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Native American impacts on fire regimes of the California coastal ranges

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Abstract

Aim Native American burning impacts on California shrubland dominated landscapes are evaluated relative to the natural lightning fire potential for affecting landscape patterns.

Location Focus was on the coastal ranges of central and southern California.

Methods Potential patterns of Indian burning were evaluated based upon historical documents, ethnographic accounts, archaeological records and consideration of contemporary land management tactics. Patterns of vegetation distribution in this region were evaluated relative to environmental factors and the resilience of the dominant shrub vegetation to different fire frequencies.

Results Lightning fire frequency in this region is one of the lowest in North America and the density of pre-Columbian populations was one of the highest. Shrublands dominate the landscape throughout most of the region. These woody communities have weak resilience to high fire frequency and are readily displaced by annual grasses and forbs under high fire frequency. Intact shrublands provided limited resources for native Americans and thus there was ample motivation for using fire to degrade this vegetation to an open mosaic of shrubland/grassland, not unlike the agropastoral modification of ecologically related shrublands by Holocene peoples in the Mediterranean Basin. Alien-dominated grasslands currently cover approximately one-quarter of the landscape and less than 1% of these grasslands have a significant native grass presence. Ecological studies in the Californian coastal ranges have failed to uncover any clear soil or climate factors explaining grassland and shrubland distribution patterns.

Main conclusions Coastal ranges of California were regions of high Indian density and low frequency of lightning fires. The natural vegetation dominants on this landscape are shrubland vegetation that often form dense impenetrable stands with limited resources for Native Americans. Natural fire frequencies are not high enough to maintain these landscapes in habitable mixtures of shrublands and grasslands but such landscape mosaics are readily produced with additional human subsidy of ignitions. It is hypothesized that a substantial fraction of the landscape was type converted from shrubland to grassland and much of the landscape that underwent such type conversion has either been maintained by Euro-American land management practices or resisted recolonization of native shrublands. It appears that these patterns are disturbance dependent and result from anthropogenic alteration of landscapes initiated by Native Americans and sustained and expanded upon by Euro-American settlers.

Keywords
Burning, fire, Indians, chaparral, coastal sage scrub, lightning, landscape history, Native Americans, type conversion.

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INTRODUCTION

Understanding the historical pattern of human impacts on landscapes is critical to correctly interpreting the ecological basis for vegetation distribution (Christensen, 1989). In some cases such as the Mediterranean Basin there has been a long intense utilization of resources that has greatly altered the distribution of forests and woodlands (Bottema *et al.*, 1990; Redman, 1999; Grove & Rackham, 2001). Throughout that region reliance upon an agropastoral existence since at least mid-Holocene has intensified the use of fire for the opening of closed canopy woodlands and increasing herbaceous associations (Pignatti, 1983; Naveh & Kutiel, 1986; Vernet, 1990; Lepart & Debussche, 1992). In North America, the history of such landscape impacts has been briefer, and there is considerable debate on the degree to which Native Americans altered vegetation distribution.

Prior to European colonization, North American Indians were heavily dependent upon a hunter-gather subsistence and one of the few tools for managing resources was fire. While there is some agreement on the use of fire, there has been a long debate on what impact Indian use of fire has had on the landscapes encountered by the first European settlers. Some contend that Indian use of fire had dramatic and widespread impacts on our landscape, and many of these anthropogenic patterns are still evident in the distribution of vegetation types (Denevan, 1992; McCann, 1999; Bonnicksen, 2000). In contrast, Vale (1998, 2000) has argued that the much of North America was little affected by indigenous populations prior to Euro-American colonization. He accepts a role for Native American burning in shaping eastern US landscapes, but has stated (Vale, 2000) that 'in the dry American West, the frequency of lightning ignitions is so high – an annual average of 5125 lightning fires in the national forests of the eleven western states alone in recent decades – that whatever additional burning was done by Native Peoples may have altered vegetation in only limited areas'. In his view (Vale, 1998), Indians might have altered landscapes in the immediate vicinity of villages (e.g. Yosemite Valley) but did not affect larger regions (e.g. the Sierra Nevada mountain range).

NATIVE AMERICAN BURNING AND BACKGROUND LIGHTNING-IGNITED FIRES

The suggestion that Native Americans have not markedly changed western US landscapes is based on two considerations dealing with the density of both lightning fires and pre-Columbian populations.

The number of lightning-ignited wildfires cited by Vale (2000) is a seemingly large quantity, although less impressive when expressed as a density of roughly 1 fire per 12,000 ha per year. It is debatable whether or not this density is sufficient to burn all available fuels at a frequency that saturates the environment to the extent that human ignitions were insignificant. More importantly, lightning-ignited fires are clumped in both time and space (Komarek, 1967; Main & Haines, 1976). On a regional scale they are very high in large parts of the southwest and very low in the coastal ranges of the Pacific slope (Fig. 1), opposite the regional pattern for native peoples prior to Euro-American contact (Krech, 1999). On a local scale lightning-ignited fires increase with elevation (Komarek, 1967; Vankat, 1985; van Wagtendonk, 1994), typically opposite the distribution of native peoples. The potential for Indian burning impacts being overshadowed by background lightning-ignited fires is seemingly greatest in the mountains of the southwest, and far less in the coastal ranges of central and southern California.

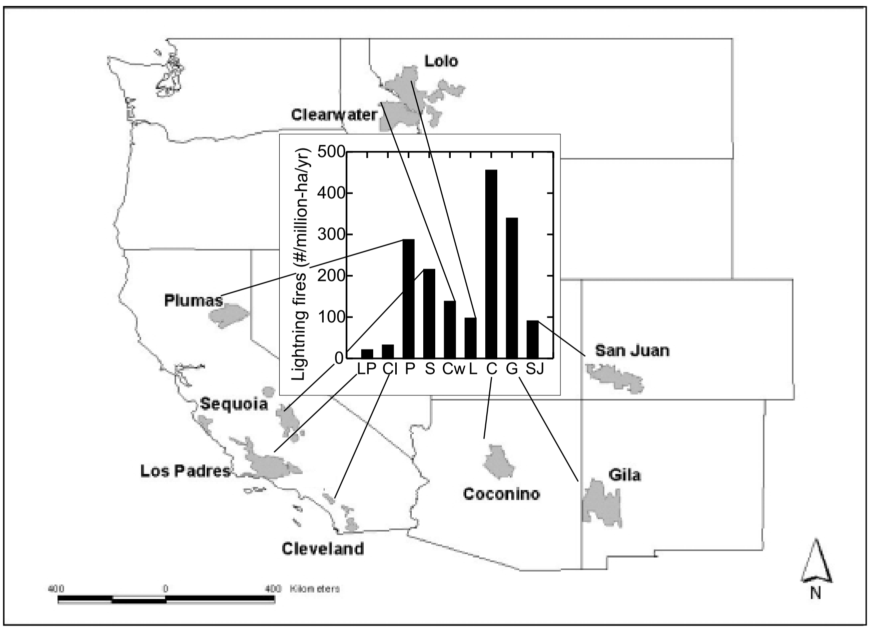

Figure 1 Lightning fire incidence on selected national forests in the western US national forests; abbreviated as follows: SJ = San Juan in Colorado, G = Gila in New Mexico, C = Coconino in Arizona, Cw = Clearwater in Idaho, L = Lolo in Montana, P = Plumas in California, S = Sequoia in California, LP = Los Padres in California and Cl = Cleveland in California. Data on lightning fire incidence are from the National Forest Fire Reports, 1970–79, USDA Forest Service, Washington, DC. Data on forest area from http://www.fs.fed.us/research/.

The second part of Vale's (2000) argument concerns the pre-Columbian 'North American population of 3.8 million', which he contends could not have occupied much living space and, because of their highly clumped distribution, were absent from the bulk of the landscape. He calculates that 'only about 0.02% of the combined areas of the United States and Canada' were directly exploited, e.g. for agriculture. However, the land area affected by burning was potentially orders of magnitude greater as a single human ignition is capable of spreading fire far beyond the point of origin. This is particularly true in the coastal ranges of central and southern California, where the worst synoptic fire weather conditions in the country occur annually (Schroeder *et al.*, 1964).

IMPACT OF NATIVE AMERICAN BURNING ON SHRUBLAND VEGETATION OF THE CALIFORNIA COASTAL RANGES

I hypothesize that Native American burning in the coastal ranges of central and southern California subsidized natural lightning ignitions to the extent that landscape patterns of grassland and open shrubland were significantly increased. Bendix (2002) has recently addressed a related but different question; whether fire prone chaparral is a 'human artefact' best explained by Indian burning. I concur with his conclusion that one need not invoke Native American burning to explain the existence of this vegetation type and that in the absence of humans 'fire would burn a given stand on time scales of decades to centuries'. However, I will argue that Native Americans greatly accelerated this natural fire frequency on shrubland dominated landscapes. As a consequence, shrublands were thinned-out or displaced and over a sizeable portion of the landscape, the physiognomy changed from shrubland to grassland. My arguments are based upon the following considerations: (1) natural lightning-ignited fire density is low relative to much of the western US. (2) Native American populations were large and widely dispersed. (3) Shrublands dominate the landscape throughout most of the region and have weak resilience to high fire frequency, and are often displaced when fires occur more than once or twice a decade. (4) Relative to herbaceous communities that establish under higher fire frequencies, undisturbed shrublands provided fewer resources and greatly limited access to those resources that were utilized by Native Americans. (5) In the absence of agriculture, fire was the only significant land management tool available to the pre-Columbian Californians. (6) Ecological studies during the last century have provided evidence of anthropogenic alteration of landscape patterns, in particular replacement of shrublands with herbaceous associations.

Natural lightning-ignited fire density

The distribution of lightning-ignited fires (Fig. 1) illustrates that the coastal ranges of California have at least an order of magnitude fewer such fires than interior ranges of California and much of the western US. This pattern derives from the fact that coastal foothills are cooled sufficiently in the summer to inhibit convective lightning storms and those resulting from winter frontal systems fail to ignite fires because of high fuel moisture (Conroy, 1928; Greenlee, 1983). Within the coastal ranges, summer lightning-ignited fires tend to clump in the higher mountains and decrease with elevation (Keeley, 1982; Greenlee, 1983), as does the elevational distribution of lightning strikes (Fig. 2). Lightning fires largely ignite fuels in forests and fewer than 20% ignite in shrublands (Keeley, 1982; Bendix 2002). In the coastal Santa Monica mountains of southern California no lightning-ignited fires are recorded in a 60-year fire record and similar patterns of few or no lightning fires are seen in other fire records from the coastal ranges (Keeley & Fotheringham, 2001a).

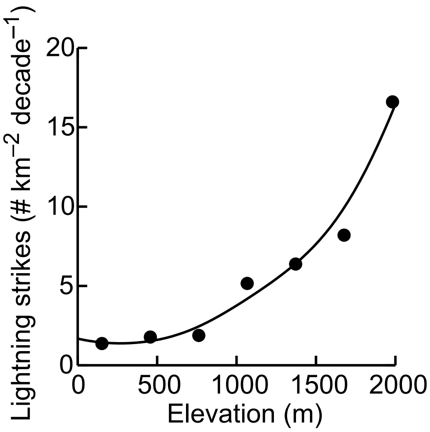

Figure 2 Elevational distribution of lightning strikes in San Diego County, California, based on the Automated Lightning Detection System of the Bureau of Land Management (corrected data from Wells & McKinsey, 1995; according to M. Wells, personal communication, 1999, the values in the original paper are one order of magnitude too high). In this region only about 2–5% of lightning strikes result in fire (Minnich *et al.*, 1993).

The natural fire regime in the absence of contemporary human subsidy is thought to have varied both spatially and temporally, with some parts of the coastal ranges perhaps experiencing century-long fire-free periods, in contrast to interior montane landscapes where fire return intervals were shorter and more predictable. Modelling studies conclude that in the central coastal region fire return intervals from just natural lightning ignitions were substantially longer than when Native Americans were present on the landscape (Greenlee & Langenheim, 1990). Fossil pollen from the central coastal ranges has also been interpreted as providing evidence for burning by Indians (Byrne *et al.*, 1991; Mensing, 1998). Other circumstantial evidence of Native American influence is from charcoal deposition studies that show, prior to European colonization, the frequency of large fires in the front range of the Santa Ynez Mountains of Santa Barbara County was similar to the contemporary period (Mensing *et al.*, 1999). Today humans are responsible for the vast majority of ignitions in this region (Keeley, 1982), suggesting that Native Americans likewise were a dominant source of ignition.

Native populations in California

Since the early Holocene, native peoples were distributed throughout the southern and central coastal ranges of California (Erlandson, 1994). By the time of contact with Europeans, they had expanded to occupy most readily inhabitable sites (e.g. Beals & Hester, 1974a; Jones, 1992) and produced population densities among the highest in North America. The density of pre-Columbian people in California was, as is the case with contemporary populations, many times greater than most other parts of the West (Krech, 1999), e.g. the estimated peaks between 310,000 and 350,000 in California (Baumhoff, 1963; Cook, 1978) vs. 25,000 in Montana (Baker, 2002). Unlike the sparse clumped pattern described for the Sierra Nevada (Vale, 1998), Indians had substantially higher population densities and were more widely dispersed along the coast (Fig. 3) and throughout the coastal foothills and valleys (Fig. 4), averaging one to three (sometimes eight) persons per km^2 (Cook, 1951, 1978; Beals & Hester, 1974b).

California was noted for its extraordinary diversity of tribes, with sixty to eighty mutually unintelligible languages spoken in the state (Shipley, 1978), and each tribe maintaining strict boundaries separating their resources from other tribes. Kroeber (1925; p. 601 and 636) described it this way for two tribes in southern California, 'the Kawaiisu were pressed close against a variety of neighbours [Yauelmani, Yokuts, Tübatulabal, Serrano, Chumash].... The Juaneño Indians ... were wedged in between the Gabrielino and the Luiseño'. In fact, some have argued that the sedentary lifestyle of these hunter-gatherers was forced upon these peoples because of over-crowding (Cohen, 1981). It appears that most-all valleys and adjacent drainages with at least seasonal water flow were inhabited partly or all the year round. Settlements of 10–250 individuals comprised politically autonomous lineages with families in widely scattered houses on cleared sites. Each family had fields in its home valley, usually in the form of wedges extending from the valley bottom up to the crest on each side of the drainage (Bean & Shipek, 1978; Shipek, 1993). Because of vagaries in the weather, food resources varied from year to year and the zone of exploitation needed to be large enough to accommodate poor resource years; thus families also maintained fields at scattered locations within a half-day walk. Within this 'home range' individuals claimed exclusive exploitation privileges that were jealously guarded (Beals & Hester,

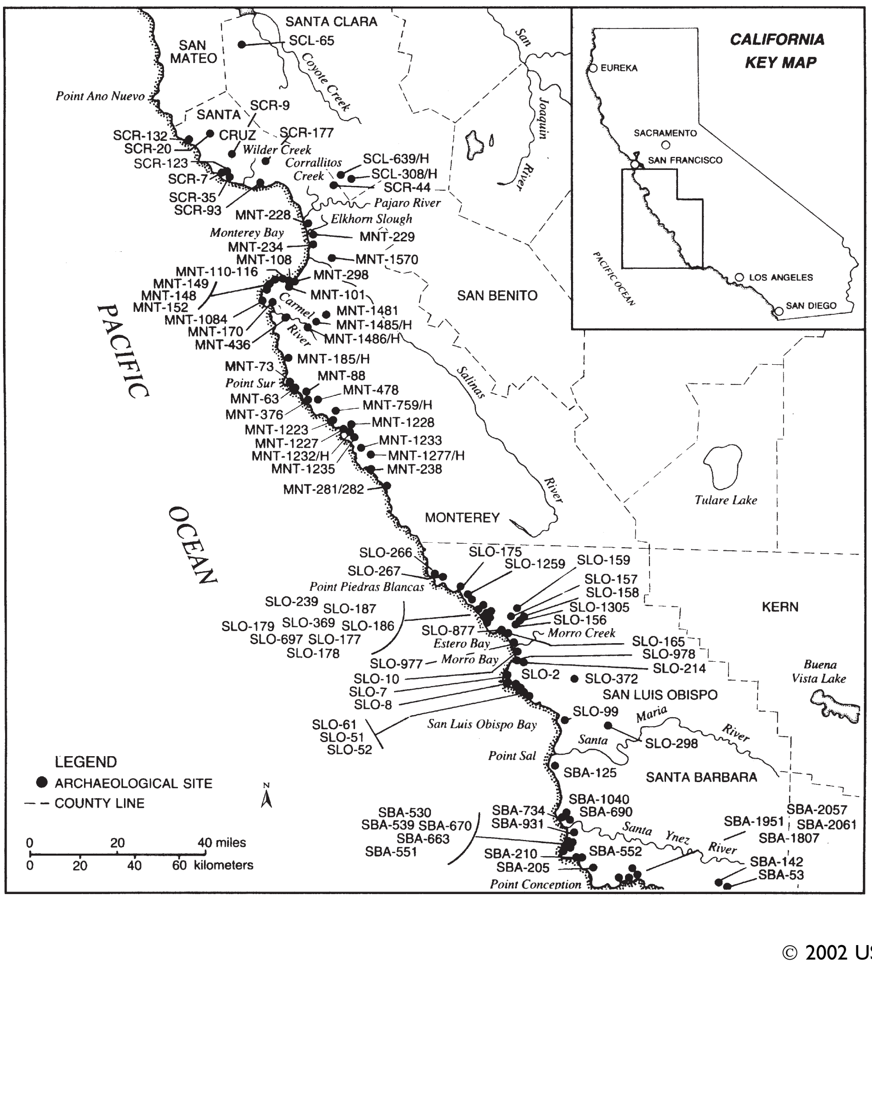

Figure 3 Central California coast archaeological sites (from Erlandson & Glassow, 1997). While the archaeological sites illustrated here may not all have been occupied at the same time, they do illustrate the potential for widespread Indian influence (reproduced with permission of the Institute of Archaeology, University of California, Los Angeles, CA).

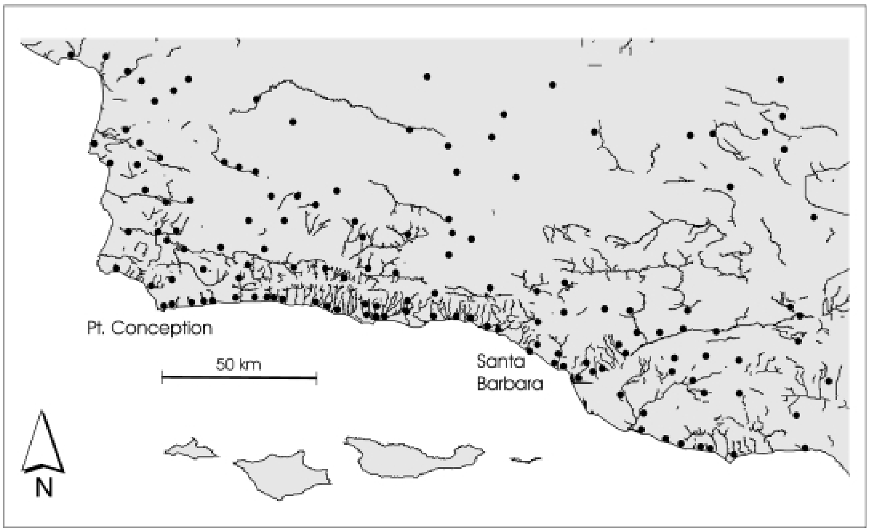

Figure 4 Approximate distribution of mainland Chumash villages (closed circles) in central coastal California at the time of European colonization in 1769 (redrawn from King, 1975; Gamble, 1991). Coastline, streams and contemporary place names also indicated.

1974a). Resource limitations occurred often enough to induce intertribal conflicts on a frequent basis (Sparkman, 1908; White, 1963; Levy, 1978; McCorkle, 1978). Many violent deaths during the late Holocene have been interpreted as resulting from population pressures (Fiedel, 1992; L. Keeley, 1996) and most accounts of warfare list resources as one or the only reason for conflict (James & Graziani, 1991). This and other patterns suggest people were 'living at or near the carrying-capacity of their local environments' (Baumhoff, 1981; Erlandson, 1997).

How much land area was directly exploited by Native Americans? Kroeber (1962) considered no land was truly 'uninhabited', rather lands only varied in the intensity of their utilization, either for subsistence or other 'customary purpose.' For inland southern California Luiseño it was suggested that only about 5% of the total territory area was unused (Beals & Hester, 1974c). Intensively utilized portions of the permanent geographical territories averaged approximately 85 km^2 (White, 1963). Considering a typical settlement pattern (e.g. Fig. 5), it is apparent that a significant portion of the landscape was potentially influenced by the indigenous populations. This zone of impact would have likely varied dependent upon annual resource availability, expanding greatly during periods of drought (Shipek, 1981).

This zone of impact has been described by Anderson *et al.* (1998) as follows: 'Every part of the region had long been discovered, walked, or settled by native people by the time Spaniards first landed on the shores of San Diego Bay'. On the surface this may seem to be a bit over-stated, but perhaps not. For example the archaeological record in San Diego County has over 11,000 Indian sites documented, and the widespread dispersion of human activity is illustrated by the fact that these sites occurred within all thirty-two US Geological Survey (USGS) 7.5 min quadrangles studied by Christenson (1990) and on all fifty-nine soil types present within the Kumeyaay (Diegueño) territory. Christenson's studies of settlement patterns showed that two-thirds were distributed in the coastal valleys and foothills and the remainder in the mountains. Average elevation was 750 m and 64% of the sites were located in what currently is chaparral or coastal sage scrub vegetation. On average, sites were within 135 m of a water source, although 74% of these are currently seasonal streams.

Despite the evidence of a dominant presence on the landscape, the rugged terrain throughout the coastal ranges makes it seem likely that there were remote areas left untouched by Native Americans.

Coastal range landscapes

Evergreen chaparral and the smaller stature coastal sage scrub are the natural dominants on upland sites over much of central and southern California (Cooper, 1922; Wells, 1962; Kuchler, 1977; Holland & Keil, 1989). Coastal sage scrub typically dominates near the coast but is replaced by chaparral further inland and at higher elevations. Oak woodlands occupy more mesic slopes and valleys, often forming a mosaic with grasslands and shrublands, and decrease in extent from north to south. Most coniferous forests only occur at the highest elevations.

The original extent of native grasslands dominated by bunchgrasses such as *Nasella pulchra* and *Poa scabrella* (plant nomenclature according to Hickman, 1993) is a matter of debate (Hamilton, 1997). Today remnants persist on deep fine textured soils and there is little doubt that their former distribution was greater, although apparently of limited extent in southern California (Kuchler, 1977), possibly restricted to isolated patches, not unlike its present distribution (Huenneke, 1989; Keeley, 1990, 1993). Natural herbaceous associations dominated by annual forbs and grasses are widespread on the very arid interior margins of the central and southern coast ranges (Hoover, 1970; Wester, 1981; Schiffman, 2000). On less arid sites on coastal slopes, such annual associations are disturbance-dependent and derive from either over-grazed native grasslands or fire-induced type conversion of shrublands and

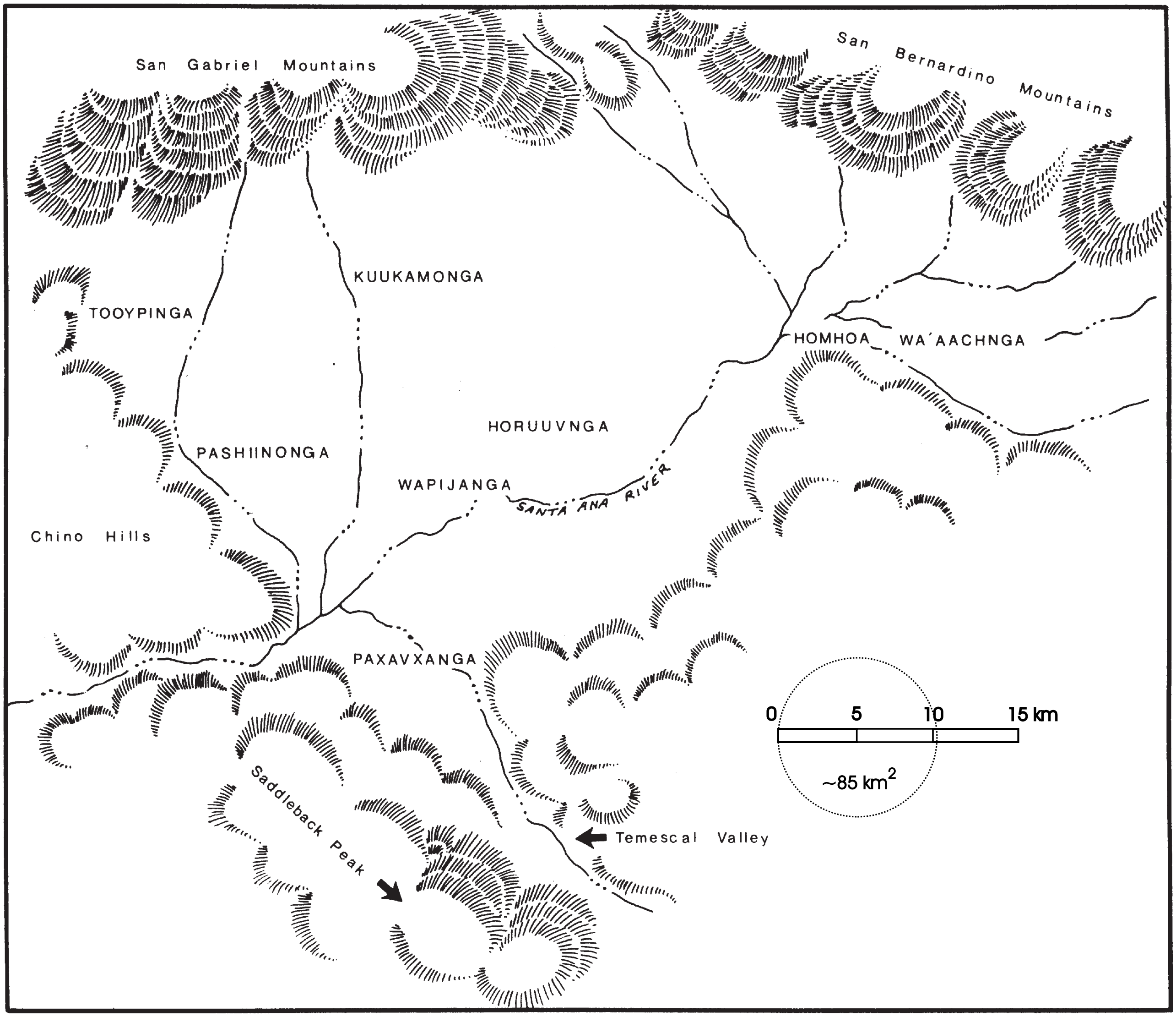

Figure 5 Gabrielino communities in the eastern end of the Los Angeles Basin in southern California (from McCawley, 1996). Included with the scale is the estimated direct impact area of 85 km^2 per settlement estimated by White (1963) for another southern California tribe. Considering the total Gabrielino territory of approximately 4200 km^2 and roughly fifty settlements it appears much of the territory was exploited. Today the portion of this landscape not developed is covered with exotic annual grassland but the natural vegetation of these plains would have been chaparral and coastal sage scrub (Leiberg, 1900; Cooper, 1922), fragments of which still persist in protected areas (J. Keeley, personal observation).

woodlands (Wells, 1962; Heady, 1977; Huenneke, 1989; Hamilton, 1997).

Chaparral is resilient to fires at intervals of two or more decades and is noted for its abundant and diverse post-fire herbaceous flora (Keeley, 2000). Shorter fire return intervals thin the vegetation by eliminating non-sprouting shrubs (e.g. the majority of *Ceanothus* and *Arctostaphylos* spp.) and promote the persistence of herbs, particularly annuals (Zedler *et al.*, 1983; Haidinger & Keeley, 1993; Stohlgren, 1993; Keeley, 2000). Continued high fire frequency can convert this herb/shrub mixture entirely to 'annual grasslands', dominated by native and non-native grass/forb associations (Sampson, 1944; Hedrick, 1951; Biswell, 1957; Bentley, 1967; Malanson & O'Leary, 1995; Fabritius & Davis, 2000). Such type-conversions are unlikely without human subsidy because lightning-ignited fires are not usually associated with weather conditions capable of spreading fire in young stands of chaparral (Minnich, 1987; Keeley *et al.*, 1999; Keeley & Fotheringham, 2001b).

Coastal sage scrub also has an abundant ephemeral post-fire herbaceous sere dominated by annuals, but often with a greater representation of perennial grasses, including the bunchgrass *N. lepida* and rhizomatous *Leymus condensatus* and *Agrostis* spp. (Keeley, 2000). Coastal sage scrub is

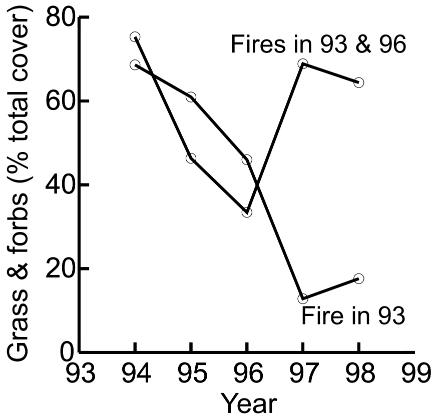

Figure 6 Post-fire coastal sage scrub abundance of forbs and grasses illustrating the typical ephemeral nature of this herbaceous component and the stimulatory effect of repeat fires 3 years apart. Both sites below 300 m adjacent to the coast in the western Santa Monica mountains (data from J. Keeley, C.J. Fotheringham, and M.B. Keeley, unpublished data).

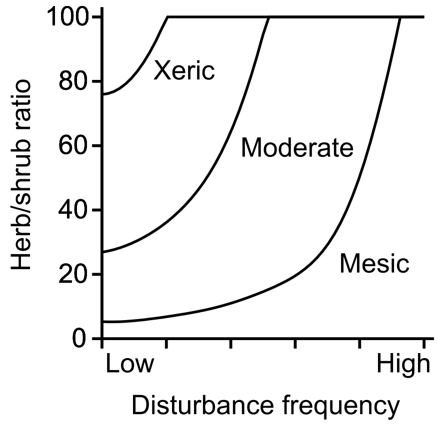

Figure 7 Interaction between soil aridity and disturbance frequency on the balance of herbs and shrubs on upland landscapes in coastal California (see for example, Cooper, 1922; Wells, 1962; Keeley, 2000).

resilient to higher fire frequency than chaparral, but fires at 3 (−5)-year intervals will promote persistence of the herbaceous component to the detriment of shrub recovery (Fig. 6). Repetition of fires at this frequency will type convert coastal sage scrub to a grass/shrub mixture (Giessow & Zedler, 1997; Minnich & Dezzani, 1998).

With respect to disturbance induced type conversion of chaparral and coastal sage scrub, there are marked interactions between disturbance frequency and other site factors. For example, on highly infertile sites, post-fire annual growth may fail to develop sufficiently to carry repeat fires, thus reducing the likelihood of type conversion. There is also a marked interaction with soil aridity, because of either climate or substrate (Cooper, 1922; Wells, 1962). At the xeric end of the soil moisture gradient, herb dominance may be unrelated to disturbance frequency, whereas at the mesic end herbs are more dependent upon repeated disturbance (Fig. 7).

Native American resources

Populations immediately along the California coast heavily exploited marine resources and those along riverine courses utilized fish for parts of the year (Erlandson, 1994). However, these as well as inland peoples, depended heavily upon terrestrial plants (Baumhoff, 1963; Beals & Hester, 1974a). At least by the middle Holocene, seeds of native grasses, forbs and acorns were a staple throughout the coastal ranges of California, as evidenced by the appearance of mortars, pestles and other milling artefacts (Erlandson & Glassow, 1997). There is documented usage of 100–200 plant species (Timbrook, 1984; McCawley, 1996), and, as in most agricultural societies today, annuals were the dominant plant resource, e.g. *Salvia columbariae* (chia), *Madia* spp., *Calandrinia* spp., *Clarkia* spp. Of these, chia seeds were a significant food source in all Indian groups in the region (Timbrook, 1986), and no wonder on a mass basis it contains three times more fat than acorns and five times more than grass seeds (Christenson, 1990).

Even for the many tribes that exploited acorns, grass and forb seeds were an absolute necessity (Baumhoff, 1963). Oaks in the coastal ranges only produce significant acorn crops in mast years at 2–5-year intervals and crop failures were synchronized over large areas (Koenig *et al.*, 1994). The marked masting behaviour of oaks raises serious questions about the extent to which native Californians depended upon acorns as a predictable source of protein and calories. Although acorns were apparently stored, there was likely a limit to the quantity and duration of successful storage. Stores must have been precarious, as they were likely vulnerable to predation by bears, particularly grizzley bears (*Ursus horribilis*, mammal nomenclature according to Burt, 1964). Native Americans shared much of the same habitat with these bears and were often in direct competition with them (Roper & Graber, 2001), illustrated by the fact that even today the less aggressive black bear may break into modern homes to obtain food resources (J. Keeley, personal observation). Thus, during years of low acorn production there would have been increased dependence on other seed sources, and this would have been for most years.

Herbaceous perennials, including bulbs and corms of geophytes and large seeded bunchgrasses, were depended upon heavily and were most readily available in grasslands or shrublands following fires. Other perennial grasses were important as food and construction material, e.g. *Leymus* (= *Elymus*) *condensatus* and *Muhlenbergia rigens* (Timbrook, 1984; Anderson, 1996). All herbaceous perennials would have been readily available after burning because post-fire regeneration is by resprouting (Keeley, 2000).

Shrubs did provide some important resources, for example seeds from woody species of sage (*Salvia* spp.) or fruits from some of the broad-leaved evergreens, primarily chaparral cherry (*Prunus ilicifolia*), toyon (*Heteromeles arbutifolia*), manzanita (*Arctostaphylos* spp.), and scrub oak (*Quercus berberidifolia*). Because of the dense spacing and divaricate branching pattern of chaparral, these resources would have been extremely hard to access in undisturbed stands.

Mule or black-tailed deer (*Odocoileus hemionus*) were potential year-round food and hide resources (Baumhoff, 1963; Beals & Hester, 1974b), but are sparse in undisturbed mature shrublands and favour open mixtures of chaparral and grassland. In the southern part of the state small game comprised a significant portion of the diet (Baumhoff, 1963). Hares (*Lepus californicus*), quail (*Callipepla* spp.; avian nomenclature according to Sibley, 2000) and mourning doves (*Zenaida macroura*) were of major importance, but avoid dense shrublands because of the lack of food resources and vulnerability to predators (Biswell *et al*., 1952). Brush rabbits (*Sylvilagus bachmani*) are common in shrublands but increase in mixtures of shrub and grassland.

According to Beals & Hester (1974c) 'The area of chaparral probably provided the most to the native economy, not because it was especially productive but because there was so much of it'. Shrubland/grassland mosaics would have been prime habitats that maximized resource biomass, accessibility of plants and animals, and firewood. Such landscape heterogeneity increased biodiversity and thus variation in food supplies. This diversity was valuable in surviving periodic droughts, some of which were severe enough to result in abandonment of settlement sites by native Californians (Jones & Kennett, 1999), or reduce populations through starvation and diminished fertility (Shipek, 1981).

Fire as a pre-Columbian land management tool

In contrast to much of the Americas, California Indians had not developed agriculture by the time of the Spanish invasion, which is surprising because such high population density and other cultural advancements are generally associated with agriculture in other parts of the globe (Diamond, 1997). Theories to explain this lack of agricultural development include limited diffusion of ideas/materials and environmental constraints of the mediterranean climate (Bean & Lawton, 1973). However, it is likely that California Indians were not motivated to develop crops because they were extraordinarily successful at managing the natural resources available (but cf. Cohen, 1981).

Shipek (1977, 1981) claims that in southern California one of the important cultural resources was a religion that rewarded knowledge on how to increase plant and animal food supplies. She pointed out that type conversion of chaparral to more open grassland/chaparral mixtures through repeated burning was the most obvious means for doing this. Likewise, Timbrook *et al*. (1982) argued that a critical adaptation of the coastal Chumash was the use of fire to convert coastal sage scrub to grassland, although they questioned whether such burning extended to inland chaparral. Others, through a combination of ethnographic accounts, historical records and inference have concluded that widespread use of repeated burning to effect type conversion of chaparral/coastal sage scrub to grassland, or maintain grass/shrub mosaics, was widespread (Longhurst *et al*., 1952; Knowles, 1953; Lewis, 1973; Baumhoff, 1978; Christenson, 1990; Anderson, 1993, 1994, 1996; Anderson & Moratto, 1996). Kroeber (1925, p. 447) described the burning of brush to promote the growth of annuals as 'The usual California practice…' The clearest documentation of this is the 1792 report by Spanish explorer José Longinos Martnez who wrote 'In all of New California from Fronteras northward the gentiles have the custom of burning the brush…' (Simpson, 1938). Additionally, there are countless other accounts of Indian burning recorded by early Spanish and American explorers in the coastal ranges (Bolton, 1927; Moraga, 1930; Fages, 1937); particularly detailed is the widely cited proclamation by the Spanish Governor Arrillaga delivered at Santa Barbara in 1793 (Clar, 1959).

Such fire-driven type conversion of shrublands was just one of the many 'intensification' processes, whereby production strategies were altered to increase exploitation of tribal territories (Bouey, 1987). In an evolutionary context this would be one additional form of cultural niche construction (e.g. Laland *et al*., 2001). I hypothesize that the primary reasons for burning in the coastal ranges were because (1) shrublands dominated much of the landscape, (2) undisturbed chaparral and coastal sage scrub provided few resources, and (3) resources that were present in shrublands were not readily accessible without burning. In addition, undisturbed shrublands had negative qualities related to, (4) their consumption of precious water resources, (5) presence as a fire hazard during autumn Santa Ana wind conditions, (6) harbouring of potentially lethal predators and enemies, and (7) as an obstacle to local travel.

The motivation for this type of land management would be the following.

Increase seed, bulb and fruit production

Post-fire shrublands and sites type converted to herbaceous associations, would have been dominated by important seed resources, e.g. *Salvia*, *Madia, Clarkia, Calandrinia*, and vegetable resources such as foliage, e.g. *Trifolium*, *Lupinus,* and bulbs/corms, e.g. *Dichlostemma capitata, Brodieae* spp., *Calochortus* spp., *Allium* spp., *Sanicula* spp., *Lomatium* spp. (Luomala, 1978; Timbrook *et al*., 1982). Following fire, diversity increases from two dozen (mostly woody species) per tenth hectare pre-fire, to as many as eighty species, largely annuals arising from dormant soil-stored seed banks (Keeley, 2000). Many have highly specific fire-related cues (Keeley, 1991). One of the most widely utilized seed resources was chia (*S. columbariae*), which often has deeply dormant seeds that are smoke stimulated (Keeley & Fotheringham, 1998). Native American's insight into these relationships is illustrated by their sowing tobacco seeds into post-fire seedbeds (Harrington, 1932). We now know that tobacco (*Nicotiana attenuata, N. quadrifolia*) germination is dependent upon exposure to smoke or charred wood, as is the case with the majority of chaparral annuals (Keeley & Fotheringham, 2000).

Repeat fires (e.g. more than one per decade) will extirpate chaparral shrubs that recruit entirely by seed (e.g. many species of *Ceanothus* and *Arctostaphylos*), and thin out facultatively seeding shrubs such as *Adenostoma fasciculatum* (Keeley, 2000). Under such high fire frequency, resprouting shrubs persist as islands in a matrix of herbaceous vegetation and these resprouters include some of the more important Native American fruit resources, chaparral cherry, toyon, manzanitas and scrub oak. Manzanitas are of interest here because there are both resprouting and obligate seeding species, represented throughout the coastal ranges by *A. glandulosa* and *A. glauca*, respectively. Just two fires in a decade will extirpate the latter, however, in terms of edible fruit tissues (Keeley & Hays, 1976) it pales in comparison with the resprouting species. Considering all of these shrubs, repeated burning reduces many of the species that are of limited value as resources and leaves those that are particularly important. There is also value added to this scenario in that these resources are far more accessible when present in isolated island remnants, plus fruit production increases following such stand thinning (Keeley & Keeley, 1988).

It is unlikely that Native Americans relied solely upon natural fires to generate post-fire herbaceous resources. The resources available in the post-fire herb flora typically lasts but a few years (Fig. 6) and natural fires in the coastal ranges occur at long intervals, perhaps only once or twice a century (Keeley & Fotheringham, 2001a). Repeated burning by Indians would maintain these herbaceous elements on the site (Fig. 6) and diminish the capacity of the woody cover to close in, thus placing the vegetation on a trajectory that favoured persistence of a strong herbaceous component. Continued burning would produce a new quasi-equilibrium, where shrub recolonization was slowed by weak seed dispersal or poor seedling establishment in grasslands (Hobbs & Mooney, 1986; Keeley, 1998). As a consequence, once the stand was opened up, less frequent burning would have been needed to preclude shrub recolonization. In other words, Horne's (1981) contention that there is no ethnographic evidence for 'annual burning of shrublands' is probably correct, i.e. once type conversion to herbaceous associations was effected, this vegetation was likely stable for a decade or longer without repeated burning (besides, 'annual burning' of shrublands is an oxymoron as this frequency of disturbance eliminates shrubs and results in type conversion to grassland).

Increase habitat for mammal resources

The hypothesis that Native Americans utilized fire to open up dense shrublands to increase deer and other animal resources is best supported by contemporary game management practices. We know from studies of deer management, that undisturbed stands of chaparral are nearly impenetrable and the new growth in older stands is commonly produced out of reach of deer (indeed, it was this observation by wildlife managers that led to the widely popular myth that old chaparral becomes senescent; Keeley, 1992). Immediately after fire the deer food available from shrubs increases 40-fold or more (Gibbens & Schultz, 1963; Hendricks, 1968) and the majority of species comprising the temporary post-fire flora are also important food resources for deer (Cronemiller & Bartholomew, 1950). Herds increase several fold in post-fire environments (Biswell *et al*., 1952), although the effect is short-lived as the vegetation closes in after 5 years (Biswell, 1961). Repeated burning produces a mosaic of grassland and shrub patches, which is ideal habitat (Salwasser, 1976), and results in a permanent three- to fivefold increase in deer herds (Taber, 1956). Other important resources such as valley quail, brush rabbits, and mourning doves increase several fold in open brush/grassland over undisturbed chaparral (Biswell *et al*., 1952), and jackrabbits, which completely avoid dense shrublands, will expand into these grassland mosaics. Opening up these shrublands would have been crucial to Native American exploitation of these animal resources because approaching prey undetected would have been unlikely in undisturbed shrublands, and lack of manoeuvrability would have prevented use of bows and arrows or the quasi-boomerang like throwing stick (McCawley, 1996).

Increase water resources

Christenson (1990) did an in-depth study of archaeological site location relative to water sources and showed that in San Diego County, 74% of the processing and habitation sites were located near seasonal watercourses. In all likelihood as the seasonal streams dried up, populations moved on, not only because of the necessity for direct access to water but because prey populations likewise would be forced to move as well. Thus, mechanisms for increasing duration of water flow would increase the annual duration that the resources in that locality could be exploited. Repeated burning and type conversion of chaparral to herbaceous associations has been shown to greatly increase annual flow from watersheds, often converting ephemeral streams to perennial flow (Veihmeyer, 1953; Biswell & Schultz, 1958; Crouse, 1961; Hill & Rice, 1963; Rowe, 1963). The primary factor is the reduction in watershed evapotranspiration and can be substantial. In one southern California study, repeated burning and type conversion of chaparral to grassland resulted in a 475% increase in summer flow (Hoyt & Troxell, 1934). There is every likelihood that many contemporary seasonal streams were capable of perennial flow under different fire management by Native Americans.

Reduce hazardous conditions

Native Americans shared the top of the food chain with the highly feared grizzly bear (*Ursus horribilis*), which was widespread throughout the valleys and foothills of the central and southern coastal ranges (Storer & Tevis, 1955; Roper & Graber, 2001). Chaparral was a favoured habitat for grizzlies and there are a sufficient number of reports of Indians being killed by these bears to explain both the general avoidance of closed chaparral stands, as well as the tendency for not travelling far from the home village (Storer & Tevis, 1955). Repeated burning to keep the brush open throughout a tribe's home range would have been prudent.

Ethnographic reports show fire was used to reduce shrublands immediately around settlements to reduce the occurrence of rattlesnakes and ambush from neighbouring Indian groups (Pilling, 1978; Davis, 1988). In addition, type conversion from shrublands to lower fuel volume grassland would have reduced fire hazard during the autumn Santa Ana wind conditions, which contributed to massive wildfires at a frequency comparable with what is observed today (Mensing *et al*., 1999).

Facilitate travel

Travel through chaparral is nearly impossible without extreme epidermal abrasion and this would have been even more pronounced for California Indians who wore little or no clothing. Additionally, the rate of movement through chaparral, as opposed to grassland, would be comparable to the difference in molecular diffusion rates through water vs. air, thus travel was generally through open land (Heizer, 1978).

Native Californians in the coastal ranges actively quarried many rock types and minerals that were used in food processing, hunting and decorations, particularly steatite, porphyry, cinnabar, tourmaline, asphaltum, clay and pigments (Heizer & Treganza, 1957; Beals & Hester, 1974b). These items were not reliably obtained through trade as conflicts with neighbouring groups would commonly disrupt trade. Exploiting local mineral resources was hindered by the fact that these rock resources were just as likely to occur in rugged areas surrounded by impenetrable brush as in more accessible areas. Thus, burning would aid in the discovery of these resources, analogous to the burning of brush commonly performed by miners in southern California during the nineteenth century (Leiberg, 1899).

Unintentional burning

Today in the coastal ranges people unintentionally cause the burning of about 220,000 ha per year (CDF, 1970–79; Keeley, 1982). While some argue that Native Americans were careful and meticulous in their use of fire, it seems unlikely in what is the worst fire climate in the USA that escaped fires did not occur fairly frequently. Not only might this occur during normal vegetation burning but the numerous ethnographic accounts of burning to capture woodrats, rabbits, ground squirrels, grasshoppers, wasp larvae, etc. all seem like risky behaviour in this regard. Such escaped fires are suggested by eighteenth century Spanish accounts of Indian burning which was described as 'universal, although on some occasions it happens that it may be greater or less, according to the winds or calm' (Burrus, 1967, cited in Timbrook *et al*., 1982). See also Horne (1981, p. 116) for an ethnohistoric account of one such escaped fire.

Anthropogenic alteration of vegetation patterns

The contemporary pattern throughout the central and southern coastal ranges of California is a mosaic of chaparral, sage scrub, grassland and oak woodland (e.g. Fig. 8). While the boundaries of these vegetations may seem timeless, there are ecological analyses that conclude disturbance has played a prominent role in their formation, patterns that may have been initiated by Native Americans and perpetuated by Spanish/Mexican and American settlers. In general, they are consistent with the hypothesis that Native Americans utilized high fire-frequency to drive type conversion from woody shrublands/woodlands to herbaceous associations.

Wells (1962) examined the substrate and slope aspect characteristics associated with grassland, shrubland and woodland vegetation in the San Luis Obispo Quadrangle of

Figure 8 Vegetation mosaic in the coastal ranges of California (photo by J. Keeley).

the central coast. Grasslands, all of which were dominated by exotic annuals, were well represented on at least half a dozen different substrates and these same substrata also supported abundant woody vegetation. Indeed, he commonly found grassland and shrubland or woodland juxtaposed side by side on the same soil type, a pattern evident in other studies (Burcham & Storie, 1957; Hill & Arkley, 1966). Wells (1962) concluded that 'since grassland, shrubland and forest occur on almost all geological substrata in the San Luis Obispo area, it is obvious that the nature of the substratum has little direct influence on the physiognomy of vegetation under this range of climate, except when considered in connection with fire', although he did acknowledge that the future trajectory induced by disturbance was affected by soil characteristics (e.g. Fig. 7). He hypothesized that the accelerated fire frequencies, beginning with the late Pleistocene human entry into California, initiated a long process of type conversion of ligneous associations to herbaceous communities. Even following cessation of disturbance, recolonization was greatly retarded because of the limited dispersal ability of many shrubs (Cooper, 1922; Wells, 1962; Keeley, 1998), and the competitive advantage of annual grasses (Da Silva & Bartolome, 1984; Davis & Mooney, 1985).

More recently Callaway & Davis (1993) have quantified the dynamic patterns inferred by Wells (1962). Using historical aerial photographs taken over a 42-year period, they were able to verify that burning increased the rate of transition from shrublands to grasslands, and in the absence of disturbance, grasslands reverted to shrublands or woodlands. They too found that soil type, while not strongly controlling vegetation boundaries, did affect the post-disturbance trajectory. Other studies of historical changes have also reported grasslands invading disturbed shrublands (Minnich & Dezzani, 1998) and shrublands re-invading grasslands following a cessation of disturbance (Hobbs, 1983; Freudenberger *et al.*, 1987).

These conclusions mirror those drawn much earlier by Sterling (1904) and Cooper (1922). The latter observed that in the central coastal range

> Mountains are controlled by chaparral and the plains by grasses. The character of the transition zone between the types is as follows: The first hills are as a rule entirely grass-covered, though even on these, and occasionally out upon the valley-floor, are patches of chaparral. These show absolutely no correlation with altitude, slope-exposure, or soil type. Their edges are sharp and the shrubs are uniformly developed throughout. They are obviously remnants…Penetrating farther into the mountain mass, the chaparral patches become more and more numerous… In short, everywhere near the valleys and plains the hills are grass, while in the depths of the ranges they are covered with scrub. The larger the extent of the mountain mass the greater is the central area of chaparral. Conversely, a small isolated area of hills, though of considerable altitude, may have none. This arrangement is so nearly universal where chaparral and grassland meet that specific examples are hardly necessary...

Cooper (1922) concluded that the mechanism driving these patterns was fire, if it occurred with great frequency, it favoured grassland at the expense of the chaparral and yearly burning would inevitably destroy the brush completely and prevent invasion by it. He hypothesized that

> The patchy transition between grassland and chaparral is also explained, for fires started in the valleys, where most of the Indian population lived, would spread into the surrounding ranges in various directions and to varying distances. Certain areas would escape, and these would be larger and more mountain systems, where paucity of population would reduce the starting of fires to a minimum.

In support of this hypothesis he noted that

> the most convincing proofs of former control of present-day grassland by chaparral are the frequent remnants… The sharply limited patches in the midst of other vegetation, in which *Adenostoma* is usually most prominent…Using this method, which has in some cases been corroborated by historical testimony, it has been possible to demonstrate that dense chaparral once covered extensive areas which are now grassland…

Other early observers noted similar patterns from other more northern coastal ranges (Sterling, 1904), and further south in the Tehacahpi Mountains, Bauer (1930) noted that

> In the grassland the islands of shrub growth, with sharp boundaries and uniform vegetative composition, indicate a more or less remote fire or fires… It is reported that in aboriginal days the natives intentionally burned the rank herbaceous vegetation yearly (Jepson '10).

Such apparently remnant islands of shrubland embedded within grassland are also reported from the northern end of the coastal ranges (Sharsmith, 1945).

Dodge (1975) studied translations of Spanish diaries written by early explorers in present day San Diego County and contended that enough site-specific detail was given to conclude that many grasslands described by these accounts are today covered by shrublands. Following Aschmann (1959), Dodge (1975) theorized that the Native Americans maintained the southern California landscape in a mixture of grassland and shrubland through repeated burning. Examples of early Spanish accounts include: 'The soil is very good; it is black, well grassed, and mellow; and the fields are thickly dotted with shrubs' (Fages, 1937), or Frey Juan Crespi's diary notes on 17 July 1769 north of San Diego 'We climbed a very grassy hill … then traveled over mesas that are in part covered with grass and in part by a grove of young oaks, rosemary, and other shrubs not known to us' (Bolton, 1927). A few days later and further north the diary describes 'we ascended a little hill and entered upon some mesas covered with dry grass, in parts burned by the heathen for the purpose of hunting hares and rabbits, which live there in abundance. In some places there are clumps of wild prickly pear and some rosemary'. Based on contemporary landscape patterns, such chaparral fragments within a grassland matrix, are most likely to result from human fire subsidy (J. Keeley, personal observations).

With the demize of the native population in the early part of the nineteenth century, fire incidence decreased and sites likely have been re-invaded by shrubs. On the mesas of coastal San Diego County Cox (1986) examined size structure of chaparral along an ecotone with grasslands and concluded that during the twentieth century chaparral has been colonizing grassland after a long hiatus of fires dating back possibly to Native American times, consistent with Dodge's thesis.

At the northern end of the central coastal region in the San Francisco Bay area there are numerous reports of shrub re-establishment into grasslands following the formation of parks and reserves, which eliminated grazing and burning (McBride & Heady, 1968; McBride, 1974; Hobbs & Mooney, 1986; Russell & McBride, in press). More vigorous suppression of natural fires is presumed to play an important role in this shrub 'invasion', but since natural lightning fires are rare in the region (for every 1000 ha in Santa Clara County there is a lightning-ignited fire only once every 200 years; Keeley, 1982), it seems more probable that shrub 'invasion' is the result of enhanced prevention of anthropogenic fires. It is likely that much of the grassland in this area originated with Native American burning as this region was densely populated with over 2000 inhabitants spread across as many as 100 village sites (Cook, 1957).

While these observations are consistent with widespread Native American impact on landscapes of the coastal ranges, assigning patterns entirely to native people is difficult because the Euro-American settlers had similar fire management practices (Barrett, 1935; Brown & Show, 1944). In some cases, this question can be addressed with historical records; e.g. the present distribution of grasslands in the San Francisco Bay area is similar to what was present at the time of the Spanish colonization (Clarke, 1959; Mayfield, 1978). Palynological records from the central coastal region are consistent with the hypothesis of anthropogenically determined type conversion during mid- to late-Holocene, although the data are also consistent with climate change explanations as well (Heusser, 1978; Russell, 1983; Byrne *et al.*, 1991; Anderson & Byrd, 1998; Mensing, 1998).

An important question is how much of the landscape physiognomy was altered by Native American burning? Answering this is challenging if not impossible. We have little way of knowing what vegetation changes occurred in some of the most heavily utilized areas because many of these are areas of contemporary development. We do not know with some certainty how much of the current exotic grassland is derived from native grassland, and how much is caused by degradation of shrublands. We do not know the extent of post-settlement changes in vegetation structure induced by Euro-American burning and grazing. Additionally, we have no estimate of the extent of reversal in Indian-induced shrubland reduction that has occurred over the past 200 years.

A starting point would be to look at the current distribution of grasslands in the ten coastal counties from Monterey southward. Today they cover almost 2 million hectares or 25% of the landscape, dominated almost entirely by non-native annuals, and less than 1% of this grassland landscape has significant patches of native perennial bunchgrass (Huenneke, 1989). If we accept the conclusions of Cooper (1922), Wells (1962), Oberbauer (1978), Huenneke (1989), Keeley (1990, 1993) and Hamilton (1997) that the origin of much of these exotic grasslands lies in type conversion from shrubland/woodland, and assume minimal expansion of grassland since Euro-American settlement, then perhaps one-quarter of the indigenous landscape was altered by fire-driven type conversion of shrublands. If we accept the view of Clements (1934), Barry (1972), Heady (1977) and others that exotic annual grasslands occupy sites that have always been grassland, then this percentage would be substantially lower. If we accept Dodge's (1975) thesis that shrublands have re-invaded many former grasslands following Euro-American settlement, then this number could be higher.

CONCLUSIONS

Indian burning in the California coastal ranges was not unique as Indians throughout North America used burning for a multitude of land management activities (e.g. Hough, 1926; Barrett, 1981; Pyne, 1982; Wickstrom, 1987; Boyd, 1999; Bonnicksen, 2000; cf. Forman & Russell, 1983). What is not so certain is the extent to which this anthropogenic subsidy to natural ignitions was sufficient to alter landscape patterns. If the case cannot be made in the coastal ranges of California, then it is doubtful whether it could be made anywhere. It is very likely that through the use of fire, Native Californians markedly altered vegetation patterns over much of the region. Further north, well into the Pacific northwest, the balance of lightning-ignited fires and pre-Columbian peoples was such that these impacts were likely experienced there as well. In light of the rather clumped distribution of both lightning and pre-Columbian people in the interior west, the question remains as to how widespread native American impacts were in the interior western US.

Despite the case for a heavy human imprint on the California landscape made here (and by others, e.g. Anderson & Moratto, 1996; Anderson *et al.*, 1998), this does not argue for a ubiquitous human presence (e.g. Denevan, 1992), or the absence of wilderness. Indeed, considering the rugged terrain and pattern of Indian impacts hypothesized by Cooper (1922), it is very likely there were significant portions of the central and southern California landscape that were remote and inaccessible, particularly as tribes did not generally occupy lands near the border of their territory (Kroeber, 1962). Indeed, such wilderness areas would have been important barriers inhibiting attacks from other tribes as most settlements were small and often lived under threat of attack (James & Graziani, 1991). There is some suggestion of remote, undisturbed areas in ethnohistoric reports of dense stands of brush on long-distance travel routes (e.g. Taber & Dasmann, 1958; Burcham, 1960). Indirect evidence of wilderness areas is suggested by the extraordinary diversity of languages in the state, which may have their origins in the isolation and long-term stability of tribelets induced by wilderness areas between groups. This is supported by the observation that the Great Central Valley, which likely had few or no remote wilderness areas, had the least language diversity in the state (Kroeber, 1925, p. 477). Pre-contact California is surpassed in the density of languages only by the island of New Guinea, where rugged topography and village isolation are believed to have played prominent roles in the evolution of language diversity (Diamond, 1992). Thus, while native Californians may have greatly altered the landscapes over broad regions, the rugged terrain of a significant portion of the coastal ranges likely remained outside their sphere of influence.

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