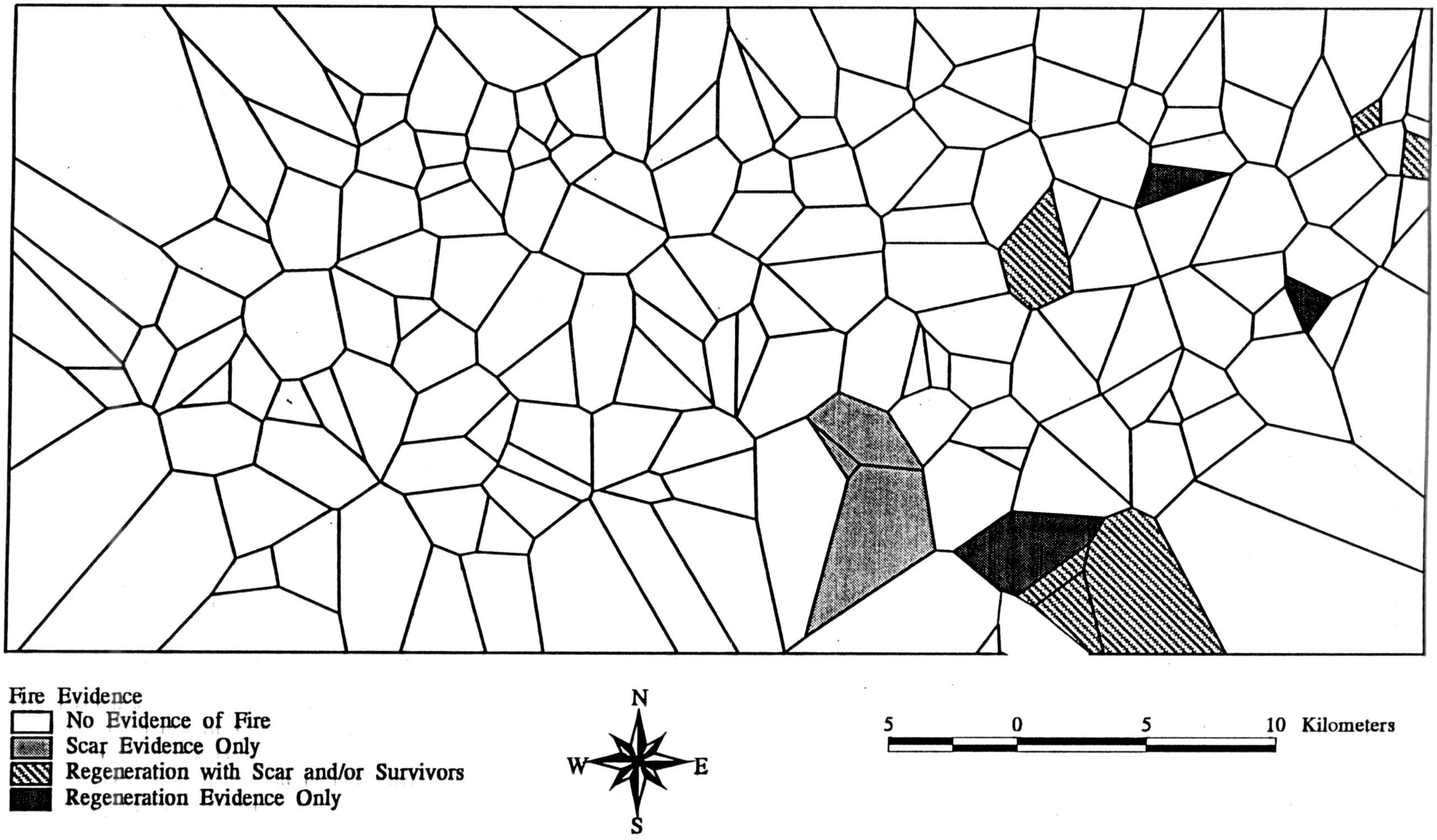
Map B.11 Thiessen Polygons for the Fire Episode of 1737



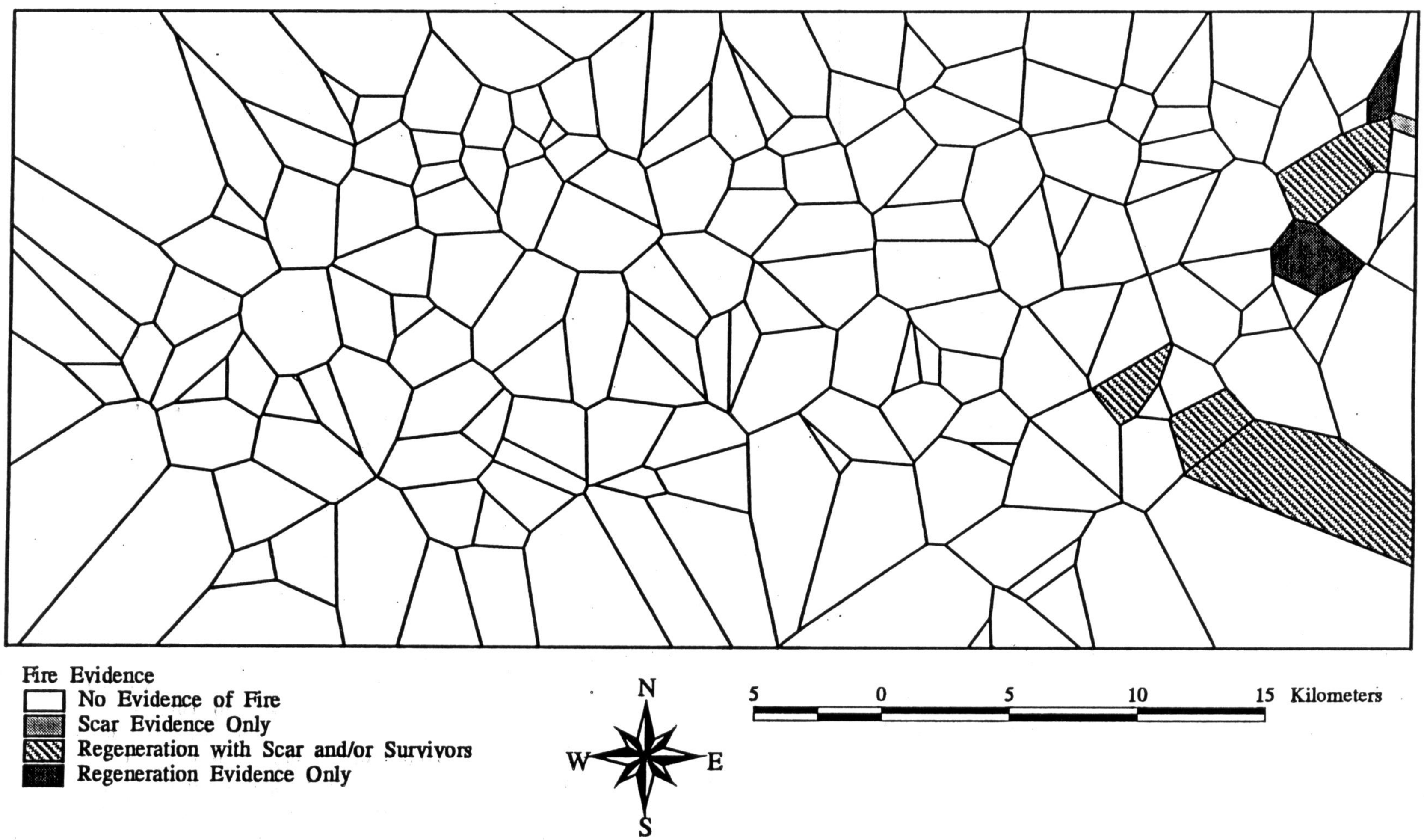
Map B.12 Thiessen Polygons for the Fire Episode of 1751



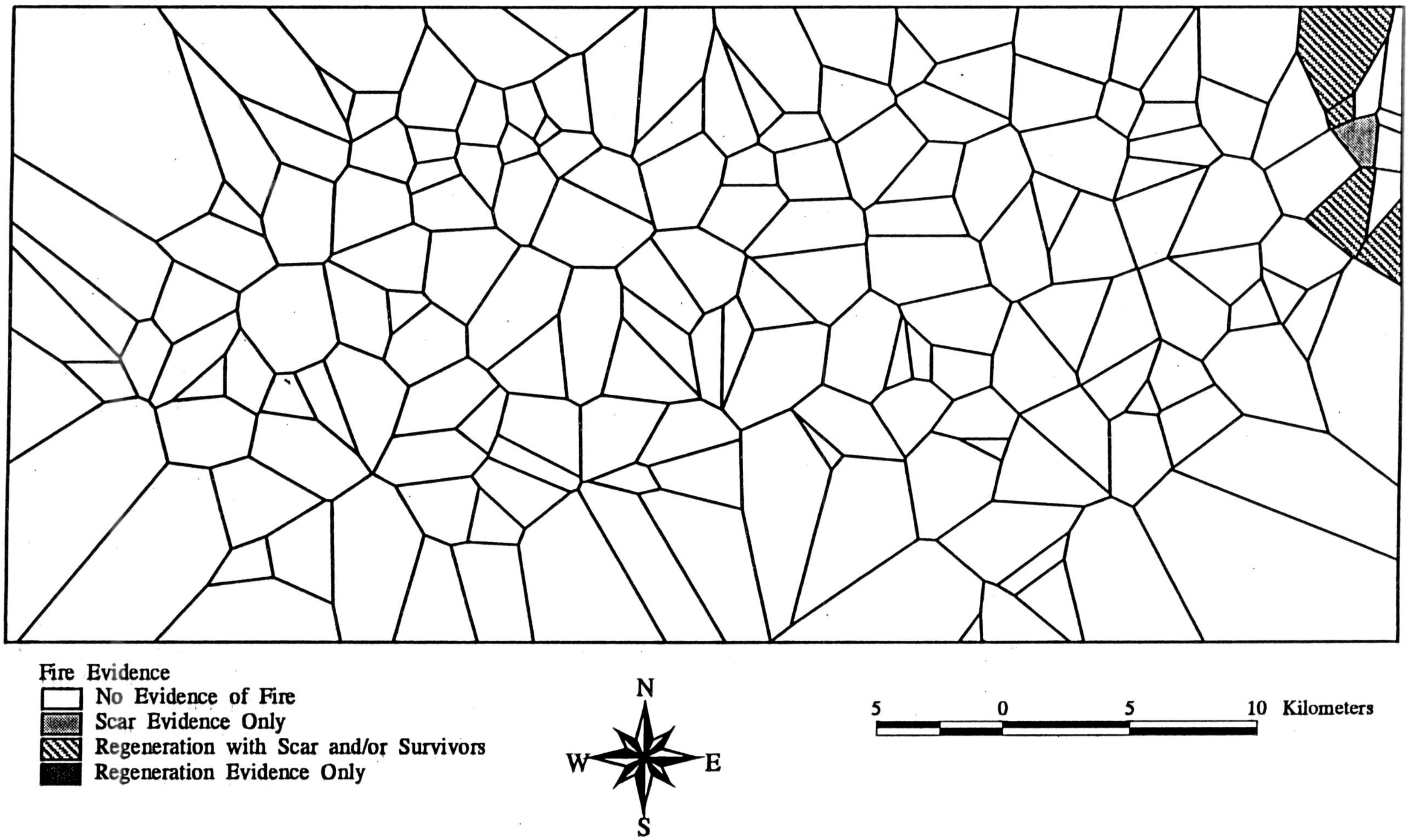
Map B.13 Thiessen Polygons for the Fire Episode of 1763



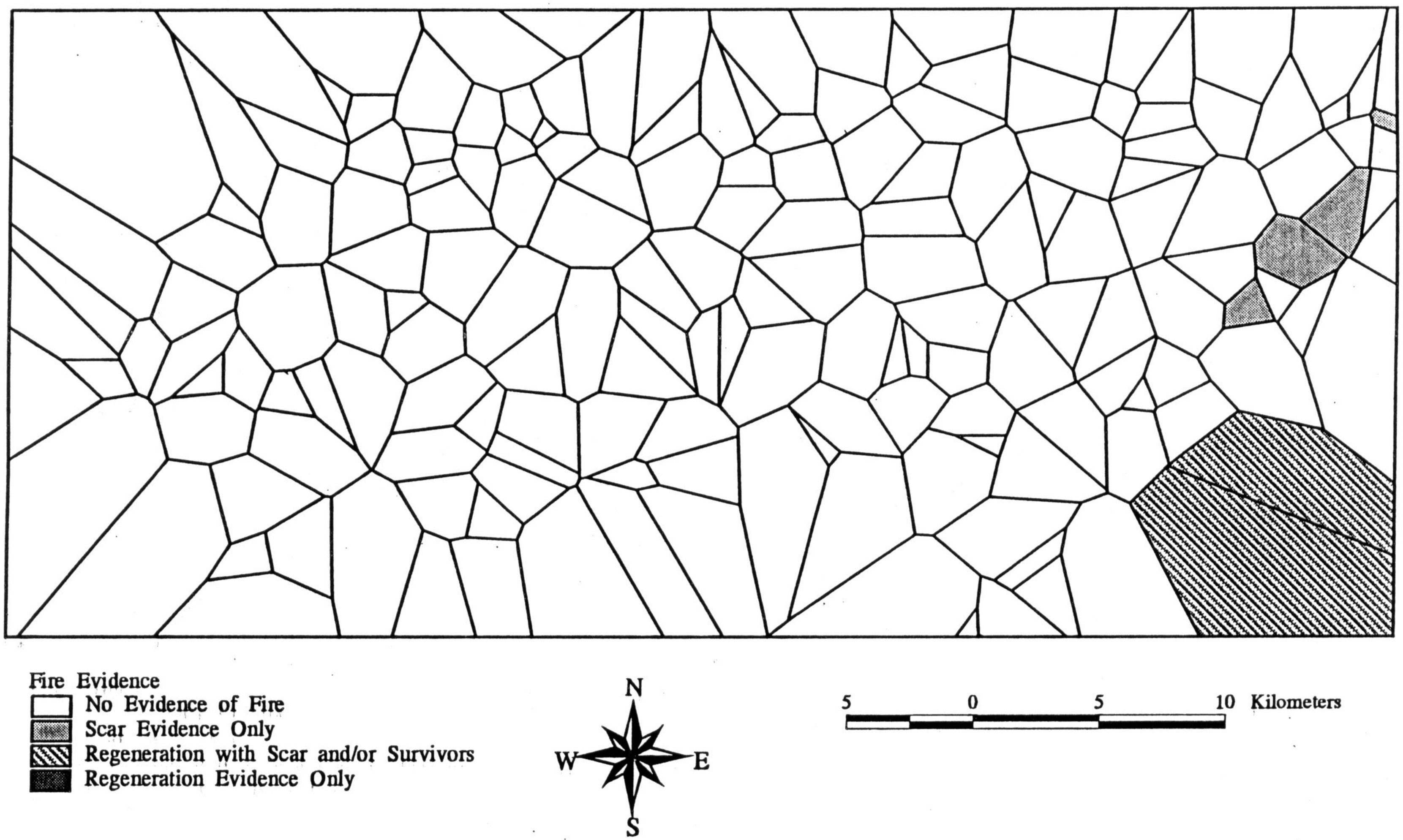
Map B.14 Thiessen Polygons for the Fire Episode of 1794



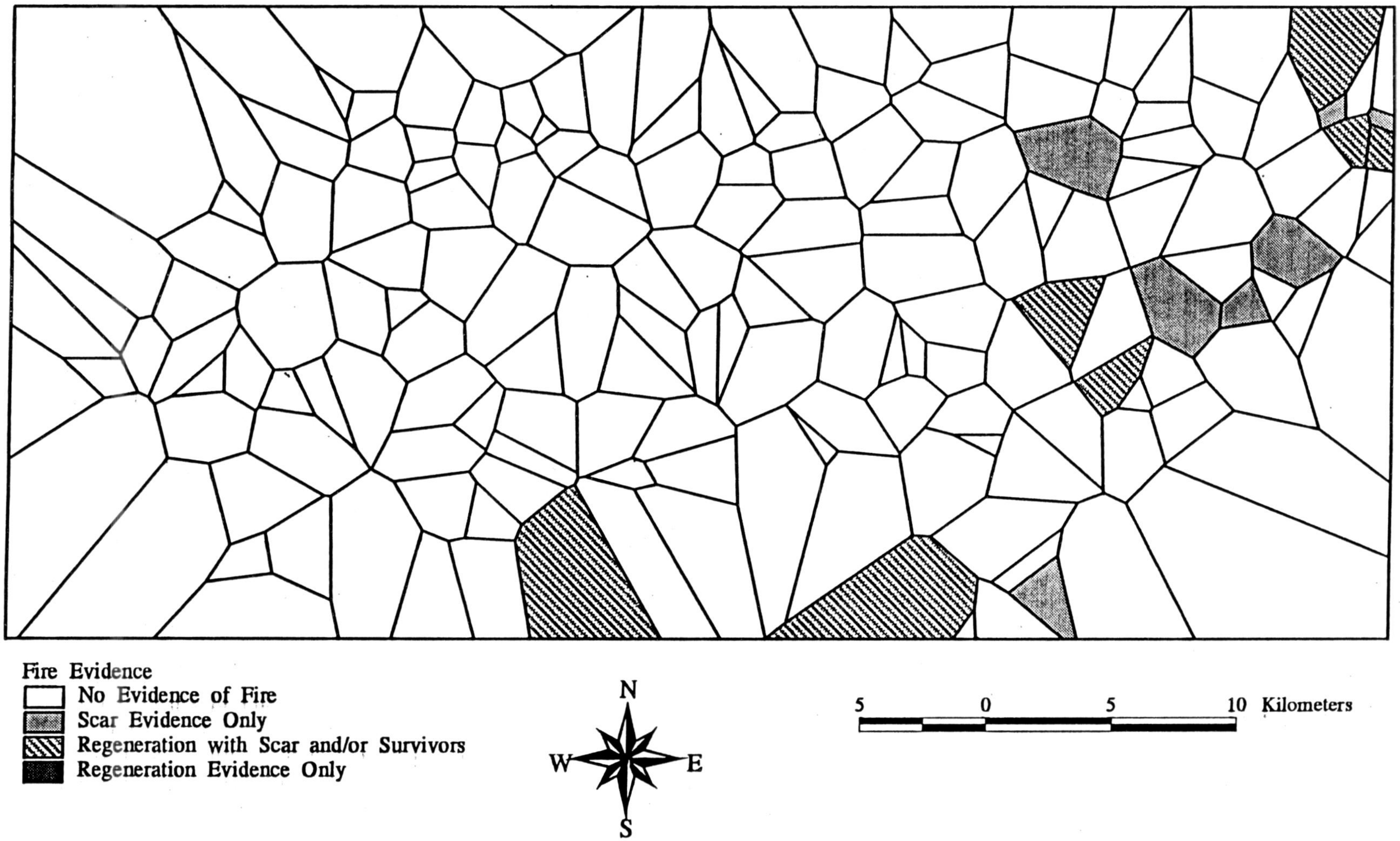
Map B.15 Thiessen Polygons for the Fire Episode of 1815



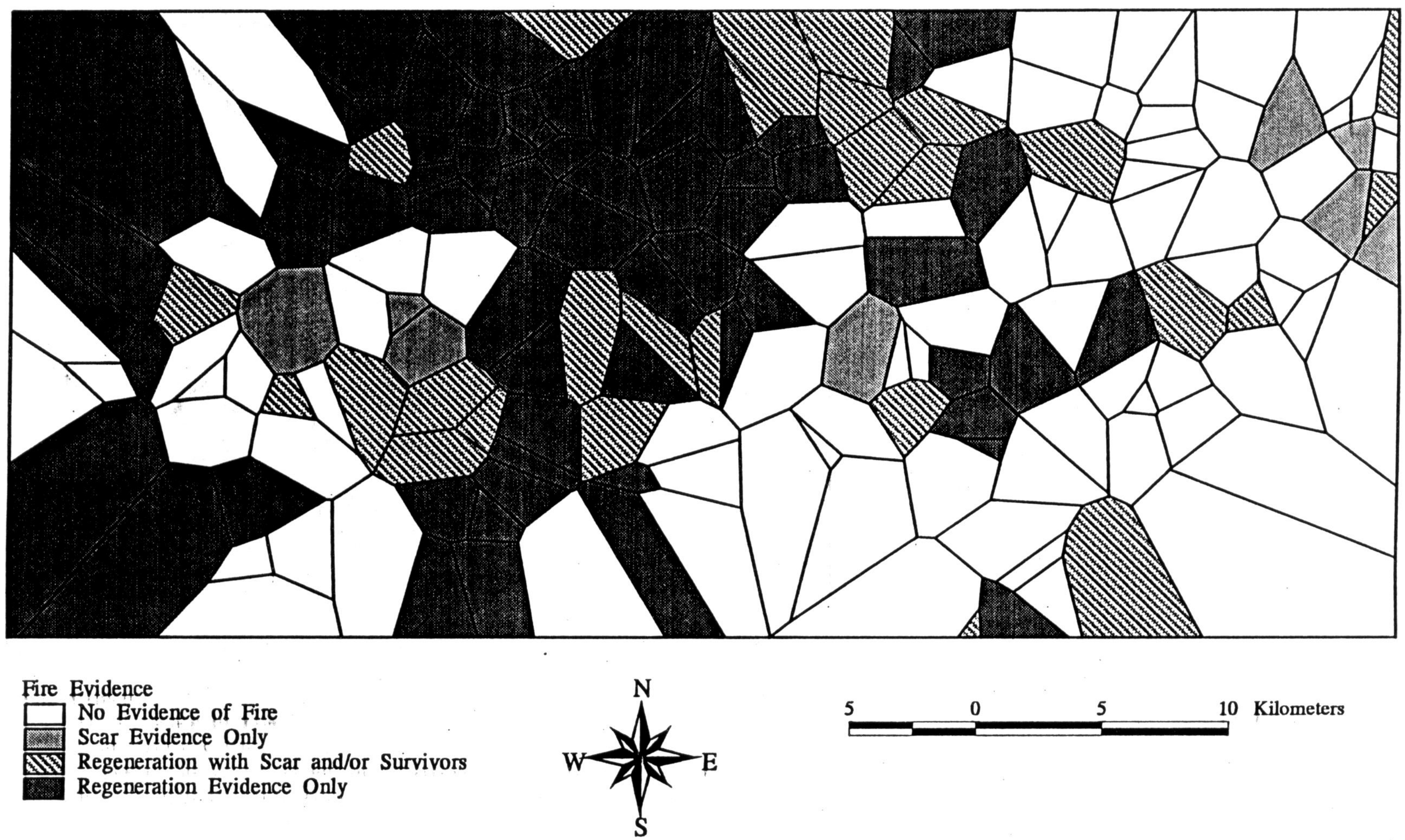
Map B.16 Thiessen Polygons for the Fire Episode of 1831



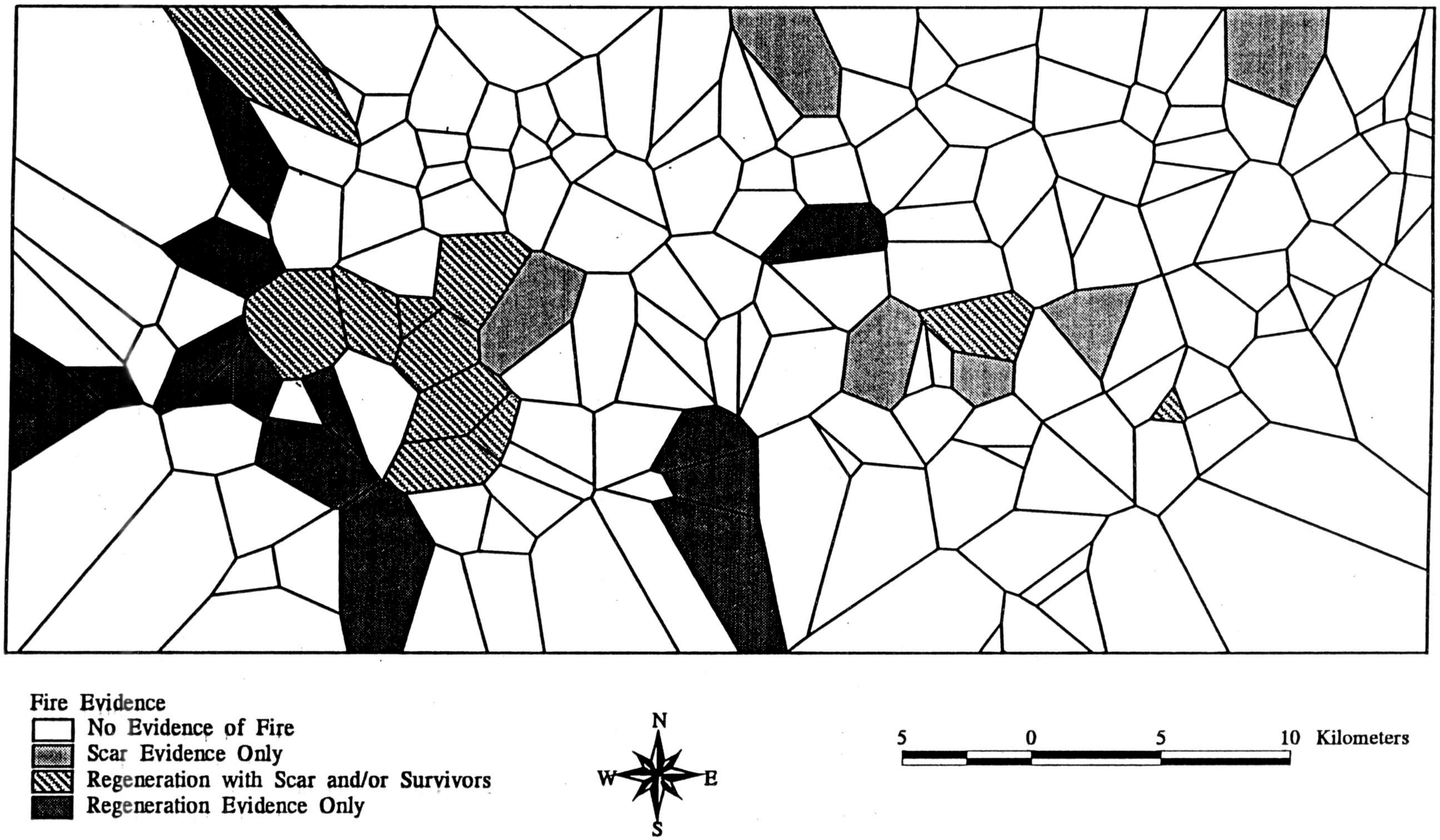
Map B.17 Thiessen Polygons for the Fire Episode of 1844



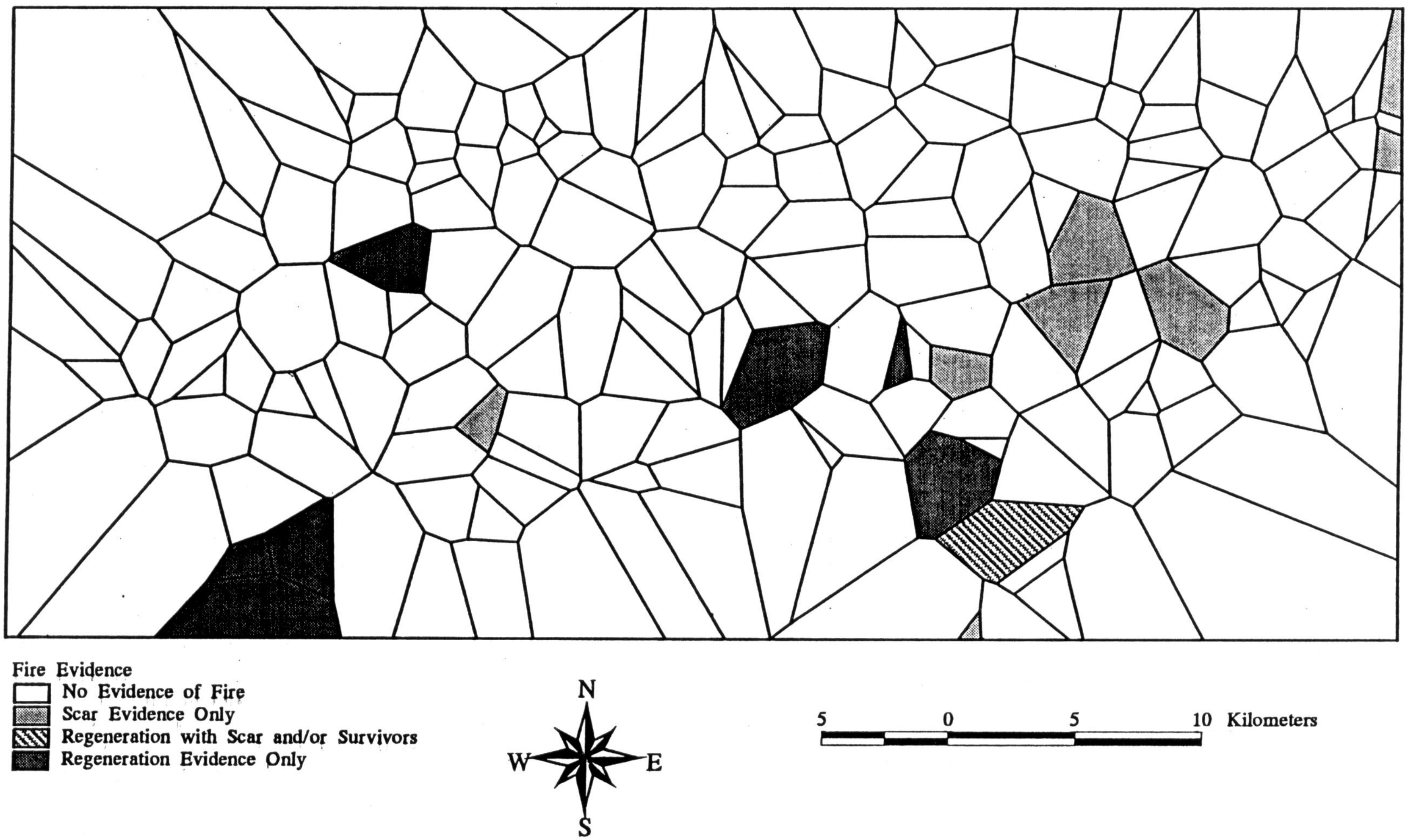
Map B.18 Thiessen Polygons for the Fire Episode of 1852



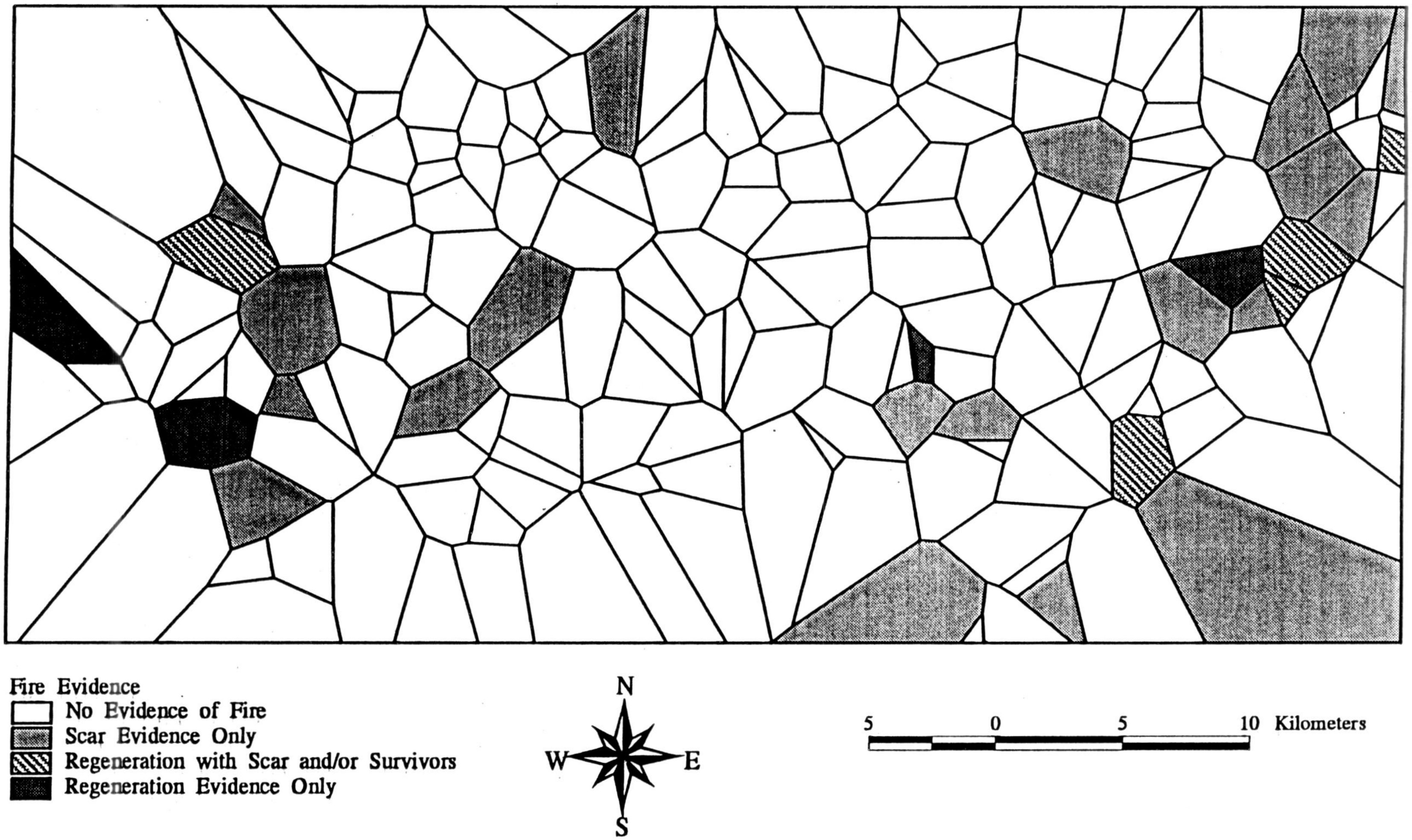
Map B.19 Thiessen Polygons for the Fire Episode of 1871



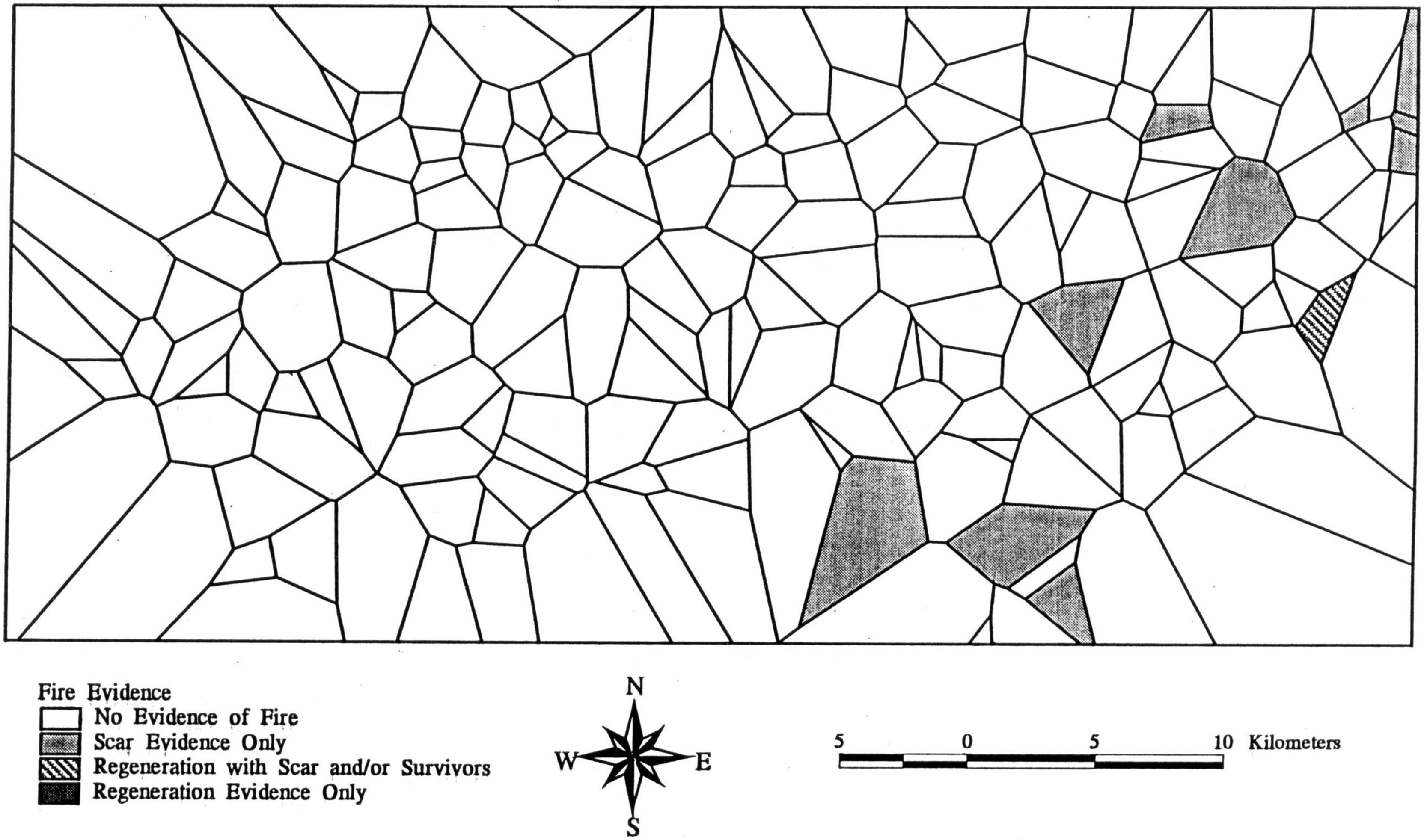
Map B.20 Thiessen Polygons for the Fire Episode of 1881



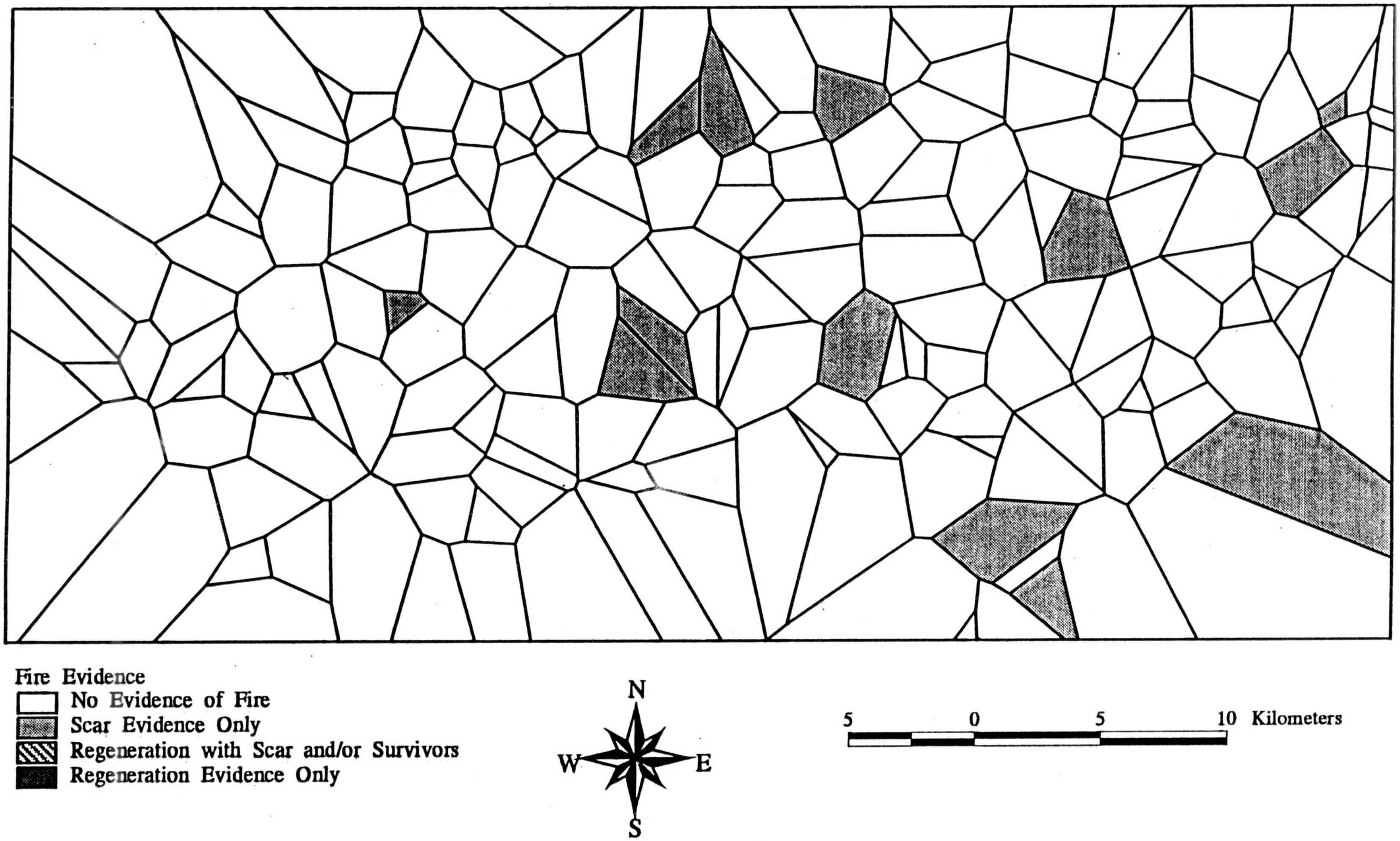
Map B.21 Thiessen Polygons for the Fire Episode of 1888



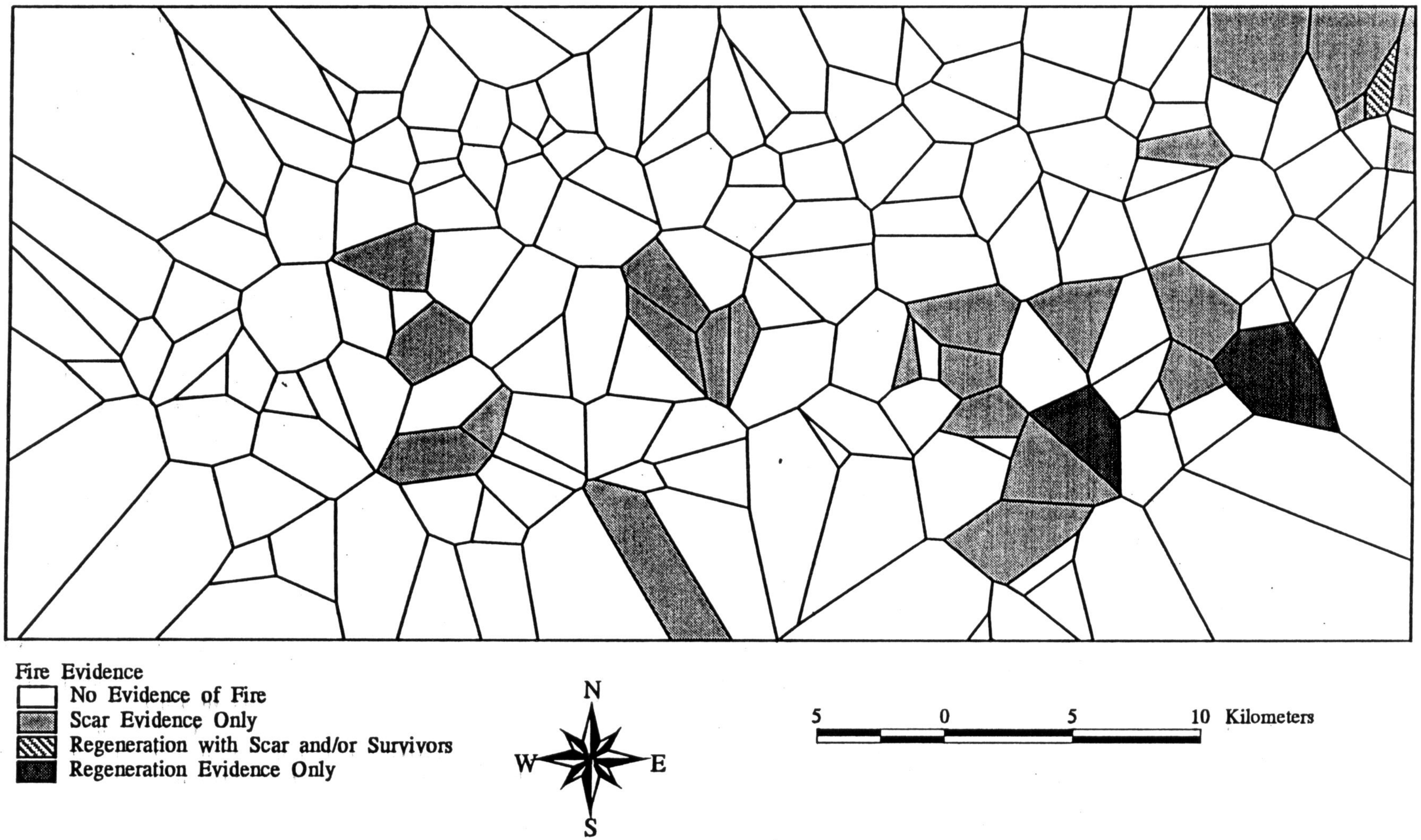
Map B.22 Thiessen Polygons for the Fire Episode of 1900



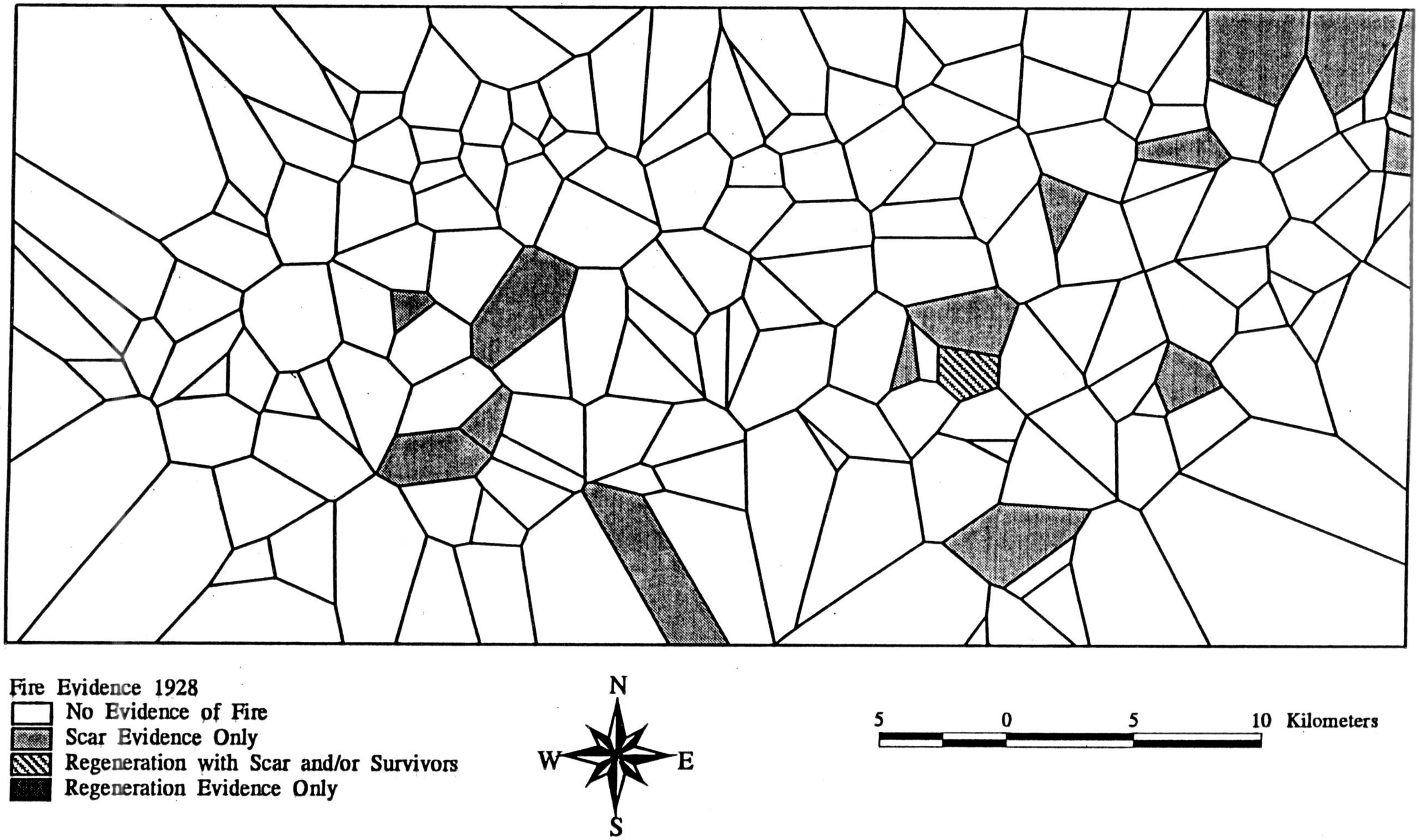
Map B.23 Thiessen Polygons for the Fire Episode of 1909



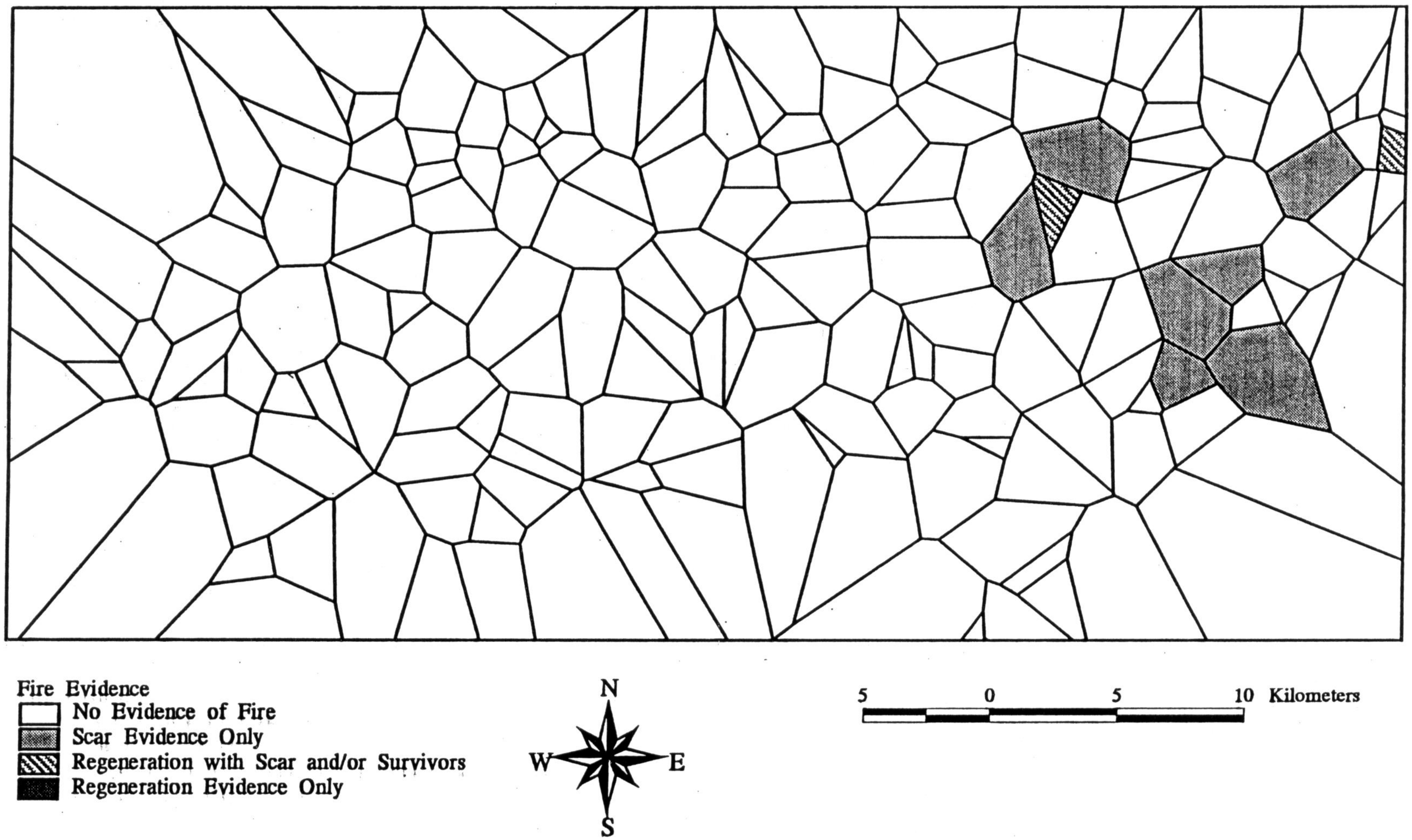
Map B.24 Thiessen Polygons for the Fire Eisode of 1920



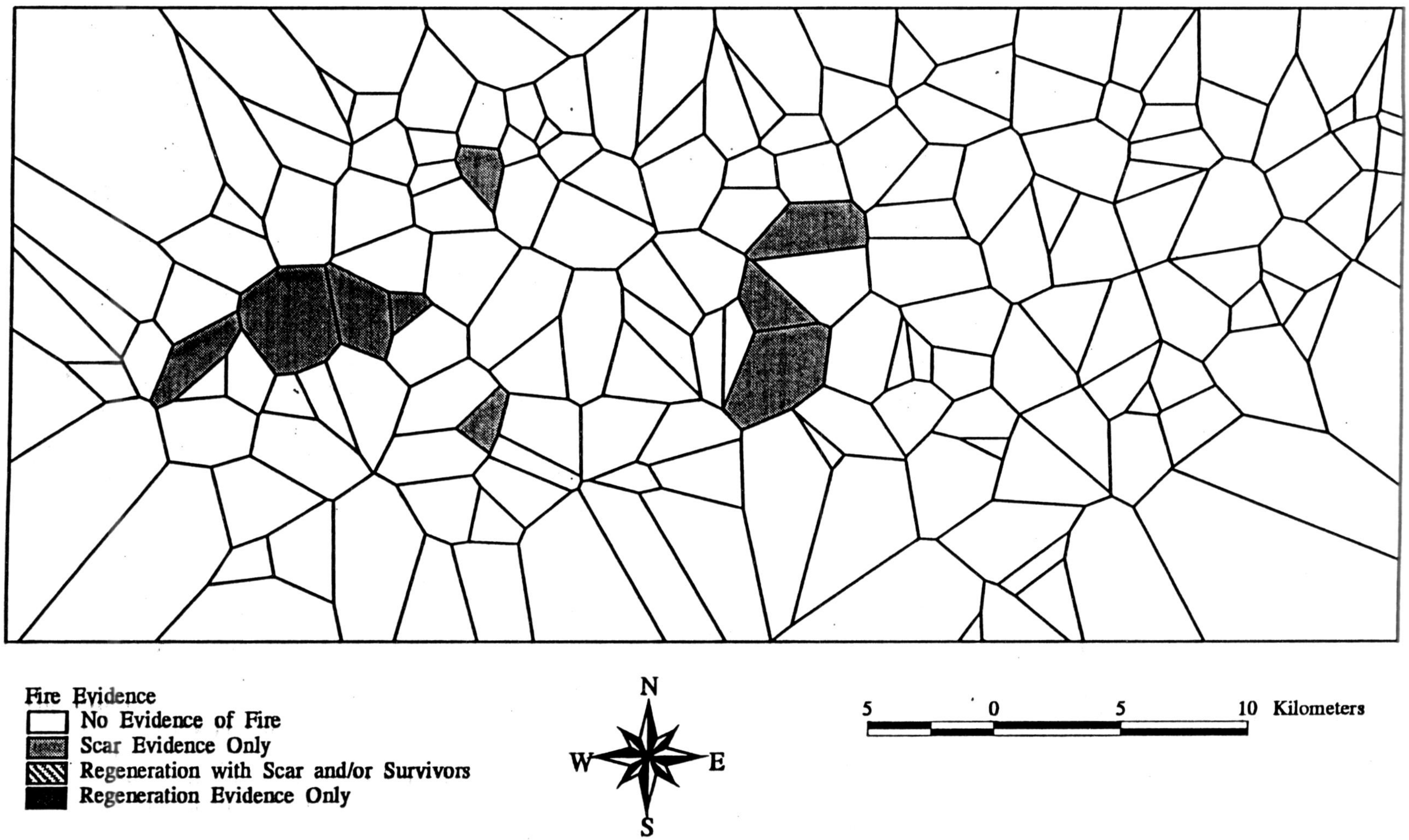
Map B.25 Thiessen Polygons for the Fire Episode of 1928



Map B.26 Thiessen Polygons for the Fire Episode of 1934

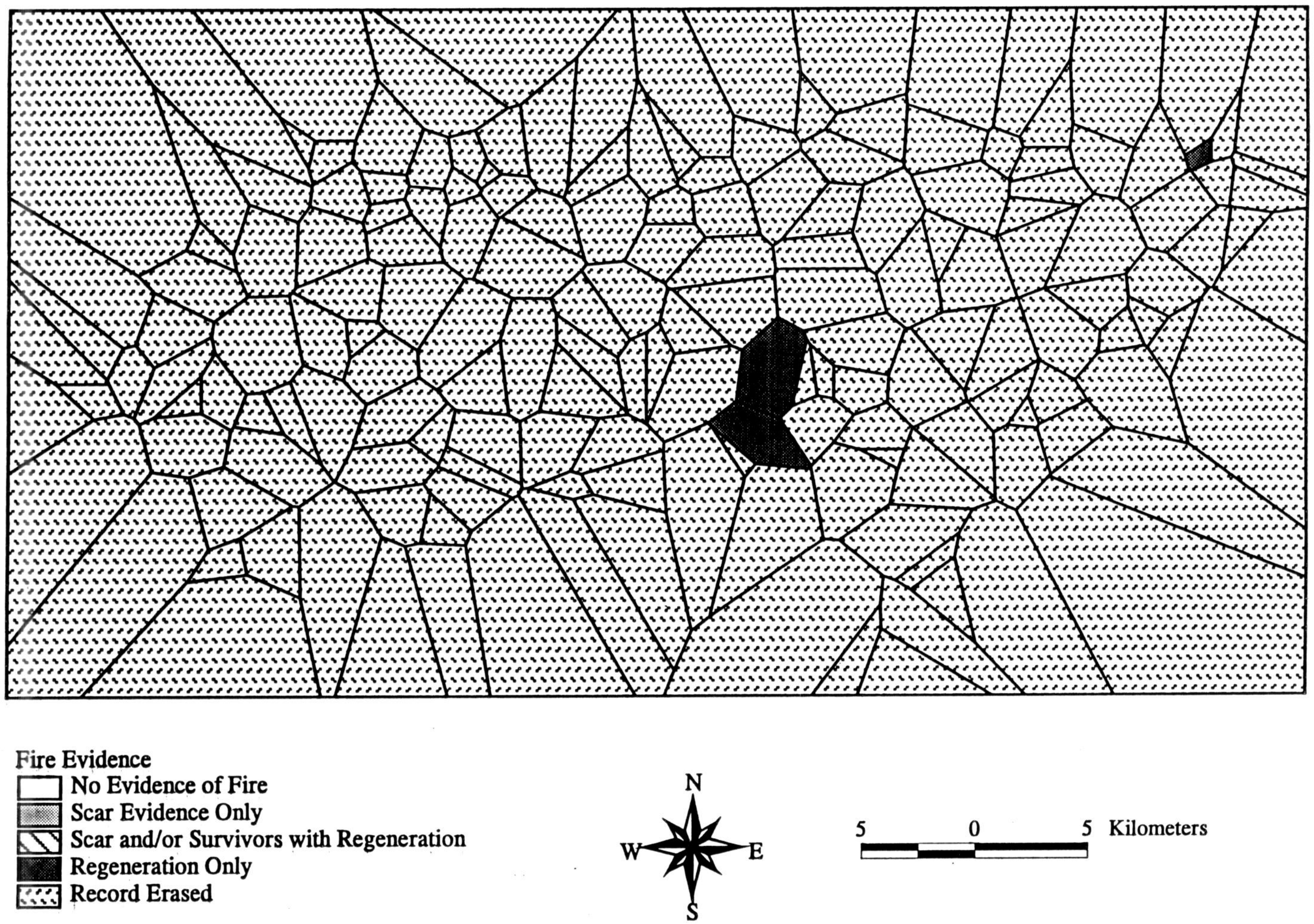


Map B.27 Thiessen Polygons for the Fire Episode of 1974

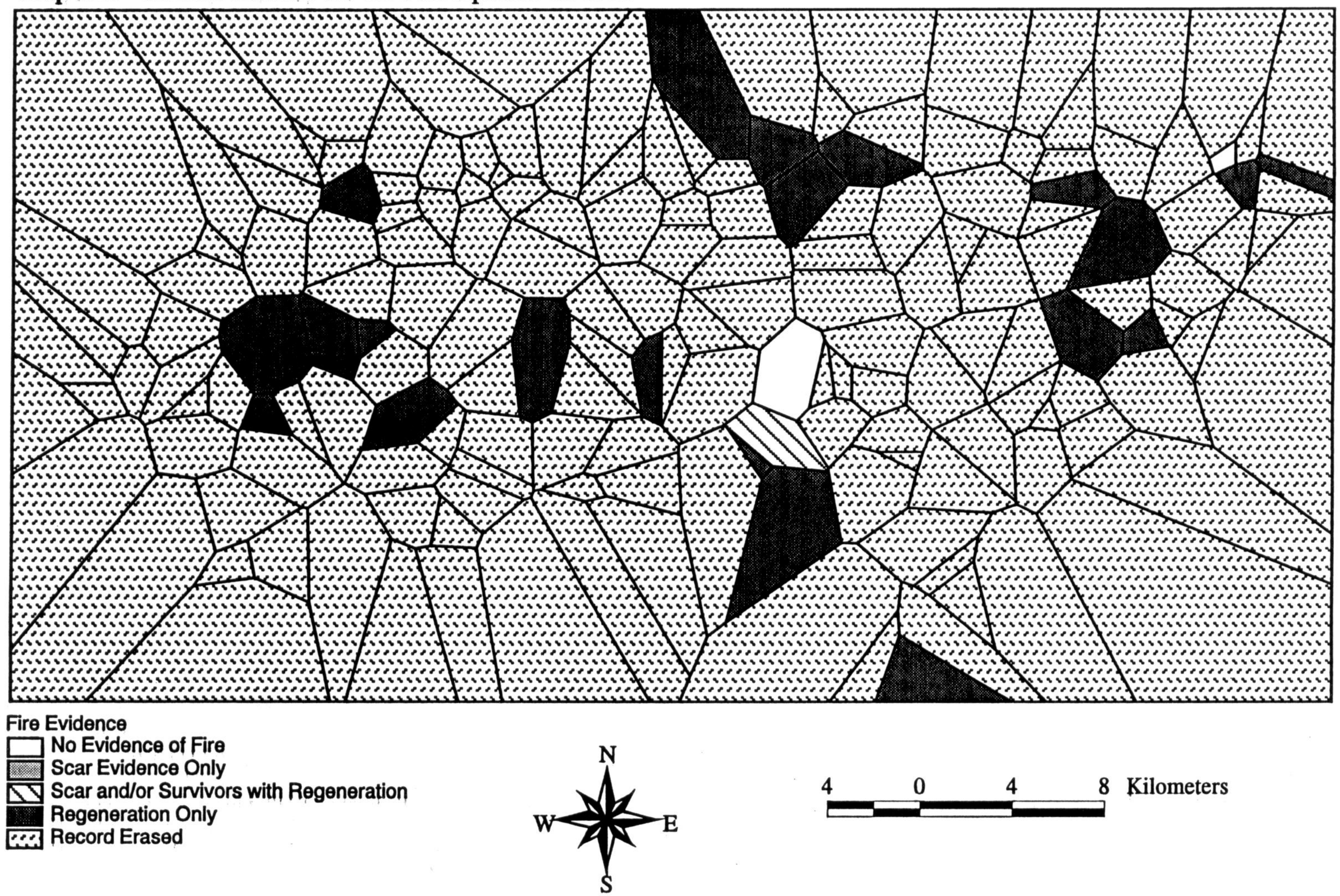


Appendix C. Record Erasure Maps

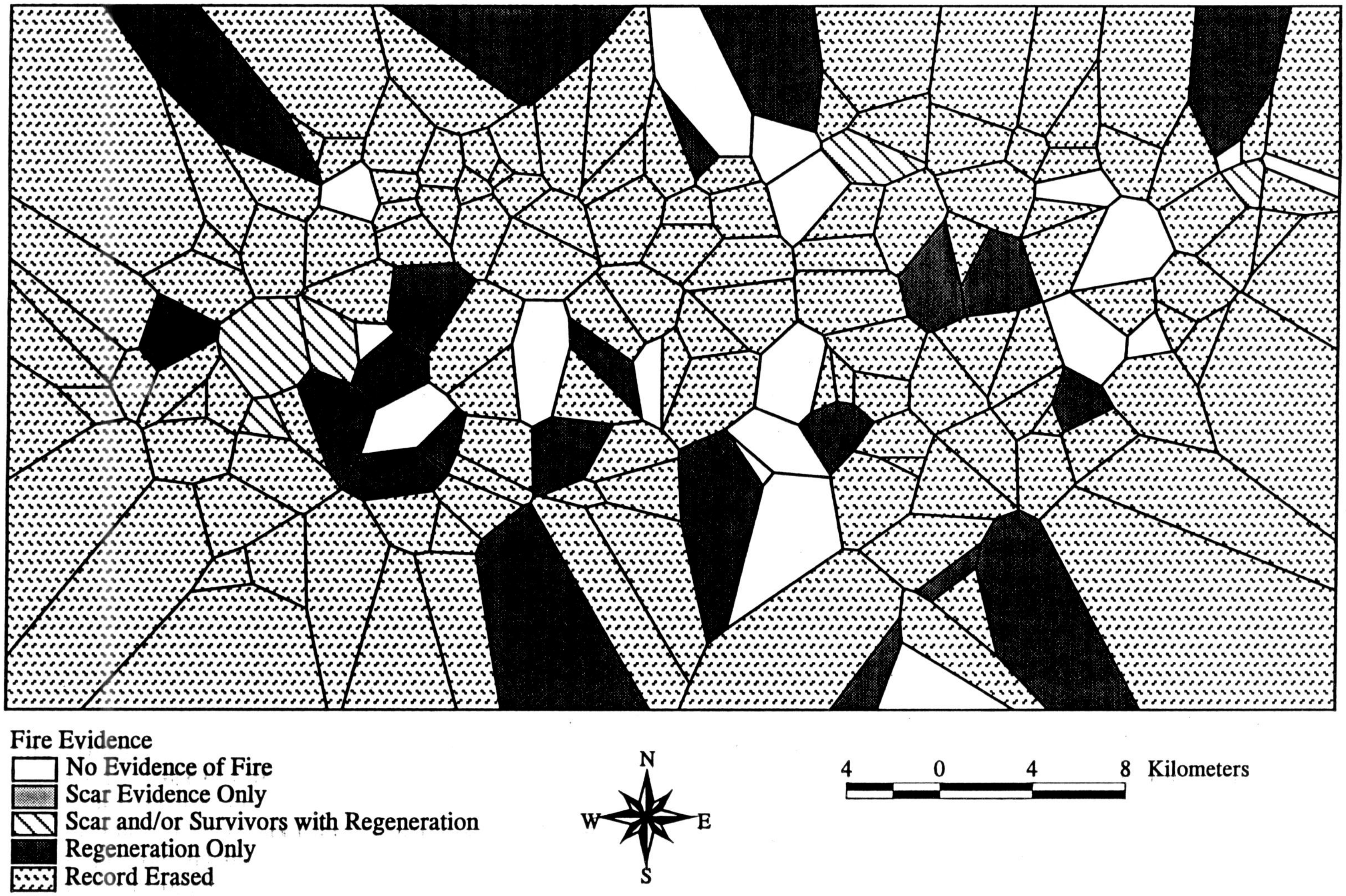
Map C.1 Record Erasure for the Fire Episode of 1478



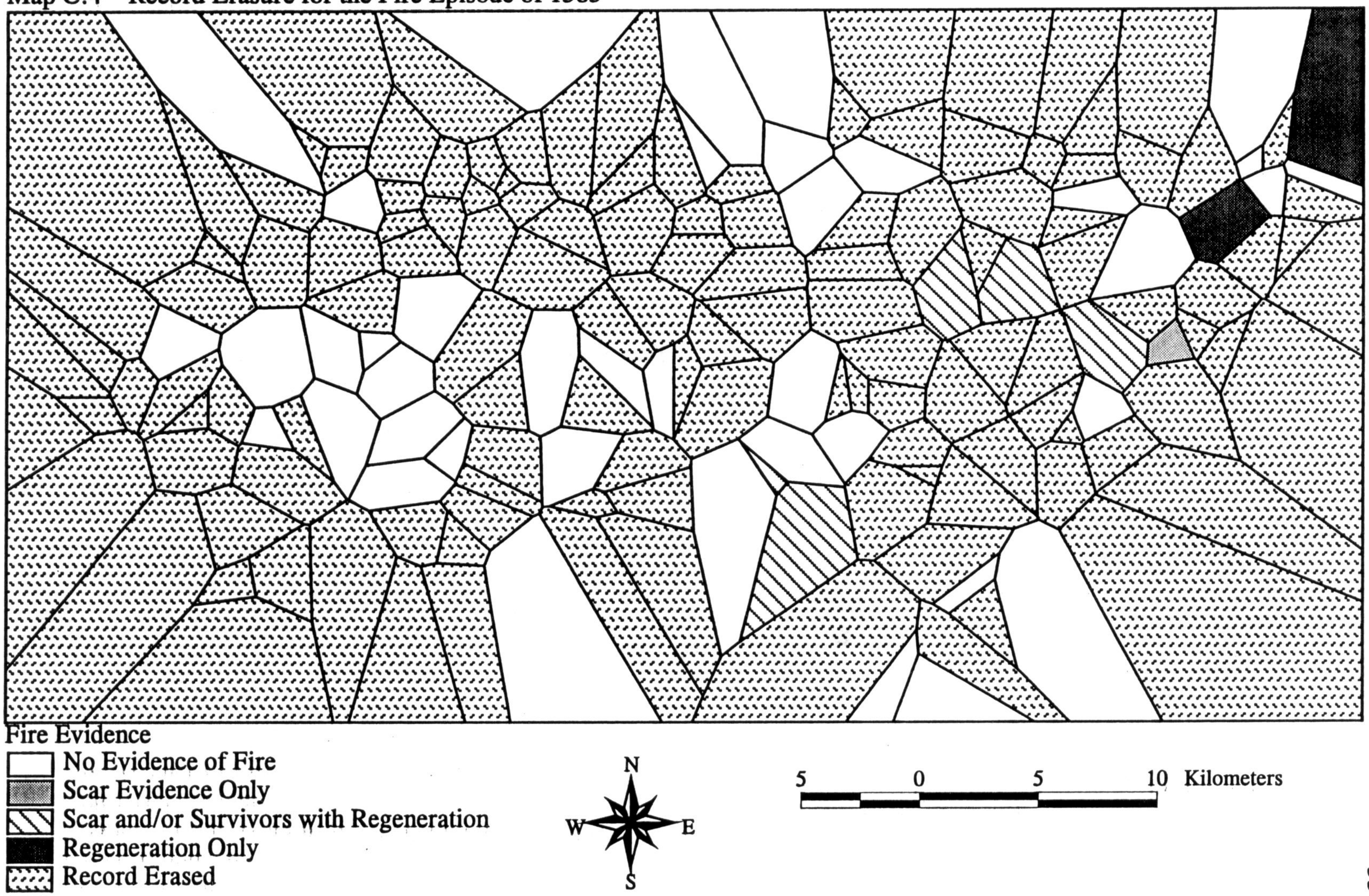
Map C.2 Record Erasure for the Fire Episode of 1531



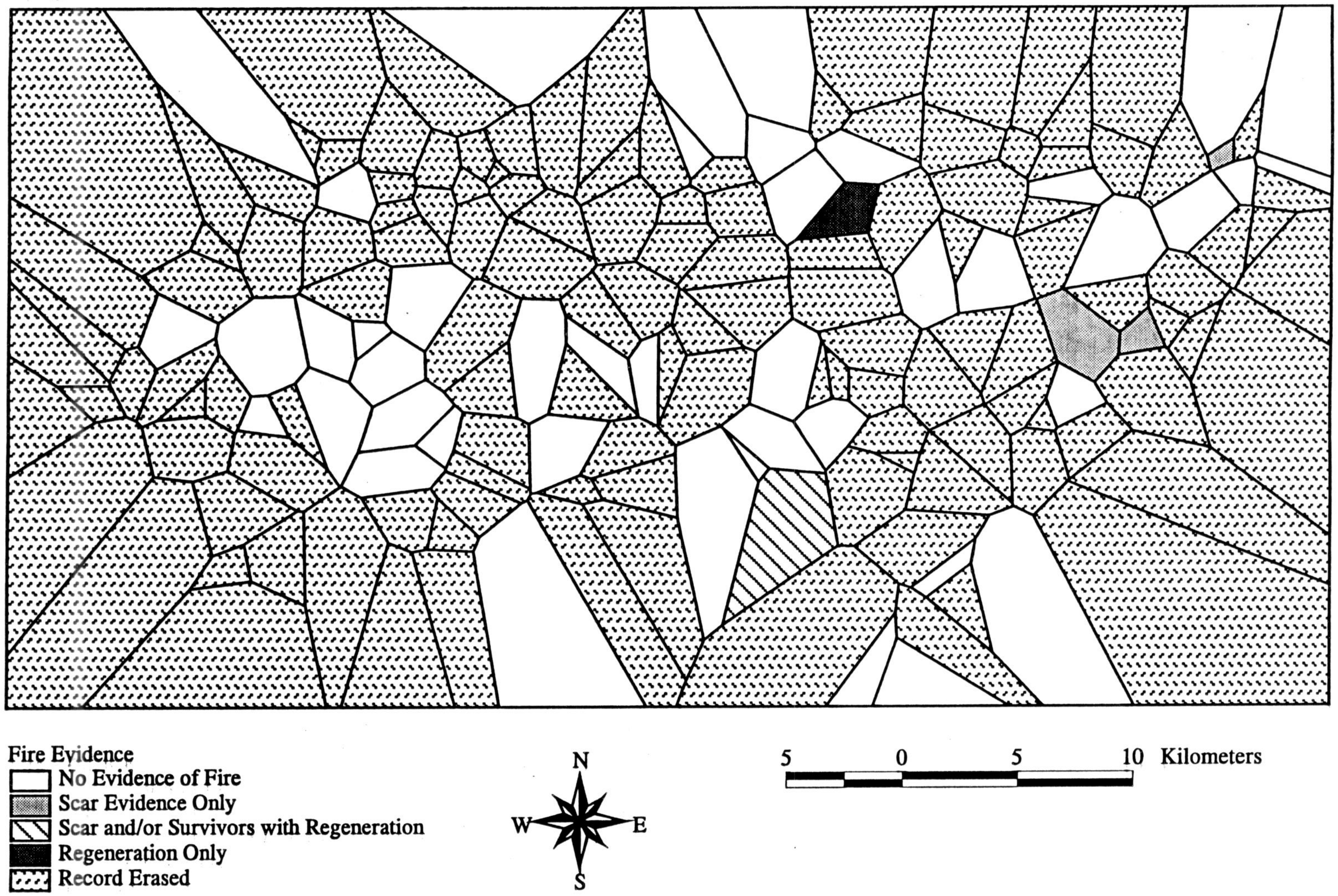
Map C.3 Record Erasure for the Fire Episode of 1555



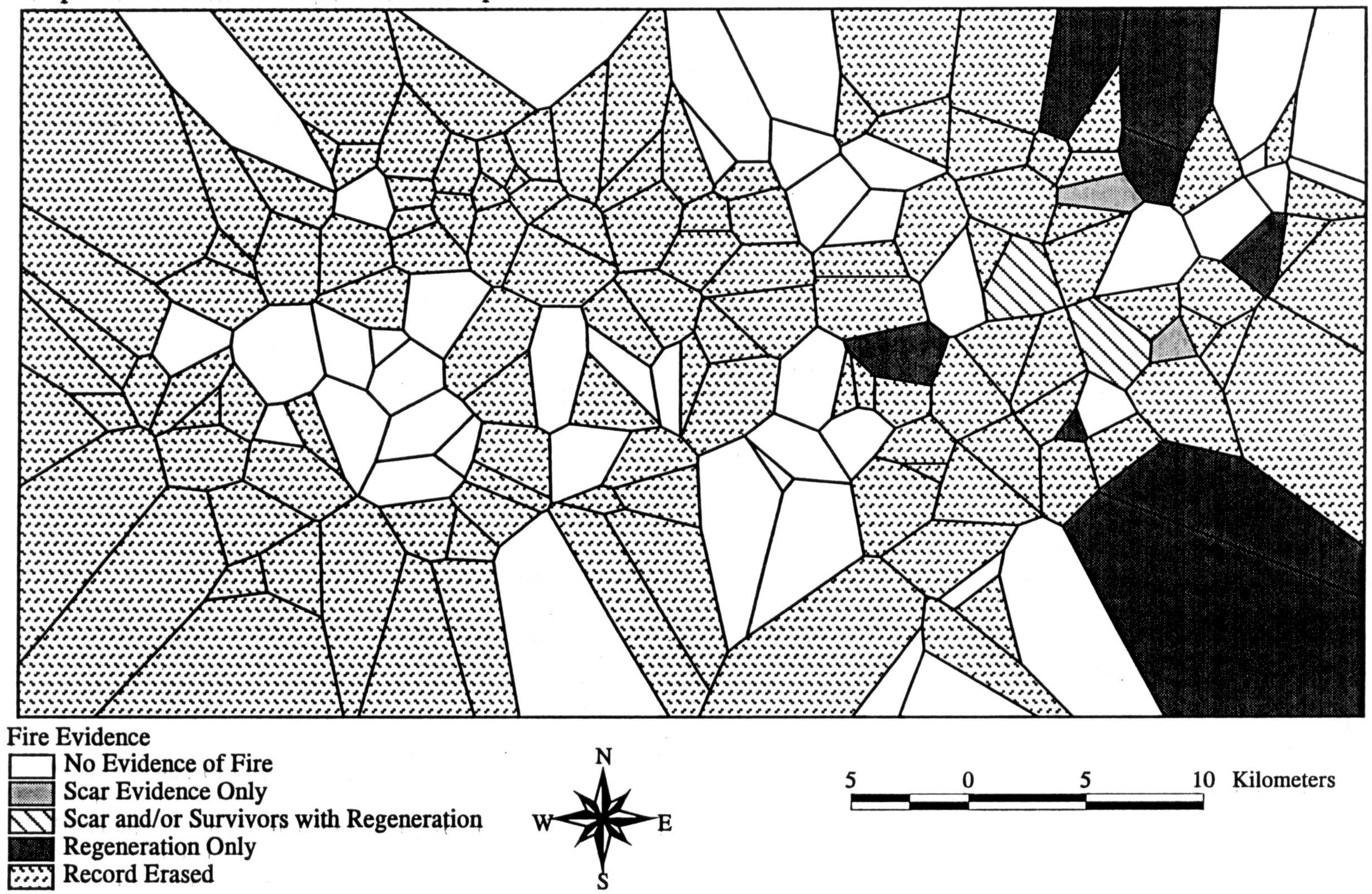
Map C.4 Record Erasure for the Fire Episode of 1585



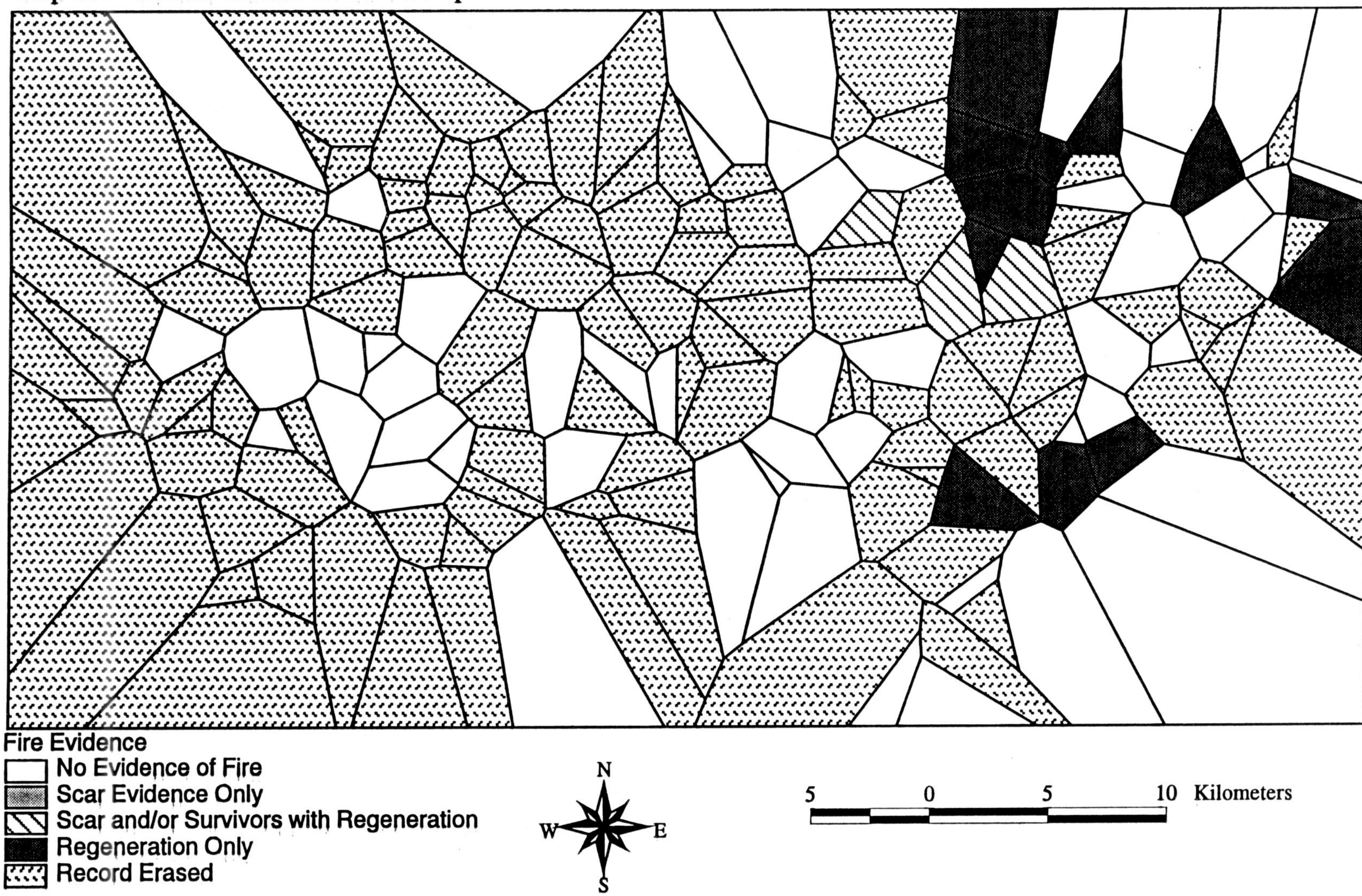
Map C.5 Record Erasure for the Fire Episode of 1629



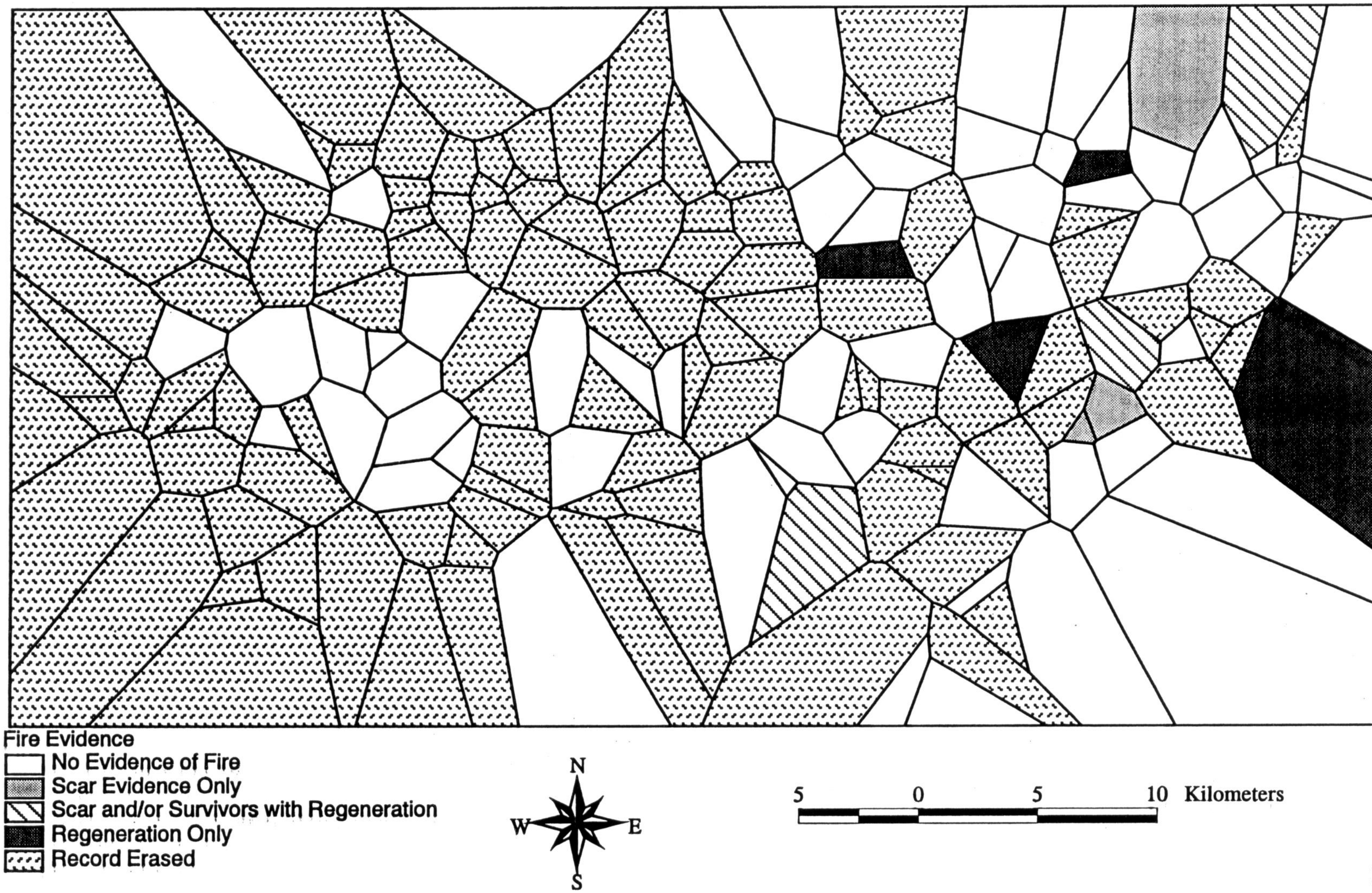
Map C.6 Record Erasure for the Fire Episode of 1637



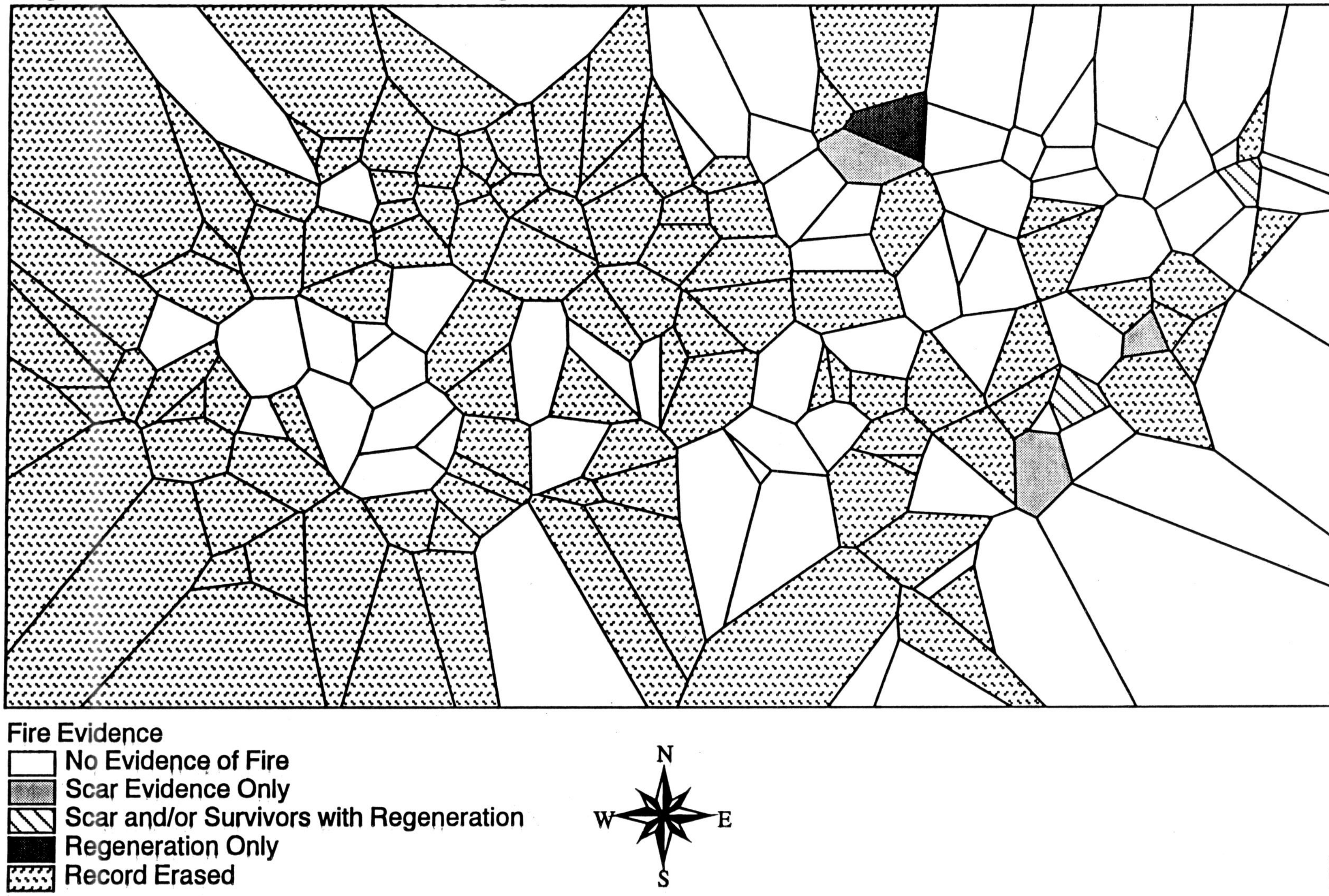
Map C.7 Record Erasure for the Fire Episode of 1655



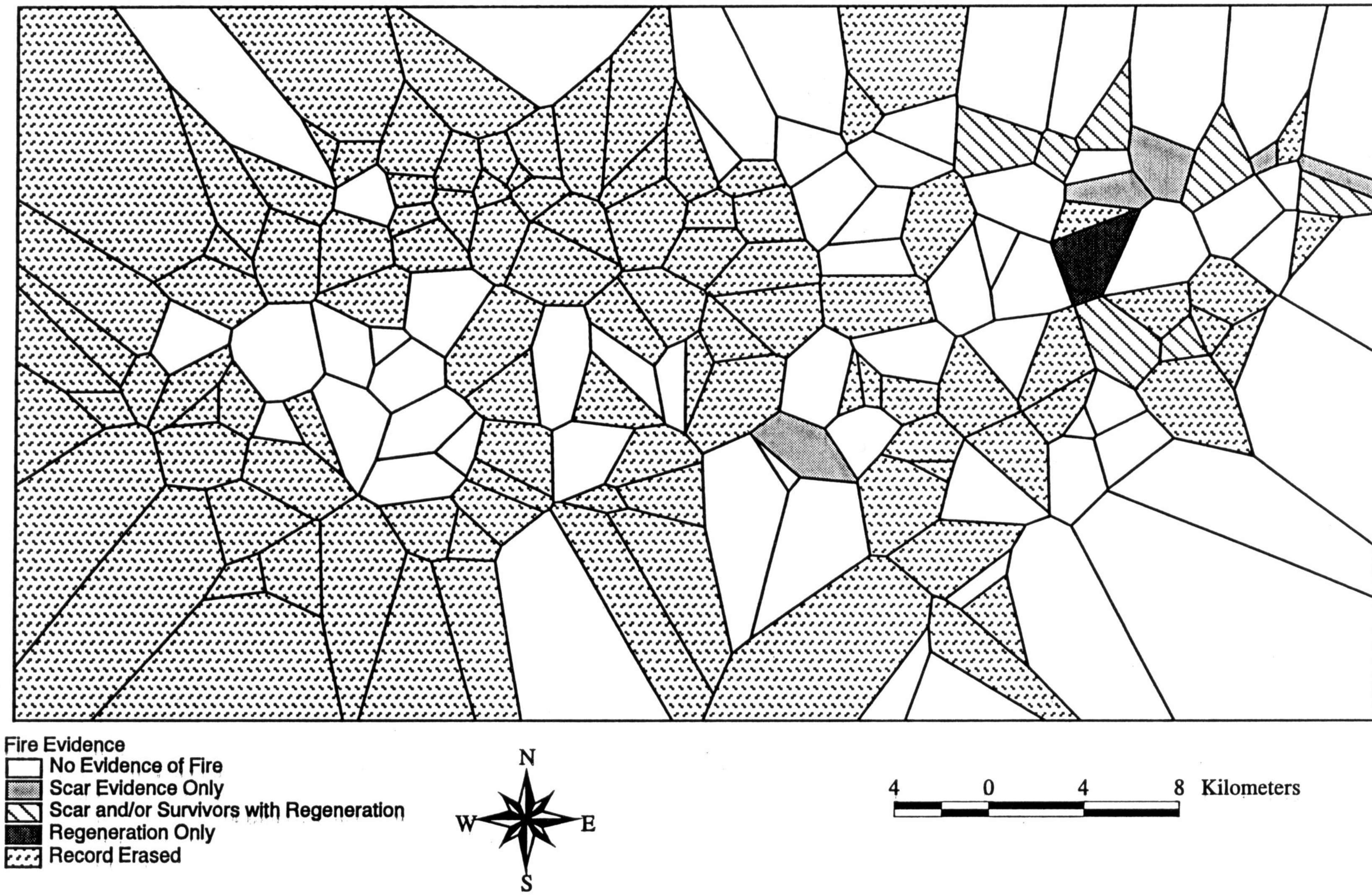
Map C.8 Record Erasure for the Fire Episode of 1666



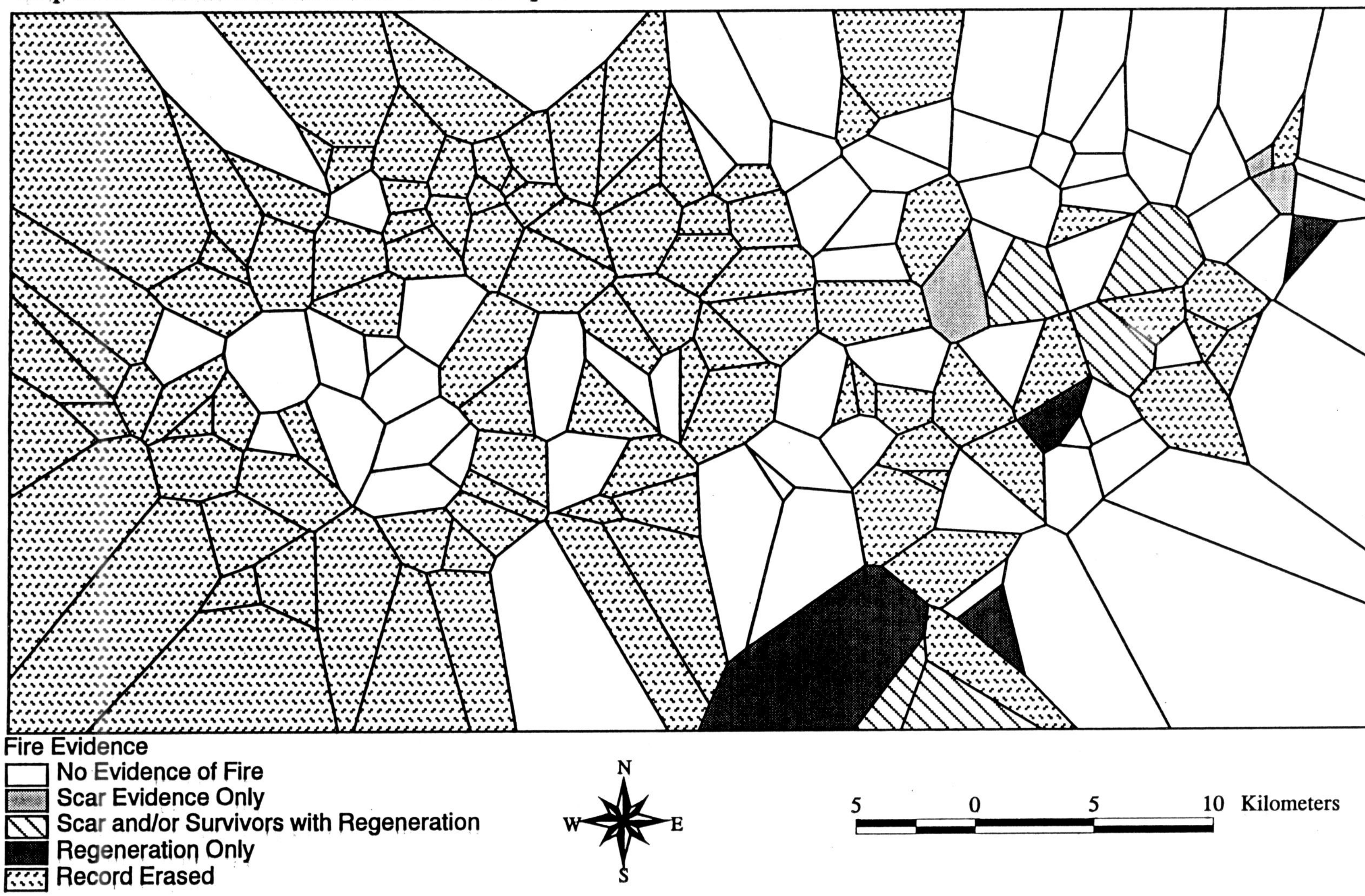
Map C.9 Record Erasure for the1689 Fire Episode



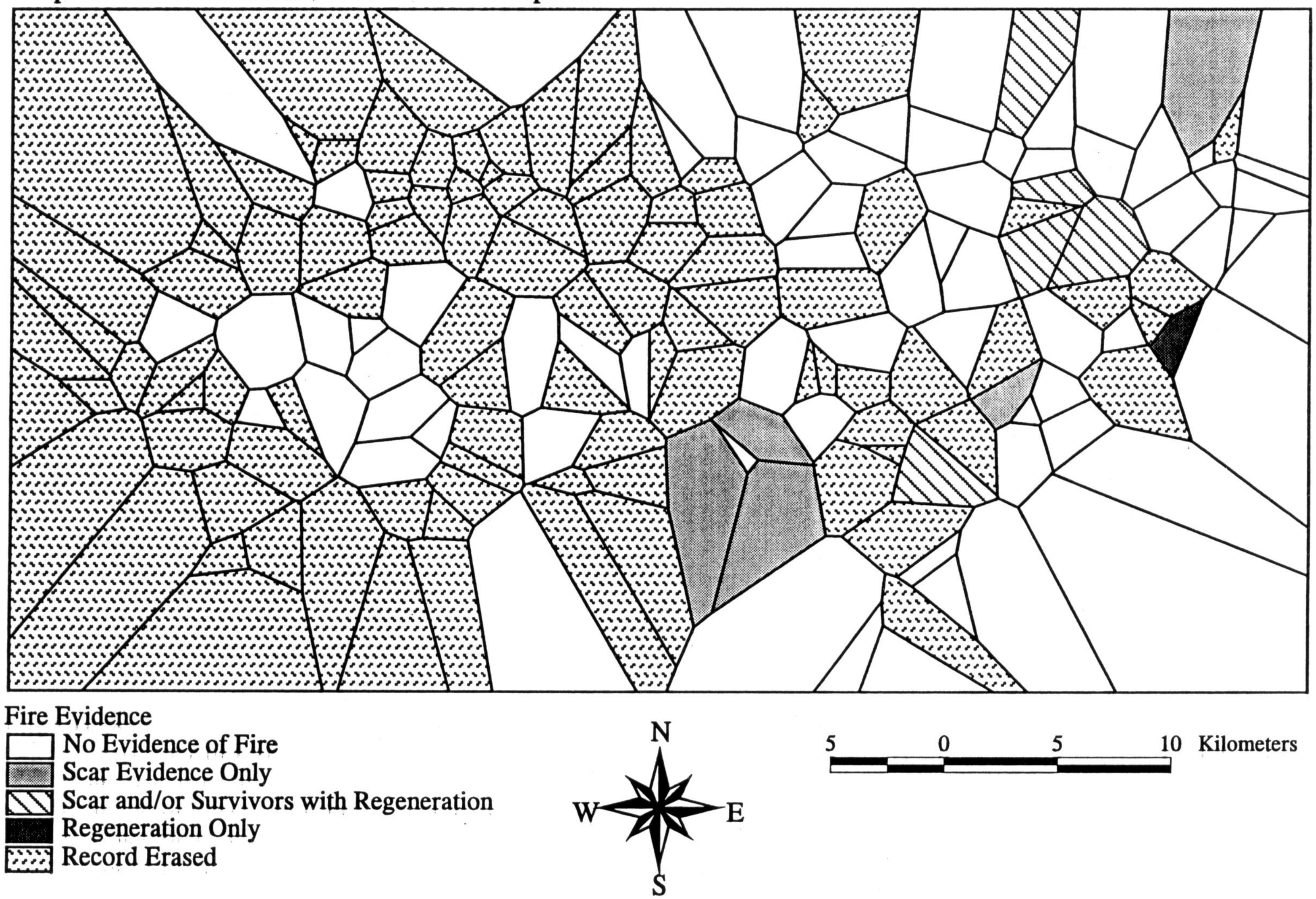
Map C.10 Record Erasure for the 1699 Fire Episode



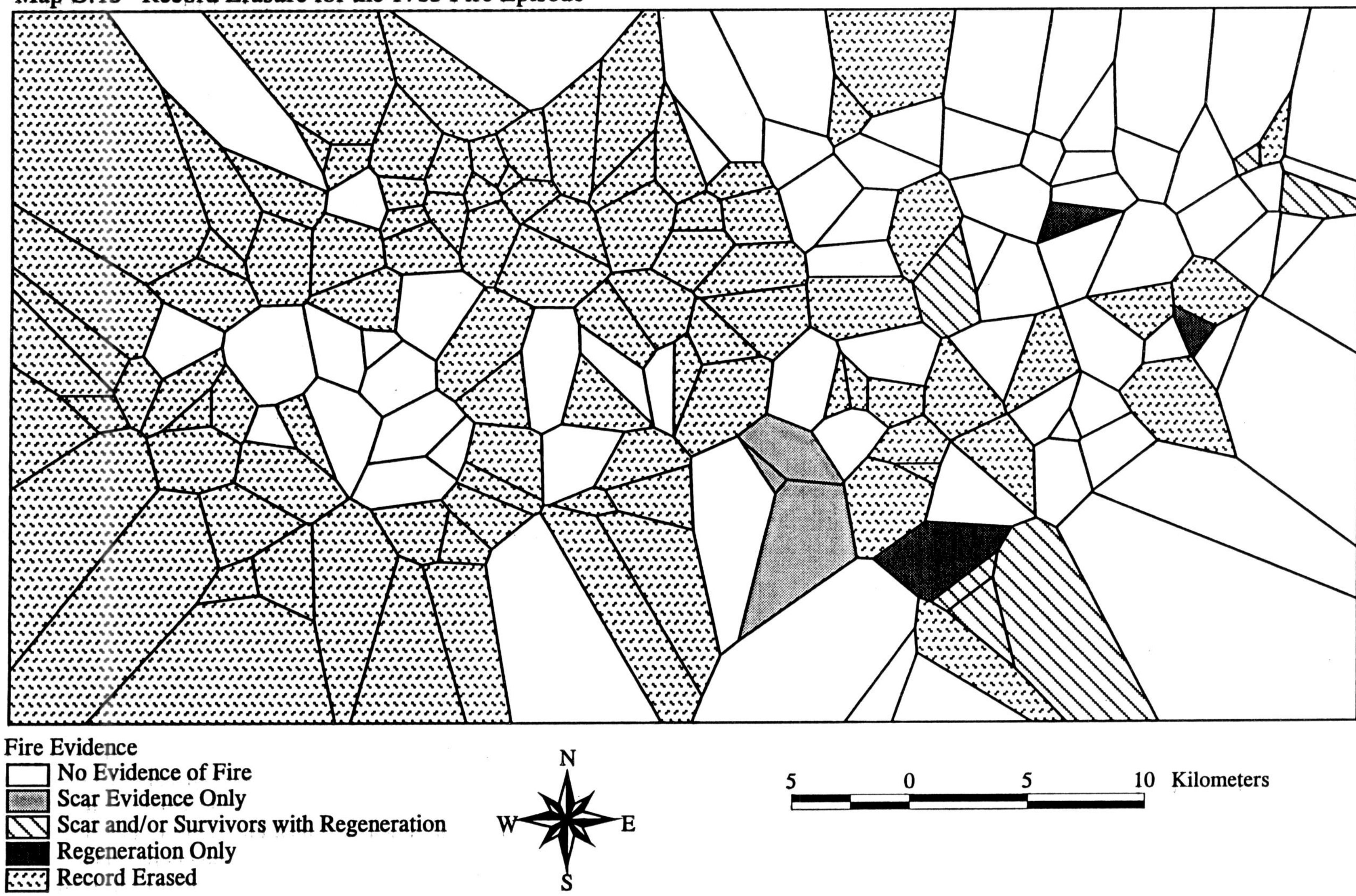
Map C.11 Record Erasure for the 1737 Fire Episode



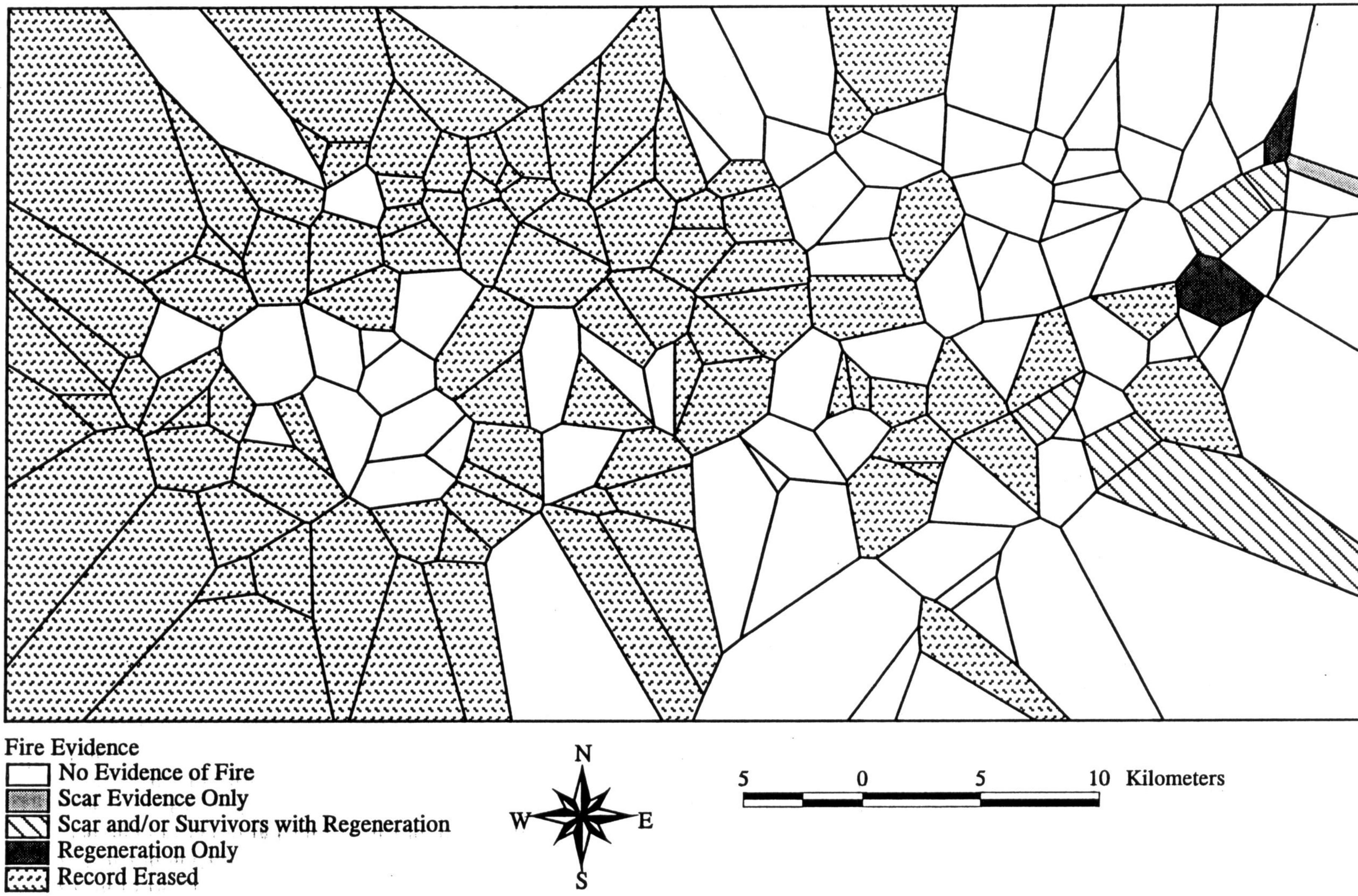
Map C.12 Record Erasure for the 1751 Fire Episode



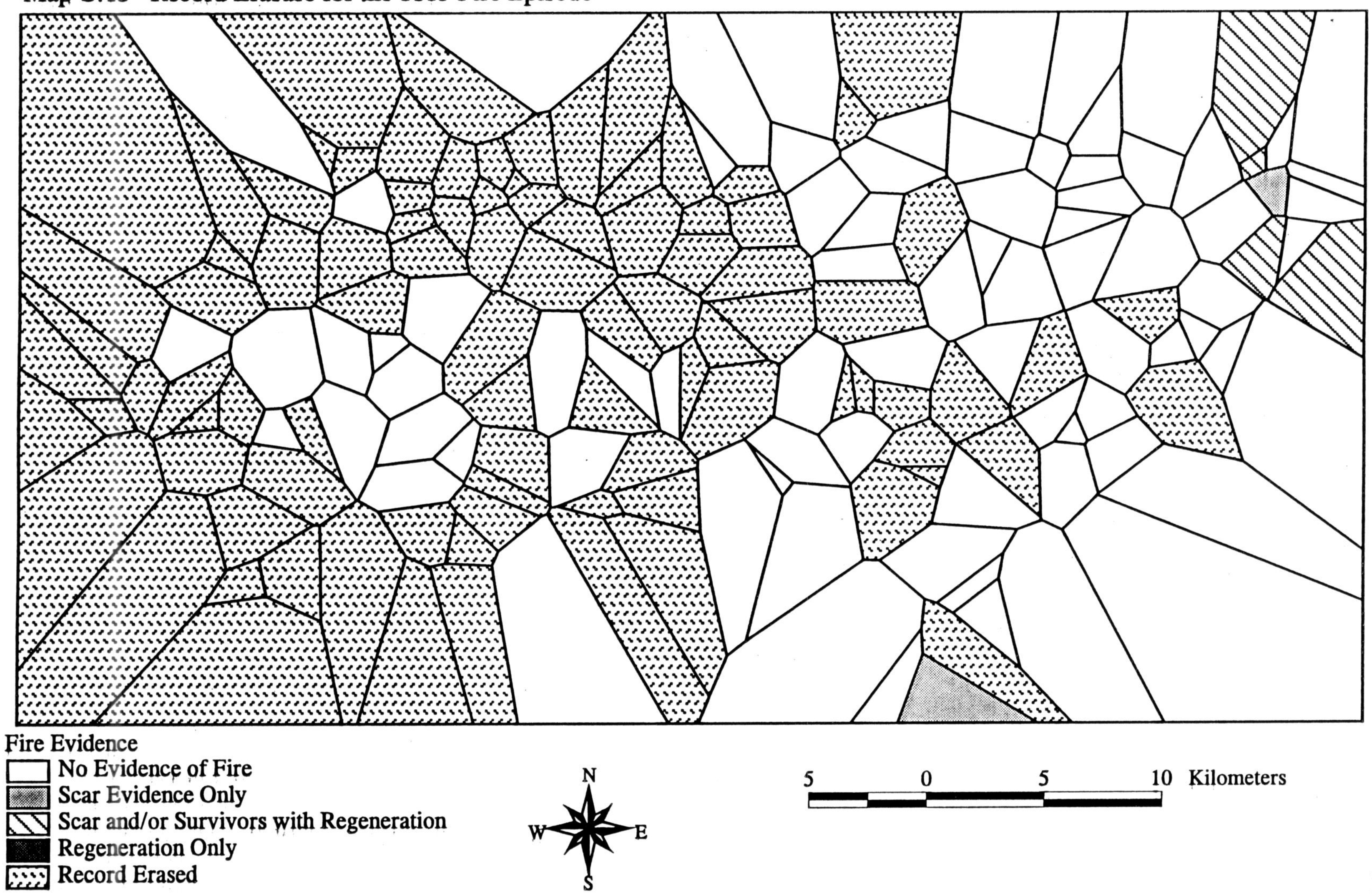
Map C.13 Record Erasure for the 1763 Fire Episode



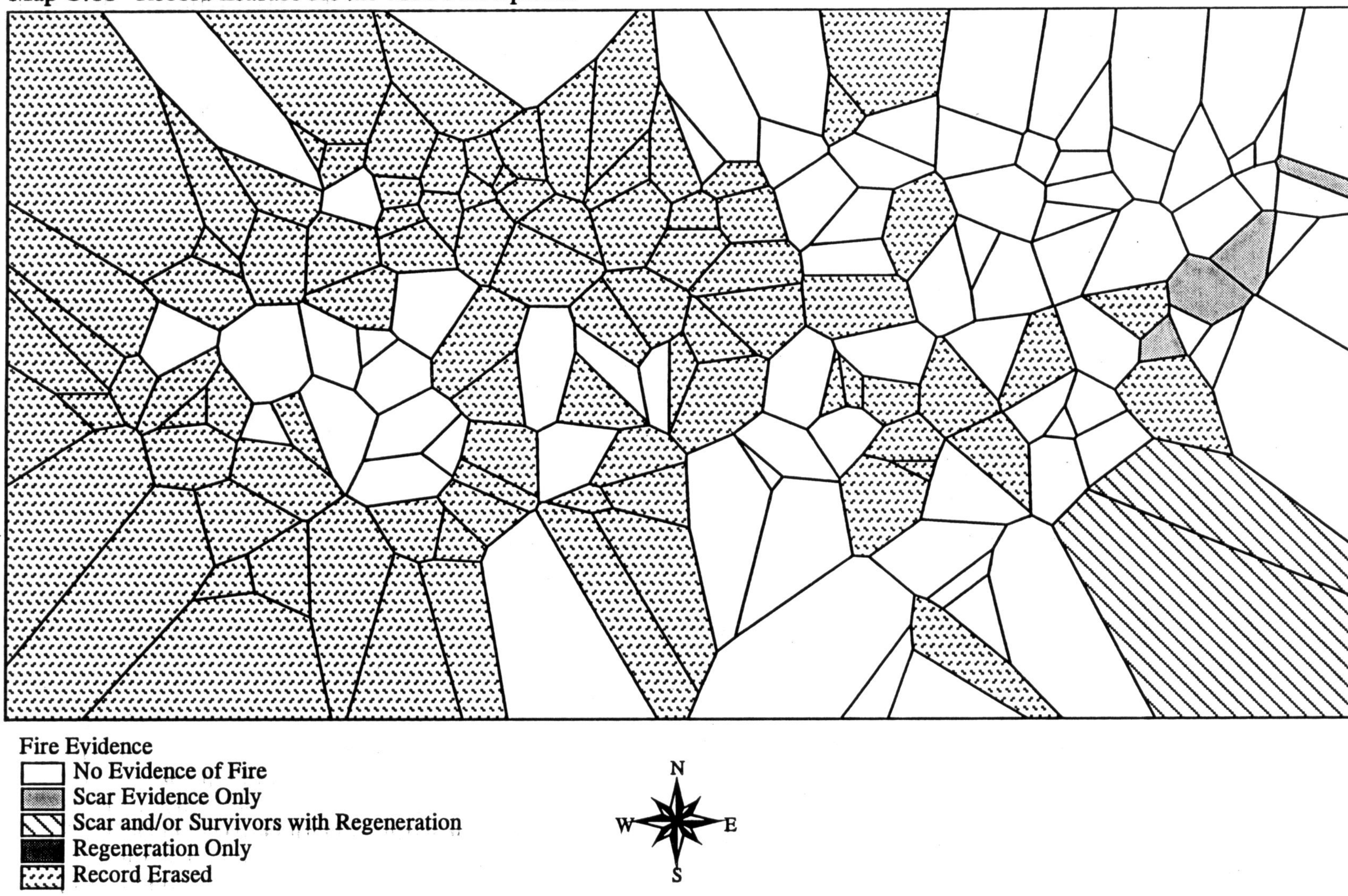
Map C.14 Record Erasure for the 1794 Fire Episode



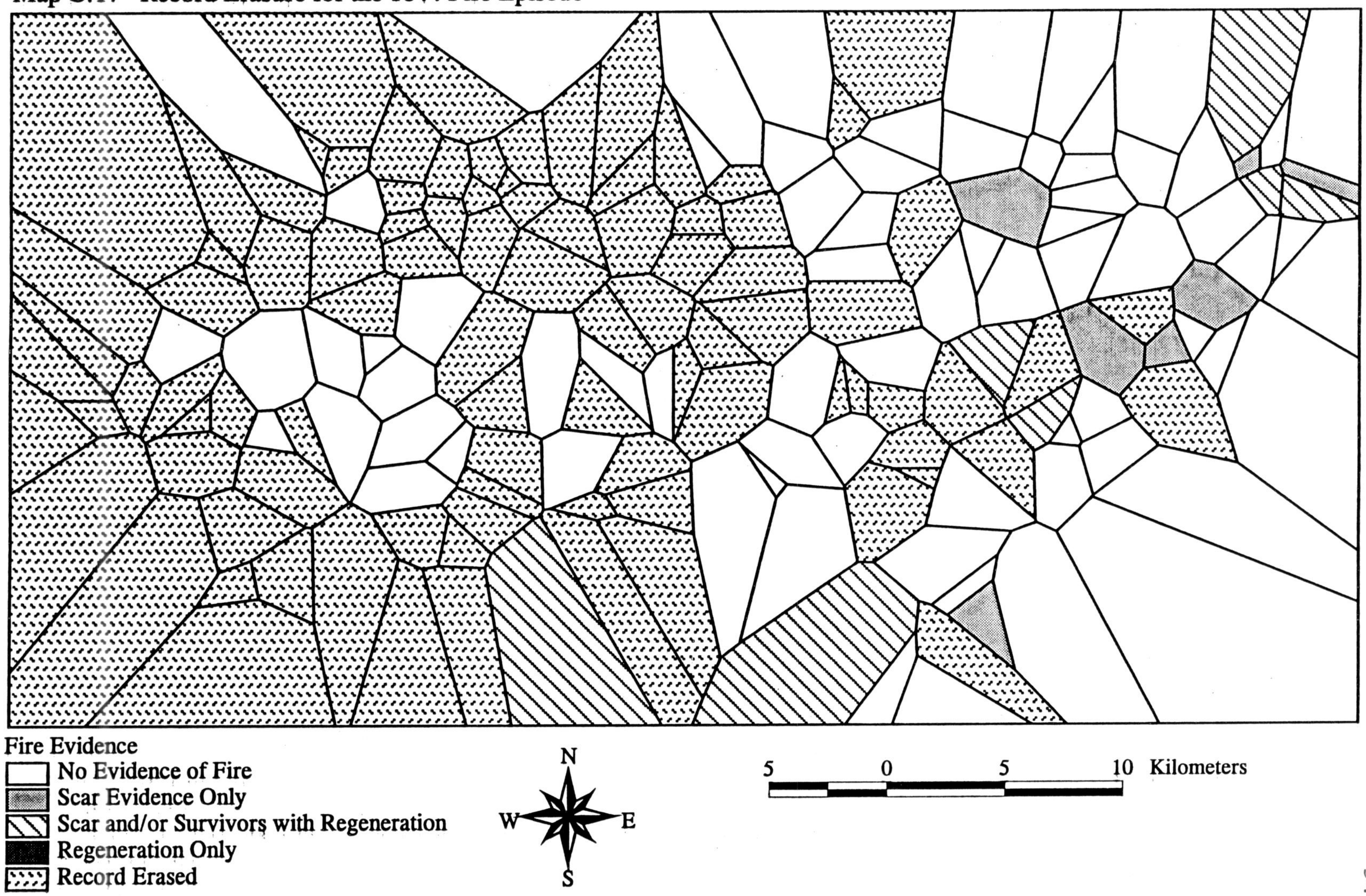
Map C.15 Record Erasure for the 1815 Fire Episode



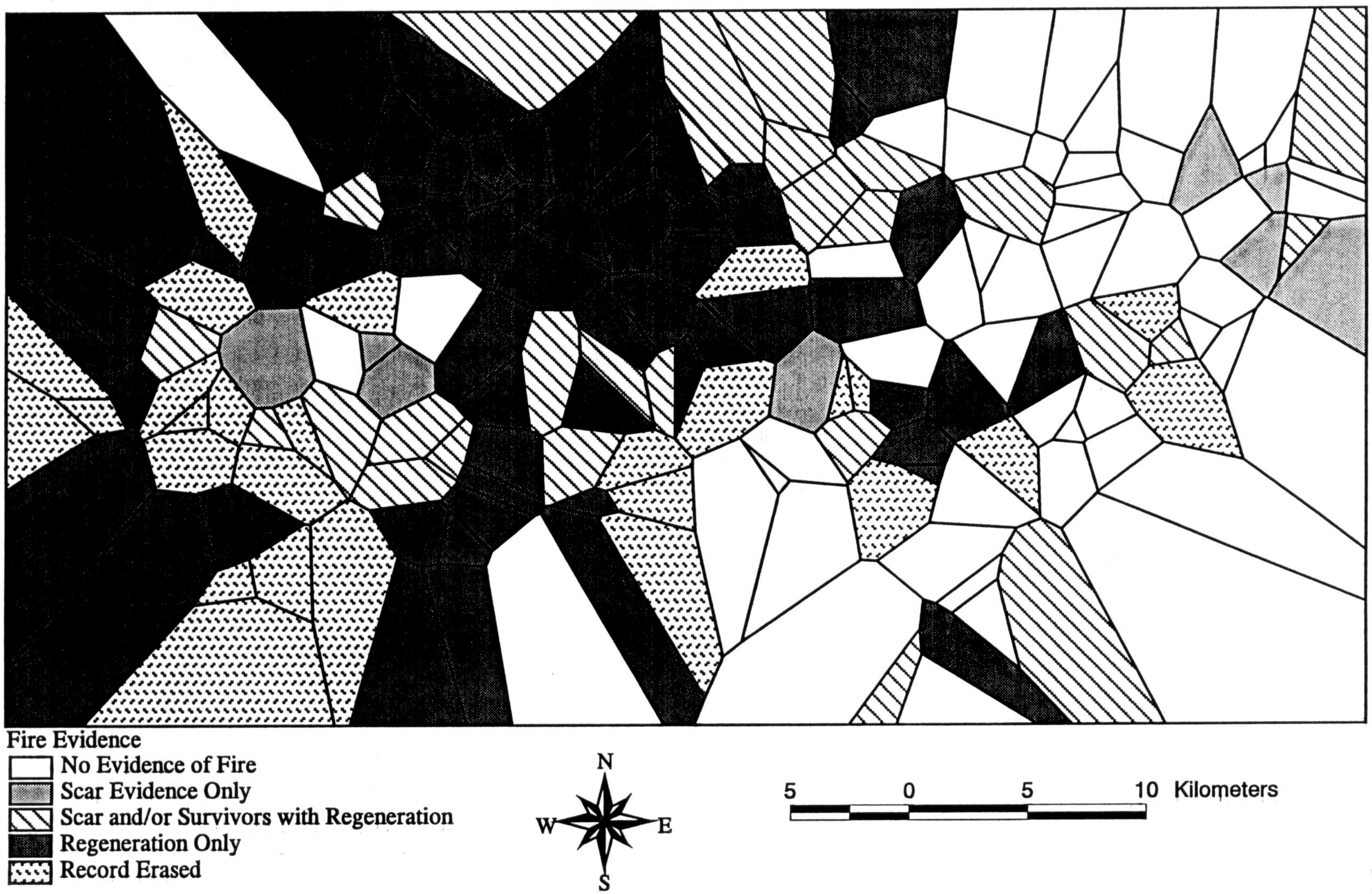
Map C.16 Record Erasure for the 1831 Fire Episode



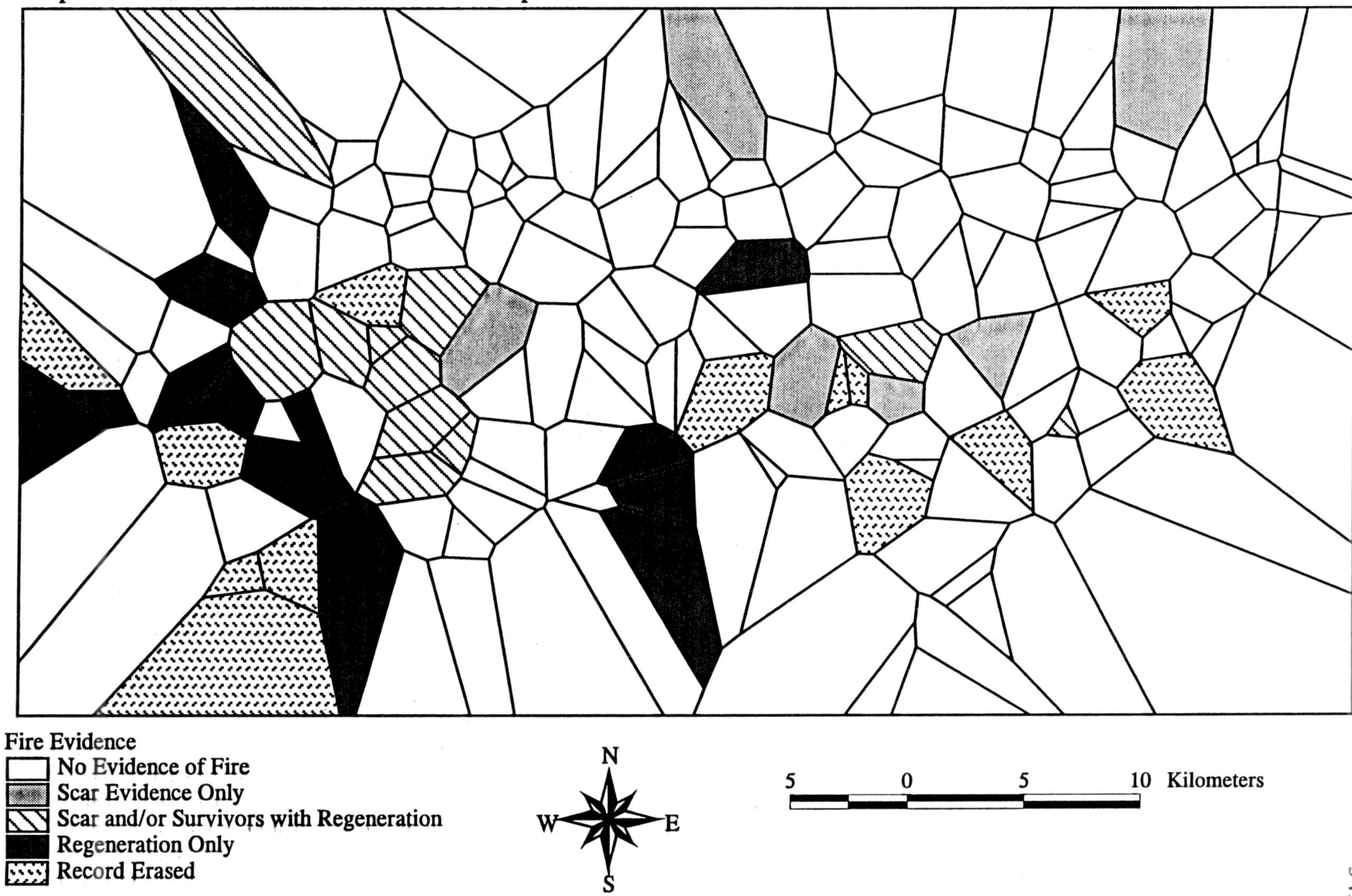
Map C.17 Record Erasure for the 1844 Fire Episode



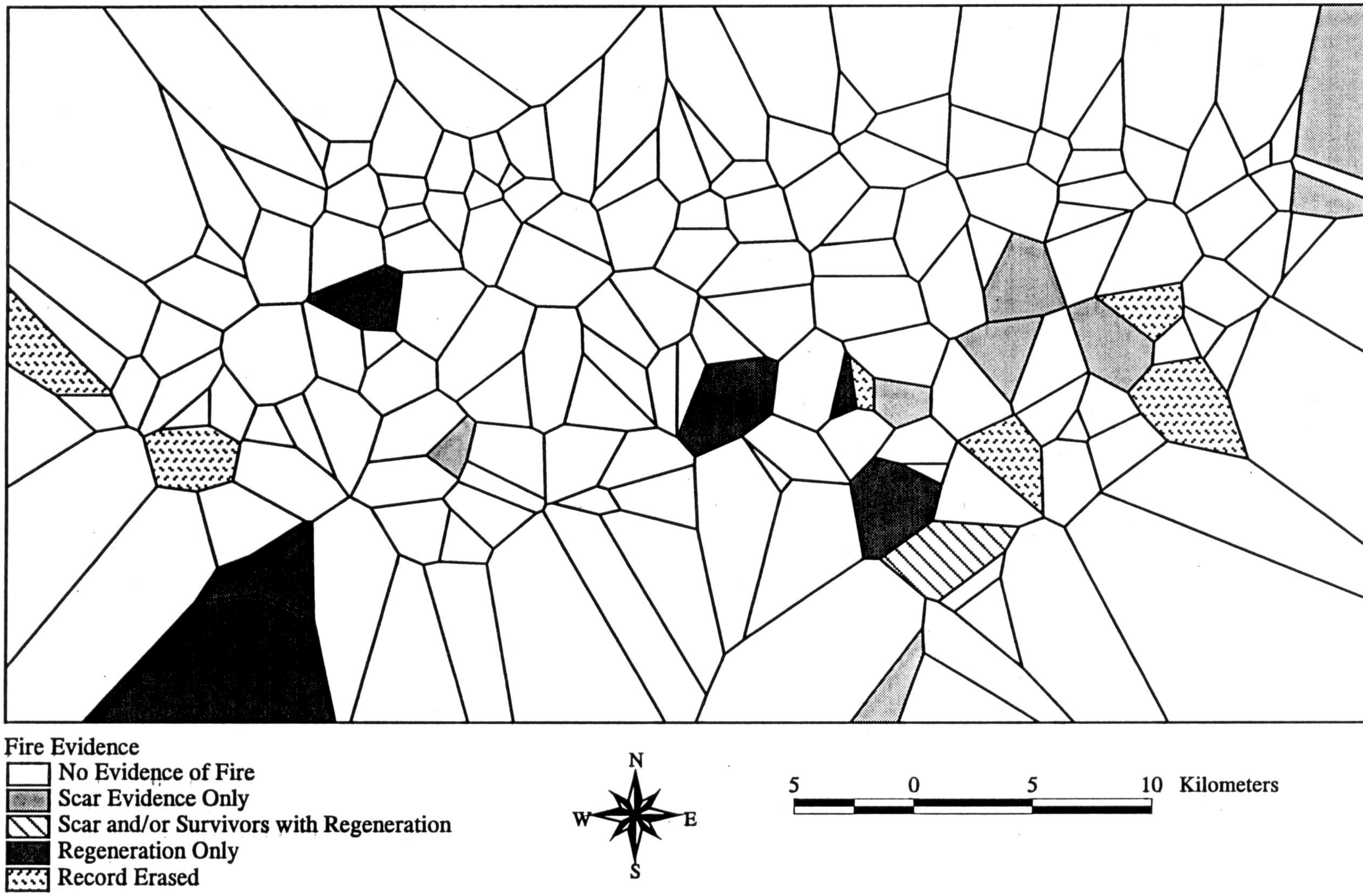
Map C.18 Record Erasure for the 1852 Fire Episode



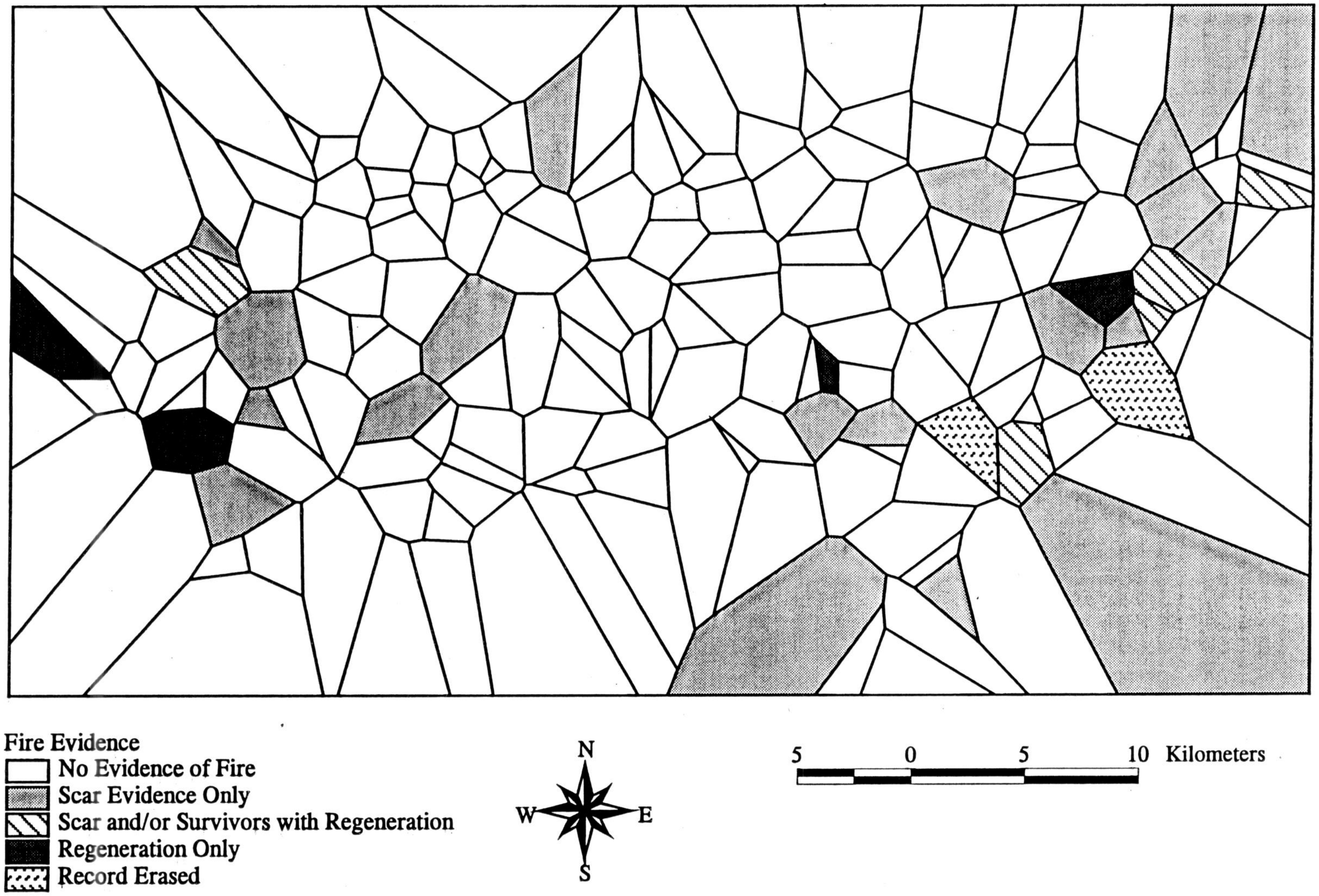
Map C.19 Record Erasure for the 1871 Fire Episode



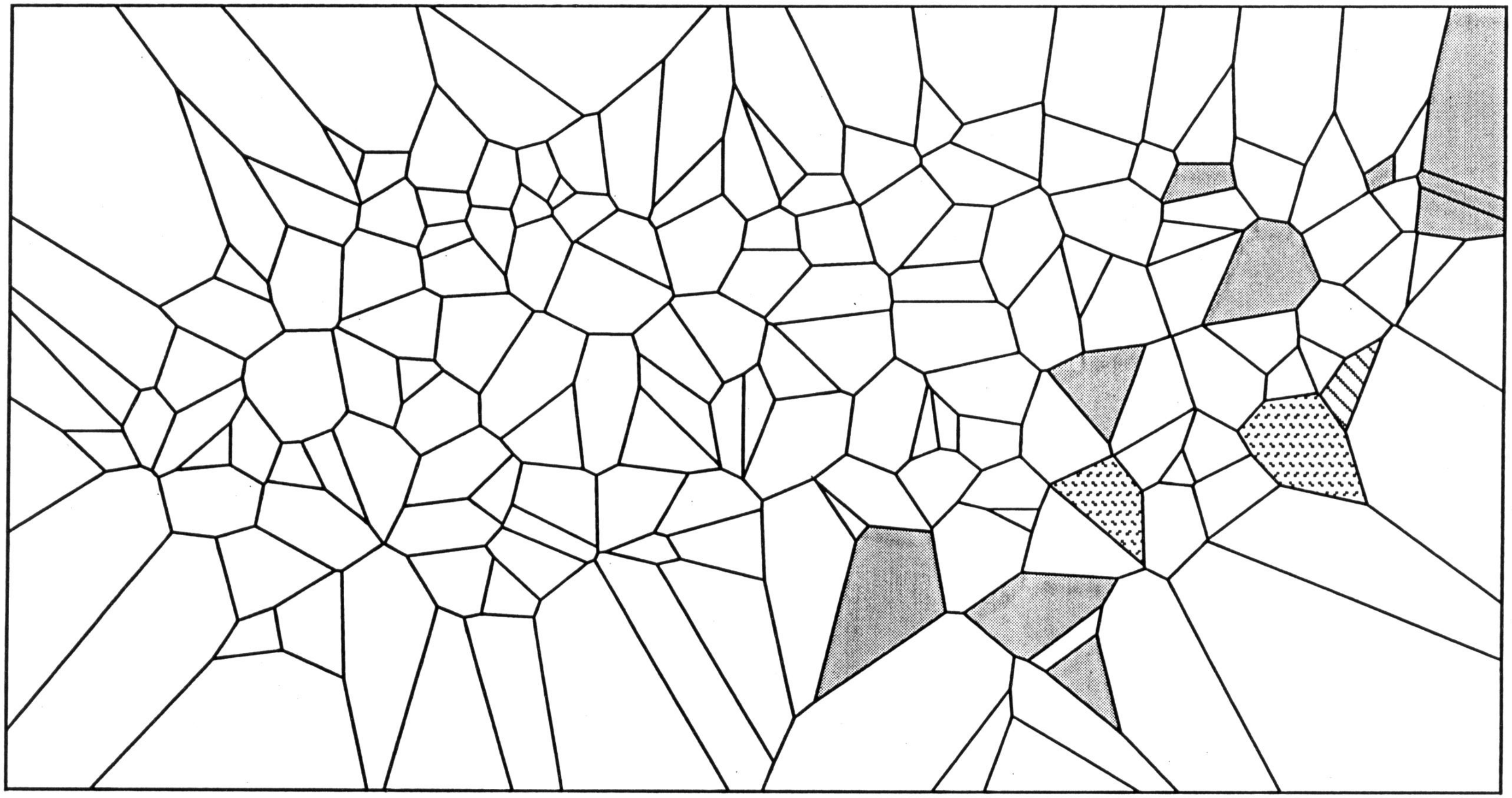
Map C.20 Record Erasure for the 1881 Fire Episode



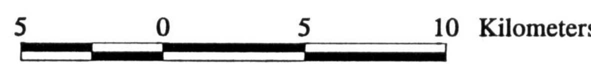
Map C.21 Record Erasure for the 1888 Fire Episode



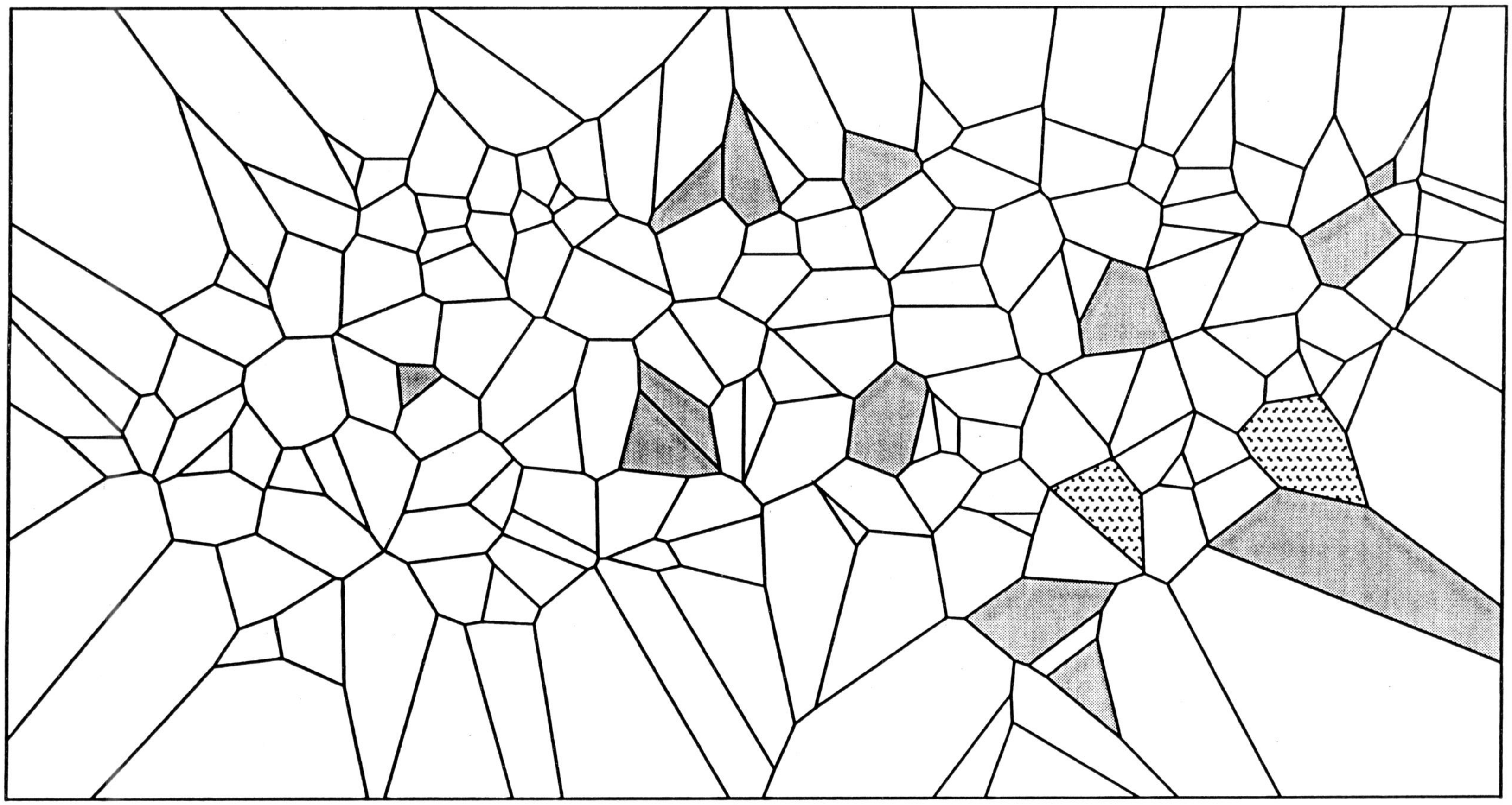
Map C.22 Record Erasure for the 1900 Fire Episode



Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Scar and/or Survivors with Regeneration
- Regeneration Only
- Record Erased



Map C.23 Record Erasure for the 1909 Fire Episode



Fire Evidence
- No Evidence of Fire
- Scar Evidence Only
- Scar and/or Survivors with Regeneration
- Regeneration Only
- Record Erased

Map C.24 Record Erasure for the 1920 Fire Episode