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Landscape scale vegetation-type conversion and fire hazard in the San Francisco bay area open spaces

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Abstract

Successional pressures resulting from fire suppression and reduced grazing have resulted in vegetation-type conversion in the open spaces surrounding the urbanized areas of the San Francisco bay area. Coverage of various vegetation types were sampled on seven sites using a chronosequence of remote images in order to measure change over time. Results suggest a significant conversion of grassland to shrubland dominated by *Baccharis pilularis*on five of the seven sites sampled. An increase in *Pseudotsuga menziesii* coverage was also measured on the sites where it was present. Increases fuel and fire hazard were determined through field sampling and use of the FARSITE fire area simulator. A significant increase in biomass resulting from succession of grass-dominated to shrub-dominated communities was evident. In addition, results from the FARSITE simulations indicated significantly higher fire-line intensity, and flame length associated with shrublands over all other vegetation types sampled. These results indicate that the replacement of grass dominated with shrub-dominated landscapes has increased the probability of high intensity fires.

Keywords: Succession; Vegetation change; Fire intensity; Urban–wildland interface

1. Introduction

The vegetation of the hills of the San Francisco bay area is a mosaic of grasslands, shrublands, and various forest types. The dominant vegetation type is a mixed evergreen forest (Kuechler, 1977). This association includes Douglas-fir (*Pseudotsuga menziesii*), tanoak (*Lithocarpus densiflorus*), canyon live oak (*Quercus crysolepis*), California buckeye (*Aesculus californica*), (*Umbellularis californica*), madrone (*Arbutus menziesii*), big leaf maple (A*cer macrophyllum*), and coast live oak (*Quercus agrifolia*). The dominance of individual species within this association varies form site to site. For example, in hills east of the San Francisco bay mixed evergreen forests are dominated by coast live oak and California bay, and in some cases give way to forests dominated by coast redwood (*Sequoia sempervirens*) (McBride, 1974; Safford, 1995). In addition to the mixed evergreen forests, large areas are covered by coastal scrub that is dominated by coyote brush (*Baccharis pilularis*), but also includes species such as California coffeeberry (*Rhamnus californica*), California blackberry (*Rubus ursinus*), and poison oak (*Toxicodendron diversilobum*). Grasslands once dominated by native perennials cover a dwindling proportion of the landscape and are currently dominated by exotic annuals such as wild oat (*Avena fatua*), brome

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(*Bromus mollis*), and ryegrass (*Lolium multiflorum*). Scattered oaks, in some areas, are common among the grasses. Where the canopies of the oaks grow together they are referred to as oak woodland and are dominated by coast live oak, though California bay and madrone are associated in some cases. On poorly drained acidic soils where fire is common bishop pine (*Pinus muricata*) exists in dense stands along the coast (Vogt et al., 1988). Exotic forest types such as Monterey pine (*Pinus radiata*) and eucalyptus (*Eucalyptus globulus*) also exist as scattered plantations.

The distribution of vegetation types over the landscape is by no means static. These vegetation types have undergone successional changes resulting from fire suppression and reduction of grazing pressure (Hall et al., 1994). Vegetation within this area has shown a tendency toward proliferation of shrub onto sites that were previously dominated by grasses. Frequent fire or livestock pressure, when present, act to keep the keep these areas in a grassland state. A reduction of these pressures, however, can facilitate the proliferation of shrub into grassland areas (McBride and Heady, 1968). In areas where grazing continues the shift from grassland to shrubland does not occur as readily (Elliot and Wehausen, 1974). In some cases, an increase in forest cover has been noted on sites previously dominated by grasses and shrubs. Examples of these trends include the invasion of *Baccharis pilularis*-dominated shrub communities into grasslands in the Oakland/Berkeley hills (Kent et al., 1977; Martinez, 1993; McBride, 1960, 1974; McBride and Heady, 1968) and invasion of *Pseudotsuga menziesii* into grasslands and shrub communities in Marin County (Dunne and Parker, 1999).

Changes in the dominance of vegetation types over the landscape are accompanied by changes in fire hazard. For instance, fuel load and structural conditions vary widely between annual grasslands, coastal scrub, and mixed evergreen forest (Sapsis, 1990). Because the San Francisco bay area open spaces are essentially imbedded in an urban matrix the propensity of these areas to carry and spread fire are of concern. In order to better understand the nature of vegetation change in this region, and its importance in altering potential fire conditions, vegetation change and potential fire hazard were measured over time. A combination of remote sensing images, fuel sampling in the field, and the FARSITE fire area simulator (Finney, 1995) were used to address the following questions: (1) What general trends in vegetation change can be discerned at a landscape level over the last 60 years? (2) How do changes in the dominance of various vegetation types relate to fuel load and potential fire hazard?

2. Methods

2.1. Remote sensing

Changes in the relative dominance of the vegetation types present within the study areas were measured using random point sampling on aerial photographs. A chronosequence of relative community dominance was developed by sampling aerial photos taken between 1939 and 1997, with a scale of 1:20,000 or less, for the six study areas. Four separate sampling years were used for each area dependent on photo availability (Table 1).

Six open space areas were selected as study sites in order to compare successional trends within various vegetation types. The areas sampled included three East Bay Regional Parks including Chabot, Redwood, and Tilden. Three sites were also selected within the north and peninsula regions including Bolinas Ridge, Point Reyes and a site near Woodside off of Skyline Boulevard.

2.2. Fuel and fire hazard

The relative fire hazard of the most common vegetation types found within the study sites was determined through two methods: (1) the measurement of surface biomass was conducted for each vegetation type; (2) fire spread simulation for each of the vegetation types using the FARSITE fire area simulator (Finney, 1995).

Table 1
Location of study sites and date of photographs used in sampling

Study site	Dates of aerial photos			
Chabot Regional Park	1939	1968	1983	1997
Redwood Regional Park	1939	1968	1983	1997
Tilden Regional Park	1939	1968	1983	1997
Bolinas Ridge	1952	1969	1984	1991
Point Reyes	1952	1971	1987	1993
Skyline	1948	1968	1987	1993

Surface fuel was measured for each the most common vegetation types with the exception of grass (coastal scrub, oaks woodlands, Monterey pine, bishop pine, and Douglas-fir) using the line intercept method (Brown, 1971, 1974) resulting in a tonnes/ha fuel estimate for each type. The live biomass associated with areas dominated by grass was measured by clipping, drying and weighing small plot samples (Brown and Marsden, 1976). In addition, clipping, drying and weighing was conducted on shrub-dominated sites in a similar manner. Results from this sampling were then included with the estimates for shrub surface fuels to give a total estimate for biomass.

Fire spread simulations were conducted using the FARSITE fire area simulator in order to determine the average rate of spread, flame length, and fire-line intensity for each of the vegetation types listed above. A hypothetical landscape provided within the program was used for each simulation in order to eliminate confounding factors related to site variability.

3. Results

3.1. Vegetation changes

Results from the sampling of aerial photographs indicate a number of significant changes in the dominant vegetation of open spaces surrounding the San Francisco bay. Many of these trends are site specific, however some generalities can be made. The relative cover of grassland, with all sites included, exhibited a strong negative linear correlation with years ($P = 0.003$) indicating a general decline grassland acreage (Fig. 1a). In contrast, the relative shrub cover was positively correlated to years ($P = 0.025$) indicating a general increase in shrubland acreage (Fig. 1b). The relative cover of trees appeared to exhibit an increase as well, however the correlation with years was not strong ($P = 0.070$) (Fig. 1c).

Analysis of each site individually illustrates trends that are more specific to the vegetation types found in each of the study areas. In addition, the division of the category of tree coverage into various forest and woodland classifications leads to a more precise understanding of the observed vegetation dynamics.

Vegetation change within Chabot Regional Park exhibited similar trends as those discussed in the general analysis (Fig. 2). Grassland coverage declined dramatically where shrub cover appeared to increase. As was indicated in the general analysis, trends in forest cover were more complex. The relative cover of the mixed evergreen, Monterey pine and eucalyptus forest types

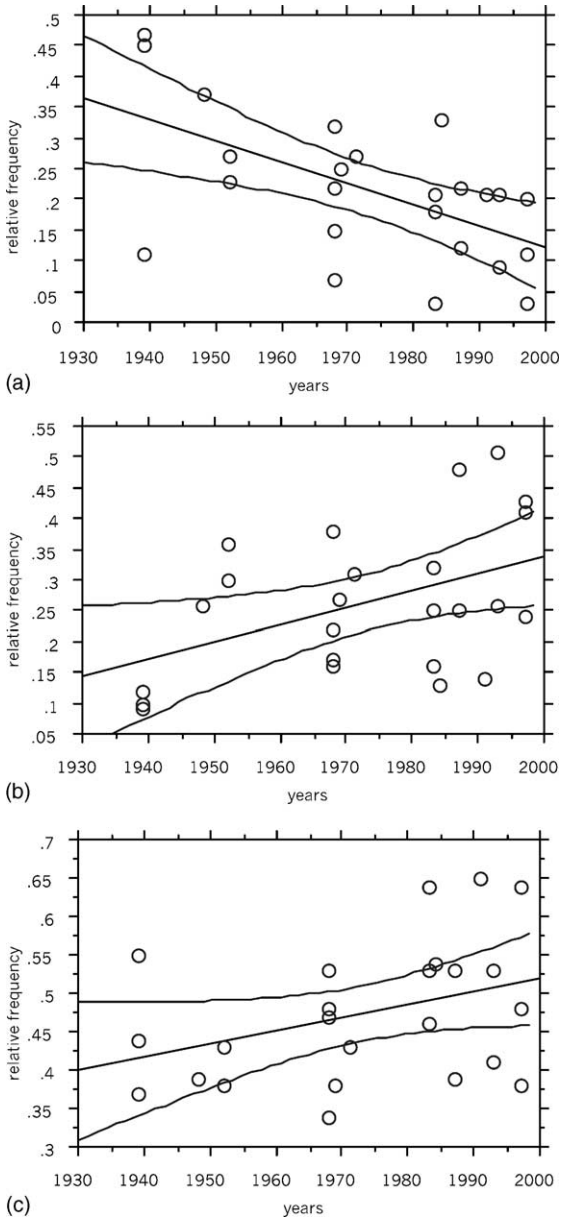

Fig. 1. (a) Relative frequency of grassland cover (a), shrub cover (b) and tree cover (c) in relation to years on six sites in the open spaces of the San Francisco bay area.

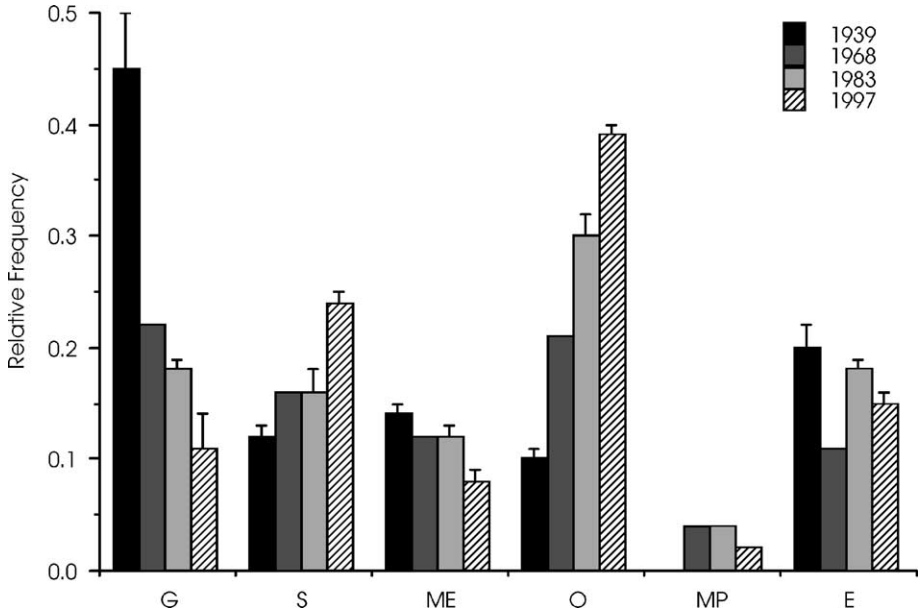

Fig. 2. Relative frequency of six vegetation types, (G: grass, S: shrub, ME: mixed evergreen, O: oak woodlands and savannas, MP: Monterey pine, E: eucalyptus), in Chabot Regional Park. Error bars indicate 1 S.E.

declined somewhat. In contrast, the relative cover of oak woodland and savanna increased significantly.

The relative cover of grass and shrubs within Redwood Regional Park followed the same trends described in the previous analysis (Fig. 3). However, in contrast to Chabot Regional Park oak woodland cover appeared to decline. All other forest types remained relatively stable with no significant variation.

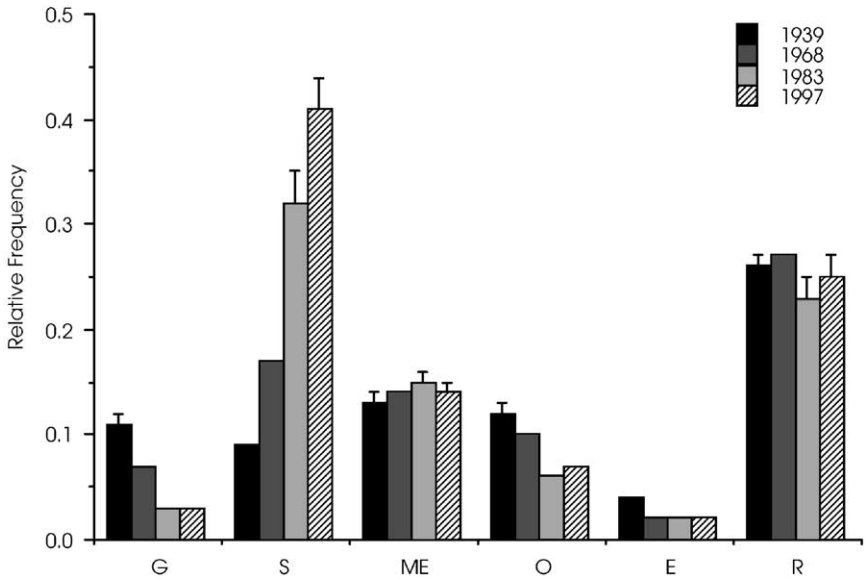

Fig. 3. Relative frequency of six vegetation types, (G: grass, S: shrub, ME: mixed evergreen, O: oak woodlands and savannas, E: eucalyptus, R: redwood), in Redwood Regional Park. Error bars indicate 1 S.E.

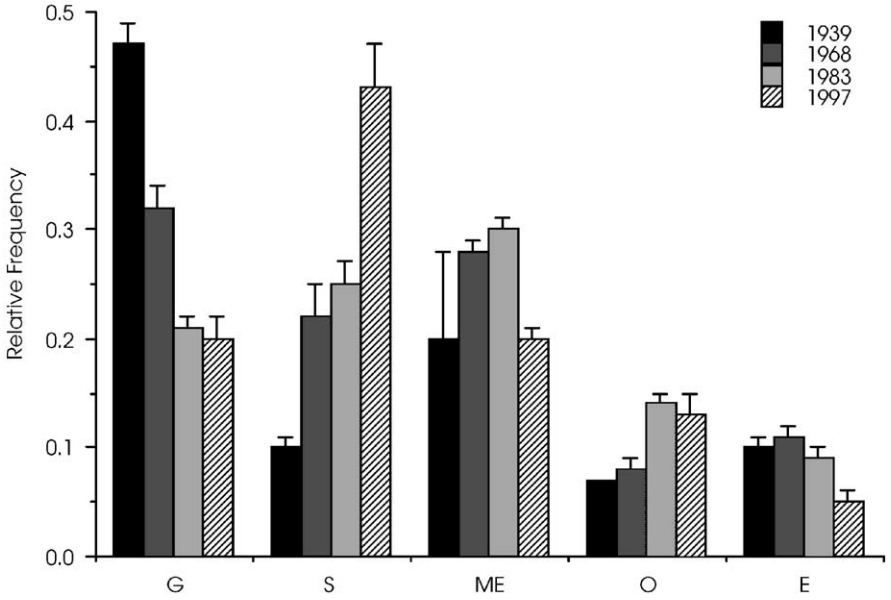

Fig. 4. Relative frequency of five vegetation types, (G: grass, S: shrub, ME: mixed evergreen, O: oak woodlands and savannas, E: eucalyptus.), in Tilden Regional Park. Error bars indicate 1 S.E.

Vegetation dynamics within Tilden Regional Park featured similar trends in grass and shrub cover as described above (Fig. 4). Oak cover appeared to increase slightly and eucalyptus to decrease. The relative cover of mixed evergreen forest remained relatively stable.

Vegetation trends on the Bolinas Ridge site were quite different from those found in the East Bay Regional Parks (Fig. 5). The relative cover of shrubs appeared to decrease on this site, where it increased on all previous sites. A general decline in grassland cover was observed, however, the high variation between years makes this determination questionable. The most apparent trend on this site was a significant increase in the relative cover of Douglas-fir (*P. menziesii*) forest. The mixed evergreen forest that included evergreen hardwoods such as *Quercus* and *Umbellularia californica* (bay laurel) remained stable.

Vegetation at the Point Reyes site exhibited limited variation within the time period of this study (Fig. 6). Analysis of the data sampled yielded little of significance in relation to the relative cover of grassland and shrubland, though a slight decline in grassland cover is discernible. Domination by oak woodland and savanna increased somewhat as did the cover of Monterey pine. The mixed evergreen component exhibited a slight decline.

Several significant changes in the relative cover of vegetation types were apparent on the Skyline site (Fig. 7). Grassland cover decreased markedly with a comparable increase in shrubland cover. Though both the mixed evergreen and redwood forest types remained relatively stable, Douglas-fir forest cover increased significantly.

3.2. Fuel and fire hazard

Fuel sampling of the vegetation types common to the sites sampled indicated a wide variation in surface biomass between types (Table 2). The lowest surface biomass was found for grassland and oak woodlands. In contrast, the *Baccharis*-dominated shrublands exhibited surface fuels 5 times greater than oak and more than 10 times greater than that found for grasslands. The surface biomass found for forested landscapes was greater still and was somewhat higher for bishop pine and Monterey pine than it was for Douglas-fir.

Results from the FARSITE simulations indicate the greatest average flame length and fire-line intensity for the shrub-dominated sites and the lowest for the

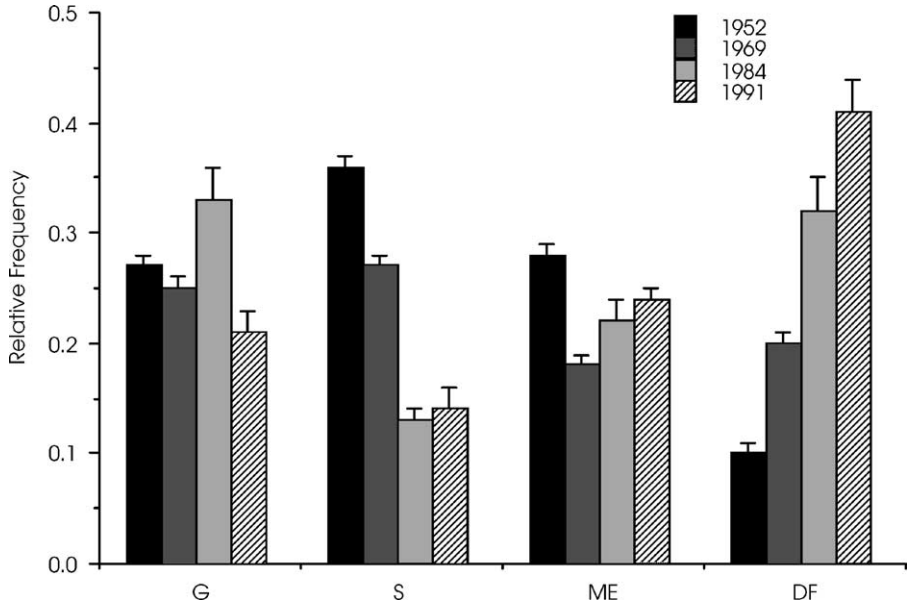

Fig. 5. Relative frequency of four vegetation types, (G: grass, S: shrub, ME: mixed evergreen, DF: Douglas-fir), on Bolinas Ridge. Error bars indicate 1 S.E.

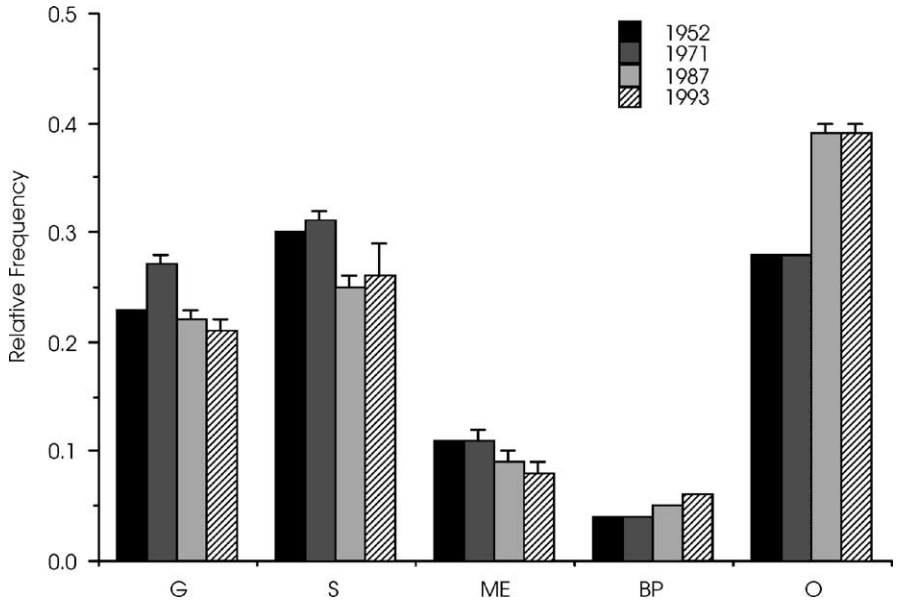

Fig. 6. Relative frequency of five vegetation types, (G: grass, S: shrub, ME: mixed evergreen, BP: bishop pine, O: oak woodland and savanna), at Point Reyes. Error bars indicate 1 S.E.

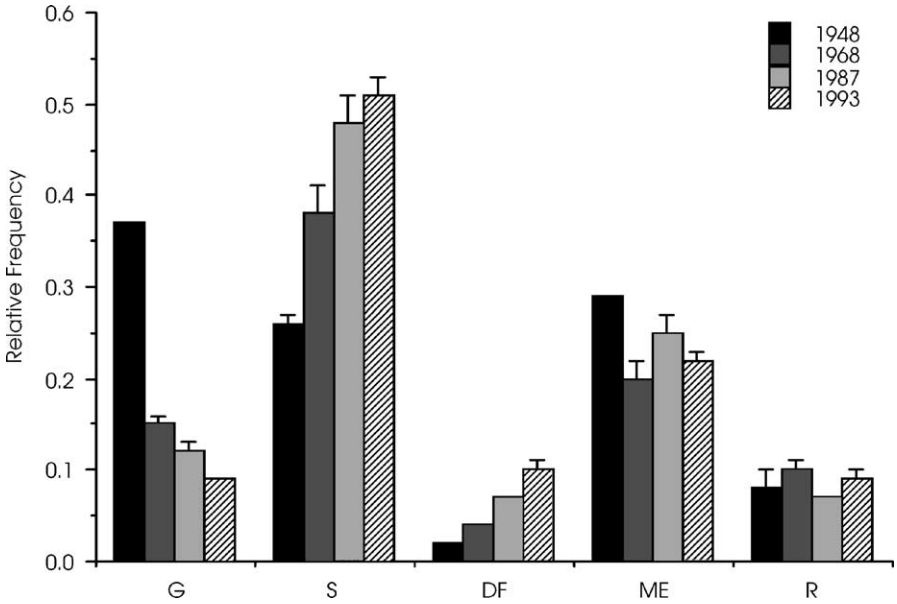

Fig. 7. Relative frequency of five vegetation types, (G: grass, S: shrub, DF: Douglas-fir, ME: mixed evergreen, R: redwood), at Skyline. Error bars indicate 1 S.E.

Table 2
Measured biomass and predicted fire characteristics using the FASITE fire simulation model

	Grass	Shrub	Oak	Douglas-fir	Bishop pine	Monterey pine
Biomass (tonnes/ha)	1.51	18.73	3.67	37.45	48.35	40.69
Rate of spread (m/min)	3.77	1.60	0.6	0.56	0.56	0.57
Fire-line intensity (kW/m)	66.50	197.00	36.00	139.88	157.40	157.89
Average flame length (m)	0.47	0.8	0.4	0.69	0.74	0.73

oak woodlands (Table 2). The highest rate of spread was found for the grass-dominated landscapes and the lowest for the forested landscapes.

4. Discussion

The analysis resulting from this study indicates that there have been significant changes in vegetation within the parameters of this study and that these changes suggest a general increase in fire hazard within the open spaces of the San Francisco bay area.

A significant increase in the cover of shrublands was apparent in the general analysis, and in all but two of the study sites. An inverse relationship was found for the cover of grass-dominated landscapes with the exception of the same two sites. The results from the fuel and fire hazard analysis suggest that the succession from grasslands to *Baccharis* shrublands indicates dramatic increase in fire hazard for those areas. Fire-line intensity, flame length, and total biomass were found to be significantly higher within the shrub-dominated areas. In the context of the landscape matrix as a whole this increased hazard indicates a greater possibility of fire being spread into adjacent forested areas and residential communities.

In contrast to grasslands and shrublands the relative cover of most forest types appeared to be relatively stable over the time period of this study with the exception of Douglas-fir which increased significantly on every site on which it was present. The relevance of this increase to fire hazard is not clear however. On the

Bolinas Ridge site the increase in Douglas-fir cover was accompanied by a decrease in shrub cover. This pattern would appear to suggest that Douglas-fir is replacing shrublands which would tend to reduce fire hazard on that site. However, the pattern is reversed on the Skyline site. Though Douglas-fir exhibits a significant increase shrub cover appears to increase as well and the cover of grassland appears to decline. It may be that we are observing an earlier stage in the succession from grassland to *Baccharis* brushland to Douglas-fir forest at the Skyline site.

The vegetation change and accompanying fire hazard increase noted in this study have occurred within a management regime under which fire has been generally excluded and grazing pressure has been reduced. Without modifications to our current management strategies fire hazard will likely continue to increase.

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