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Threats and biodiversity in the mediterranean biome

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ABSTRACT

Aim Global conservation assessments recognize the mediterranean biome as a priority for the conservation of the world's biodiversity. To better direct future conservation efforts in the biome, an improved understanding of the location, magnitude and trend of key threats and their relationship with species of conservation importance is needed.

Location Mediterranean-climate regions in California-Baja California, Chile, South Africa, Australia and the Mediterranean Basin.

Methods We undertook a systematic, pan-regional assessment of threats in the mediterranean biome including human population density, urban area and agriculture. To realize the full implications of these threats on mediterranean biodiversity, we examined their relationship with species of conservation concern: threatened mammals at the global scale and threatened plants at the subecoregional scale in California, USA.

Results Across the biome, population density and urban area increased by 13% and agriculture by 1% between 1990 and 2000. Both population density and urban area were greatest in California-Baja California and least in Australia while, in contrast, agriculture was greatest in Australia and least in California-Baja California. In all regions lowlands were most affected by the threats analysed, with the exception of population density in the Chilean matorral. Threatened species richness had a significant positive correlation with population density at global and subecoregional scales, while threatened species were found to increase with the amount of urban area and decrease as the amount of natural area and unfragmented core area increased.

Main conclusions Threats to mediterranean biodiversity have increased from 1990 to 2000, although patterns vary both across and within the five regions. The need for future conservation efforts is further underlined by the positive correlation between species of conservation concern and the increase in population density over the last decade. Challenges to reducing threats extend beyond those analysed to include human–environmental interactions and their synergistic effects, such as urbanization and invasive species and wildfires.

Keywords

Conservation biogeography, mediterranean-type ecosystems, population density, threatened species, urbanization.

INTRODUCTION

The world's five mediterranean-climate regions are renowned for high levels of plant richness and endemism – exceeding the combined floras of tropical Africa and Asia (Arroyo & Cavieres, 1991; Heywood, 1993; Cowling *et al.*, 1996). However, the mediterranean biome, spanning coastal and interior portions of California, USA, and Mexico, Chile, South Africa, Australia and the Mediterranean Basin, is also recognized as one of the most imperilled. The mediterranean biome is estimated to experience greatest proportional change in biodiversity by 2100 owing to its sensitivity to land use change and climate (Sala *et al.*, 2000). To reduce the rate of biodiversity loss in the face of such dire predictions, a detailed, pan-regional evaluation of the location,

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magnitude and trend of key threats and their correlative relationship with species of conservation importance is needed. Without a deeper understanding than that afforded by current global-scale assessments, the effectiveness of conservation efforts to reduce the loss of biodiversity in the mediterranean biome is likely to be limited.

Previous coarse-scale assessments associate a number of factors such as population density, urban area and agriculture with threats to biodiversity. Correlations between population density and biodiversity have been made by Cincotta *et al.* (2000) who estimate that the human population growth rate in the biodiversity hotspots is 1.8% per year compared to a global average of 1.3%. Similarly, Balmford *et al.* (2001) find a positive correlation between population density and areas of high species and threatened species richness in continental Africa. Conversion of natural areas to urban and high intensity agriculture is also reported from assessments utilizing global land cover and vegetation data sets (e.g. Hoekstra *et al.*, 2005; Miles *et al.*, 2006).

Studies from within the five mediterranean regions provide evidence that these threats are also of concern to mediterranean biodiversity: e.g. population density and growth of urban areas (Rouget *et al.*, 2003a; Schwartz *et al.*, 2006), conversion to agriculture (le Houérou, 1981; Hobbs, 1998) and conversion of natural areas for tourism-related development (Grenon & Batisse, 1989; Paskoff & Manriquez, 1999). However, the magnitude of threats to mediterranean biodiversity differs between the five regions. Plant extinction rates, for example, are suggested to correlate with the age and duration of large-scale western colonization, with lowest extinction rates in the Mediterranean Basin (1.1%) compared to Western Australia (6.6%) (Greuter, 1994). The 'old world' Mediterranean Basin has experienced agriculture for thousands of years; its high plant diversity is often attributed to the coevolution of plants with people (Di Castri, 1981). In contrast, 'new world' mediterranean regions have experienced rapid transformation after colonization by European settlers over a much shorter timeframe. Threats are also likely to differ within each mediterranean region. For example, coastal lowlands compared to higher elevation areas are disproportionately affected since they were often the first to be settled.

We conduct the first global analysis of threats within an entire terrestrial biome. We first report on static and recent trends in three primary threats: population density, urban area and conversion to agriculture, informed by regional scale data. Then, to understand the implications of these threats on biodiversity, we assess the correlative relationship between threats and species of conservation importance. These findings, although they cannot infer causality, provide the foundation for more detailed exploration of causality within the five mediterranean regions. We conclude by discussing the implications of these findings for future conservation efforts in the mediterranean biome.

METHODS

We examined threats with species of conservation concern at two spatial scales: globally across the entire mediterranean biome and within the mediterranean region of California, USA. For the global scale analysis we defined the spatial extent of the mediterranean biome using the World Wildlife Fund's (WWF) 39 ecoregions in the Mediterranean Forest, Woodland and Scrub biome (Olson & Dinerstein, 2002). Within this spatial footprint we reported threats using three elevation zones which aim to capture distinct assemblages of biodiversity (see Underwood *et al.* in press): lowland (0–300 m), foothill (300–1000 m) and montane (> 1000 m). We then conducted an analysis using finer spatial units in California, called CalJep ecological subunits (hereafter referred to as 'subecoregions' *sensu* Williams *et al.* (2005)) – a spatial data base reconciliation of two prominent electronic floras (CalFlora and Jepson) (Viers *et al.*, 2006). We selected 97 out of the 228 CalJep units which were within the footprint of the three WWF mediterranean ecoregions (excluding Baja California). For the subecoregional threats analysis, we excluded two units representing the Channel Islands due to incomplete data. Our analysis focused on two questions:

How do threats and trends in threats vary across the five mediterranean regions?

We used spatially explicit data describing factors known to impact biodiversity (see Table S1 in Supporting Information). Data included land cover information from country (Chile, Australia, South Africa), state (California, USA, and Baja California Norte, Mexico) or, in their absence, regional data bases (Mediterranean Basin) (Conaf-Conama-Birf, 1997; Council for Scientific and Industrial Research (CSIR), 1997; California Department of Forestry and Fire Protection, 2002; Bureau of Rural Sciences, 2003; MDA Federal Inc., 2003; European Topic Centre on Land Use and Spatial Information, 2005). For each ecoregion and subecoregion in California, these land cover data were used to calculate the percent urban area ('urban'), percent high intensity agriculture including exotic species plantations ('agriculture') and available natural area ('available', i.e. the amount of each unit that was not urban, not agriculture and not protected). To indicate the quality of the remaining natural area, we calculated the amount of 'core area' that is greater than 1 km from urban, high intensity agriculture and roads. Population density data at the global scale were compiled from the Gridded Population of the World (version 3) (CIESIN *et al.*, 2005) and for subecoregions in California from census block data (US Census Bureau, 2000).

To measure trends in the three key threats from 1990 to 2000 we calculated the change in population density (based on the CIESIN data), change in urban area, and change in agriculture (for three of the five regions where data permitted – California-Baja California, Australia and the Mediterranean Basin). A variety of techniques were used to estimate the change in urban area over the 10-year period. For the Mediterranean Basin and California-Baja California, comparable land cover was available for 1990 and 2000. Australia had comparable land cover maps from 1990 and 1995, and a linear trend from these two dates was used to extrapolate urban and agricultural extent in 2000. For Chile, South Africa and Baja California, existing land cover information was used for one of the two dates and the extent of urban area in the other year was digitized using visual interpretation of freely available Landsat TM imagery and high resolution imagery in Google Earth™.

What is the relationship between threats and threatened species?

Data on threatened vertebrate species for each ecoregion were compiled from the WildFinder data base (World Wildlife Fund, 2006). We included vertebrates from all IUCN Redlist classes except those classified as Data Deficient, Not Evaluated, Lower Risk or Extinct (IUCN Species Survival Commission 2006). There were 2118 vertebrates that met these criteria (hereafter referred to as 'threatened'). Threatened mammals comprised the majority of records (74%), therefore we focused analyses on these species. For the subecoregional analysis in California we compiled the number of State-listed threatened and endangered vascular plant species from the CalJep data base. Threatened species richness ranged from 0 to 14 across the 97 subecoregional units.

To remove the effect of area, tabular data on the number of threatened species were log transformed ($\log_e$ count + 1) and plotted against log area ($\log_e$ km^2) of the study unit. The residuals about a fitted line, representing the number of threatened species when the area of the unit has been accounted for (Balmford & Long, 1995), were used in subsequent analyses. To account for the effect of area in the threat data layers we used the percent of each unit that was impacted by urban or agriculture which was arcsine transformed where values clustered around zero. Data on population density per km^2 were log transformed.

We first investigated the degree to which population density was associated with biodiversity in the mediterranean biome, as found in other studies (e.g. Balmford *et al.*, 2001). We conducted Pearson's product–moment correlation between population density and the number of threatened mammals in each ecoregion at the global scale and the number of threatened plants at the subecoregional scale in California, USA. Analysis of threatened species using more detailed data on land cover characteristics (i.e. urban, agriculture, available natural area, core area and population density) was performed using multiple regression techniques. Independent variables were first screened to assess collinearity; population density was removed from further analysis as it was highly correlated with percent urban at the global scale and subecoregional units within California (see Table S2 in Supporting Information). The residuals of the analysis were tested to ensure they met the assumptions of parametric analysis (Shapiro–Wilk Goodness of Fit test) (Zar, 1999) and any outlying units removed from the final models. For the subecoregional analysis the relationship between percent urban and threatened species was best described by a quadratic polynomial rather than linear fit. For both global and subecoregional analyses we assumed that the number of threatened species would vary as a function of land cover characteristics. We assumed that more habitat (evaluated as the amount of land available and core area) would result in decreased numbers of threatened species. Conversely, we assumed that the number of threatened species would increase as either urban or agricultural area increased.

To infer the status of threatened mediterranean biodiversity in the future we conducted a correlation between threatened species and the amount of protection and trends in population density from 1990 to 2000 at both the global and subecoregional scale. Percent protection data (IUCN categories I–IV) were compiled from country and state scale data sets, with the exception of the Mediterranean Basin that used the World Data base on Protected Areas (2006). All GIS analyses were conducted in ArcGIS 9.1 (ESRI, Inc., Redlands, CA, USA) and all statistical analyses were conducted in JmpIn5.1 (SAS Institute, Cary, NC, USA).

RESULTS

How do threats, and trends in threats, vary across the five mediterranean regions?

Across the five mediterranean regions population density was highest in California-Baja California with 246 people km^{-2} – more than twice the amount of the next densest region, and lowest in Australia (five people km^{-2}) (Table 1). Within each region population density was concentrated in the lowlands, particularly in California-Baja California with 591 people km^{-2}, followed by the Mediterranean Basin, South Africa, Chile and Australia (Fig. 1). In the foothill elevation zone, Chile, California-Baja California and the Mediterranean Basin had similar population densities with an average of 75 people km^{-2}, approximately nine times higher than the density in foothills in South Africa. In

Table 1 Key spatial threats occurring in the five mediterranean regions in 2000 and change in threats between 1990 and 2000 (i.e. amount in 2000 as a proportion of the amount in 1990).

		Pop per km^2		% Urban area		% Agriculture	
Region	Area (km^2)	2000	Change 1990–2000	2000	Change 1990–2000	2000	Change 1990–2000
California-Baja California	118,340	246	11%	9.2%	11%	6%	–3.6%
Chile	146,839	46	19%	0.7%	6%	24%	ND
South Africa	95,554	57	17%	1.0%	7%	24%	ND
Australia	785,274	5	12%	0.3%	8%	37%	–0.4%
Mediterranean Basin	2,022,672	123	12%	1.5%	17%	29%	1.0%

ND, not determined.

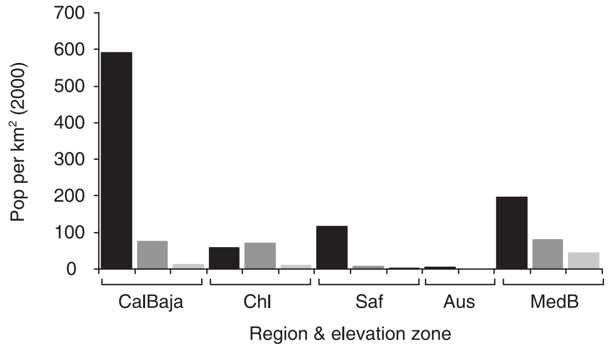

Figure 1 Population per km^2 in the five mediterranean regions by elevation zones (note: area of montane region in Australia was too small relative to spatial data on threats to assess). Black = lowland (0–300 m), mid-grey = foothill (300–1000 m), light grey = montane (> 1000 m).

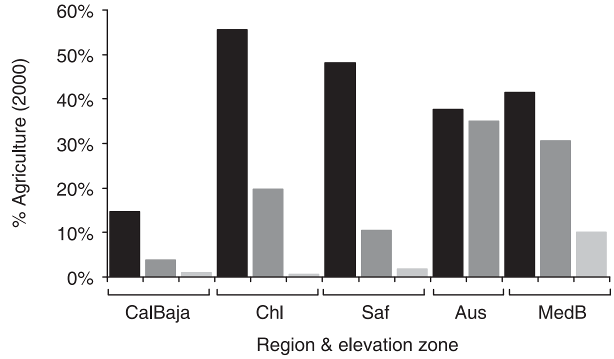

Figure 3 Percent agriculture in the five mediterranean regions by elevation zones. Black = lowland (0–300 m), mid-grey = foothill (300–1000 m), light grey = montane (> 1000 m).

the montane zone above 1000 m, the density of people in the Mediterranean Basin at 44 people km^{-2} was substantially higher than in the other three regions which had an average of eight people km^{-2}. Trends in population density, i.e. the amount in 2000 as a proportion of the amount in 1990, increased by 13% across the entire biome. Chile experienced the greatest change over the 10-year period (19%), with least change occurring in California-Baja California (11%) (Table 1). Each of the elevation zones experienced an increase in population density with greatest occurring in the lowlands, particularly California-Baja California and the Mediterranean Basin (by 47 and 19 people km^{-2}, respectively) (see Table S3 in Supporting Information). Foothill zones in California-Baja, Chile and the Mediterranean Basin also experienced an increase of 10 people km^{-2} or more (Table S3).

Patterns of urban area were similar to population density: California-Baja California had the greatest amount of urban area at 9% and Australia the lowest at 0.3% (Table 1). Across the three elevation zones, urban area in California-Baja California was consistently greater compared to the other four regions (Fig. 2). For example, 20% of California-Baja California lowlands were classified as urban compared to lowlands in the four other regions that averaged 2%. From 1990 to 2000 urban area increased by 13% across the biome. Greatest change occurred in the Mediterranean Basin (17%) and least occurred in Chile (6%) (Table 1). Although change in percent urban is relatively small by elevation zone over the 10-year interval, the greatest increase occurred in lowland and foothill regions of California-Baja California (by 578 km^2 and 247 km^2, respectively) and the Mediterranean Basin (2840 km^2 and 1431 km^2) (Table S3). No change in urban area was detected in foothill and montane zones in South Africa or the montane zone in Chile.

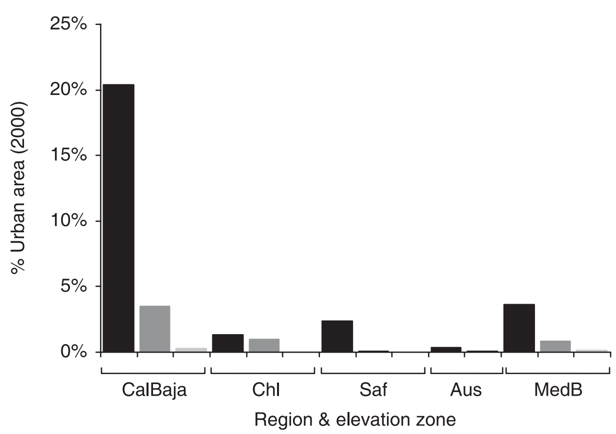

Figure 2 Percent urban area in the five mediterranean regions by elevation zones. Black = lowland (0–300 m), mid-grey = foothill (300–1000 m), light grey = montane (> 1000 m).

The amount of agriculture was highest in the mediterranean region of Australia (37%) and California-Baja California had the least (6%) (Table 1). Among low elevation areas, agriculture was greatest in Chile (55%) and, again, least in California-Baja California (15%) (Fig. 3). In foothill elevations, Australia had the highest percent of agriculture (35%). In the montane zones, the Mediterranean Basin had the highest amount of agriculture (10%) compared to an average of 1% for the other regions. Change in agriculture, for three of the five regions that could be assessed, was less than 1% between 1990 and 2000. In the Mediterranean Basin, agriculture increased marginally in all three elevation zones, but declined marginally in the Australian lowlands and California-Baja California foothill and montane zones (Table S3).

What is the relationship between threats and threatened species?

At the global scale, a significant positive correlation between population density and the number of threatened mammals was found ($r = 0.37$, $P = 0.02$) (Fig. 4a). Using more detailed data on land cover characteristics (urban, agriculture, available natural area and core natural area) compiled from country and regional scale data, we found that over half of the variance in the number of threatened mammals was accounted for by these four threats ($r^2 = 0.52$, $P < 0.0001$) (Table 2). As we had assumed, the number of threatened mammals: increased as urban area increased ($P = 0.07$), decreased as core area increased ($P = 0.006$) and decreased as available natural area increased ($P = 0.007$).

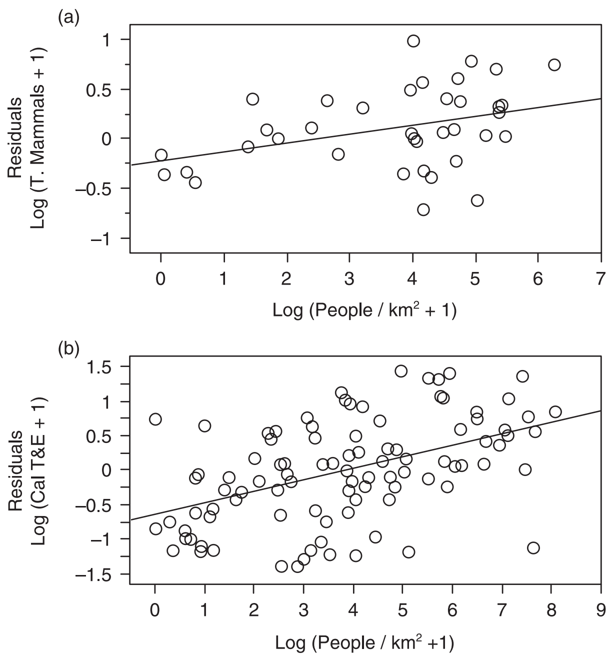

Figure 4 (a) Correlation between human population density (population per km^2) and threatened mammal richness in the 39 mediterranean ecoregions. (b) Correlation between human population density (population per km^2) and threatened and endangered ('T&E') plant richness in the 97 subecoregional units within the mediterranean biome of California, USA.

Table 2 Multiple regression statistic between threatened mammals and threat variables for the 39 mediterranean ecoregions.

Source	d.f.	Estimate	Sum of squares	*F* ratio	Prob > *F*
ArcSine(% Urban)	1	1.155	0.315	3.486	0.071
% Core	1	–0.993	0.769	8.518	0.006
% Available	1	–1.177	0.759	8.403	0.007
% Agriculture	1	–1.763	1.389	15.373	0.0004

Contrary to expectations, however, the number of threatened species decreased as agricultural area increased ($P = 0.0004$).

In the subecoregional analysis in California USA, we also found a significant positive correlation with the number of threatened plants increasing as population density increased ($r = 0.46$, $P < 0.0001$) (Fig. 4b). Results using more detailed data on land cover were highly significant ($P < 0.0001$) and explained 33% of the variance (Table 3). In agreement with findings at the global scale, the number of threatened plants increased as urban area increased ($P = 0.08$) (until urbanization reached a certain threshold), decreased as available natural area increased ($P = 0.007$), and a decreasing trend in the number of threatened plants was detected as core area increased ($P = 0.16$). Again, similar to findings at the global scale, the number of threatened plants decreased as the amount of agricultural area increased ($P = 0.13$).

At the global scale, no correlation was detected between the number of threatened mammals and the percent of protection,

Table 3 Multiple regression statistic between threatened plants and threat variables for the 97 subecoregional units within the mediterranean ecoregions of California.

Source	d.f.	Estimate	Sum of squares	*F* ratio	Prob > *F*
ArcSine(% Urban)	1	2.208	1.232	3.135	0.080
Arcsine(% Urban)* Arcsine(% Urban)	1	–2.025	2.537	6.454	0.013
% Core	1	–0.822	0.782	1.990	0.162
% Available	1	–0.926	2.954	7.513	0.007
ArcSine(% Agriculture)	1	–0.695	0.945	2.403	0.125

while at the subecoregional scale, a positive trend was detected between threatened plants and protection ($r = 0.17$, $P = 0.1$). In evaluating whether ecoregions or subecoregional units with a high number of threatened species also had greater trends in threats, we found a positive correlation between the number of threatened plants and the percent change in population density between 1990 and 2000 in California ($r = 0.21$, $P = 0.04$), but a negative correlation at the global scale ($r = –0.34$, $P = 0.04$).

DISCUSSION

Patterns of threat across the mediterranean biome

The three key threats we analysed varied substantially in magnitude between the five regions and across elevation zones within each region. Specific findings, however, must be interpreted with caution since they are based on one of many spatial delineations of mediterranean regions, along with the particular elevation thresholds selected for this study. The WWF mediterranean ecoregions, for example, exclude the Central Valley of California – an area dominated by cropland that clearly affects the amount of agricultural area. With this ecoregion included in analysis, for example, the amount of agriculture in California-Baja California increases from 6% to 17%.

As might be expected, patterns of population density and urban area were similar (Table S2), especially in lowland regions (i.e. the region with the highest population density also had the highest percent urban area). Particularly striking was the high population density and urban area in the California-Baja California lowlands. Settlement of easily developed coastal lowlands in southern California was fuelled by economic growth associated with military and industrial expansion after the Second World War (Walter, 1998). Our results also indicated increases in population density and urban area at higher elevations, which is particularly acute in the foothills surrounding the Central Valley of California, USA. Following the decline of commercial gold mines and the traditional natural resource-based economy, these areas have experienced exurban migration from expanding lowland metropolitan areas over recent decades, motivated by a desire to live in a relatively natural setting (Jones *et al.*, 2003). The corresponding land speculation and rising land prices has led to the conversion of large farms and rangelands to residential 'ranchette' type housing and other developments (Walker *et al*., 2003; Sierra Business Council, 2006).

The Mediterranean Basin had the second highest population density and urban area, and experienced greatest increase in urban area from 1990 to 2000. Coastal lowlands have experienced urbanization and development associated with tourism for decades (Grenon & Batisse, 1989; Vogiatzakis *et al*., 2005). However, urban area has also increased in foothills within commutable distances to major cities as a result of second home construction and the tourism and leisure industry, e.g. the Sierra de Guadarrama region near Madrid (P. Regato, pers. comm.). Within South Africa, urban development is concentrated around coastal Cape Town, but unlike the Mediterranean Basin no change was detected in foothill and montane zones. This might be due to a combination of the high degree of protection that exists at upper elevations, for example, approximately 70% of areas between 530 and 1000 m are protected in statutory and non-statutory reserves, and their location far from existing urban centres (Rouget *et al*., 2003b). The single ecoregion in Chile, the Chilean matorral, was characterized by relatively low population density in 2000 (46 people km^{-2}) but experienced the greatest increase between 1990 and 2000 (19%). Eighty-seven percent of Chile's population lives in cities which are primarily concentrated in the mediterranean region (INE, 2002; Pauchard *et al*., 2006). Urban expansion in the mid-size town of Los Angeles, for example, grew by 133% over a 20-year period (Henriquez *et al*., 2006). In turn, this exerts a negative impact on biodiversity, as recorded in Concepción – located in a highly diverse transition zone between the mediterranean and the temperate biomes (Pauchard *et al*., 2006). In contrast, population density and the amount of urban area were lowest in Australia, although summary data mask the concentration of people in Perth, which is described as one of fastest growing urban areas in Australia (Hobbs, 1998).

Agriculture in the five mediterranean regions was highest in Australia where clearing of native vegetation for wheat cultivation in the south-west is estimated to have reached 1 million acres a year by 1980 (Rijavec *et al*., 2002). As a result, only 2–3% of the native vegetation that contains high numbers of rare and endangered plant species remains (Hobbs, 1993; Hopper & Gioia, 2004). In the Mediterranean Basin, almost one-third of the mediterranean extent was classified as agriculture with slight increases recorded in all elevation zones from 1990 to 2000. While the European Union's Common Market agricultural policies have increasingly resulted in the abandonment of small farms in northern Mediterranean Basin countries (Barbéro *et al*., 1990), increased mechanization in the southern Mediterranean Basin countries has led to cereal cultivation over large areas of steppe vegetation (le Houérou, 1992).

What is the relationship between threats and threatened species?

We evaluated the extent to which various factors were associated with species of conservation importance. While we did not examine causality per se, we believe that these observed trends represent real phenomena and pave the way for a more detailed examination of threats in the mediterranean biome. In concurrence with previous studies (e.g. Balmford *et al*., 2001) we found a positive correlation between the number of threatened species and population density. However, more detailed data on land cover characteristics explained more of the variance. For three of these threat variables the correlative relationship with threatened species was expected. As the amount of urban area increased the number of threatened species also increased – for plants, for example, urbanization is clearly a threat given their inherent dispersal limitations (Trakhtenbrot *et al*., 2005). Nevertheless, the subecoregional analysis in California showed this positive relationship became negative once the percent of urban area in the subecoregional unit exceeded 80%, e.g. south-east of the San Francisco Bay in Santa Clara and Alameda counties (92% and 87%, respectively) or Orange County in southern California (85% urban). One explanation is that species have already been lost to severe transformation in these areas but is not reflected in the threatened species data (i.e. lost before recording began). Schwartz *et al*. (2006) also reported considerably more extirpations of rare species in counties with higher human density which is likely related to human-associated habitat loss and degradation.

As we might expect, both threatened mammals and plants showed a negative correlative relationship with the amount of available natural area, with more species threatened where less area remained. Complementary to this finding, and most strongly shown in the global analysis with threatened mammals, was the importance of the condition of the remaining habitat (core area): i.e. lowest numbers of threatened species were detected in regions with the largest unfragmented core area. Maintaining core area is particularly important given the findings from the mediterranean region of Australia which indicate species loss greatly accelerates when < 30% of original native vegetation remains (James & Saunders, 2001). Nonetheless, identifying a minimum size of core natural area sufficient to maintain mediterranean biodiversity is challenging. Kemper *et al*. (1999) found fragments of 5–15 ha in South Africa were sufficient providing fire processes were maintained, while 10–100 ha has been suggested for coastal scrub habitat in California, USA (Fleishman & Murphy, 1993).

The role of agriculture and its impact on threatened species is more difficult to interpret. At both spatial scales the number of threatened species decreased as agriculture increased. One explanation is that increases in agriculture leads to greater definition of the remaining landscape matrix which reinforces the role of core areas for harbouring threatened species (Posillico, 2004). Furthermore, Davidson *et al*. (2001) found amphibians were almost exclusively extirpated from agricultural lands in California, thus the low frequency persistence of certain species may mask the threat of agricultural impacts on their, once widespread, distribution and abundance. One reason for the absence of the expected negative relationship between threatened plants and agriculture (i.e. threatened plant richness increases as agriculture increases) is that threatened plant status often arises from their natural rarity as a function of endemism and insularity. This is often associated with inhospitable edaphic conditions, which precludes most agriculture in those locales. Nonetheless, the role of covariates, such as socioeconomic factors, which might obscure the expected relationship warrants further exploration.

Conserving biodiversity in the mediterranean biome in the future

To date, the lack of a global scale, systematic analysis of threats in mediterranean regions has been in part due to the difficulty of characterizing land cover in a biome which is not dominated by forest cover (Brooks *et al.*, 2002); shrublands, for example, account for almost one-fifth of the biome area. However, by compiling finer-than-global resolution land cover data, we have been able to characterize threats, trends in threats and impacts on threatened species more accurately, thereby advancing previous global threats studies.

Our analysis revealed an increase in key threats across the mediterranean biome between 1990 and 2000: population density and urban area increased by 13% and agriculture by 1%, with substantial variation in these threats between and within the five mediterranean regions. It must be noted, though, that natural areas not classified as urban or agricultural are not necessarily pristine. Degradation from exotic goat grazing in the northern Chilean matorral, for example, is not detected owing to the spatial resolution of the land cover data. We also found correlative relationships between species of conservation concern and population density, urban area, amount of remaining area and core area. While some have suggested that the very act of listing a species as threatened should stimulate conservation measures to avoid further decline to extinction (Collar, 1996), in the mediterranean biome, we found no correlation between the number of threatened mammals and protection and only a positive trend between the number of threatened plants and protection at the subecoregional scale in California.

Our findings indicate there have been considerable human-induced changes that have occurred in the mediterranean biome, and factors such as population density, urban area and the amount and quality of remaining natural areas are important considerations for future efforts to reduce the loss of mediterranean biodiversity. More specifically, it reinforces the need, as is generally recognized in conservation, to maximize the amount of natural area available (Margules & Pressey, 2000) and maintain or, where necessary, restore the quality of the available area thereby maximizing the core natural area (Dale *et al.*, 2000). The challenges to effective conservation in the mediterranean biome are many and further compounded by the fact that past patterns of threat do not necessarily indicate future conditions. For example, our trend analysis of agricultural area between 1990 and 2000 (for three regions where analysis was possible) suggests agricultural expansion may be of low concern, although research into particular agricultural commodities driven by global trade and its impact on threatened species is warranted. Vineyard expansion, for example, is occurring at unprecedented rates in California-Baja California (Merenlender, 2000), South Africa (Fairbanks *et al.*, 2004) and Spain (Cots-Folch *et al.*, 2006). Similarly, demand for other commodities such as avocados in Chile (Evans & Nalampang, 2006) and olives in Greece (Allen *et al.*, 2006) is driving the conversion of natural habitat in other mediterranean regions.

Other challenges to effective conservation include the lack of understanding of human–environment interactions and the synergistic effects of threats to biodiversity. Urbanization, for example, is a pervasive threat throughout the biome, e.g. the increasing wildland–urban interface in California, where houses intermingle with undeveloped vegetation (Radeloff *et al.*, 2005). This interface represents not only habitat fragmentation but associated human habitation promotes the introduction of invasive alien species (Seabloom *et al.*, 2006) and intensifies the severity of wildfire (Spyratos *et al.*, 2007). Similarly, modifications of natural fire regimes is promoting the invasion of alien plant species (Keeley *et al.*, 2005; Vogiatzakis *et al.*, 2005) and altering successional trajectories of recovering plant communities (Franklin *et al.*, 2005) in some mediterranean regions, while in the Chilean matorral, which is poorly adapted to fire, increasing numbers of anthropogenic fires are causing disruption to native plant species and communities (Montenegro *et al.*, 2004). Finally, the exceptional diversity in the mediterranean biome is due largely to the number of rare and endemic plant species, which are often supported by unique climatic and edaphic conditions (e.g. Harrison *et al.*, 2008). Effective conservation action of these species, however, is hindered by our inability to accurately predict at appropriate scales the consequences of global climate change on precipitation patterns and shifts in vegetation (Mooney *et al.*, 2001; Hayhoe *et al.*, 2004).

One of the goals of future conservation in the mediterranean biome should be to ensure that species currently listed as threatened are sufficiently protected. Furthermore, these efforts need to occur sufficiently fast to outpace the increase in threats and prevent more species from being listed. It is alarming to note in California, USA, that areas with the highest number of threatened plants were also the ones experiencing the greatest percent change in population density between 1990 and 2000. Effective conservation to reduce the loss of biodiversity in the mediterranean biome will require increased attention to global anthropogenic change and the synergistic effects of this, which even if known, are poorly understood.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table S1 Source, date and scale of data used in threats analyses. Region codes: Cal, USA = California, USA; Mex = Mexico; Chl = Chile; SA = South Africa; Aus = Australia; and MedBasin = Mediterranean Basin.

Table S2 Correlation among threat variables at the global (ecoregion unit) and subecoregional scale.

Table S3 Trends in key spatial threats between 1990 and 2000 in the five mediterranean regions by elevation zone. Trends are positive except where text appears in italics. (Area of montane region in Australia was too small relative to spatial data on threats to assess).

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