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Fire history of the San Francisco East Bay region and implications for landscape patterns*

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Abstract. The San Francisco East Bay landscape is a rich mosaic of grasslands, shrublands and woodlands that is experiencing losses of grassland due to colonization by shrubs and succession towards woodland associations. The instability of these grasslands is apparently due to their disturbance-dependent nature coupled with 20th century changes in fire and grazing activity. This study uses fire history records to determine the potential for fire in this region and for evidence of changes in the second half of the 20th century that would account for shrubland expansion. This region has a largely anthropogenic fire regime with no lightning-ignited fires in most years. Fire suppression policy has not excluded fire from this region; however, it has been effective at maintaining roughly similar burning levels in the face of increasing anthropogenic fires, and effective at decreasing the size of fires. Fire frequency parallels increasing population growth until the latter part of the 20th century, when it reached a plateau. Fire does not appear to have been a major factor in the shrub colonization of grasslands, and cessation of grazing is a more likely immediate cause. Because grasslands are not under strong edaphic control, rather their distribution appears to be disturbance-dependent, and natural lightning ignitions are rare in the region, I hypothesize that, before the entrance of people into the region, grasslands were of limited extent. Native Americans played a major role in creation of grasslands through repeated burning and these disturbance-dependent grasslands were maintained by early European settlers through overstocking of these range lands with cattle and sheep. Twentieth century reduction in grazing, coupled with a lack of natural fires and effective suppression of anthropogenic fires, have acted in concert to favor shrubland expansion.

Additional keywords: anthropogenic fire regime; California Department of Forestry and Fire Protection; fire climate; fire suppression; grasslands; lightning-ignited fires; Native American burning; shrublands.

Introduction

The East Bay region of San Francisco, California (Fig. 1) has had a long history of human impact beginning with Native American occupation during the early Holocene (Jones 1992). Throughout time humans have had an effect on the local ecology, first through burning by the Native Americans and later through a combination of burning and grazing by the Euro-American settlers (McMinn 1916; Clarke 1959; Roof 1971). Beginning in the early 20th century there has been an effort to alter the course of impact on selected portions of the landscape through the development of a series of parks for purposes of conservation, fire protection and recreation (Harris 1927; McBride 1970).

This landscape is a rich mosaic of grasslands, shrublands and woodlands (Fig. 2), with limited coniferous forests (McMinn 1916; McBride 1970; Edwards 2002). Currently grasslands occupy the greatest proportion of the landscape in the northern part of the East Bay (38% in Contra Costa County) with decreasing proportions southward (29% in Alameda and 17% in Santa Clara counties) (Huenneke 1989). These are mostly dominated by alien annual grasses and forbs. Native perennial grasslands are restricted to a handful of sites in the region and account for a small percentage of the total grassland area (Edwards and Havlik 1984; Huenneke 1989).

Throughout the latter half of the 20th century, alien-dominated grasslands in many of the protected conservation areas of the East Bay have decreased markedly due to colonization by shrubs and succession to woodland associations (Fig. 3). The shrub *Baccharis pilularis*, known as baccharis or coyote brush, is typically the first woody species to invade

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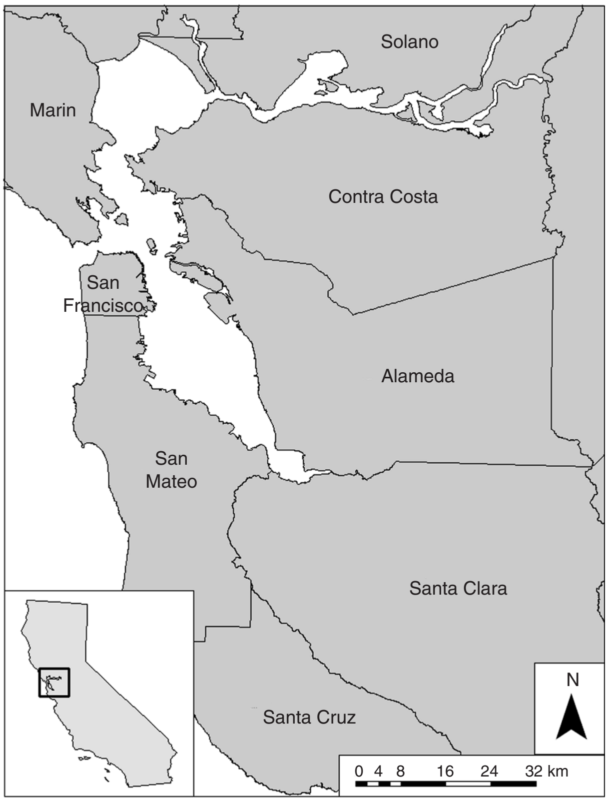

Fig. 1. The San Francisco East Bay counties included in this study. Most local residents include only the two northern counties in the designation 'East Bay'; however, Santa Clara is included here because it is a natural southern extension of this ecological region.

Fig. 2. Vegetation mosaic of alien-dominated annual grassland, shrublands and woodlands in the East Bay foothills (photograph by Oliver Pearson, courtesy of Anita Pearson).

grasslands following a cessation of grazing and increased fire protection (McBride 1964; McBride and Heady 1968). These shrubs provide suitable sites for establishment of woodland species that appear to progress through a series of replacements (McBride 1974; Safford 1995). Baccharis colonization of grasslands is in fact a widespread phenomenon throughout the central and northern coastal regions of California (Elliott and Wehausen 1974; DaSilva and Bartolome 1984; Hobbs and Mooney 1986; Williams *et al*. 1987).

It appears that cessation of livestock grazing on areas set aside for parklands has played a major role in the type conversion of grasslands to baccharis shrublands (Harris 1927; McBride and Heady 1968; McBride 1974). In addition, a reduction in burning due to fire suppression policy is thought by many to have also played a role in these landscape changes (McBride 1970; Roof 1971; Edwards 2002; Russell and McBride 2002). This model is consistent with fire-suppression induced increases in forest density demonstrated from historical photographs in many western US forested landscapes (Gibbens and Heady 1964; Gruell 1983). These forests historically burned for eons by frequent lightning fires, but a century of effective fire suppression management has all but eliminated fire, allowing increased density and expansion of forests.

The vegetation changes in the San Francisco East Bay (Fig. 3) have created landscapes with greater fuels and potential for higher intensity wildfires. This, coupled with urban sprawl, has created an increased fire hazard, which is of profound concern to many in the region because of the history of devastating wildfires, e.g. the 1923 Berkeley Fire and the 1991 Tunnel Fire (Martin and Sapsis 1995). Management requires a clear understanding of the role of fire on these landscapes, and how historical land use changes have affected fire activity.

The purpose of this paper is to evaluate the extent to which changes in fire activity can account for landscape changes. In addition to documenting the known fire history for the last half of the 20th century, I evaluate the sources of ignition and changes in burning patterns that have accompanied rapid population growth in the region and the extent to which historical variations in climate, which are important drivers of fire activity in other parts of the western USA (Westerling *et al*. 2002), may have affected these fire history patterns.

Methods

Fire statistics were from the California Department of Forestry and Fire Protection written records, variously named Annual Fire Report, Fire Statistics or Wildfire Activity Statistics (State of California Department of Forestry and Fire Protection, 1931–2002). These data include all fires for which action was taken and represent a much more comprehensive picture of fire activity than the recently available electronic California Statewide Fire History database (e.g. Keeley *et al*. 1999). Data before 1945, which included only Santa Clara County, were reported as Clarke-McNary lands and non-Clarke-McNary lands. The latter were largely local rural areas and were not included in this study. After 1945 the

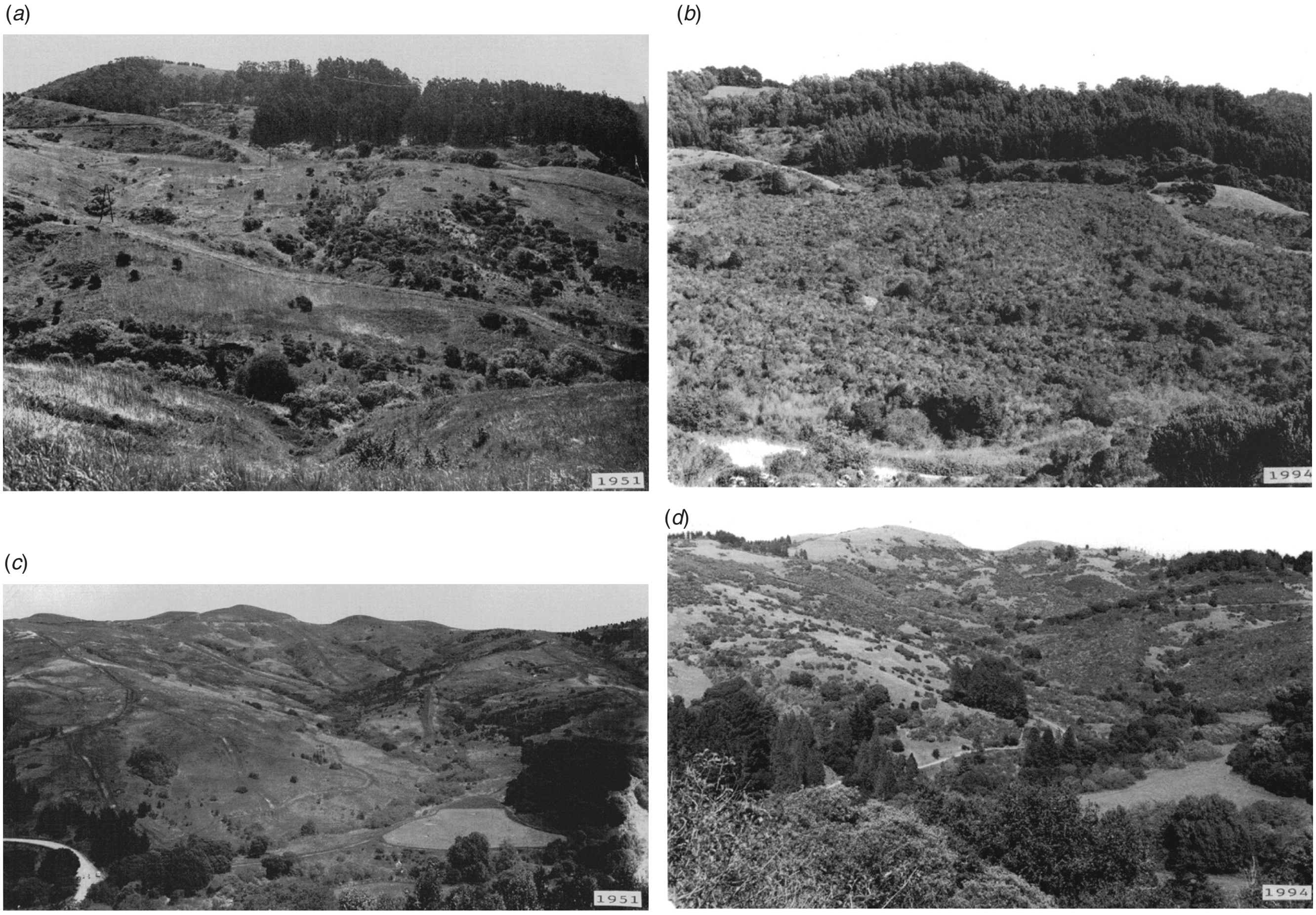

Fig. 3. Changes in the vegetation mosaic in the East Bay foothills during the latter half of the 20th century. (*a*) View south-east to part of San Pablo Ridge just west of Inspiration Point in 1951; (*b*) approximately the same view as panel (*a*) in 1994; (*c*) view east to Nimitz Way north of Inspiration Point in 1951; and (*d*) the same view as panel (*c*) in 1994 (photographs by Oliver Pearson, courtesy of Anita Pearson).

Clarke-McNary lands were separated into Zone I and Zone II lands and after 1970 these were designated Direct Protection Areas (DPAs). Total area included in Clarke-McNary, Zones I and II, and DPAs varied slightly through time and thus all statistics were expressed as fire activity per unit area protected, based on the areas reported in the annual fire summaries. For years where area protected was not presented in the database, the last known area reported was used. These data are for wildfires and do not include prescription burning, but they may include backfires used in suppression activities.

Climatic data for the Palmer Drought Severity Index (PDSI) were downloaded from the National Oceanographic and Atmospheric Administration website (http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/xmgrg3.html, accessed February 2004). This NOAA website presents north central coast of California indices based on combined values from all available stations in the region. Their circumscribed areas roughly parallel the counties studied here. Decadal census data by county were obtained from http://www.census.gov/population/cencounts/ca190090.txt.

Preliminary analysis, before regression analysis, fitted a smoothed curve to each scatter plot, generated with locally weighted scatter plot smoothing (Wilkinson *et al.* 1996). In instances where data did not closely follow a linear relationship, the smoothed curve was presented. When log or log-log-transforms produced a linear relationship, these regression statistics were presented. Ordinary least-squares regression was used to investigate bivariate relationships between fire activity and the chronological year January–December. Statistics calculated from these regressions assume that the residuals from the regression are normally distributed and so residuals were regressed against the expected values for a normal probability plot. Residuals from regressions gave reasonably tight fits in these normal probability plots. Since statistics calculated from ordinary least-square regression are generally robust to departures from normality, this level of approximation was considered acceptable for these analyses.

When investigating bivariate relationships between variables that occur in an ordered chronological sequence, autocorrelation of variables in the time series complicates interpretation of the bivariate model. The Durbin-Watson statistic indicates whether the residuals are correlated and lack independence. Durbin-Watson statistics greater than 1 were considered sufficiently auto-correlated to require correction. This autocorrelation was corrected with the time series technique of differencing, where the value of the variable at time $t - 1$ is subtracted from the value at time t. These first-order difference values were then used in ordinary least-squares regression and the Durbin-Watson statistic for these regressions indicated that autocorrelation had been removed.

Results

Relative frequency of human-caused and lightning-caused fires for the three East Bay counties are compared with interior mountain ranges in the Sierra Nevada and southern Rocky Mountains (Fig. 4). Human ignitions were several times more common in the East Bay than in mountainous areas to the east. In contrast, lightning-ignited fires were rare. For every 100 000 ha of area under CDF protection the lightning fire frequency varied from 1.8 per decade in Alameda County to 5.3 in Santa Clara County. East Bay lightning fire frequency was about two orders of magnitude lower than observed in interior mountain ranges. Across the entire period of record for all counties (1945–2002) there was an average of 3.4 lightning fires per 100 000 ha each decade for the three counties combined. Most years were without any lightning-ignited fires: in Contra Costa County 86% of the years had no lighting-ignited fires, in Alameda the figure was 74% and in Santa Clara it was 60%. Thus, most fires in the East Bay region were started by people.

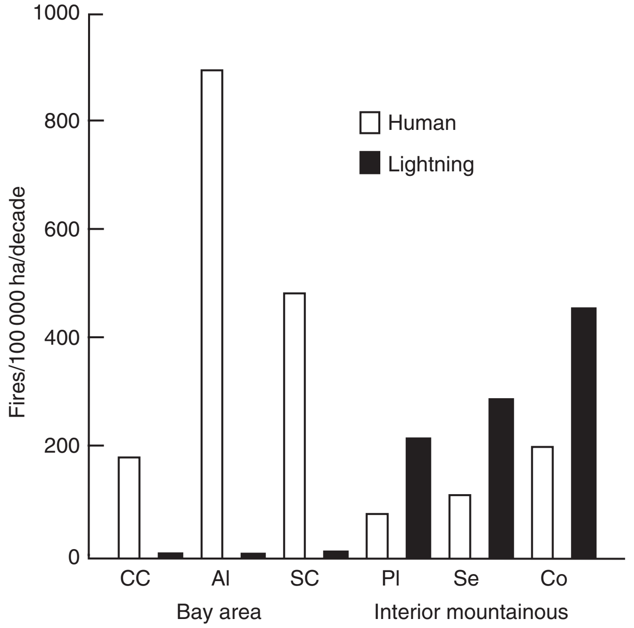

Fig. 4. Human and lightning-ignited fires in the three Bay Area counties compared with interior mountainous areas, including the Plumas and Sequoia national forests in the Sierra Nevada Range of California and the Coconino National Forest in central Arizona. Based on data from the decade 1970–1979, Bay Area data from this paper, data from the three national forests are from US Forest Service fire records.

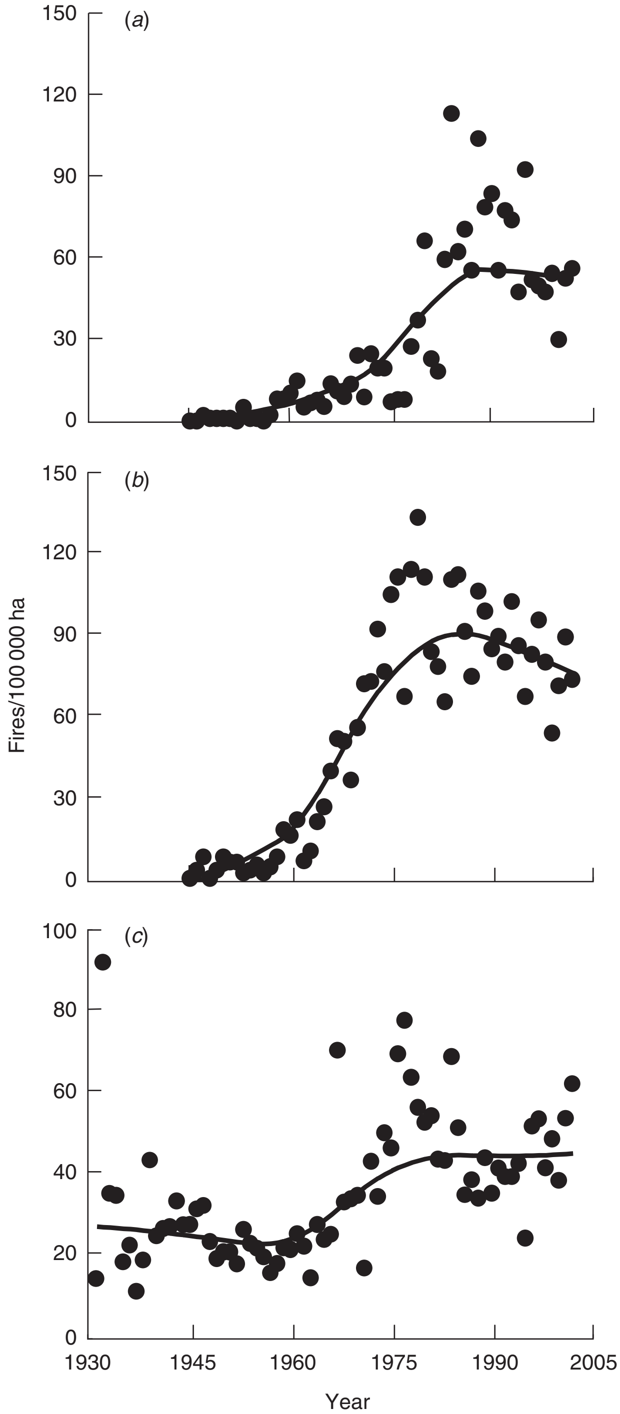

Fig. 5. Annual fire frequency for the East Bay counties with the locally weighted scatterplot smoothing. (*a*) Contra Costa County; (*b*) Alameda County; and (*c*) Santa Clara County.

Annual fire frequency showed a sharp rise after 1950 but a leveling off of fires in the last decade of the 20th century (Fig. 5). Considering the linear portion of this curve, ∼1950–1985, there was a highly significant ($P < 0.001$) increase in fire frequency ($r^2 = 0.458$, 0.823, 0.593, for Contra Costa, Alameda and Santa Clara counties, respectively, $n = 58$, 58, 72). For all counties combined over the period from 1945 to 2002 there was a highly significant positive relationship between year and fire frequency ($r^2 = 0.752$, $P < 0.001$, $n = 58$).

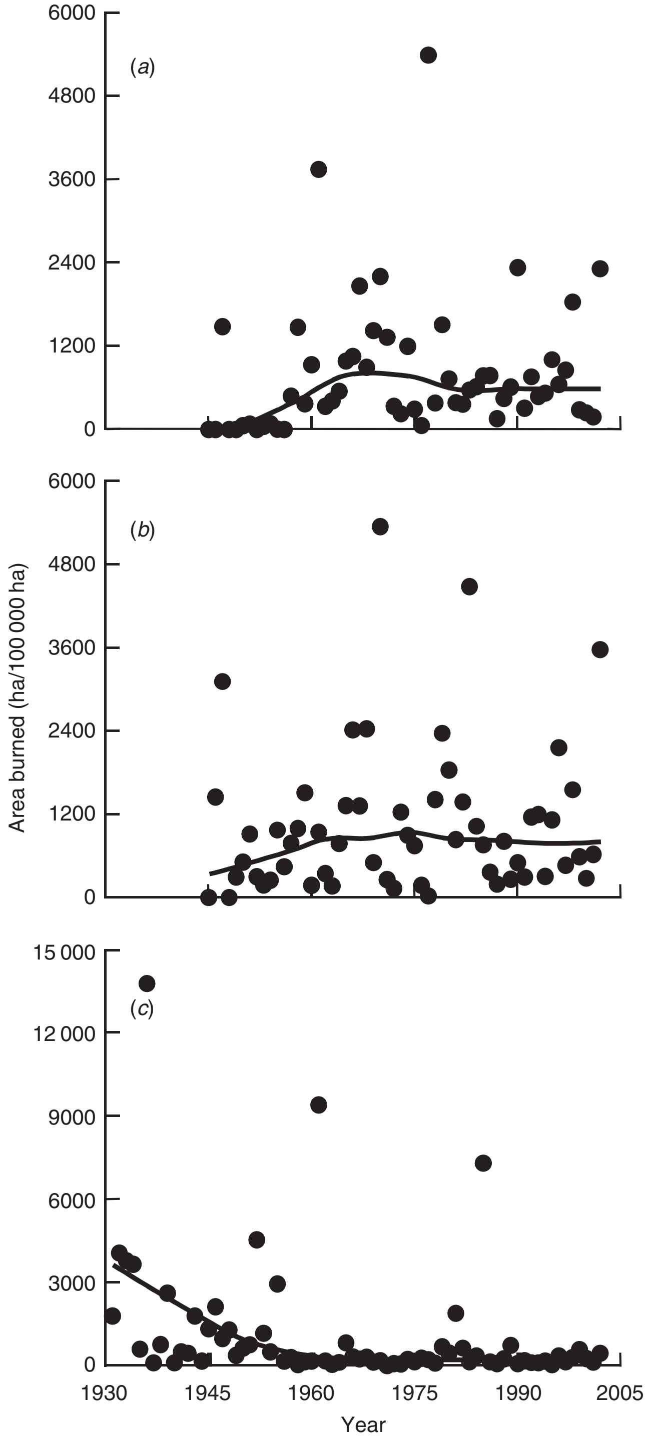

Fig. 6. Annual area burned for the East Bay counties with the locally weighted scatterplot smoothing. (*a*) Contra Costa County; (*b*) Alameda County; and (*c*) Santa Clara County.

Area burned on the other hand exhibited relatively little directional change over the period of record from 1945 to 2002 (Fig. 6). Santa Clara County, with records extending back to 1931, did exhibit a significant ($P < 0.01$) negative relationship, driven by the very high area burned during the 1930s. Throughout the record, annual area burned varied by several orders of magnitude. Comparing annual burning (Fig. 6) with decadal totals (Fig. 7), it is apparent that commonly 50% or more of the area burned during a decade may come from just a single year. In all three counties the 1950s were one of the lowest decades and the 1960s were highest. In general, very little of the area protected by CDF burns each decade. The peak was ∼30% for Santa Clara County during the decade of the 1930s. Since then only ∼10% of each county has burned each decade. Thus, the fire rotation interval, or estimated time to burn the entire protected area, is roughly 100 years.

Since nearly all ignitions were due to humans, the population growth during this time period is illustrated (Fig. 8). During the latter half of the 20th century, population growth as a function of area protected grew most sharply in Contra Costa and Alameda counties. For the three counties combined there was a highly significant ($P < 0.001$) relationship between population density per unit of area protected and number of fires for the years 1945–2002 ($r^2 = 0.706$, differencing not used because the Durban-Watson statistic = 0.731). However, unlike the patterns for annual fire frequency, which leveled off during the 1990s (Fig. 5), population growth increased linearly throughout the 20th century (Fig. 8). Thus, while human population growth was strongly correlated with fire frequency for much of the record, some changes occurred in the behavior of people to put a cap on fire ignitions. Factors in the record that appear to have changed during this period include changes in smoking and arson. Beginning in the mid-1950s smoking steadily decreased as a source of ignition (Fig. 9*a*). Arson as a proportion of all fire starts increased during the first half of the record and then decreased and the smooth curve closely follows a quadratic function (Fig. 9*b*). Early in the record these intentional fires were known as incendiary fires whereas today they are called arson fires. This reflects changing attitudes towards fires, where early on it was more sociologically acceptable to intentionally burn wildland landscapes but today it is usually considered a criminal act. In recent years the primary causes of fires are vehicles and equipment use (data not shown).

Although there are no obvious patterns with area burned (Figs 6, 7), the size of fires changed markedly, with moderate to large fires decreasing (Fig. 10*a*) and small fires increasing

(Fig. 10*b*). The rank order of all fire years showed that human-ignited fires were distributed over a broad range with many moderate size fire years (Fig. 11*a*) whereas in most years there was little or no area burned by lightning, save three significant years (Fig. 11*b*). Changes in annual area burned as a function of the proportion burned in brush or grassland for the counties combined showed that, as the proportion of area burned by grassland increased, the total area burned declined, and the opposite pattern for brush (Fig. 12).

Using time series differencing for regressions of PDSI *v.* fire activity showed very few significant relationships. Specifically, the number of fires and area burned were not significantly related to the seasonal PDSI (August–June), or winter, spring or summer PDSI. The only significant relationship was area burned by lightning fires, which was negatively related to autumn PDSI ($R^2 = 0.120$, $P < 0.01$), indicating that lightning fire size was a function of the severity of the autumn drought.

Discussion

The East Bay of San Francisco has a largely anthropogenic fire regime with no lightning-ignited fires in most years, and when they do occur they are generally on the higher peaks in the region. This pattern is typical for coastal northern California (Keeley 1982). Thus, before the entrance of people into the region, it seems unlikely that fire played a major role in landscape patterns of vegetation distribution.

Although fire suppression policy has not excluded fire from this region, it has been effective at maintaining similar levels of burning (Figs 6, 7) despite increasing ignitions (Fig. 5). Fire frequency paralleled population growth until the latter part of the century when it leveled off (Figs 5, 8). Sorting out the factors responsible for this non-linear relationship between fires and population density is complicated by the fact that the causes of fires have changed over this period (e.g. Fig. 9*a*). A significant contributor is more effective fire prevention, evident by the reduction in incendiary/arson fires (Fig. 9*b*). Other evidence of fire suppression effectiveness

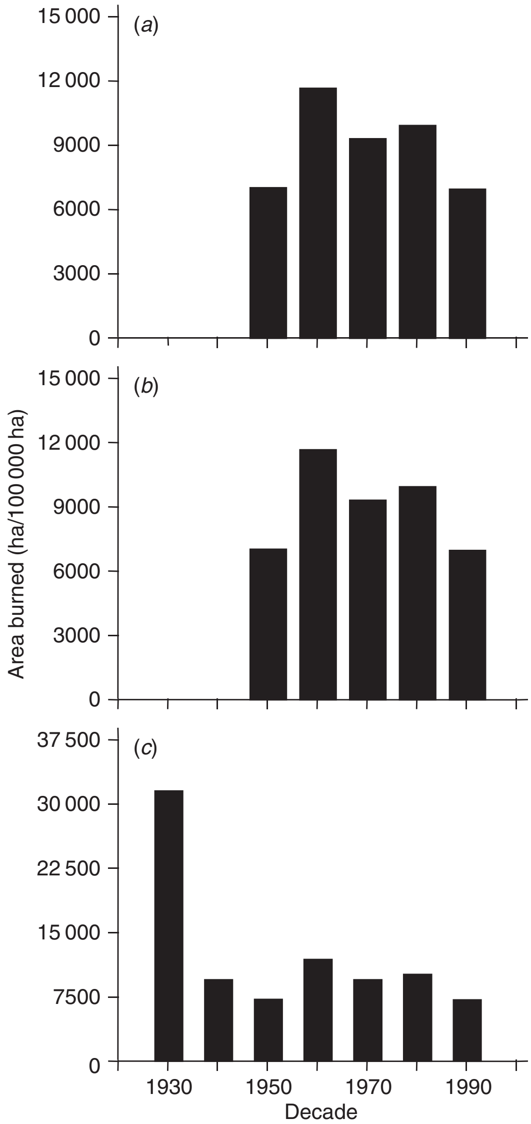

Fig. 7. Decadal area burned for the East Bay counties. (*a*) Contra Costa County; (*b*) Alameda County; and (*c*) Santa Clara County.

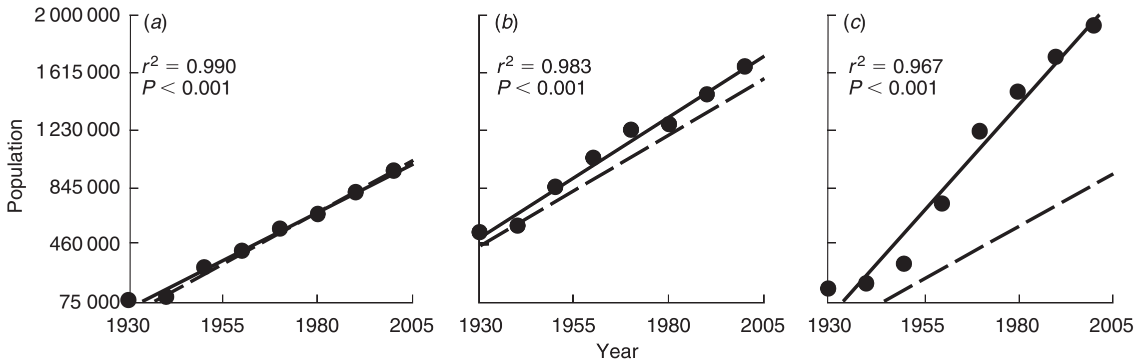

Fig. 8. Population growth for the East Bay counties expressed for the entire county (solid line) or per 100 000 ha of area protected by the California Department of Forestry and Fire Protection (dashed line). (*a*) Contra Costa County; (*b*) Alameda County; and (*c*) Santa Clara County.

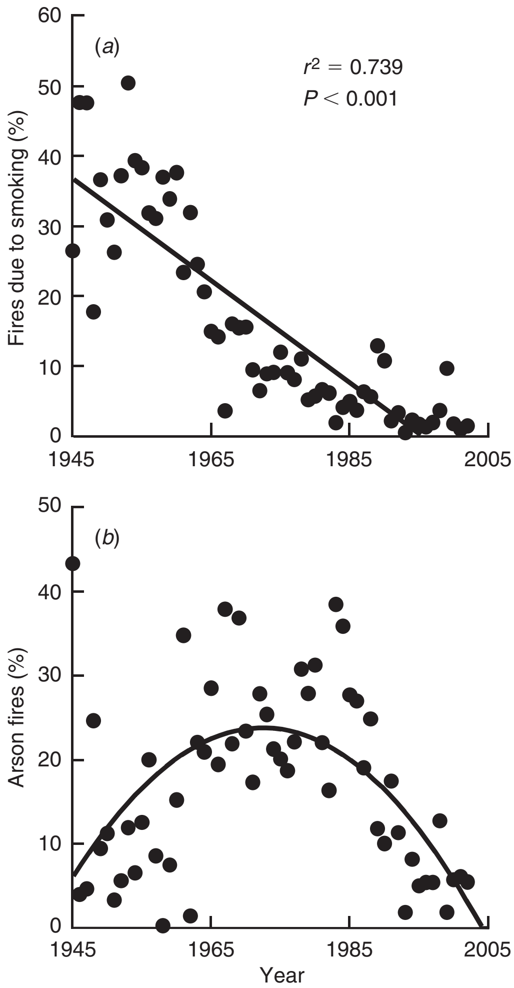

Fig. 9. Changes in fire ignition sources of (*a*) smoking and (*b*) arson for the East Bay counties combined. Arson is a recent term (first used in 1981); before then these were called incendiary fires.

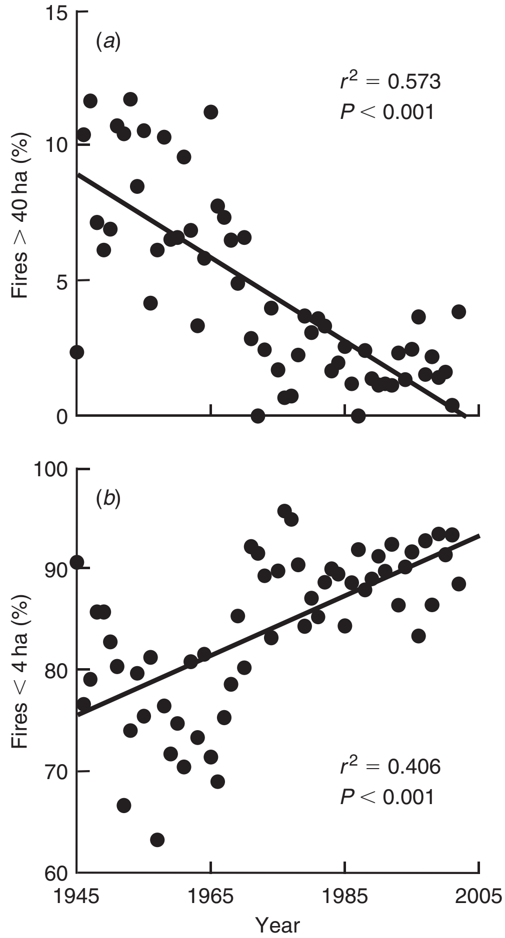

Fig. 10. Annual changes in percentage of (*a*) large fires and (*b*) small fires for the East Bay counties combined.

is the trend towards increasing frequency of small fires (Fig. 10*a*), although increased habitat fragmentation from urban sprawl may also be a factor.

There is little evidence that changes in burning patterns are a major factor in the widely reported colonization of grasslands by shrubs and woodland elements (Fig. 3) during the latter half of the 20th century (McBride 1964, 1970; Roof 1971; Edwards 2002; Russell and McBride 2002). Rather, the elimination of grazing, as emphasized by McBride (1974; McBride and Heady 1968), would seem to be a bigger factor.

This model, though, is at odds with other models for grassland invasion by woody plants in the South-west, where intense livestock grazing, not cessation of grazing, is tied to what is often termed 'brush encroachment' of grasslands (Archer 1994). These models, however, apply to two very different ecosystems. In the absence of grazing, the very high lightning fire frequency in the South-west (Fig. 4) results in frequent grass fires that eliminate less fire-tolerant shrubs. Grazing reduces grass fuels and thus fire frequency declines, allowing shrub invasion. In California, natural fires are infrequent enough to eliminate shrublands and thus grazing introduces less of a change in fire frequency. These two ecosystems also respond differently to grazing. In the South-west, spiny shrubs such as *Prosopis* that invade grasslands are noxious to livestock and generally avoided whereas, in California, shrub colonizers are slightly palatable, and even desirable in the summer dry season (Harris 1927; Sampson and Jespersen 1963).

One of the important implications of this East Bay model is that shrub colonization of grasslands (Fig. 3) occurs when disturbance is removed from the system, implying that these grasslands are disturbance-dependent. I hypothesize that, just like the contemporary scene, the indigenous landscape also comprised a mosaic of grasslands, shrublands, woodlands and coniferous forests, but because of limited natural fires it had very limited grasslands and a decidedly greater representation of woody associations than today. Thus, the

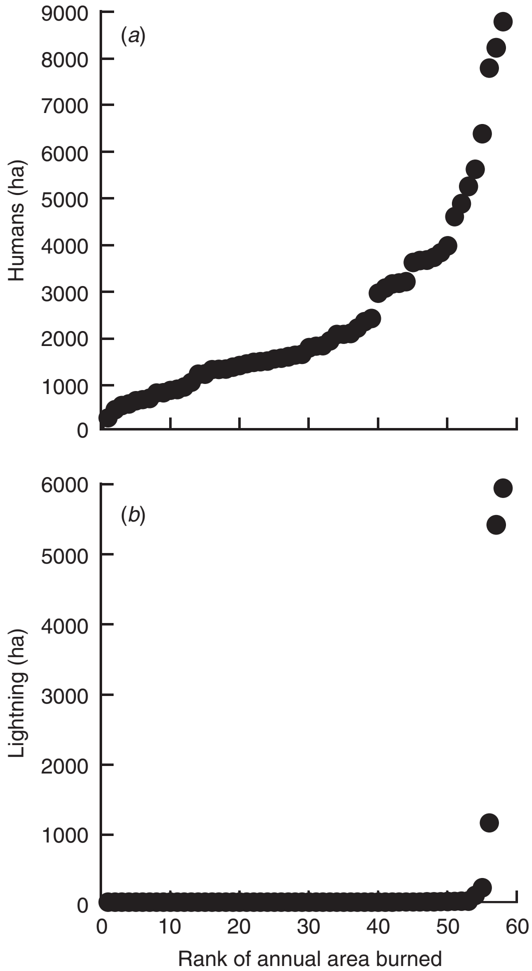

Fig. 11. Rank order fires by size for (*a*) human and (*b*) lightning ignited fires for the East Bay counties combined.

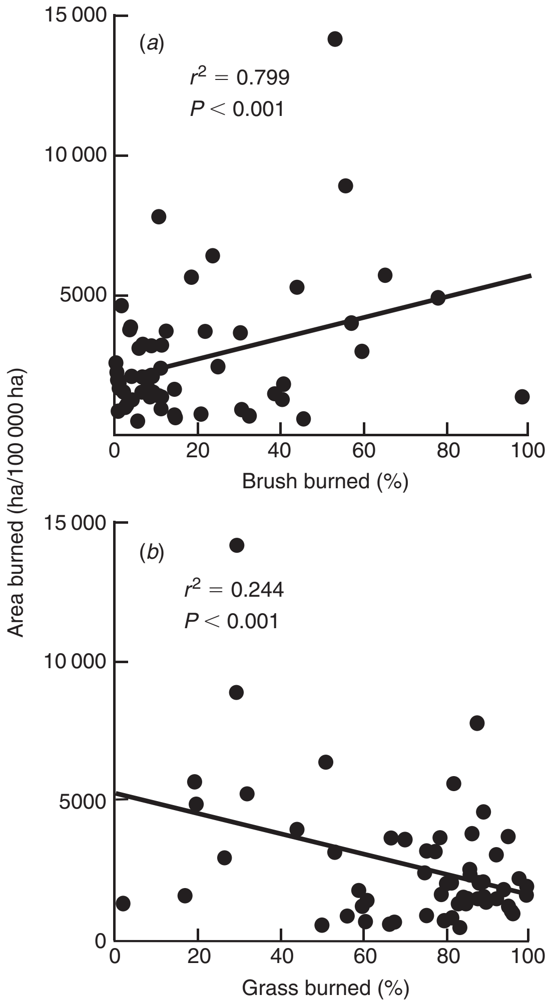

Fig. 12. Changes in annual area burned as a function of the proportion burned in (*a*) brush or (*b*) grassland for the East Bay counties combined. High Durbin-Watson statistics (>1.5) indicate substantial temporal autocorrelation and thus all statistics are calculated after time series differencing.

widespread extent of contemporary grasslands is the result of type conversion of woody vegetation to grasslands, a model that has been applied to other parts of the state (Cooper 1922; Wells 1962; Huenneke 1989; Keeley 1990; Hamilton 1997; Holstein 2001), and applies to the creation of other grasslands in the world (Bond *et al*. 2005; Keeley and Rundel 2005). In the East Bay this model is supported by microfossil studies of grass phytoliths. Over a dozen grassland sites examined by Hopkinson (2003) showed that most sites had at one time been dominated by more mesic woodland vegetation types.

While frequent fires are certainly capable of maintaining grasslands free of woody species, the recent history for these sites suggests that livestock grazing has been a more important factor, and perhaps the dominant factor since the early Euro-Americans introduced cattle and sheep ~225 years ago. However, grasslands in this region did not originate from the European introduction of livestock, since the current grassland distribution appears to be little changed from that reported by the first Spanish explorers (DeNier 1928; Clarke 1959; Mayfield 1978), with the exception that a substantial amount has been lost to development. In order for grasslands to have been maintained in this environment by natural fires, one would have to expect that every lightning ignited fire was enormously large, on the order of 10^5–10^6 ha. Even under current landscape patterns with extensive grasslands that cure to form highly flammable fuels during the summer lightning fire season, there is no evidence that they would commonly reach this size. Indeed during the latter half of the 20th century, only on three occasions did a lightning-ignited fire exceed 1000 ha. It is even more unlikely that natural lightning-ignited fires could have carved out the current grasslands from a shrubland or woodland landscape of more mesic fuels, since these fuels have an even shorter fire season, generally later in the fall after the summer lightning fire season.

One possibility is that the native grazing/browsing fauna, including deer (which still maintain sizeable populations in the East Bay), antelope and elk, maintained extensive grasslands by excluding woody plant invasion before Euro-American contact. Several factors make this unlikely. This region was heavily dominated by Native American settlements, with over 100 village sites and more than 2000 inhabitants in the East Bay area at the time of contact (Cook 1957). Hunting would have had a significant impact on the size of these herds. In addition, herbivory *per se* is not responsible for conversion of woody associations to grasslands but rather the over-stocking of rangelands with livestock.

A more likely factor in the origin and maintenance of these grasslands was the frequent use of fire by the high density of Native Americans in the East Bay. There are many reasons for believing that these Native Americans managed their environment with fire in order to expand grasslands and other herbaceous associations over woody vegetation (Bean and Lawton 1973; Lewis 1973; Keeley 2002). Indirect evidence of Native American burning in this region are the frequent fires documented for the 18th and 19th centuries from fire-scarred redwoods just across the bay in Muir Woods (Jacobs *et al*. 1985), and in other redwood forests farther north (Finney and Martin 1989; Brown and Swetnam 1994) and south (Stephens and Fry 2005). These fire scar records of 10–20 year intervals are not consistent with the very limited lightning fire potential for the East Bay (Fig. 4) and the rest of the north coast region (Keeley 1982) and likely reflect Native American burning.

Frequent burning by Native Americans was an effective means of altering landscapes to provide more readily utilizable resources, since open herbaceous vegetation enhanced both wildlife habitat and seed resources relative to closed canopy woodlands (Timbrook *et al*. 1982; Keeley 2002). Countless studies have shown that even resprouter-dominated shrubland communities in this region can be readily type-converted to herbaceous associations with repeat fires at 2–10 year intervals (Sampson 1944, 1952; Burcham 1957; Nichols *et al*. 1984; Heady and Child 1994). Native Americans were skilled in the use of fire to type convert shrublands to grasslands; however, those grasslands were substantially different in composition from those currently dominating the region. Today most grasslands in California are composed of alien assemblages of annual grasses and forbs from the Mediterranean Basin. Type conversion of shrublands by Native Americans would have favored native perennial bunchgrasses as well as a rich assemblage of native annual and perennial forbs.

European colonization of the East Bay resulted in the rapid decimation of Native American populations and loss of their fire management activities. However, fire was used by the Spanish, and later the Mexicans, to expand grazing lands in the region (Roof 1971). Since hides and tallow, not meat, were the primary products being produced, it was often productive to overstock these rangelands. Thus, fire and grazing combined to maintain a quasi-equilibrium of disturbance-maintained grasslands.

Conclusions

The limited role of natural fires in the East Bay, coupled with the disturbance-dependent character of grasslands in the region, suggest that before human entry into the region the landscape mosaic heavily favored shrublands and woodlands with coniferous forests and smaller pockets of grasslands. A projected time line of these changes is suggested in Table 1.

Prior to human entry into California the only potential source of disturbance would have been the grazing and browsing mammals. Potentially the diverse Pleistocene fauna of the region would have been an important disturbance factor that may have played a role in the maintenance of grasslands (Edwards 1990, 1992, 1995). The cooler more mesic Pleistocene climates, however, would have favored faster recovery by mesic woodland elements (Keeley 2002), working against widespread grassland formation, but to be sure, we lack a clear quantitative picture of how natural grazing and browsing during this epoch would have affected vegetation patterns.

Humans entered this region in the late Pleistocene and rapidly decimated much of the native fauna (Martin 1984), thus removing this disturbance factor. Early Holocene populations likely had limited impact on vegetation patterns due to low population density and cool, mesic conditions. As populations grew, coupled with the mid-Holocene drying and transition to a seed-based economy (Jones 1992), the uniquely new disturbance factor of fire became an important vegetation management tool. Native American burning greatly expanded grassland distribution. This impact would have been light at first but, based on the population density of the region at the time of contact with Europeans in the late 18th century, it likely became very intense. It appears that the contemporary distribution of grasslands had already been established by the time of contact with Spanish settlers. Landscape burning did not die with the demise of Native American cultures since fire was an important feature of European agropastoral land management practices (Pyne 1995). However, 19th and 20th century development increased urban sprawl into watersheds of dangerous fuels (Hornbeck 1983), and thus there was an increasing pressure on fire prevention and suppression (Clar 1959).

Throughout the 20th century there was an increasing need to manage much of this landscape for recreation and conservation. With this came a reduction in livestock grazing resulting in successional changes towards shrublands and woodlands (Fig. 2). These changes are commonly referred to as shrub invasion or brush encroachment of grasslands. Alternatively, this is perhaps best viewed as a natural recolonization of grasslands that have been maintained by millennia of human disturbance. There is little evidence that changes

Table 1. Proposed time line of changes in vegetation and disturbance history for the East Bay expected from the patterns of natural and human fires on these landscapes

Period	Human impact	Expected or observed vegetation
Late Pleistocene to mid-Holocene	Limited Native American populations. Fire regime dominated by lightning with fire rotation intervals on the scale of centuries.	Woodland-dominated landscape with mosaic of shrublands, forests and patches of grassland.
Mid-Holocene to late 18th century	Increasing density of Native Americans and increasing dependence on plant products with frequent use of fire for landscape management. Expected fire rotation interval on the order of a decade or less.	Grassland-dominated landscape in a mosaic of shrublands and woodlands maintained by high fire frequency. Dominated by a combination of native perennial grasses and native annual forbs.
19th century	Euro-American settlement with heavy livestock grazing Fire frequency probably lower than earlier periods. Expected fire rotation interval perhaps several decades, maybe longer.	Grassland-dominated landscape maintained by replacing frequent fire with heavy grazing. Natives replaced by alien annual grasses and alien annual forbs.
20th century	Increasing protection, reduction of lifestock grazing. Increasing fire frequency due to population growth and urban sprawl coupled with increasing effectiveness of fire suppression. Fire rotation intervals very long on the order of a century or more.	Gradual recolonization of grasslands by native shrubs (baccharis) and trees, also invasion by alien shrubs (brooms).

in fire activity during the latter half of the 20th century can explain these successional changes.

These successional changes in vegetation have created landscapes with increased fire hazard from the greater fuel loads (Russell and Tompkins 2005). Adding to this problem is urban sprawl with its ever expanding wildland–urban interface, and this increasing periphery means an increasing number of people at risk (Russell and McBride 2002). Shrublands with their enhanced fuel loads produce more intense fires that are more difficult to suppress and result in somewhat larger fires (Fig. 12*a*). On the other hand, the alien dominated grasses cure by early summer and likely expand the fire season far longer than the shrubland fuels. Regardless of fuel type, however, the primary risk is associated with extreme weather events. Under these severe fire weather conditions, fire spread is extremely rapid and the area has a history of devastating fires (Martin and Sapsis 1995). These, however, have all been relatively small fires that involved fuels at the wildland–urban interface. Fuels far removed from this interface zone (Fig. 2) played very little role in these conflagrations. Thus, it would seem the most cost-effective approach to fire hazard reduction should be focused at the interface zone and here the problem is often as much due to exotic fuels (Gallagher 2004) as it is to natural successional processes (Fig. 3).

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