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Conservation Threats Due to Human-Caused Increases in Fire Frequency in Mediterranean-Climate Ecosystems

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Abstract: *Periodic wildfire is an important natural process in Mediterranean-climate ecosystems, but increasing fire recurrence threatens the fragile ecology of these regions. Because most fires are human-caused, we investigated how human population patterns affect fire frequency. Prior research in California suggests the relationship between population density and fire frequency is not linear. There are few human ignitions in areas with low population density, so fire frequency is low. As population density increases, human ignitions and fire frequency also increase, but beyond a density threshold, the relationship becomes negative as fuels become sparser and fire suppression resources are concentrated. We tested whether this hypothesis also applies to the other Mediterranean-climate ecosystems of the world. We used global satellite databases of population, fire activity, and land cover to evaluate the spatial relationship between humans and fire in the world's five Mediterranean-climate ecosystems. Both the mean and median population densities were consistently and substantially higher in areas with than without fire, but fire again peaked at intermediate population densities, which suggests that the spatial relationship is complex and nonlinear. Some land-cover types burned more frequently than expected, but no systematic differences were observed across the five regions. The consistent association between higher population densities and fire suggests that regardless of differences between land-cover types, natural fire regimes, or overall population, the presence of people in Mediterranean-climate regions strongly affects the frequency of fires; thus, population growth in areas now sparsely settled presents a conservation concern. Considering the sensitivity of plant species to repeated burning and the global conservation significance of Mediterranean-climate ecosystems, conservation planning needs to consider the human influence on fire frequency. Fine-scale spatial analysis of relationships between people and fire may help identify areas where increases in fire frequency will threaten ecologically valuable areas.*

Keywords: fire, land cover, Mediterranean, MODIS, population density, remote sensing

Amenazas a la Conservación Debido a Incrementos en la Frecuencia de Incendios Causados por Humanos en Ecosistemas de Clima Mediterráneo

Resumen: *El fuego periódico es un proceso natural importante en los ecosistemas de clima mediterráneo, pero el incremento de la recurrencia de fuego amenaza la frágil ecología de esas regiones. Debido a que la mayoría de los incendios son causados por humanos, investigamos el efecto de los patrones de población humana sobre la frecuencia del fuego. Investigaciones previas en California sugieren que la relación entre la densidad poblacional y la frecuencia de incendios no es lineal. Hay pocas igniciones humanas en áreas con baja densidad poblacional, así que la frecuencia de incendios es baja. A medida que aumenta la densidad poblacional, los incendios causados por humanos y la frecuencia de incendios también incrementa; pero al*

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llegar a un umbral de densidad, la relación se vuelve negativa ya que los combustibles son escasos y se concentran recursos para la supresión de fuego. Probamos sí esta hipótesis también aplica a los otros ecosistemas de clima mediterráneo en el mundo. Utilizamos bases de datos de satélite de población, actividad de fuego y cobertura de suelo para evaluar la relación espacial entre humanos y fuego en los cinco ecosistemas de clima mediterráneo en el mundo. Tanto las densidades medias y medianas fueron consistente y sustancialmente más altas en áreas con fuego como sin fuego, pero los incendios alcanzaron su máximo en densidades poblacionales intermedias, lo que sugiere que la relación espacial es compleja y no lineal. Algunos tipos de cobertura de suelo tuvieron incendios más frecuentemente de lo esperado, pero no se observaron diferencias significativas en las cinco regiones. La asociación consistente entre mayores densidades poblacionales y fuego sugiere que, independientemente de las diferencias entre tipos de cobertura de suelo, los regímenes de fuego naturales o la población total, la presencia de gente en regiones de clima mediterráneo afecta fuertemente a la frecuencia de incendios; por lo tanto, el crecimiento poblacional en áreas escasamente pobladas es preocupante para la conservación. Considerando la sensibilidad de las especies de plantas a incendios recurrentes y la significancia para la conservación de los ecosistemas de clima mediterráneo, la planificación de la conservación requiere que se considera la influencia humana sobre la frecuencia de incendios. El análisis espacial a fina escala de las relaciones entre gente y fuego puede ayudar a identificar áreas en las que el incremento en la frecuencia de fuego amenazará a áreas valiosas ecológicamente.

Palabras Clave: cobertura de suelo, densidad poblacional, fuego, Mediterráneo, MODIS, percepción remota

Introduction

The biodiversity of Mediterranean-climate ecosystems is among the highest of any biome in the world. The five regions in the world with Mediterranean climates (the Mediterranean Basin, central Chile, the Cape Region of South Africa, southwestern Australia, and parts of California and northern Baja California in North America) collectively occupy <5% of the Earth's unglaciated land surface, yet they contain 20% of the world's flora (Cowling et al. 1996), and many species are endemic (Mittermeier et al. 1998). Because of rapid global change and increasing anthropogenic pressure, all Mediterranean regions are of high global conservation concern (Médail & Quézel 1999; Olson & Dinerstein 2002; Vogiatzakis et al. 2006).

Although Mediterranean-climate ecosystems are geographically disjunct, they are classic examples of convergence in ecosystem structure and dynamics (Cody & Mooney 1978). The Mediterranean climate is characterized by cool, wet winters and warm to hot, dry summers, and the summer drought produces water stress that affects the seasonal distribution of wildfires. Vegetation in Mediterranean-climate regions is dominated by evergreen, woody, sclerophyllous shrubs that are very flammable and support crown fires (Christensen 1985). Nevertheless, specialized postfire persistence traits (e.g., seed banking in the soil and canopy and resprouting) make plant species resilient to periodic wildfire (Naveh 1975). The presence of fire-stimulated reproduction indicates an adaptive response to fire, and seed banking evolved independently in all Mediterranean-climate ecosystems except Chile (Bond & van Wilgen 1996). Nevertheless, all the woody shrubs in Chile resprout in response to fire, which is now frequent due to anthropogenic ignitions (Montenegro et al. 2004).

Fire in Mediterranean-climate ecosystems predates humans (except in Chile), and natural fire frequencies have varied between and among regions over time and in response to climate fluctuations (Rundel 1998). The history of human impact on fire regimes also differs among regions. For example, humans ignited fires in the Mediterranean Basin for thousands of years to support agropastoral activities (Lozano et al. 2008), Native Americans ignited fires in California since the early Holocene (Keeley 2002), and small populations of hunter-gatherers ignited fires in other regions until a few centuries ago (Rundel 1998). Evidence regarding early human influence on fire is circumstantial and controversial, but human activity is now thought to be a major determinant of the timing and location of fire. In fact, humans ignite most fires in Mediterranean regions (Bond & van Wilgen 1996). Current human influence on fire regimes and the potential ecological impact of their influence on fire is similar among Mediterranean-climate regions and differs strongly from fire problems in other forested systems.

In dry coniferous forests, like those in the western United States, the primary concern is a lack of fire primarily due to 20th-century fire suppression. Lower fire frequency in forests that naturally experienced high-frequency, low-intensity surface fires resulted in high accumulation of surface and canopy fuels (Parsons & Landres 1998). Fuel accumulation increases the likelihood fires will become uncharacteristically large and intense, which can kill even large, surface-fire-resistant trees.

Conservation threats and changes in fire regimes in Mediterranean-climate regions, however, are different. The shrublands are adapted to fire-return intervals that are generally longer than those historically experienced in conifer forests (Sugihara et al. 2006). Despite their capacity for rapid postfire regeneration, many shrubland plant species are sensitive to repeated burning. Serotinous species are particularly vulnerable (e.g., Wark et al. 1987; Pausas 1999; Syphard et al. 2006), but repeated burning may also extirpate resprouting species by reducing their capacity to regenerate and constraining their reproductive ability (e.g., Haidinger & Keeley 1993; Montenegro et al. 2004; Espelta et al. 2008). A related issue is that exotic species may facilitate fire and may expand under frequent fire (Mack & D'Antonio 1998). In California biodiversity is critically threatened by shrubland conversion to exotic annual grasses caused by atypically frequent fire (Keeley et al. 2005). Therefore, where the primary concern in dry coniferous forests is fire exclusion, the problem in Mediterranean-climate regions is repeated fires in the same location (Montenegro et al. 2004; Badia-Perpinyà & Pallares-Barbera 2006; Forsyth & van Wilgen 2008), although the intensity of fires may vary from region to region because of differences in prescribed management practices. Thus, understanding the causes and spatial distribution of altered fire regimes in Mediterranean-climate ecosystems has become a major research priority with strong conservation implications (Lavorel et al. 1998) and is particularly important given population growth in Mediterranean-climate ecosystems.

Studies in California show that area burned and number of fires are highest when population and housing densities are intermediate (Keeley 2005; Syphard et al. 2007). Fires initially increase with population and housing density and then decline where a threshold density is reached. There are several interrelated reasons for this. Ninety-five percent of California's fires are human caused; therefore, anthropogenic ignitions are lower in areas with low population density. As population and housing densities increase, fuels are still abundant and contiguous enough to carry fire, and the number and frequency of fires increase (Syphard et al. 2007). As population density increases further and an area is developed, wildland fuel is reduced and fragmented and fire-suppression resources are concentrated, resulting in lower fire frequencies at high population densities. Finally, even if fire frequency remains stable, fires may cluster in certain areas (e.g., human settlements) or land-cover types (Nunes et al. 2005; Forsyth & van Wilgen 2008), resulting in high fire frequency in localized areas.

Although the relationship between human population densities and fires has been studied in California, less is known about fire trends and patterns in other Mediterranean ecosystems. In recent years, fire frequency has escalated because of population growth and human ignitions in Chile (e.g., Montenegro et al. 2004) and South Africa (Forsyth & van Wilgen 2008), and fires increased exponentially in many areas in the Mediterranean Basin, in part due to the abandonment of traditional land-use practices (Pausas & Vallejo 1999). Interactions between fire and exotic species have been exacerbated by recurrent human-caused fires in Chile (Montenegro et al. 2004), South Africa (Bond & van Wilgen 1996), the Mediterranean Basin (Kark & Sol 2005; Vogiatzakis et al. 2006), and Australia (Offor 1990). In Spain fire ignitions cluster near urban areas (Badia-Perpinyà & Pallares-Barbera 2006), and population density has been correlated with the number of fires and area burned (Vázquez de la Cueva et al. 2006). Results of previous studies thus suggest that the relationship between human populations and fire frequency may be similar in all Mediterranean-climate ecosystems, but this idea has not been examined systematically across the different areas. Whether fire frequencies consistently peak at intermediate densities of human population is unclear. Nor is it clear whether certain land-cover types are more likely to burn.

Our objective was to quantify the relationship between humans and fire in Mediterranean-climate ecosystems across the globe. We asked, Are population densities higher in places where fires occur than in places without fires? Are fires consistently most frequent at intermediate population densities? Are certain land-cover types in each region more prone to fires?

Methods

Study Area

We used Bailey's ecoregion boundaries to demarcate Mediterranean-climate ecoregions (Bailey 1989). (Table 1). This is a hierarchical system with four levels (domains, divisions, provinces, and sections). For all five

Table 1. Number of Bailey's ecoregions, total area, and biogeographic characteristics* of Mediterranean-climate regions.

	Number of ecoregions	*Total area (km^2)*	*Number of native vascular plants*	*Endemic species (%)*	*Threatened species (%)*
Mediterranean Basin	25	2,392,048	23,300	50	18
North America	5	407,654	4,300	35	17
Chile	2	74,863	2,100	23	unknown
South Africa	1	69,401	8,550	68	15
Southwest Australia	1	118,882	8,000	75	18

**Biogeographic characteristics based on Calow (1998) and Vogiatzakis et al. (2006).*

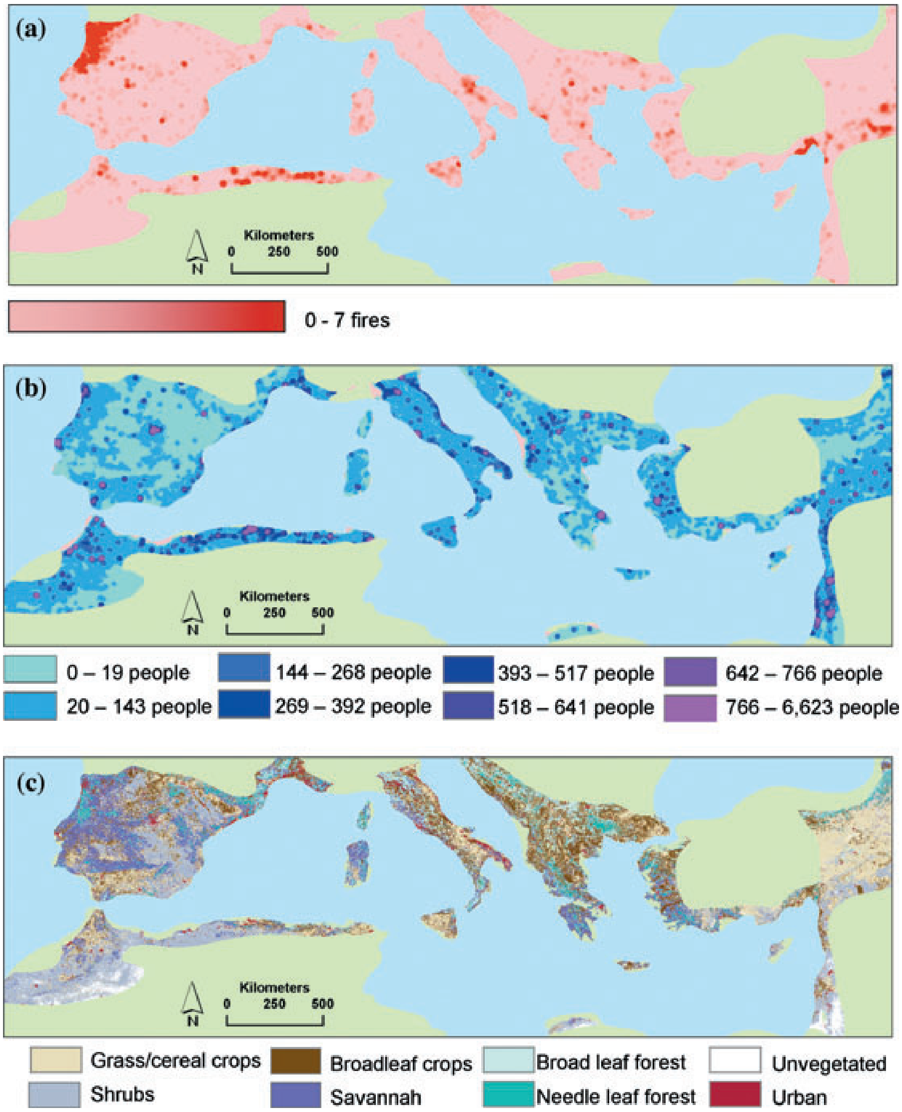

Figure 1. For the Mediterranean Basin, (a) MODIS active-fire detections in 2005, (b) LandScan population density in 2005, and (c) MODIS land-cover data. Fire and population density values are averaged across 225-km^2 pixels.

continents, we selected all ecoregions classified as either the Mediterranean Division or the Mediterranean Regime Mountains. To ensure comparability of area calculations, all spatial data were projected into an Albers equal area projection.

Processing of Population Data

We used population data from the LandScan Global Population Product because it has the finest resolution (<1 km) of any global population data set (Dobson et al. 2000). The LandScan database represents ambient population, accounting for diurnal movement and travel patterns. Every grid cell is allocated a population count based on a distribution model that incorporates the best available data on human population for every country, proximity of people to roads, land cover, nighttime lights, and urban density.

Because the accuracy and precision of LandScan are continually being improved, we restricted our analysis to 2005, the year with the most current data (Fig. 1). For comparison purposes, we divided the population counts by area and analyzed population density.

Processing of MODIS Fire Data

We used fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) to assess fire activity in Mediterranean-climate ecoregions because of its unmatched spatial and temporal detail (Justice 2002). With two polar-orbiting satellites, the MODIS active-fire product provides daily global information on fires. These data show actively burning fires based on radiant energy and comparisons of target pixels with surrounding pixels (Giglio et al. 2003).

Instead of mapping individual fires and area burned, MODIS indicates pixels in which fire activity was detected. Thus, there could be more than one fire active within a 1-km^2 MODIS pixel (Csiszar et al. 2006). In addition, fires occupying only a portion of a pixel can be detected (Dozier 1981). Although many small fires are missed, MODIS consistently detects larger fires that are ecologically relevant (Hawbaker et al. 2008), and the number of contiguous MODIS fire pixels tends to correlate with fire size (Giglio et al. 2006).

We analyzed MODIS fire data from the Land Processes Distributed Active Archive Center (LPDAAC, http://edcdaac.usgs.gov/modis/dataproducts.asp) for both sensors every day in 2005 to match the date of the population data. Using the boundaries of the Mediterranean ecoregions, we put all images into a mosaic (i.e., joined them together to form daily continuous tiles) for both sensors and summarized the daily data to create annual maps of fire for each region (Fig. 1). We included fire detections from all classified confidence levels because detection accuracy varies little whether fires are classified as low or high confidence (Hawbaker et al. 2008).

Processing of MODIS Land-Cover Data

In addition to the active-fire product, we used the 2003 MODIS 1 km Land Cover Dataset (Friedl et al. 2002) to analyze fire activity by land-cover class (Fig. 1). We used the LAI/fPAR Biome land-cover classification scheme because it was designed to capture differences in vegetation structural types (grasslands and cereal crops, shrubs, broadleaf crops, savannah, broadleaf forest, needle leaf forest, unvegetated, and urban; Myneni et al. 1997).

Analysis

In California fires are most likely to occur when the distance to housing is <15 km (Syphard et al. 2007). Because scale dependencies of ecological patterns and processes vary by region (Shugart 1998) and because people are mobile and affect their surroundings, we conducted our analysis of humans and fire at three levels of resolution (1, 15, and 45 km). Land-cover analyses were conducted only at the 1-km resolution, however, because we did not consider relationships between land cover and population measures.

We conducted a moving-window GIS analysis to summarize data across the entire land area. Within each window and at each resolution, we summarized the population density and the number of fires. Satellite fire detections can be obscured by clouds, and the MODIS active-fire product explicitly masks cloud cover in every daily image (Giglio et al. 2003). Therefore, we excluded cloud pixels, calculated the number of "observable days" within each window, and used this number to calculate average fire frequency. Uncertainty due to land-cover misclassification, undetected fires, and errors in population distribution was assumed to be consistent among the Mediterranean-climate ecoregions.

To determine whether population densities were higher in areas with fires, we selected all pixels and windows where there was one or more fires and calculated the mean and median population densities. We compared those with mean and median population densities in pixels and windows where no fires occurred. If there is a relationship between humans and fire, the proportion of fire should be higher where population is higher and lower where population is lower. We did not conduct a statistical test to determine whether the distributions differed because our data represent a complete enumeration, not a sample, and any difference would be statistically significant. Instead, we distributed the population data into 25 equally spaced categories and plotted the proportion of fires that occurred within each category for the three window sizes. The resulting bar charts showed whether more fires occurred at low, intermediate, or high population densities.

To determine whether fires burned more often (selectively) in different land-cover types, we calculated the total proportion of land-cover types in each region, then selected only the pixels with fires and recalculated the proportion. We calculated the ratio of the proportion of fires in the land-cover types and the proportion of the land-cover types in the landscape. A ratio of 1.0 means fire occurred in a land-cover type as often as would be expected by chance, >1.0 means fire occurred in the land-cover type more often, and <1.0 means fire occurred less often than expected by chance.

Results

We observed substantial differences in population density among the regions. Both the mean and median population densities in southwestern Australia were lowest of all the regions, and those in the Mediterranean Basin were highest. Although median population densities were substantially lower than mean population densities for all regions, the difference in North America was so substantial that mean population density was highest among the regions, but median population density was equal to that in southwestern Australia.

Pixels or windows with fires typically had higher population densities than pixels or windows without fires (Fig. 2). The only exception was in the 1-km pixels in North America, where mean population density was higher in the pixels without fires. Median population densities were nearly equal with and without fire in 1-km pixels in North America, South Africa, and southwestern Australia.

The relationship between population density and fire was more pronounced at 15 km than at 1 km, and at 45 km the mean population densities in areas with fires were much higher than where there were no fires (Fig. 2a). The median population density with fire was almost 3 times larger than the population density without fire at 45-km resolution.

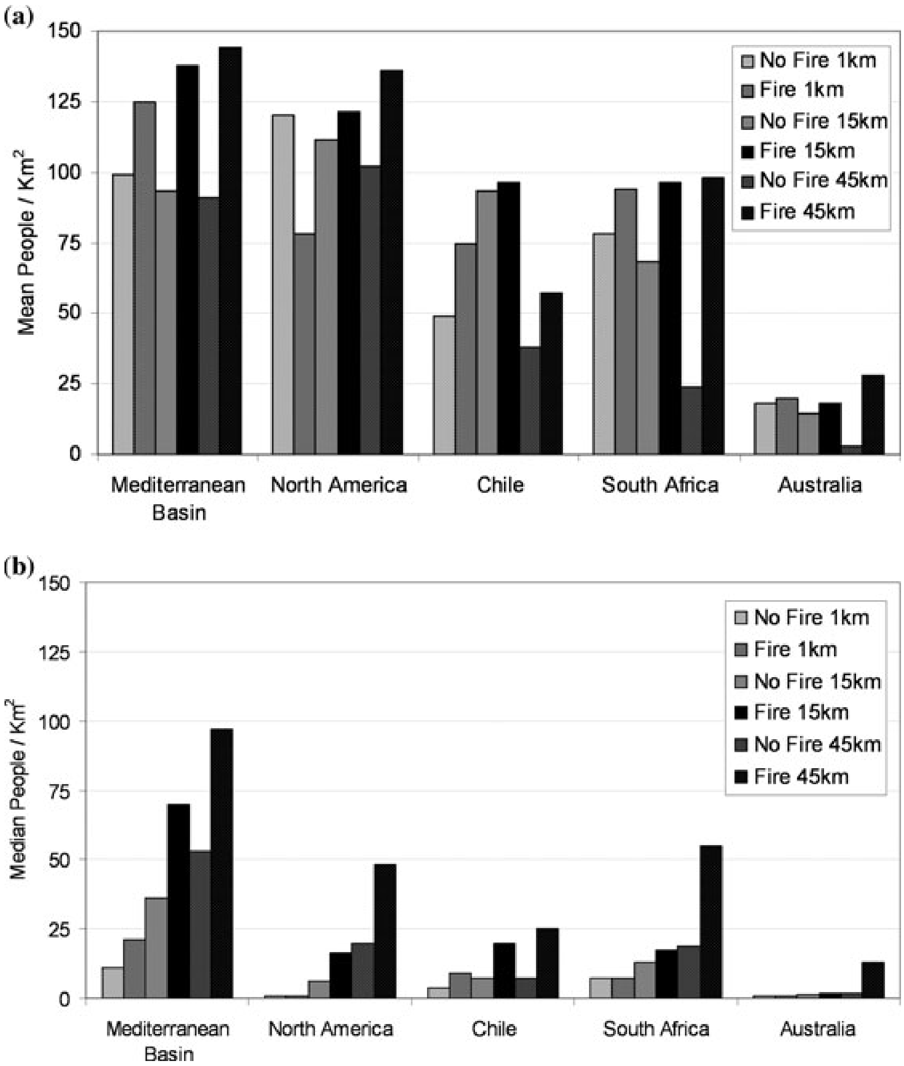

Figure 2. (a) Mean and (b) median population densities in areas with and without fires for 1-, 15-, and 45-km resolution windows. The y-axis scales differ.

Although population densities were, on average, higher where there were fires, the largest proportion of fires peaked at intermediate population densities (Fig. 3). Patterns of variation and peak population densities varied from region to region though, particularly at the 1- and 15-km window sizes. In addition, the peak in proportion of fires occurred in areas of lower population densities in North America at the 1-km resolution. In Chile and southwestern Australia, peak in proportion of fires occurred at the higher end of the population density distribution in the 1- and 45-km window sizes. The most consistent trend was apparent at the 45-km window size, where the highest proportion of fires occurred between 100 and 250 people per 45 km^2.

Land cover in the five regions included grasslands and cereal crops, shrubs, and savanna, with lower proportions of broad-leaf crops, broad-leaf forest, needle-leaf forest, unvegetated, and urban cover (Fig. 4). Distribution of these land-cover types, however, varied widely from region to region. Grasslands and cereal crops accounted for 40% of land cover in South Africa and southwestern Australia, but in Chile and North America they were just 20% of land cover. Substantially more needle-leaf forest was present in North America (21%) than in the other regions (<10%), and much of Chile was unvegetated (23%).

Some land-cover classes burned proportionately more than expected by chance given their areal distribution in the regions, but patterns were not consistent (Table 2; Fig. 4). In North America and Chile grasslands and cereal crops burned substantially more than expected but only as much as expected in the other three regions. Broad-leaf forest burned more than expected in southwestern Australia but not in the other regions. In North America shrubs burned more than expected and needle-leaf forest burned less than expected, but in the Mediterranean Basin, shrubs burned less than expected and needle-leaf forest burned more. In all regions, except for North America, more fires occurred in savannah than expected. Overall, very little fire occurred in unvegetated or urban areas.

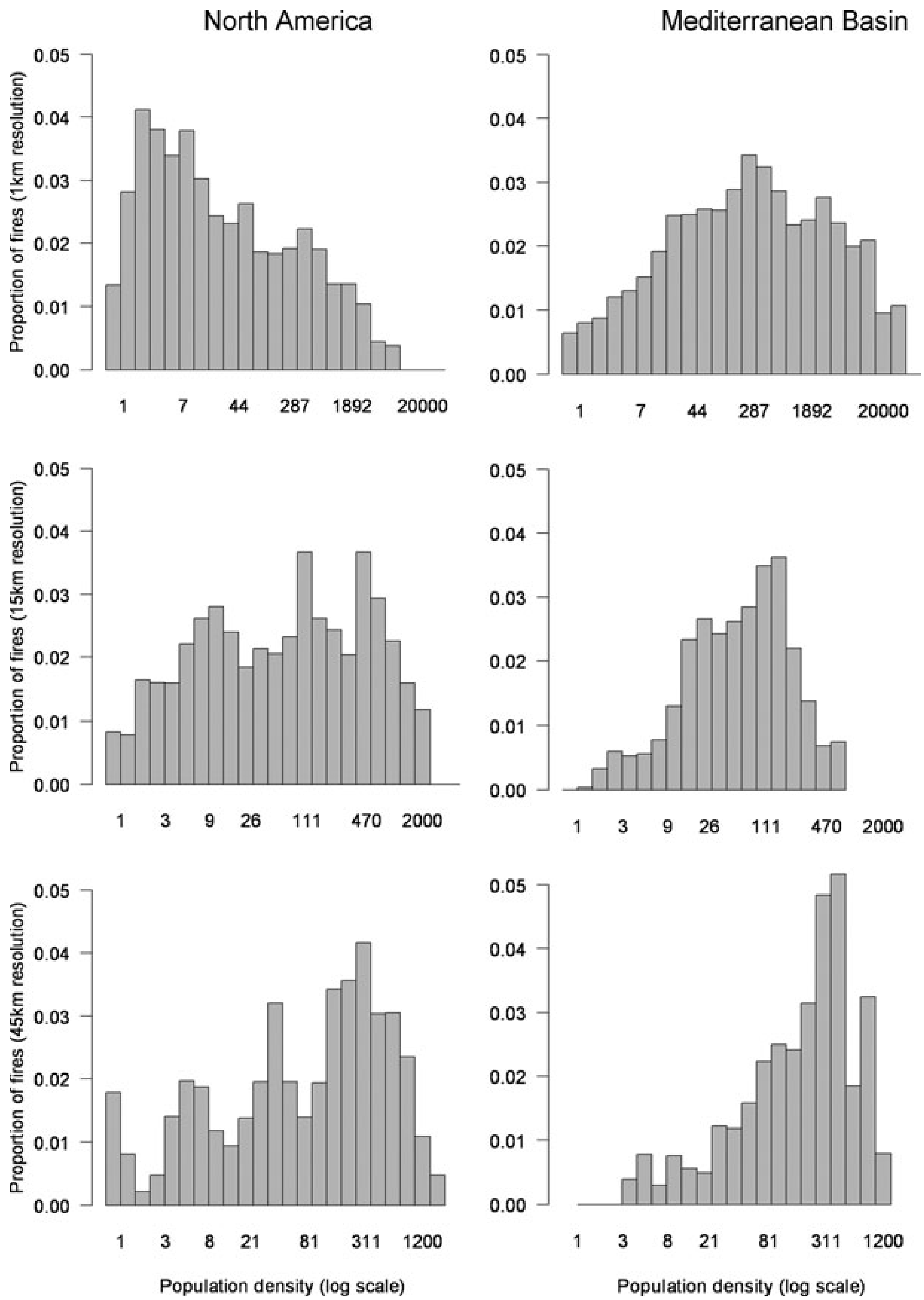

Figure 3. Proportion of fires within population density classes for 1-, 15-, and 45-km resolution windows.

Discussion

We found strong evidence that people are associated with the frequency and spatial distribution of fire similarly in all five Mediterranean-climate regions. Both mean and median population densities were consistently and substantially higher in areas with fire than in areas that did not burn; fires in Mediterranean-climate regions tended to occur close to people. Despite their convergence in ecosystem structure and function, Mediterranean-climate regions do vary in fire history, land-use history, or socioeconomic and political conditions (Pignatti et al. 2002; Carmel & Flather 2004; Vogiatzakis et al. 2006). Because of these differences, variations among the regions in population densities and land cover are not surprising. But these differences make the consistency of spatial relationships between people and fire across the five regions even more striking. The spatial pattern of fires

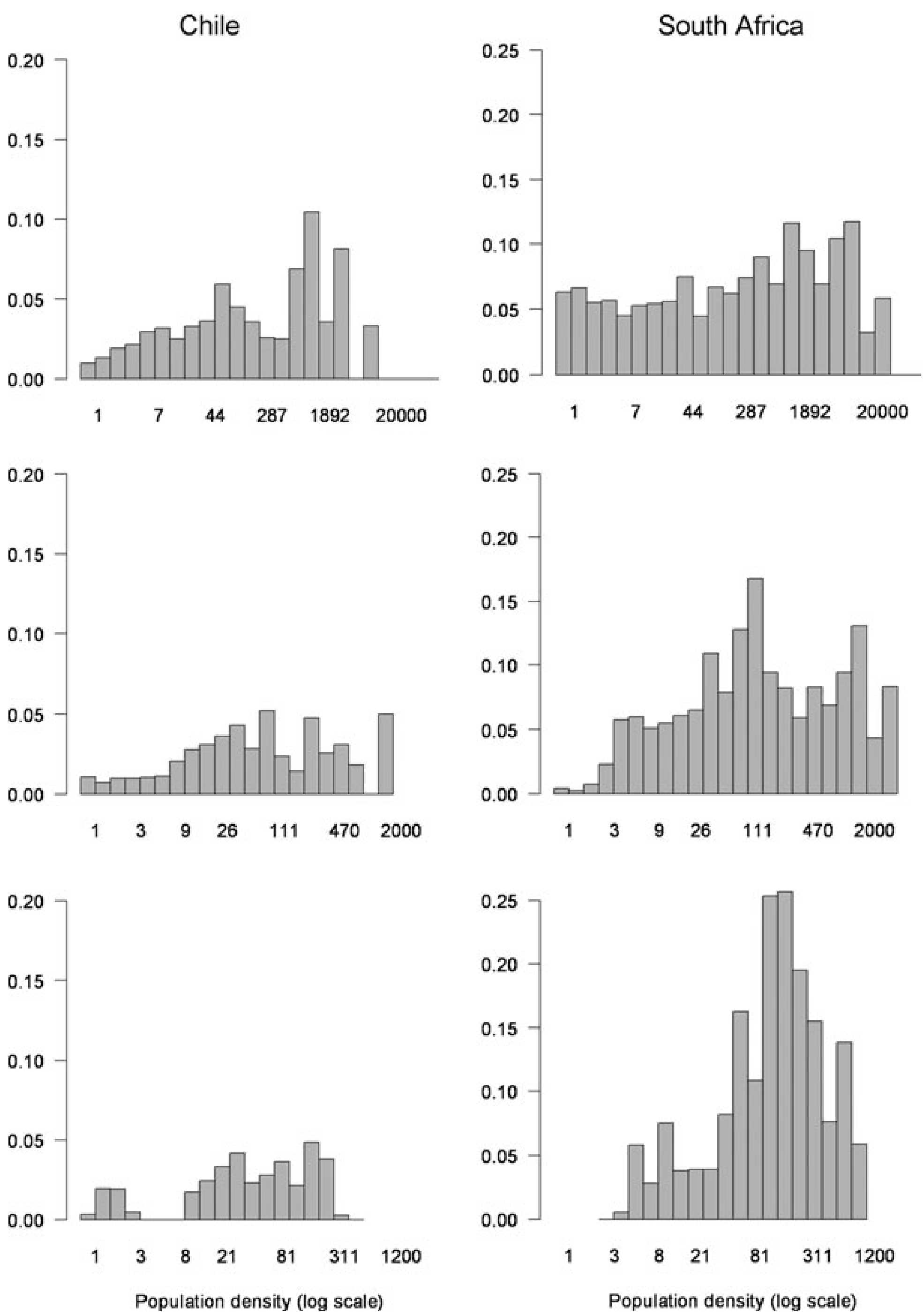

Figure 3. (continued)

in any region depends on complex interactions between ignition sources, landscape characteristics, and fuel continuity (Whelen 1995). So the consistent relationship between fire and population density suggests that the presence of people in Mediterranean-climate regions overrides these other factors.

Understanding the distribution of fire in Mediterranean-climate ecosystems is critical due to the vulnerability of its unique vegetation to repeated burning. Unlike other ecoregions in which decreased fire frequency threatens some species (Allen et al. 2002), in Mediterranean-climate ecoregions, the conservation concern is increased fire frequency (e.g., Keeley et al. 1999; Montenegro et al. 2004; Badia-Perpinyà & Pallares-Barbera 2006). The persistence of native plants is threatened and may have cascading ecological effects (Barro & Conard 1991; DellaSalla et al. 2004). Because Mediterranean regions are highly heterogeneous, the

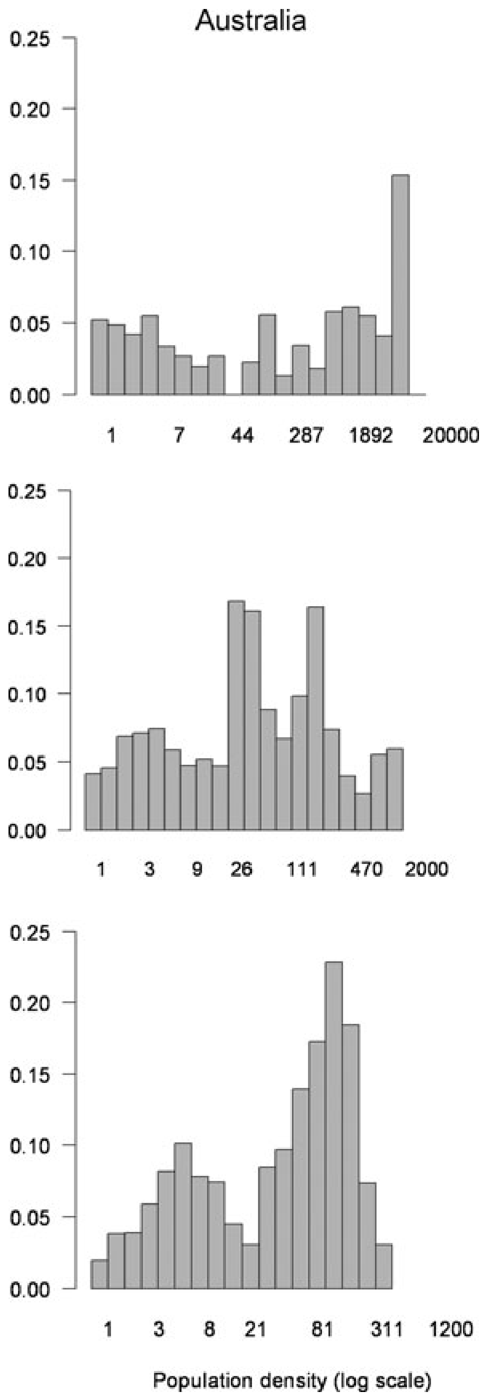

Figure 3. (continued)

Table 2. Ratio of the proportion of fires by land-cover type and proportion of land-cover type in the landscape.*

Land-cover type	*Mediterranean Basin*	*North America*	*Chile*	*South Africa*	*SW Australia*
Grass/cereal	0.79	1.76	1.72	1.09	0.85
Broad crops	1.07	1.70	1.65	0.55	0.49
Shrubs	0.42	1.35	1.00	0.79	0.43
Savannah	2.01	0.72	1.51	1.46	1.35
Broad leaf	0.80	0.45	1.02	1.62	1.90
Needle leaf	2.01	0.54	1.03	0.94	2.64
Unvegetated	0.06	0.17	0.03	0.13	0.06
Urban	1.92	0.89	1.88	1.41	0.96

**A ratio of 1.0 means fire occurred in a land-cover type as often as would be expected by chance, >1.0 means that fire occurred more often than expected, and <1.0 less often than expected by chance.*

sensitivity of different plant species to specific fire frequencies will vary (Public Library of Science ONE DOI:10.1371/journal.pone.0000938. 2007). Nevertheless, identifying where the landscape is likely to burn frequently is an important step in identifying areas vulnerable to the extirpation of native species.

The association of people with the spatial distribution of fire occurrence is likely due to the fact that humans now cause the majority of ignitions in all five Mediterranean-climate regions (Bond & van Wilgen 1996), and human ignitions are likely to occur close to roads and human infrastructure (e.g., Yang et al. 2007; Syphard et al. 2008). Nevertheless, our results also showed that fire occurrence consistently peaked where population densities were intermediate, which suggests that fire patterns in Mediterranean-climate regions are related to the spatial arrangement between people, urban development, and fuel. When population density is lowest, human ignitions are also low but increase with population density. Nevertheless, there appears to be a threshold above which fire occurrence declines, possibly due to less open space and fuel fragmentation caused by urban development or other land-use change. Fire-suppression resources also tend to be concentrated near urban areas (Calkin et al. 2005), and intermediate-density housing when located within wildland vegetation is classified as the wildland–urban interface (WUI) in the United States and given special fire-management considerations (Radeloff et al. 2005).

The relationship between people and fire in our study was most pronounced at the 15- and 45-km scales of analysis. Many ecological processes and spatial relationships have characteristic scales or space and time intervals over which the process can be detected (Shugart 1998). One explanation for the scale effect in our results is that analysis with the 15- and 45-km window sizes could include pixels where fires did, and did not, burn. The observed relationship and scale dependence of the results may therefore have been related to the relative proportion of burned cells within a window. At the 1-km resolution, the pixel either burned or it did not, and the analysis did not account for neighborhood effects.

Although our primary focus was to assess the relationship between population density and fire, other researchers have shown that land use and land cover may be important covariates of fire patterns due to their effects on fuel types, flammability, and human use of fire (e.g., Viedma et al. 2006; Baeza et al. 2007). In our analysis some land-cover types burned more frequently than expected, but no systematic differences were observed.

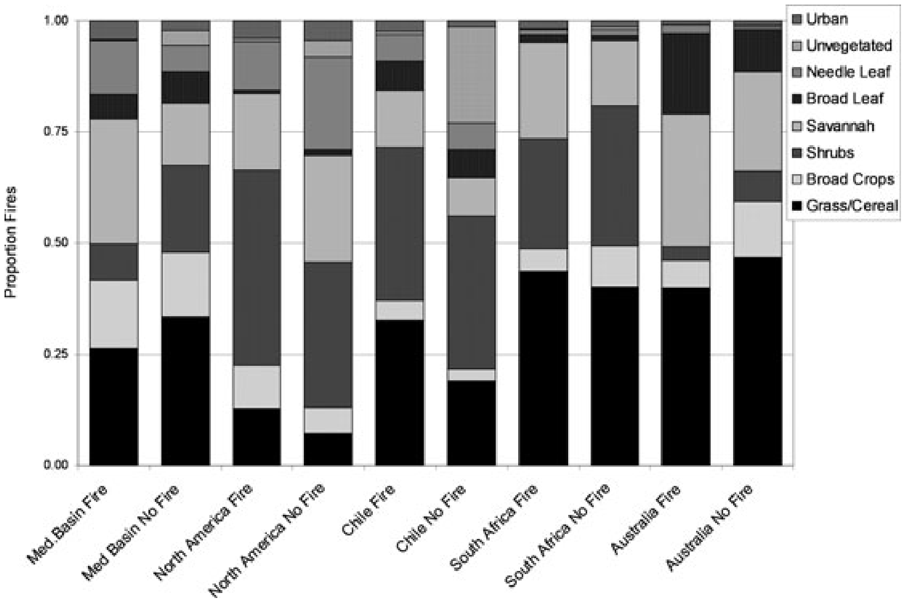

Figure 4. Aerial proportion of land-cover classes in the ecoregions and within pixels with an active fire in 2005.

Therefore, the patterns we observed in land-cover types were likely related to unique combinations of human land use and management practices within each region. For example, in North America, needle-leaf forest burned less than expected, whereas shrublands burned more. Fire suppression has successfully excluded fire from California's high-elevation-mixed conifer forests. On the other hand, the disproportionately high level of fire in shrubs is likely due to housing development and increased human ignitions in low-elevation areas where these shrubs (i.e., chaparral) are common (Keeley et al. 1999). More fires than expected in needle-leaf forests in the Mediterranean Basin may be due to land abandonment, which has resulted in substantial increases of fire in pine forests (Pausas & Vallejo 1999).

In North America and Chile fire burned more in grasslands and cereal crops than expected. Grasslands can sustain and even promote higher fire frequencies than other land-cover types (Mack & D'Antonio 1998), a major conservation concern in southern California, where exotic annual grasses have replaced native shrublands under unnaturally high fire frequencies (Haidinger & Keeley 1993). Problems with exotic annual grasses have also been reported in Chile and Australia (Pignatti et al. 2002) and may become more pronounced if fire frequency continues to increase.

Conclusions

Mediterranean-climate ecosystems are among the most biologically diverse regions in the world with rates of endemism ranging from 23% (Chile) to 75% (southwestern Australia), and at least 15% of the taxa in Mediterranean-climate ecosystems are threatened (Calow 1998). Our results suggest that conservation planners in Mediterranean-climate regions should seriously consider human alteration of fire patterns. Although we used fire data for only 1 year, the consistency in our results demonstrates that, regardless of the overall fire frequency in a region and its annual weather-driven variations, it may be possible to predict where fires are concentrated. Our results therefore provide a foundation for further research and planning to identify where frequent fire threatens vulnerable Mediterranean-climate plant species.

Future research should identify regionally specific ranges of population densities where fire occurrence is highest, be conducted at the scales most relevant to planning and management, and incorporate other drivers of fire pattern, such as biophysical variables. Finally, compact development should be studied for its potential to mitigate the effects of human presence by limiting expansion into undeveloped vegetation. Education efforts to reduce human-caused ignitions were once the foundation of outreach programs, such as Smokey Bear; perhaps the time has come to bring the bear back from semiretirement.

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