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Historic Fire Regimes and Their Relation to Vegetation Patterns in the Monterey Bay Area of California

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ABSTRACT.—A study of historic fire regimes in the Monterey Bay area, with emphasis on the coastal redwood (*Sequoia sempervirens*) community is described. Five distinct historic fire regimes were initially distinguished from the literature on land-use history. Fire scar dating, historical research and fire behavior modeling were used to create maps, or "scenarios," representing fire coverage during each regime. Although effects of ignition and moisture gradient apparently influenced the vegetation pattern in each of the five fire regimes, only three regimes were particularly significant to the vegetation of the area. Prior to human habitation, a lightning fire regime existed which, along with the vegetation, was disturbed by the arrival of humans around 11,000 BP. After adjusting to a series of three burning regimes under different human occupations, the vegetation was again disturbed when fire suppression became effective in the 20th century. The present regime is similar in several respects to that which existed prior to the arrival of humans. We propose that computer modeling of fire behavior combined with historic lightning fire incidence may provide useful information on prehuman fire regimes here and elsewhere.

INTRODUCTION

Early in this century plant ecologists debated the importance of climatic vs. edaphic influences on the vegetation pattern of California's Coast ranges. More recently, however, the influence of fire in creating and maintaining the pattern of vegetation is being emphasized. For example, from analysis of vegetation ecology, Wells (1962) hypothesized that most physiognomic vegetation types in the San Luis Obispo area of the California Coast ranges were influenced primarily by their tolerance to fire and soil types. In this study, we use several common fire history techniques and introduce a new technique to examine the possible role of fire history with regard to Wells' hypothesis in the Monterey Bay of California.

When fuel, weather, topography and ignition combine in a consistent way, a fire regime results (Pyne, 1982). The fire regime is considered stable when the perturbations caused by individual fires form a recurring pattern (Loucks, 1970). With the establishment of a stable fire regime, some plant reproduction systems become dependent on the perturbations created by fire (Parker and Kelly, 1989). Disturbance to vegetation can be caused by a change in fire regime; in our view, a single fire in a fire-dependent system is not regarded as a disturbance, but a change in fire regime may create a disturbance. Elucidating the details of each fire regime and its effect on the vegetation presents unique problems. Some regimes provide physical data, such as sedimentary or terrestrial charcoal or fire scars; some leave historic records or circumstantial evidence, but ancient fire regimes, such as those that existed in natural lightning or volcanic eras have previously eluded investigators.

This study was designed to investigate the historic effect of changed ignition patterns on fire regime and to determine whether the vegetation has been disturbed by these changes.

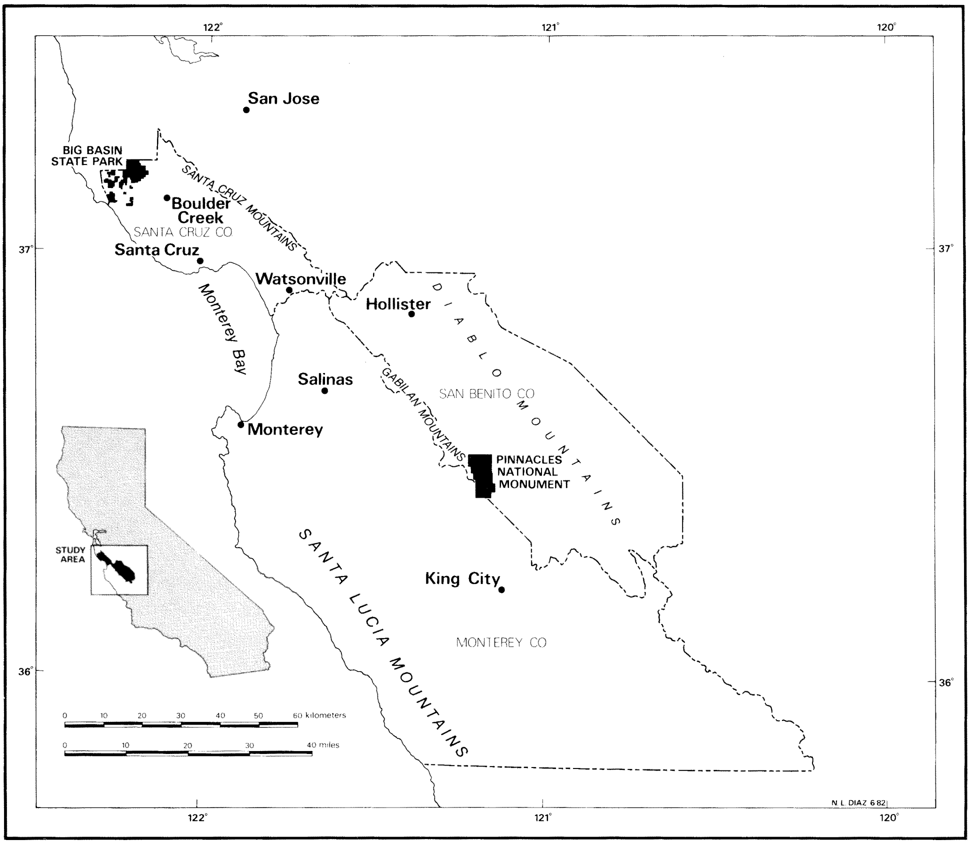

FIG. 1.—Locations in the Monterey Bay area referred to in the text.

As our investigation of the historical data suggested that one of the primary disturbances to vegetation resulted from a prehistoric event (the arrival of humans), we attempted to develop methods of analysis to investigate this event. Although most of the fieldwork was done over two field seasons in Big Basin Redwoods State Park in Santa Cruz County, we found it useful to obtain information on the Lightning, Aboriginal and Spanish fire regimes from the surrounding Monterey Bay area, which includes Monterey and San Benito counties (Fig. 1). We likewise extrapolated some of our detailed results from Santa Cruz County to the larger area.

The study area, like all of California, has a Mediterranean climate with a drought cycle that causes an annual fire season from July to November. Rainfall generally decreases both from N-S and from the coast inland, with Pinnacles National Monument (inland S) averaging 41 cm and Big Basin Redwoods State Park (coastal N) averaging 125 cm (Greenlee, 1986). Fog during the dry summer months is a significant determinant of redwood (*Sequoia sempervirens*) distribution (Cooper, 1917).

The Monterey Bay area has seven vegetation types relevant to our study: redwood forest, mixed evergreen forest, oak (*Quercus* spp.) woodlands, chaparral, coastal prairie, valley prairie, and coastal sage (Barbour and Major, 1977; Thomas, 1961). Forests are predominant in Santa Cruz County, whereas prairies and chaparral dominate the southern ranges in San Benito and Monterey counties.

Fire history in the coastal redwood community was first studied in the northern part of the range, where fire intervals were reported to be ca. 25 yr (Fritz, 1931). Veirs (1980a, b, 1982), in comparing mesic and xeric sites, found fire intervals to vary from 50–500 yr depending on the moisture regime. Fire intervals were also reported to be affected by the arrival of settlers in northern California, decreasing at one site from a mean of 13.3 yr to 7.5 yr (Stuart, 1987). In the southern range, average fire intervals of 82 yr near Big Sur (our analysis of data from Jackson, 1977), 22–27 yr in Muir Woods (Jacobs *et al.,* 1985), and 30–35 yr in Big Creek (Greenlee, 1980) have been reported.

METHODS

We distinguished in the literature on fire history for this region five fire regimes: (1) Lightning (up to 11,000 BP); (2) Aboriginal (11,000 BP to 1792 A.D.); (3) Spanish (Spanish and Mexican eras—1792–1848); (4) Anglo (1848–1929), and (5) Recent (1929 to present) (Burcham, 1957; Clar, 1959; Bennett, 1962; Wells, 1962; Lewis, 1973; Talley, 1974; Biswell, 1976; Gordon, 1977; Jackson, 1977; Griffin, 1978; Greenlee, 1980; Greenlee and Langenheim, 1980; Griffin and Talley, 1980; Keeley, 1981; Greenlee and Moldenke, 1982; Greenlee *et al.,* 1983; Jacobs *et al.,* 1985; West, 1988).

We have used both graphical and numerical methods to analyze events and present the results. For the graphical analysis, "scenarios" are presented. A scenario, as we use the term, is a map representing fire distribution and size during a fire regime. The scenario is developed from analysis of fire scars, historical documents, fire report maps or computer modeling, depending on the age of the regime. A scenario by itself contains valuable information, but the probable effect on vegetation can best be seen when scenarios from different periods are compared.

The scenario for prehuman lightning fires was developed using a fire-spread modeling technique, which is based on fire-behavior prediction methods developed for fire suppression and fire planning (Rothermel, 1972; Greenlee, 1982; Rothermel and Rinehart, 1983). First, we plotted actual ignition points of lightning fires from 1930 to 1979 on a topographic map. Because climatic conditions have apparently changed relatively little in this region in the past 10,000 yr (Johnson, 1977), we are able to use current lightning data to approximate the distribution in time and space of lightning in a former era. To simulate a fire under natural conditions (no human barriers or interference), we analyzed wind, rainfall, temperatures and relative humidity records for the periods before, during and after each ignition to characterize the conditions under which the fire burned. If calculations based on weather conditions (Rothermel and Rinehart, 1983) indicated intense fire behavior, we reasoned that fires could have crossed minor barriers, but would have been stopped by wide streams. If predicted fire behavior was less intense, we reasoned that any minor natural barrier would have stopped fires (roads and other pavement were not considered). Fire boundaries ceased to expand in the model when significant rainfall (greater than 5 cm) occurred. These assumptions are conservative, because, under some conditions, fires could have "held-over" and continued to expand after a significant amount of precipitation. The 5-cm cut-off was based on observations of naturally ignited fires in the Sierra Nevada. Where they are allowed to burn under certain conditions, fires can spread over great distances because they persist, once ignited, until the heavy autumn rains (Greenlee *et al.,* 1979).

Fire modeling was possible for the Lightning fire regime because we accepted historical data on lightning fire ignition patterns and weather conditions. Assuming both that fuel conditions in each vegetation type and that the pattern of vegetation was the same in the

Lightning fire regime as today is, of course, not possible. For this reason, any fire interval deduced would be a first approximation, and would be factored into a second run of the model with a new fuel load and vegetation pattern. This factoring and iterative modeling is particularly critical in vegetation types that are prone to rapid succession in the absence of disturbance. The physiognomic structure of these vegetation types may change in a matter of a few years (Gordon, 1977), causing different fire behavior. Without the benefit of a computer program to run these iterations, the results of our hand-drawn fire model probably are only adequate for the redwood vegetation type. Fire intervals in several of the other vegetation types in this regime were deduced from literature on their succession rates in the absence of fire (Barbour and Major, 1977), but we cannot estimate with our model how extensive these vegetation types would have been.

Modeling was not used in building scenarios for the Aboriginal and Spanish fire regimes because data were too limited to locate ignition points. In these cases, scenarios were developed by outlining those vegetation types for which historical evidence supported their being human activity. The assumption was made that these areas would have burned at least once in the 50-yr period covered by each scenario (*cf.* Lewis, 1973; Clar, 1959).

A scenario was drawn for the Anglo fire regime by searching newspapers from 1855–1929 for references to fires (Greenlee *et al.,* 1983). The place names and property owners referred to were located on old property maps. Boundaries were drawn around these known points which were plotted on a map to indicate a minimal area for each fire (*cf.* Arno and Sneck, 1977). Fire maps for the Recent fire regime were obtained from the California Department of Forestry and Fire Protection archives in Sacramento, California.

The Mean Fire Interval (MFI) (McBride, 1983) is a useful tool for describing fire regimes quantitatively. Where physical evidence for MFI is not available from fire scars on trees, the scenario approach may be helpful in estimating MFI for comparison with regimes where physical evidence is available. Using the scenario, we calculated MFI by totaling the area burned in the 50-yr scenario and dividing this value by 50 to get annual area burned. This value was divided into the total area of the present redwood vegetation type to get the frequency with which each acre would have burned. In doing these calculations, we relied heavily on the accuracy of our scenario. The same technique was used to project MFIs for the Recent fire regime.

Fire scar data were used to corroborate MFIs estimated in this manner for scenarios of the more recent fire regimes. MFIs for forested areas in the Aboriginal, Spanish and Anglo fire regimes were based on analysis of fire scars on trees in Big Basin Redwoods State Park, where a survey was made on 400 randomly located plots (*cf.* Arno and Sneck, 1977). In using fire scars to date past fires, problems can be encountered with missing and double rings in redwood (H. Fritts, pers. comm., 1982). Cross-dating of fire scars on selected samples indicated that most fire scar dates were only accurate to plus or minus 10 yr. Comparison of approximate dates from the scars with historic data allowed a more precise date to be established for recent fires. In shrub or grass vegetation types fire intervals were deduced from analysis of scenarios, from historical and anthropological sources and from circumstantial evidence.

RESULTS AND DISCUSSION

Lightning fire regime.—Modeling fire coverage in the Lightning fire regime provides a scenario (Fig. 2) indicating that lightning fires covered approximately 37% of the redwood forest (20% of the land surface) of Santa Cruz County in a 50-yr period. This suggests that the MFI in the redwood forests prior to aboriginal occupation may have been approximately 135 yr (Table 1). Although data from the fire modeling were not used for the other vegetation

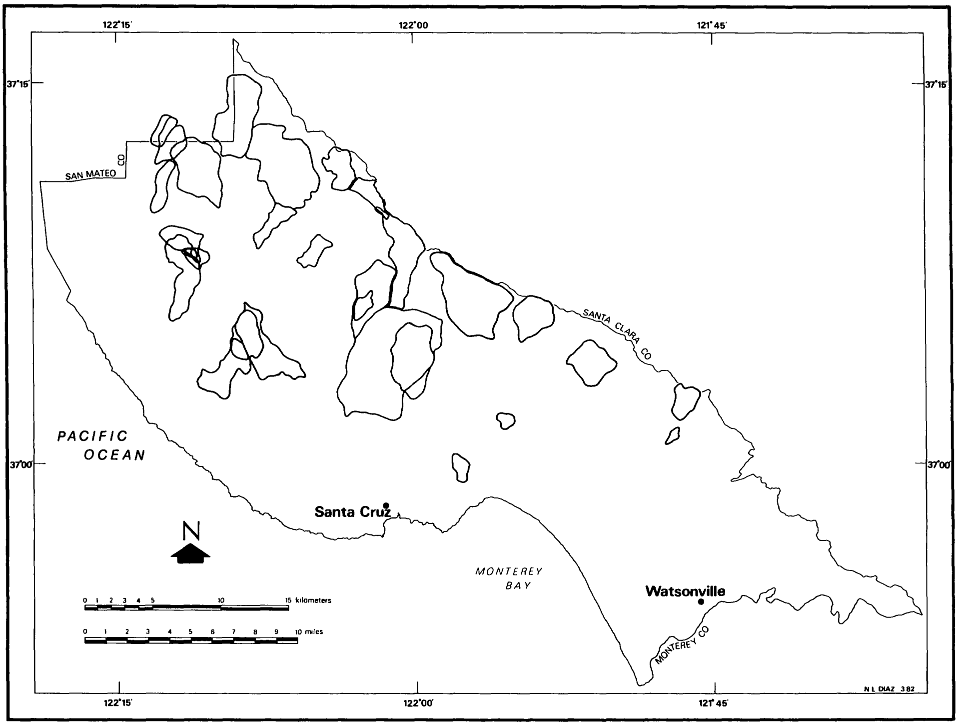

FIG. 2.—Fifty-yr coverage of possible lightning fires in the Lightning regime

types, studies in ocean deposits of charcoal may provide future data for this period (*cf.* Byrne *et al.,* 1977; West, 1988).

This scenario can be corroborated by examining the recent historical activity of lightning. From historical records, Santa Cruz County has one of the lowest recorded incidents of lightning fires in California (Keeley, 1981). From 1893 to 1979, only 101 lightning storms were recorded in Santa Cruz County, igniting 34 fires. Ninety-one of these occurred during the moist winter season, with only one fire resulting, and the remaining 10 storms started 33 fires (Greenlee and Langenheim, 1980). The same pattern applies to the larger Monterey Bay area. In the nearby Gabilan Range, 51 storms occurred from 1930 to 1979, three storms igniting 35% of the range's 142 lightning fires (Greenlee and Moldenke, 1982). Thirty-nine lightning fires were ignited from 1931 to 1977 in the Monterey County portion of the Santa Lucia Range (Griffin and Talley, 1980). Lightning fires occur throughout this region from May to October, but two peaks related to fuel moisture appear in all studies, one in June–July and the other in September–October.

Some of these ignitions show little potential for becoming large fires. For instance, 9% of the lightning fires in the Gabilan and Diablo ranges extinguished naturally, and another 37% were still small when firefighters arrived (1930–1979 fire records reviewed by Greenlee and Moldenke, 1982). Only three fires reached 80 ha and none exceeded 200 ha. In the Santa Cruz Mountains only two lightning fires reached 4 ha, both in the early part of the Recent regime (1924 and 1930), when response time of firefighters was longer. Although most lightning fires in the Santa Lucia Mountains also remained small (Talley, 1974), one

TABLE 1.—Mean Fire Intervals in various vegetation types in each historic fire regime in the Monterey Bay area. Refer to the text for explanation of our selection of localities where burning was concentrated or incidental. "Recorded or calculated MFI" data are derived from historic documents, fire scars, or published data (described in the text). "Probable MFI" data are derived, for lack of historic or physical evidence, from data from the literature (*see* text)

Fire regime	Vegetation where burning concentrated	Vegetation where burning incidental	Recorded or calculated MFI (yr)	Probable MFI (yr)
Lightning		Prairies		1–15
		Coastal sage		1–15
		Chaparral		10–30
		Oak woodland		10–30
	Mixed evergreen			30–135
	Redwood forest		135	
Aboriginal	Prairies		1–2	1–15
	Coastal sage		1–2	1–15
		Chaparral	18–21	
	Oak woodland		1–2	
		Mixed evergreen		50–75
		Redwood forest	17–82	
Spanish		Prairies		1–15
		Coastal sage		1–15
	Chaparral		19–21	
		Oak woodland		2–30
		Mixed evergreen		50–75
		Redwood forest	82	
Anglo		Prairies		20–30
		Coastal sage		20–30
		Chaparral	10–27	
		Oak woodland	50–75	
	Mixed evergreen		7–29	
	Redwood		20–50	
Recent		Prairies		20–30
		Coastal sage	155	
		Chaparral	155	
		Oak woodland	225	
		Mixed evergreen	215	
		Redwood forest	130	

fire burned 2800 ha in 1916 and two lightning fires merged to burn 72,500 ha in 1977 (Griffin, 1978). Ninety percent of the small fires have a potential as "sleeper fires"; in the absence of efforts to suppress them, they could have "held over" and emerged in dry weather to burn vast areas, particularly in prairie, coastal scrub or chaparral vegetation (Greenlee and Moldenke, 1982).

Aboriginal fire regime.—When humans entered the area, the Monterey Bay area supported one of the most dense aborigine populations in North America. Human influx began at least 11,000 yr ago, and, by the beginning of the Spanish regime, the population may have reached 26,000 (Cook, 1978). These people were tideland collectors and riverine fishermen, and they lived, hunted and traveled in the prairies and oak woodlands. Because of the presence of grizzly bears and the lack of important food resources, they often did not venture into the redwood or mixed evergreen forests. They were known to have used fire, and many investigators have discussed the possible ecological impact of their burning (Wells, 1962; Lewis, 1973; Gordon, 1977). Estimates of the frequency of aboriginal burning in California vary widely, but annual burning of prairies has been documented for the Monterey Bay area (Lewis, 1973; Gordon, 1977). Jackson (1977) found evidence for an 82-yr MFI in a southern redwood drainage during the Aboriginal fire regime (our analysis of his data). Historic documents suggest that aboriginal fires, like lightning fires, occurred in the autumn (Levy, 1978), but some spring burning could have taken place. Prairies are easily ignited during most of the dry season from June to November. Clar (1957) and Lewis (1974) have made a strong case for the use of historical records and circumstantial evidence to refute the contention that the use of fire by California aborigines was not important (Fritz, 1931). From analysis of historical records, it is now commonly agreed that, at the time of first European contact, fire was being used in California to cook, cremate the dead, burn fleas out of infested shelters, remove vegetation to make travel easier and to prevent surprise attack, flush wildlife, harass enemies, provide building material (Lewis, 1973), encourage certain plants such as hazel (*Corylus californica*) (Gordon, 1977), and reduce potential fire hazard around villages (Biswell, 1976). Circumstantial evidence supports aboriginal burning in the oak woodlands; early travelers reported that these woodlands were free of chaparral shrubs and other understory, and this effect was most likely produced by burning (Biswell, 1976). The extent of aboriginal burning in chaparral is problematic, as there is little authentic documentation.

The assumptions used to make a scenario (Fig. 3) of the coverage of fires during the Aboriginal regime are conservative. The scenario shows the aboriginal burn zone not entering inland areas; a less conservative scenario would extend the zone up many of the coastal drainages, because fires were free to advance up slopes and canyons. Fire scars originating in the Aboriginal regime, at an MFI of 50 yr (Greenlee and Langenheim, 1980), deep in Big Basin Park drainages that exceed the number that would be expected from lightning ignitions (135 yr MFI) support this view.

Although fire scars cannot be used to estimate early fire periodicity in the prairies, this vegetation type could not persist without burning (or other disturbance) at an interval from 1–15 yr (Vogl, 1977; Gordon, 1977). Grass burns rapidly, having little effect on existing trees, but suppresses further woody plant invasion by killing regeneration (Gordon, 1977). Because the Spaniards found prairies along the coast, we can assume an MFI of less than 15 yr existed here during the Aboriginal regime. Data on past fire frequencies in coastal sage are difficult to obtain, but Hanes (1971) states that sage has an MFI of 2–10 yr. From data from Vogl (1977), Gordon (1977) and Barbour and Major (1977) we drew inference on MFI ranges in several of the vegetation types not studied in detail (Table 1).

In contrast to lightning fires, aboriginal burning was more frequent and occurred in the lowlands rather than the upper slopes of the mountain ranges. Lightning fires were still occurring in the Aboriginal regime, but the natural MFI was decreased in coastal areas by the spread of accidental and deliberate human fires.

Spanish fire regime.—To develop a scenario (Fig. 4) of burning in a 50 yr period during the Spanish regime (1792–1848), we again relied on data from the entire Monterey Bay area. Although documentation of Spanish and Mexican burning is negligible (*cf.* Clar, 1959), a new regime certainly began shortly after Portola's exploration in 1769. Seven missions were established in or near the Monterey Bay area between 1770 and 1797 (Levy, 1978). As most aborigines were incarcerated in the missions, causing virtual extinction of

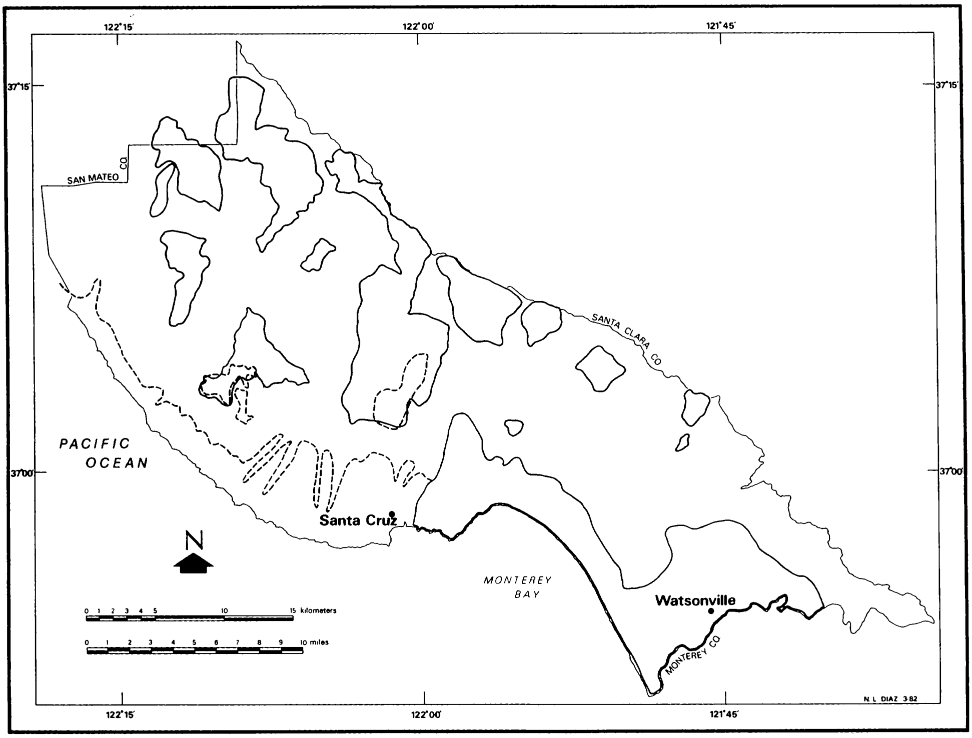

FIG. 3.—Fifty-yr coverage of possible aboriginal (dashed lines) and lightning fires (solid lines) in the Aboriginal regime

the aborigine population and its way of life, the rate of burning declined (Levy, 1978). While some aborigines were free, the government made regulations against burning to protect the summer and autumn standing hay crop, which was required for cattle (Gordon, 1977). Despite these sanctions, Spanish rancheros began to burn chaparral and oak woodlands to expand pastures (Gordon, 1977). Thus, while the Spanish curtailed grass fires to protect hay, they used fire in the bordering chaparral to expand the prairie. In the prairie, overgrazing, a change in the kind of grazing animals and grazing patterns, cultivation, and fire suppression gradually led to the replacement in most areas of native perennial grasses by exotic annual species (Burcham, 1957). This change had a dramatic consequence on fire behavior: annual grasses, though shorter, have greater density, mature by July, and burn more intensely than perennial grasses. We can assume that this change in fire behavior led to a new fire regime in prairies, one that contributed to woody vegetation removal, effects already taking place as a result of domestic grazing. Assuming that aboriginal burning was successfully curtailed on the prairies, the Spanish fire regime is best represented by frequent human ignitions occurring within the boundaries of ranchos. Lightning fires were an exception, continuing to burn in the inland regions. A less conservative scenario would show coastal fires extending deeper inland, some burning of coastal and valley prairies, and escape of some fires into the middle slope woodlands.

Anglo fire regime.—A scenario of fires in the 82-yr period from 1847 to 1929 (Fig. 5) is

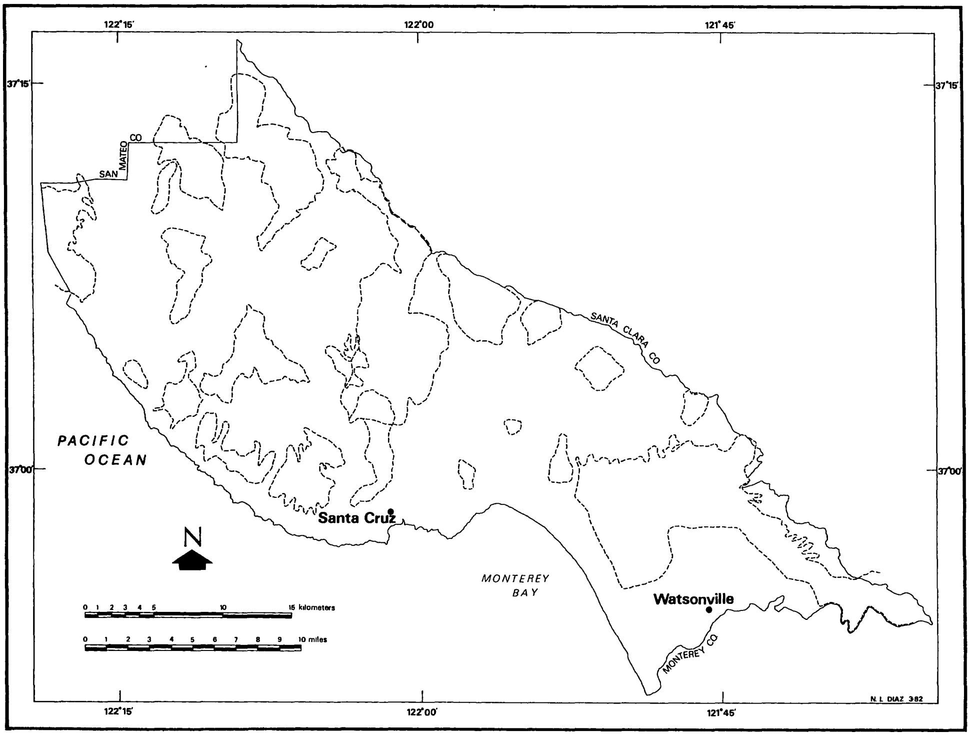

FIG. 4.—Fifty-yr coverage of possible fires in the Spanish regime

based on reports of fires in newspapers, fire records and journals (Greenlee and Langenheim, 1980). Because land use in the Anglo and Recent fire regimes was different in the Santa Cruz Mountains from the rest of the Monterey Bay area, we cannot pool the data for these regimes. As Anglos moved into the Santa Cruz Mountains, logging became a dominant activity; by 1880 50 logging mills were operating in the area. To aid removal of logs, logging slash was burned in place. Since control lines were not used, fires frequently escaped. Where these human-caused fires burned under extreme weather conditions in heavy fuels, they were not usually stopped by a change in weather or by minor barriers (Greenlee and Langenheim, 1980). Newspapers from this time described these as large, intense conflagrations, which frequently became crown fires (Greenlee *et al.*, 1983). Fires often escaped control; by 1888 the State Forester considered escaped logging fires to be a major problem (Anonymous, 1888). Simultaneously, Anglo stockmen in the south and on the coast continued the practice of burning chaparral. The southern ranges had little timber, but burning was used extensively in attempts to convert chaparral into pasture and farmland. These, too, were hot fires, harmful to soil structure, and they probably increased erosion and ultimately encouraged widespread invasion of chaparral into the region (Dodge, 1975). California chaparral usually burns in the dry season, with extreme fire behavior occurring in September and October, especially if fire suppression has been successful in the area (Griffin, 1978). Fires in chaparral kill any commingling trees and occasionally cause chaparral invasion in forest understories. Fire would be required every 10–40 yr in California today to maintain a chaparral cover (Vogl, 1977).

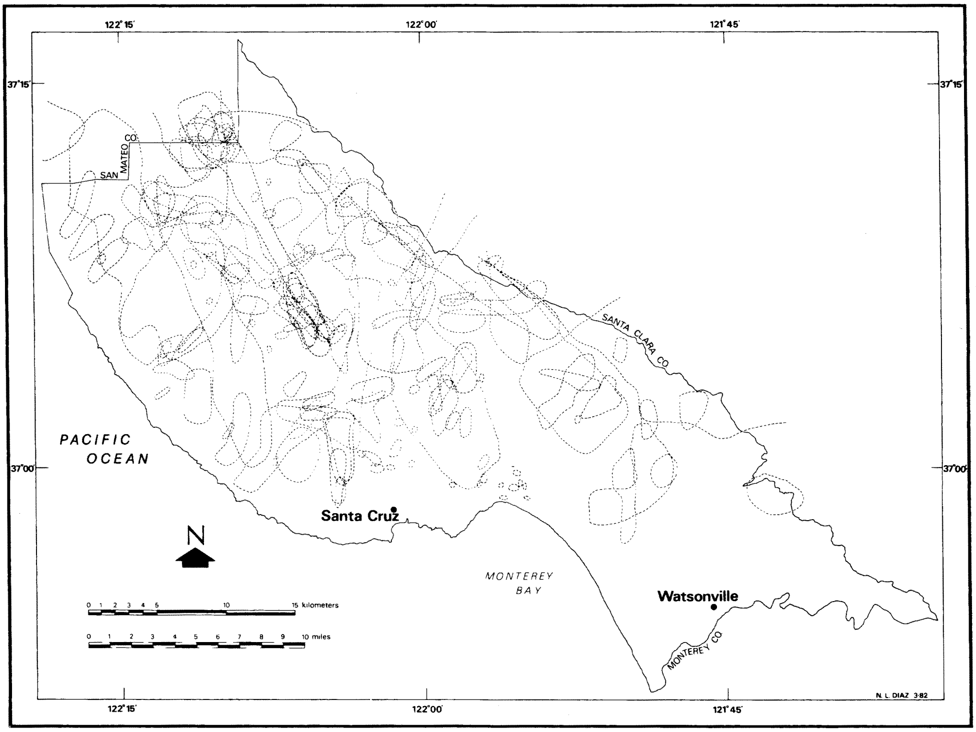

FIG. 5.—Eighty-two-yr coverage of burning in the Anglo regime

Fire scars dating from the Anglo regime support our scenario in indicating that the entire logged inland portion of the county was burned over at least once and, in many places, two or three times during this regime. In contrast to the Aboriginal and Spanish eras, these fires generally occurred in the inland rather than in the coastal zone, and were larger, more frequent and more intense than previous lightning fires.

Recent fire regime.—As the legislature moved to end the massive burning, both deliberate and accidental, a new fire regime began in 1929. In the 50-yr period (1929–1979) of the Recent fire regime (Fig. 6), fire coverage in Santa Cruz County was greatly reduced (Greenlee *et al.*, 1983). Laws punishing anyone who allowed a fire to enter another's property were enacted, and fire companies worked to improve their ability to respond to wildfire calls (Clar, 1959). In Santa Cruz County in the Recent regime, 3765 fires burned only 21,500 of the county's 115,000 ha from 1929 to 1979 (19% coverage, Fig. 6). Ninety-two percent of these fires were less than 4 ha. In contrast, the ranges S of the Santa Cruz Mountains continued to have large fires. In the Gabilan and Diablo ranges (an area of 530,000 ha), 3483 fires burned 214,200 ha (40% coverage) from 1929 to 1979. Fires tend to be much smaller in the Santa Cruz Mountains; the largest fire in the southern ranges was a 72,500-ha lightning fire at Big Sur in 1977, whereas the largest in Santa Cruz Mountains was an 8000-ha fire in 1948. Fire scars and tree age distribution in Pinnacles National Monument (Biswell, 1976; Bennett, 1962; Greenlee and Moldenke, 1982) and on Junipera Serra Peak (Talley, 1984; Griffin and Talley, 1980) indicate that fire intervals in chaparral near King City, California, are less than 50 yr.

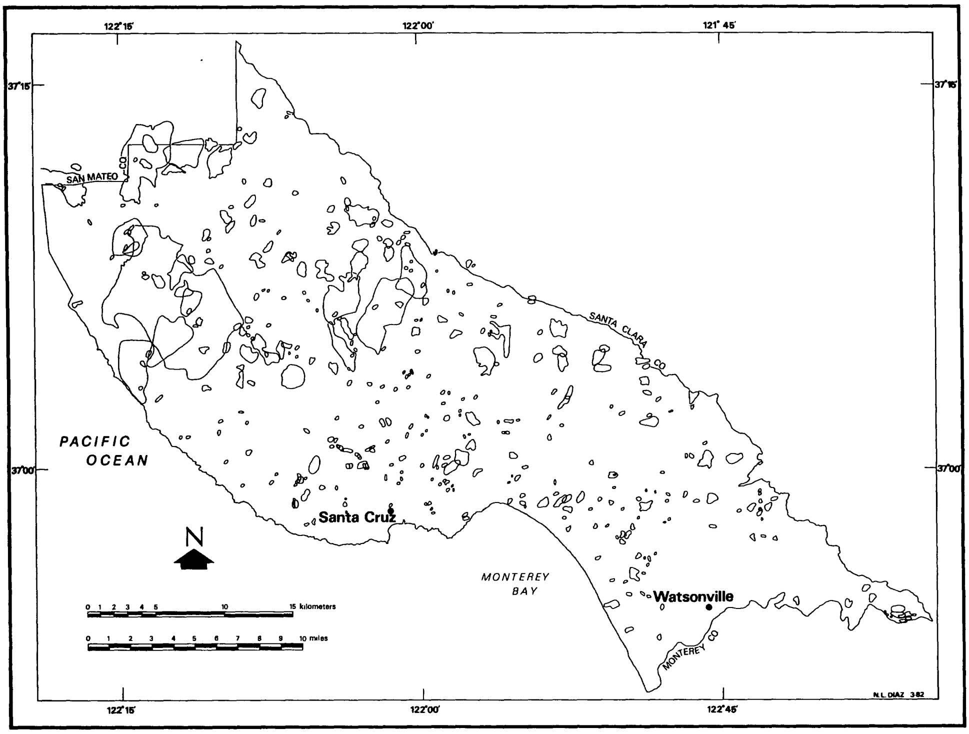

FIG. 6.—Fifty-yr coverage of burning in the Recent regime. Fires less than 4 ha are not mapped

Moisture gradient within two fire regimes.—In comparing our data with those of other investigators, we found a possible relationship of fire interval with moisture gradient. Our fire scar data in the southern coastal redwood forest of Big Basin Redwoods State Park for the Anglo and Recent regimes compare well with other reports from this southern region. In Big Creek State Reserve, which is also close to the southernmost extent of redwood, fire scars indicated short MFIs in the Anglo and Recent fire regimes (Greenlee, 1980). Of five locations sampled, MFI in the Anglo fire regime averaged 33 yr (range 23–50), and MFI in the Recent fire regime averaged 34 yr (range 23–56). Data from Muir Woods, also near the southern extent of coastal redwoods, reveal a 20-yr MFI in the southern range of redwoods during the Anglo fire era (Jacobs *et al.,* 1985). These reports tend to confirm that MFIs are relatively small in the southern range of redwoods. A different pattern appears, however, when data from the southern end of coastal redwood distribution are compared with some northerly mesic sites, where Veirs (1980b) reports MFIs as long as 500 yr. This observation agrees with that of Stuart (1987), who states that fire frequency in the coastal redwood forest is a function of the climatic gradient from mesic to relatively xeric sites.

Fire regime as an influence on vegetation pattern.—While MFI within a fire regime may vary with a moisture gradient, our data indicate that changing patterns of ignition have created at least three more or less distinct fire regimes. Data from the qualitative scenarios and quantitative MFI differences in the five fire regimes, suggest changes in vegetation that correspond with variation in the fire regimes. Our evidence indicates that a pattern of long MFIs, which occurred before human arrival, was disturbed by human burning, and has

TABLE 2.—Burned acreage in major vegetation types in Santa Cruz County in the Recent fire regime, 1929–1979

Vegetation type	Total ha burned in 50 years	Total ha in Santa Cruz Co.	Percent burned in 50 years	MFI
Prairies	1600	36,336	4.4	1100
Chaparral/coastal sage	4000	12,351	32.4	155
Oak woodland	4150	18,604	22.3	225
Mixed evergreen	3650	15,727	23.2	215
Redwood forest	8100	21,574	37.5	130

been restored in the last century by fire suppression. As an example, MFI in coastal redwood appear to have dropped from ca. 135 yr in the Lightning fire regime to ca. 50 yr in Aboriginal, Spanish, Anglo and Recent regimes. In the Recent regime, the MFI in the redwood vegetation type is trending back to 130 yr in the Santa Cruz Mountains. Because of efficient fire suppression, prairies also are not burning at previous rates in the Recent fire regime. From 1929 to 1979, only 1600 ha of the prairies, an average of 50 ha/yr burned in Santa Cruz County (Table 2). If this trend were to continue, it would take 1100 yr for the 36,000 ha of prairie in Santa Cruz to burn just once. In the absence of other disturbance, such a long MFI would cause vegetation succession to brush (*Baccharis pilularis*) cover within 15 yr (Vogl, 1977; Gordon, 1977). In Big Basin Redwoods State Park prairies protected from domestic grazing and fire are, in fact, disappearing. The same may be happening to the chaparral vegetation type, which requires fire each 20 to 40 yr, depending the slope and exposure (Sweeney, 1956; Vogl, 1977). In the Recent fire regime, MFI in chaparral may be as great as 155 yr in the Santa Cruz Mountains, and we observed in Big Basin that douglas fir (*Pseudotsuga menziesii*) is invading chaparral as a result (Greenlee *et al.*, 1983). Based on these observations and on our estimates of prehuman fire occurrence, we propose that chaparral and prairies are now much smaller than in the early part of this century, when human burning must have greatly expanded these two vegetation types to their peak coverage. This increasing MFI also suggests that we can expect more intense fires in the future, as described by Griffin (1978).

Fire history methods.—Researchers in the fire history of coastal redwoods have employed an interesting array of tools (*cf.* Alexander, 1979, 1980; Mastrogiuseppe *et al.*, 1983). Traditionally, derivation of MFI in the coastal redwoods has relied heavily on fire-scar dating (Fritz, 1931; Jacobs *et al.*, 1985). Clar (1959) and Lewis (1973), however, used historical records to describe fire use and periodicity. Veirs (1980a, b) and Stuart (1987) used the age of unburned trees to help develop a fire history. Rice (1985) used the shape of fire scars to investigate the possible intensity of past fires. Several (Jackson, 1977; West, 1988; Zinke, 1964; Russell, 1983) have contributed the use of charcoal dating. The possible use of modeling, however, has not been proposed. We have offered here two modeling techniques that may contribute to the understanding of the historic effects of fire in redwoods and other vegetation types: (1) Fire modeling to investigate the periodicity of prehuman lightning fires, and (2) estimates of fire coverage from graphic scenarios of early fire regimes.

It seems clear that an interpretation of the present mosaic of vegetation patterns in Santa Cruz County and adjacent areas of the Monterey Bay is greatly enhanced through an understanding of fire history. The use of fire modeling, as demonstrated on part of the study area, provides insight on prehuman fire coverage. The methodology employed here as an example of fire modeling is relatively crude compared to technology we see approaching.

When fire behavior can be computer-modeled (*cf.* Albinet *et al.,* 1986), it will be enhanced by the automatic production of scenarios and by iterative sequencing of model runs. Other techniques, such as pollen, phytolith and charcoal analysis, would be valuable in verifying data on fire frequencies from computer modeling (*cf.* Adam *et al.,* 1982). Adding historical investigations and fieldwork to the results of the modeling provides reasonable scenarios of more recent historic fire regimes. The use of fire-behavior modeling in fire history studies may allow an indication of the patterns of prehistoric fires for periods for which we have no other evidence. This information is valuable in assisting researchers and managers in understanding the "natural" role of fire in ecosystems.

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