Conservation Threat of Increasing Fire Frequencies in the Western Ghats, India

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Abstract: *The acceleration of processes such as forest fragmentation and forest fires in landscapes under intense human pressures makes it imperative to quantify and understand the effects of these processes on the conservation of biodiversity in these landscapes. We combined information from remote-sensing imagery and ground maps of all fires in the Mudumalai Wildlife Sanctuary (MWLS) in the Western Ghats of India over 14 years (1989–2002). These spatial data on fire occurrence were integrated with maps of vegetation types found in the MWLS to examine fire conditions in each. We calculated the average fire-return interval for each of the vegetation types individually and for the MWLS as a whole. Using vegetation data from the larger Nilgiri Biosphere Reserve and the entire Western Ghats region, we conservatively estimated fire-frequency information for these larger regions. Because the MWLS does not contain tropical evergreen or montane forests, we were unable to estimate fire conditions in these forest types, which represent 31% of all Western Ghats vegetation cover. For the MWLS, all vegetation types had average fire-return intervals of <7 years, and the sanctuary as a whole had a fire-return interval of 3.3 years. Compared with a 13-year MWLS fire data set from 1909–1921, this represents a threefold increase in fire frequency over the last 80 years. We estimated average fire-return intervals of roughly 5 years for both the larger Nilgiri Biosphere Reserve and the entire Western Ghats region. Given other recent reports, the estimated fire frequencies for the Western Ghats forests outside protected reserves are conservative. We conclude that the current fire regime of the Western Ghats poses a severe and persistent conservation threat to forests both within and outside protected reserves.*

Key Words: fire frequency, fire-return interval, forest fires, Western Ghats

Amenaza del Incremento de Frecuencias de Incendios a la Conservación en las Ghats Occidentales, India

Resumen: *La aceleración de procesos como la fragmentación de bosques e incendios forestales en paisajes bajo intensa presión humana hace imperativo cuantificar y comprender los efectos de estos procesos sobre la conservación de biodiversidad en estos paisajes. A partir de imágenes de sensores remotos y mapas combinamos información sobre todos los incendios en el Santuario Mudumalai de Vida Silvestre (SMVS) en las Ghats Occidentales a lo largo de 14 años (1989-2002). Los datos espaciales de la ocurrencia de incendios fueron integrados con mapas de tipos de vegetación del SMVS para examinar las condiciones de fuego en cada uno. Calculamos el intervalo promedio de retorno de fuego individualmente para cada uno de los tipos de vegetación y en conjunto para el SMVS. Utilizando datos de vegetación de la Reserva de la Biosfera Nilgiri y de toda la región de las Ghats Occidentales conservadoramente estimamos información de frecuencia de incendios para estas regiones más extensas. Debido a que el SMVS no contiene bosques tropicales siempre verdes ni montanos, no pudimos estimar las condiciones de fuego en estos tipos de bosque, que representan el 31% de la cobertura vegetal de las Ghats Occidentales. Para el SMVS, todos los tipos de vegetación tuvieron intervalos promedio de retorno de fuego de <7 años, y el santuario como un todo tuvo un intervalo de retorno de fuego de 3.3 años. En comparación con un conjunto de datos sobre fuego de 13 años en el SMVS de 1909-1921,*

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esto representa un incremento de tres veces en la frecuencia de incendios en los últimos 80 años. Estimamos intervalos promedio de retorno de fuego de aproximadamente 5 años para Reserva de la Biosfera Nilgiri y de toda la región de las Ghats Occidentales. Dados otros reportes recientes, las estimaciones de frecuencias de incendios para bosques en las Ghats Occidentales afuera de reservas protegidas son conservadoras. Concluimos que el actual régimen de fuego en las Ghats Occidentales constituye una amenaza severa y persistente a los bosques tanto dentro como afuera de reservas protegidas.

Palabras Clave: frecuencia de incendios, Ghats Occidentales, intervalo de retorno de fuego

Introduction

Research in the tropics has focused on deforestation or static evaluations of forested areas and seldom has considered the contributing effects of landscape processes and biotic pressures in the loss of biodiversity (Sanchez-Azofeifa et al. 1999). Although studied separately to varying degrees, the combined ecological impacts of forest fragmentation and biotic pressures, such as grazing, logging, and forest fires, are poorly understood. The interactions and synergies between multiple disturbances have recently become a focus of study in the New World tropics (e.g., Cochrane 2001; Peres 2001; Laurance & Williamson 2001; Peres et al. 2003). Similar research and understanding, however, is lacking in the Old World tropics, which have been affected by millennia of human occupation and associated disturbances. Regions such as the Western Ghats in India are logical places in which to evaluate the ongoing effects of multiple, human-related disturbances.

In the Old World tropics, especially in India, human population growth has led to extensive deforestation, greatly fragmenting remaining forests (Menon & Bawa 1998; Jha et al. 2000). Rainforests in various countries, including India, have largely been deforested in recent decades (Myers 1994; Whitmore 1997). Reports from the Ministry of Environment and Forests in India suggest that forest fires affect 37 million ha of forests annually, and about 55% of the country's forest areas are being subjected to forest fires each year (Gubbi 2003). The Western Ghats is one of the world's biodiversity hotspots (Myers et al. 2000), but reserves are limited in size and surrounded by an intervening matrix of land that is under intense human pressures. Furthermore, landscape processes such as fragmentation and forest fires have been overlooked in conservation studies in the Western Ghats (Daniels et al. 1995; Jha et al. 2000). The spatial and temporal scales of disturbance, forest-fragment configuration and shape, land-use activity in the surrounding matrix, and additional ongoing disturbances can synergistically manifest as subtle deforestation events in tropical landscapes, threatening forest remnants with elimination (Aubreville 1947; Cochrane et al. 1999; Gascon et al. 2000; Cochrane & Laurance 2002). Thus, understanding the effects of these disturbances, especially forest fires and forest fragmentation, can provide insights into current deforestation processes and help direct conservation programs in these ecosystems.

As in other parts of the world, fire has been the tool of choice for clearing forests in the Western Ghats. Researchers have examined the rates of deforestation and degree of fragmentation in the region, but they assumed that forest remnants remain unchanged (Menon & Bawa 1997; Nagendra & Utkarsh 2003). Furthermore, the potential synergistic effects of fragmentation and fire have not been considered. Disturbance in ecosystems occurs at various scales. Certain events are fine grained and affect individuals in a population, whereas other disturbances are larger grained and affect assemblages of species in a community. Still larger disturbance events affect entire landscapes and ecosystems (Forman 1995; Ross et al. 2002). Although spatial scale is an important variable in all disturbance events, the spatial configuration of landscape elements and the disturbance history of the landscape are vital to the holistic understanding of disturbance events in ecosystems (Turton & Freiburger 1997).

In human-affected landscapes, the current distribution of forests is largely a result of the spatial and temporal interactions between humans and their environment. One disturbance that is strongly related to human activity is fire. The nature, amount, and spatial distribution of ignitable fuel largely govern the character of the fire in any forest location (Goldammer 1990). Increasing dependence on forests by humans for a variety of uses leads to forest fragmentation that further exacerbates future fire events in the landscape (Cochrane 2003). The spatial juxtaposition of forests and other land covers, derived through anthropogenic land use, has a large influence on the extent and frequency of fire events on fragmented landscapes (Cochrane et al. 1999; Cochrane 2001). The ecological characteristics of forests, combined with previous disturbance history and prevalent weather patterns, lead to variability in the pattern of burning in forests (Uhl & Kauffman 1990; Glitzenstein et al. 1995; Cochrane & Schulze 1999). The differences among forests in terms of ecological characteristics, climatic factors, and associated disturbance histories translates into differences in susceptibility to and intensity of forest fires among vegetation communities across the landscape. Within the Western Ghats, the remaining forests are fragmented and immersed in a human-dominated landscape, where fire is

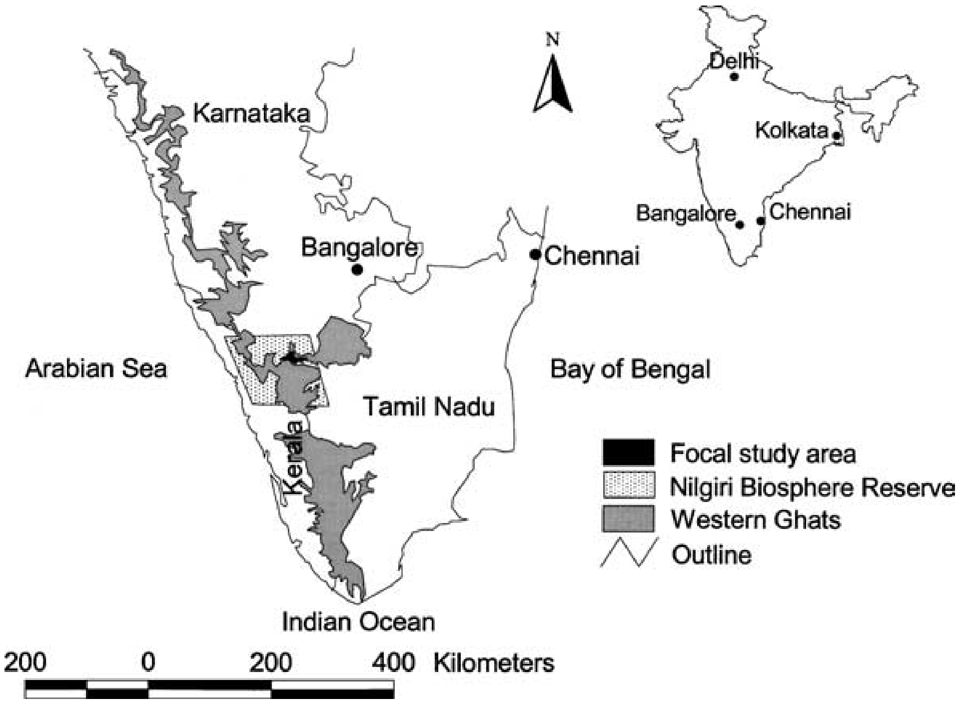

Figure 1. Map of the Western Ghats showing study regions.

frequent. Current conservation strategies center on reserves, but deforestation continues and no account is made of dynamic processes in assessing the performance or capability of these protected areas to conserve biodiversity or ecosystems. Thus, detailed studies on fragmentation and fires may yield critical insights for sustainable conservation of biodiversity in this region.

As a first step in generating a clearer understanding of landscape-scale spatial and ecological processes in the Western Ghats, we sought to place fire disturbance in perspective as an agent of change and as a potential conservation threat in the region. Our objectives were to (1) assess the differences in forest fire frequency of different vegetation types in the focus study area in the Western Ghats, (2) delineate current fire-return intervals in a representative sample landscape of the region, (3) assess forest fire frequency at various spatial scales (vegetation type, landscape, and regional scale) in the area, (4) explore possible synergisms between forest fires and forest fragmentation and implications of these synergisms to the biodiversity of the Western Ghats.

Study Areas

To examine these disturbances at different spatial scales, we chose three nested study areas. The Western Ghats region is a long mountainous massif (8–22°N, 73–77°E) that runs along the entire west coast of peninsular southern India (Fig. 1). This distinctive ecoregion covers 1.7×10^5 km^2 and has been categorized as the Western Ghats Moist Forest major habitat type (WWF 1998). Experiencing much higher levels of precipitation than the adjoining regions of peninsular India, the natural biota of the region exhibit a high level of endemicity (Subramanyam & Nayar 2001). Variations in topography and climate have created a highly diverse landscape with land cover that ranges from tropical evergreen forest to tropical dry thorn forests. All regions of the Western Ghats currently exhibit additional diversity, in terms of their landscape components, ranging from nearly undisturbed to highly degraded (Nagendra & Gadgil 1999). The current landscape is testimony to the ever-changing social and economic interactions between forest growth and human use of these resources. Although human occupation of the Ghats is ancient, large-scale deforestation and destruction of forests is a more recent phenomenon (Chandran 1997; Subramanyam & Nayar 2001). The increased use of forests and rapid changes in the land cover of the region have fragmented the remaining forests, which has led to increased susceptibility of the remaining forests to large and recurrent fires. The current land cover is characterized by the presence of fire-maintained agricultural fields adjacent to forests, large-scale use of forests for various activities (e.g., firewood and nontimber forest product collections), and altered fire regimes of the remaining forests.

The Nilgiri Biosphere Reserve (NBR) is spread over the states of Karnataka, Kerala, and Tamilnadu in southern India (Fig. 1). The forested area of the reserve is 5520 km^2 (Sukumar 1990). There is a distinct west–east climatic gradient, which gives rise to a diversity of vegetation types. The NBR supports all the major vegetation types of peninsular India (Champion & Seth 1968). These include tropical evergreen and semievergreen forest, tropical moist deciduous forest, tropical dry deciduous forest, and tropical dry thorn forest. At higher elevations (>1800 m) there are characteristic patches of tropical montane stunted evergreen forest in the valleys and folds of the hills and extensive grassland on the hill slopes. More detailed descriptions of the vegetation are available elsewhere (Nair et al. 1977). The NBR is representative of the Western Ghats in terms of its vegetation types and, despite its protections, a region under immense human pressures.

We conducted detailed analysis of fire-return intervals across the different vegetation types in the Mudumalai Wildlife Sanctuary (MWLS). The sanctuary, a long-term ecological research site, is part of the NBR. The sanctuary is 320 km^2 and harbors diverse flora and fauna, including 616 vascular plant species. A single 50-ha plot in deciduous forest at the sanctuary contained 71 woody species $\geq$1 cm dbh (Sukumar et al. 1992). Fire maps for the sanctuary were available from 1989 to 2002, and annual areas burned for an earlier period (1909–1921) were also available from a working plan for the sanctuary (Hicks 1928).

Methods

We surveyed and mapped fire occurrence in the MWLS on topographic maps of 1:50,000 scale. Two topographic maps covering the entire sanctuary were used, map sheets 58 A6 and 58 A10 (of the Survey of India). The burned areas were first located on the ground and then on the topographic maps based on key features such as rivers, swamps, or roads. Burned areas were mapped after walking the perimeter of the affected vegetation. Mapping of burned areas was done during April and May, the dry season, before the onset of the southwestern monsoon. Mapping took about 2 weeks; there were occasions, however, when the source and timing of ignitions increased mapping time. These detailed maps are available for the years 1989 to 2002. During 1996 and 1997 the western part of the sanctuary could not be mapped; therefore, we used remotely sensed data to complete the mapping. Fire maps of MWLS from 1989 to 2002 were individually overlaid with the vegetation map of the sanctuary. The resultant map yielded polygons with attributes of vegetation type and presence or absence of fire. We obtained proportion of area burned in the different vegetation types for the different years from this map and used statistical tests to examine differences in fire frequency across the different vegetation types.

We used satellite data from (Indian Remote Sensing) IRS I-B, (LISS II, row 60, path 26; 6 March 1996) and 1997 satellite data from Landsat (L5, row 144, path 52; 16 March 1997). Satellite data for the study area were extracted, geocorrected, and classified into burned and unburned areas with supervised classification. We used ERDAS Imagine 8.3 (Leica Geosystems GIS & Mapping Division, Leica Geosystems, Heerbrugg, Switzerland), to analyze the satellite data. The raster data for these 2 years were converted into vector form and combined along with the vector data of other years. We assigned unique identity values to the burned and unburned areas. The data for 14 years were combined and a single composite map obtained.

We estimated fire frequency by spatially quantifying the number of fires for each location in the composite map. There were 1727 distinct areas in the combined map. Frequency of burning in each location was calculated as the number of years (out of 14) in which fire had been detected. We converted fire-frequency maps into an estimated fire-return interval map for each forest land-cover type. A fire-return interval is the amount of time required to burn an area, equivalent to the entire forested area, with the understanding that some areas may not burn whereas others may burn more than once during a cycle (Van Wagner 1978).

We delineated the vegetation map of MWLS with supervised classification of the IRS I-D (LISS III row 65, path 99, 27 March 1996) satellite data. Six land-cover types were classified: tropical dry deciduous forests, tropical dry deciduous (*Shorea*) forests, tropical moist deciduous forests, tropical moist deciduous (degraded) forests, tropical dry thorn forests, and settlements (Fig. 2). The classification system followed by Prabhakar and Pascal (1996) served as a reference in the preparation of the vegetation map. The accuracy of vegetation types ranged from 80% in the case of the tropical moist deciduous (degraded) type to 100% in the case of the tropical dry thorn type.

To extrapolate the results from the MWLS to both the entire NBR and the larger area of the Western Ghats, we made the conservative assumption that the results from the various vegetation cover types within the MWLS are representative of fire frequency and extent of these vegetation types in these larger regions. This extrapolation is conservative because the MWLS is a protected region of forest, nested within a similar, but larger, protected area, the NBR. Human use of these forests is therefore limited, and because 90% of all forest fires are estimated to be anthropogenic in origin (Bahuguna 1999), fire conditions

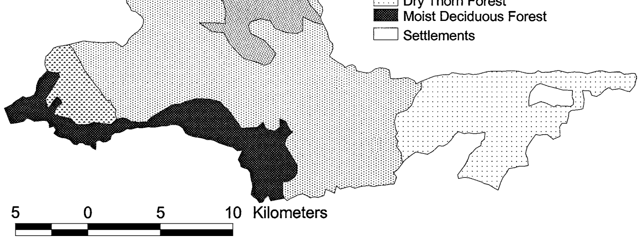

Figure 2. Vegetation map of the Mudumalai Wildlife Sanctuary, Western Ghats.

are expected to be less severe than those in the majority of unprotected forests of the Ghats. Unfortunately, the MWLS does not contain two Western Ghats forest types, the tropical evergreen forests and the high-elevation montane/grassland ecosystems. These forests are known to burn (Hegde et al. 1998), but because we do not have quantitative data on fire occurrence in these vegetation types, we excluded them from the larger scale estimations of regional burning. For the estimation of mid-level-scale fire extent in the NBR, we used the vegetation cover data from Narendran et al. (2001). Of the total forested area of 5520 km^2, the tropical dry thorn, tropical dry deciduous, and tropical moist deciduous forest types are the predominant land covers, accounting for 38%, 29.7%, and 16.3% of the area, respectively. The tropical evergreen forests and tropical montane forests/grasslands accounted for the remaining land cover in the NBR, 10.6% and 5.2% of the area, respectively.

For the regional scale assessment, we adapted the vegetation cover information from a recent assessment of terrestrial ecoregions (Olson et al. 2001). In the assessment, distinction was made between northern and southern tropical moist and tropical montane rainforests, but we combined northern and southern classes because we were concerned with physiological conditions and not species compositions. Therefore, for the subsequent analyses, tropical dry deciduous and tropical moist forests accounted for 27% and 42% of the area, respectively. Tropical evergreen and grassland/montane rainforests accounted for roughly 31% of the vegetation cover but were excluded from the fire analysis because they do not occur in the MWLS.

Results

Forest fires were common in forests of the MWLS and an average of 30% of the landscape burned in a given year (Table 1). The vegetation type with the highest mean

Table 1. Mean area and percentage of area burned in different land cover types of the Mudumalai Wildlife Sanctuary, Western Ghats, between 1989 and 2002.*

Vegetation type	*Mean area (km^2) burned/year (±SE)*	*Vegetation type (%)*	*Fire-return interval (years)*
Dry deciduous	62 ± 45.0	34.0	2.9
Dry deciduous *Shorea* type	17 ± 9.0	56.6	1.7
Moist deciduous (degraded)	2.3 ± 4.9	15.0	6.6
Dry thorn	8.8 ± 15.8	14.6	6.8
Moist deciduous	7.5 ± 12.0	18.3	5.5
Total area	98 ± 74.0	30.0	3.3

**The sixth land use-type settlement was excluded.*

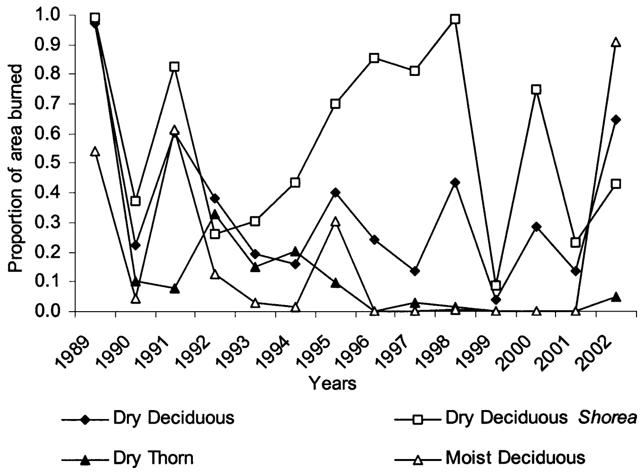

Figure 3. Temporal variability in the area burned across the different vegetation types in the Mudumalai Wildlife Sanctuary, Western Ghats.

area burned was the tropical dry deciduous (*Shorea*) with 56.6%, whereas the tropical dry thorn vegetation had the lowest mean area burned with 14.6%.

There was variability in the susceptibility to fires across the different vegetation types (Fig. 3). Significant differences existed between the tropical dry deciduous vegetation and all other vegetation types in the MWLS ($p < 0.01$). Fire extent in the tropical dry deciduous (*Shorea*) vegetation was significantly higher than the tropical moist deciduous (degraded), tropical dry thorn, and tropical moist deciduous vegetation types ($p < 0.001$–0.100). To investigate whether small sample sizes were responsible for these patterns, we also conducted Mann-Whitney U tests, which also showed significant differences (all $p < 0.01$). Because these samples were random and independent, we ruled out inflation of results resulting from temporal auto correlation. Spatiotemporal auto correlation, however, is important in assessing patterns of fire occurrence across a landscape, and this is under investigation. Fuel loads from both grasses and leaf litter were also significantly higher in tropical dry deciduous (*Shorea*) and tropical dry deciduous forests compared with all other vegetation types (H.S. Dattaraja, unpublished data).

The fire-return intervals in the forests of the study region were short. More than 50% of the study site experienced fire between 4–10 times in the past 14 years (1989–2002), implying that half the study site will experience a fire every 3.5 or fewer years (Fig. 4). The tropical dry deciduous (*Shorea*) type had the shortest fire-return interval of 1.7 years, whereas the tropical dry thorn forests had the longest fire-return interval of 6.8 years. Based on the last 14 years of fire data, the average fire-return interval of the entire sanctuary is 3.3 years. This was considerably shorter than the average 10-year fire-return interval for a similar period 90 years ago (1909–1921). The current fire dynamic is one of rapid-return fires and is more frequent

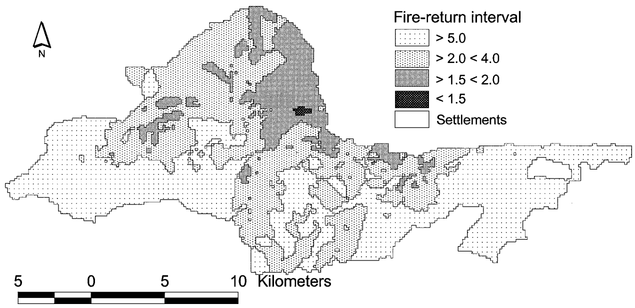

Figure 4. Fire-return intervals (years) in the landscape of the Mudumalai Wildlife Sanctuary, Western Ghats.

than the earlier time period for the study region (Fig. 5). Forest fires burned an average of 30% (98 km^2/year) of the forests in the landscape of the MWLS each year. At the mid scale of the NBR, an estimated average of 19% (1,029 km^2/year) of the forests burned every year. At the regional scale of the Western Ghats, average annual burning was estimated to cover 17% (28,306 km^2/year) of the forests.

Discussion

This analysis of forest fires in the Western Ghats demonstrates the importance of forest fires as recurrent disturbance events, with potentially severe consequences for the conservation of biodiversity in the Western Ghats. Our results showed that although the frequency of forest fires varied across the different vegetation types of the MWLS, all of these ecosystems burned frequently.

Forest fires have been a part of these ecosystems for many thousands of years (Gadgil & Chandran 1988; Gadgil & Guha 1993). In many ecosystems, fire is part of the natural regeneration process, stimulating the germination of certain species, clearing space for the invasion and growth of others, and releasing a periodic flush of nutrients into the soil (Dawson et al. 2002). In the Western Ghats, however, only the grasslands associated with montane forests are considered to be fire-maintained ecosystems (Meher-Homji 1984). What is clear from our results is that the character of fire disturbance events has been altered fundamentally in recent decades, resulting in much shorter fire-return intervals. This problem has been compounded by land-cover transformations in the surrounding landscape. Large tracts of forests have been lost to agricultural plantations of coffee, tea, rubber, and eucalyptus, and to a number of hydroelectric projects (Subramanyam & Nayar 2001; Ramesh 2001). Across the Western Ghats, 40% of the natural vegetation was lost between 1920 and 1990. This has resulted in increased fragmentation of the remaining habitats, with the number of patches growing fourfold and a concomitant 83% reduction in mean patch size during this time period (Menon & Bawa 1997). We hypothesize that this fragmentation of the forests makes them more vulnerable to escaped agricultural fires along their extensive edges and that the reduced patch size makes it more likely that entire fragments will burn during each fire event.

With a sanctuary-wide fire-return interval of only 3.3 years, it is doubtful that the current vegetation composition of the MWLS can persist. Although fires were common in the decade between 1910 and 1920, it is clear that the fire rotation is accelerating. Fires in tropical forests affect the species composition, demography, structure, and biomass of forests (Holdsworth & Uhl 1997; Cochrane & Schulze 1999; Haugaasen 2000). The mechanism by which these fires have modified the vegetation cover of the Western Ghats is outlined by Hegde et al. (1998). As the fire-return intervals decrease, it becomes more unlikely that the majority of tree species will be able to recruit new trees to a size resistant to mortality from the frequent fires. A study on the demography of woody plant species in the sanctuary showed a decline in abundance of many species, which resulted from poor recruitment and high mortality from ground fires, between 1988 and 1996 (John et al. 2002). These persistent fires could lead to an increase in dominance and a decrease in diversity in this forest even on short time scales. In general, it is to be expected that fewer species will be able to persist. Already, the effects of the short fire-return intervals in the sanctuary have led to some monodominant and even-aged stands of *Shorea roxbburghii* (Kodandapani 2001).

In addition to direct mortality from fire, frequent fires may contribute to the rapid invasion of the sanctuary by exotic fire-adapted species. Already, *Lantana camara* and *Chromoleana odorata* (L.) R. M. King & Robinson have colonized regions subjected to repeated forest fires (Kodandapani 2001). Besides competing with native species for resources and space, these and other exotic

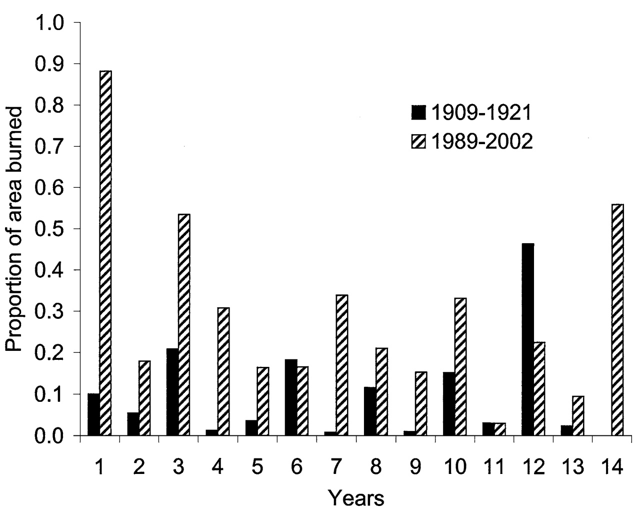

Figure 5. Temporal variability of forest fires in the Mudumalai Wildlife Sanctuary, Western Ghats, during 1910–1920 and 1990–2000.

invasive species may also alter the fire behavior in these forests by changing the fuel structure and hence potentially creating more intense fires that could further accelerate the loss of native species.

Although we were unable to include the high-elevation grassland/montane forests and the tropical evergreen forests, both of these ecosystems do burn in the Western Ghats. The tropical evergreen forests may be the most threatened by fire. Although these wetter forests are resistant to fire propagation, they are sensitive to fire-related damage and high mortality levels when fires do occur (Uhl & Kauffman 1990; Cochrane & Schulze 1999; Slik et al. 2002). In general, species in tropical evergreen forests are poorly adapted to fire disturbance (Uhl and Kauffman 1990) because of their thin bark, buttressed trunks, and stilt root systems (Hegde et al. 1998; Barlow et al. 2003).

Our results clearly show that there has been a long-standing and strong selective pressure against fire-sensitive species throughout much of the Western Ghats. The environmental changes brought about by forest fragmentation and accelerated fire-return intervals are expected to favor deciduous species at the cost of shade-tolerant and moisture-loving evergreen species (Daniels et al. 1995). Further, as the extent and the frequency of burning increase, the remaining fire-sensitive and even the moderately fire-resistant species may be eradicated through both fire-related mortality and recruitment failure. Apart from changing the demography and structure of surviving plant communities, high tree mortality can result in increased fuel loads and more rapid rates of desiccation in the damaged forests. This can result in a positive feedback wherein successive fires become both more likely and more severe until complete deforestation occurs (Cochrane et al. 1999). Depending on the frequency of burning, fires can therefore be expected to either facilitate invasion by more fire-resistant species (e.g., thicker barked drought-deciduous species) or, potentially, lead to total eradication of all trees. Invasion of the evergreen forests by more disturbance-tolerant species may be masking the erosion of these ecosystems if they are concurrently being replaced with other vegetation types.

Throughout the Western Ghats, deforestation continues to be a severe problem despite a legal moratorium on deforestation that has been in place since the Indian government enacted the Forest Conservation Act of 1980. Because systematically collected spatial data on forest cover change is lacking, it is currently unclear how much of this deforestation is actually the result of intentional, illegal deforestation. What is clear from the comparative analysis of fire occurrence during 1910–1920 and 1990–2000 (Fig. 5) is that the landscape fire dynamic has changed, with a 200% increase in the amount of burning. Although it is possible that some species of trees may be able to persist under the current fire regime, we have not discovered any forested ecosystems that regularly experience and thrive in fire-return intervals of <5 years. The increased amount of fire in these forests is likely the result of increased anthropogenic sources of ignition, forest fragmentation, altered fire regimes, and possible synergisms, among other factors. These accelerated disturbance cycles may be, in part, responsible for the ongoing deforestation in this region. The observed fire-return intervals in the MWLS are short enough to result in gradual eradication of many of the surviving forests. Similarly, our data show that current fire frequencies in the NBR and the Western Ghats are also rapid and could result in the gradual transformation of forests in these two regions. This deforestation would most likely occur as progressive elimination of fragments (Aubreville 1947; Gascon et al. 2000; Cochrane & Laurance 2002) but could also occur rapidly in sections of interior forests that have been severely damaged by previous disturbances (Cochrane et al. 1999). We stress that the fire-return intervals for regions of the Western Ghats outside protected reserves are likely much worse than the conservative estimate of roughly 17% burned per year that we provide here. This is because these unprotected forests have much higher human population densities, are more heavily used for various activities, are more fragmented, and are closer in proximity to fire-dependent agriculture. Recent studies on the extent of forest fires in India suggest that about 50% of the country's forests burn yearly (WWF 2003).

Conclusions

Forest fires are frequent across the landscapes of the Western Ghats. Forest fires, fragmentation, and their synergisms may be driving deforestation processes that are fundamentally altering the landscape of the Western Ghats. Although a number of local, national, and international efforts are under way to conserve the biological wealth of this region, these initiatives will be unsuccessful if the processes driving deforestation and forest degradation are not taken into account. It is imperative to understand these landscape changes and their drivers to promulgate effective strategies for the conservation of the ecosystems and biodiversity of the Western Ghats. The current static policy of nature conservation through demarcation of reserves and legislation against intentional deforestation might not be the only answer to protecting the region's biodiversity. Instead, a more dynamic approach that incorporates policies affecting land use and land cover change, together with management and monitoring of landscape-level disturbances such as fragmentation and forest fires, could prove more beneficial in future conservation programs.

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