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Parks protect forest cover in a tropical biodiversity hotspot, but high human population densities can limit success

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ABSTRACT

Maintaining forest cover is important for Biodiversity Hotspots that support many endangered and endemic species but have lost much of their original forest extent. In developing countries, ongoing economic and demographic growth within Hotspots can alter rates and patterns of deforestation, making it a concern to quantify rates of forest loss and assess landscape-scale correlates of deforestation within Hotspots. Such analyses can help set baselines for future monitoring and provide landscape-scale perspectives to design conservation policy. For the Western Ghats Biodiversity Hotspot in India, we examined correlates of forest loss following rapid economic expansion (post-2000 CE). First, we used open-source remote-sensing data to estimate annual trends in recent forest loss (from 2000 to 2016) for the entire Hotspot. Across the entire Western Ghats, we assessed the relative importance of and interactions among demographic, administrative, and biophysical factors that predicted rates of forest loss—measured as the number of 30 × 30-m pixels of forest lost within randomly selected 1 km^2 cells. Protected areas reduced forest loss by 30%, especially when forests were closer to roads (33%) and towns (36%). However, the advantage of protection declined by 32% when local population densities increased, implying that the difference in forest loss between protected and non-protected areas disappears at high local population densities. To check scale-dependency of spatial extent, we repeated the modelling process for two landscape subsets within Western Ghats. In contrast with results for the entire Western Ghats, both focal landscapes showed no difference in deforestation with protection status alone or its interactions with village population density and distance to towns. However, deforestation was 88% lower when forests were protected and farther from roads. Overall, our results indicate that protected areas help retain forest cover within a global Biodiversity Hotspot even with rapid development, but high human population densities and road development can reduce the benefits of protection.

1. Introduction

Tropical forests hold nearly half of Earth's biodiversity and provide ecosystem services to millions of humans. Despite a slowing of the tropical deforestation trends from 1990 to 2000 (Butler and Laurance, 2008; Wright and Muller-Landau, 2006), recent global analyses of forest-cover change indicate that forests continue to be lost at nearly 3% annually (Asner et al., 2009; Hansen et al., 2013; Margono et al., 2014). Meanwhile, global agreements to stem climate change and biodiversity losses mandate that 17% forest cover be maintained as biodiversity habitats (CBD; Aichi Biodiversity Targets, Strategic Goals C, Target 11). Such biodiversity goals established by global agreements are eventually met through national policies for forest protection and local drivers of deforestation (Abood et al., 2015; Kremen et al., 2000; Margono et al., 2014). Hence, underscoring the need for multiscale assessments of deforestation, the UNFCCC negotiations have encouraged countries to identify local factors linked to forest loss, and use that information to design conservation policy (UNFCCC, 2009).

Understanding contemporary patterns and identifying associated factors of forest loss is especially important for Biodiversity Hotspots—1.5% of Earth's area that hold nearly 44% of global plant richness and 35% of vertebrate richness (Myers et al., 2000). Most Hotspots encompass areas with differing intensities of human use, where protected areas are distributed in a matrix of human-dominated

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landscapes such as agriculture and multiple-use forests that are subject to greater pressures for land-use change than strictly protected forests (Barber et al., 2014; Berkes, 2009; Shahabuddin and Rao, 2010). Patterns of forest loss due to land-use change are often correlated with biophysical variables such as local climate, topography, and proximity to water sources, which determine suitability of land for conversion to agriculture or settlements. For example, forest loss tends be greater at lower elevations, shallower slopes, and closer to rivers and lakes (Green et al., 2013). However, the biophysical correlates of forest loss are mediated by land-use decisions in relation to demographic pressures of local population size and socio-economic conditions (Gardner et al., 2007; Laurance and Wright, 2009; Roy and Srivastava, 2012; Sirén, 2007; Wright and Muller-Landau, 2006).

Specifically, higher rural populations in the proximity of forests could cause greater forest loss, either through conversion of land for agriculture or through increased resource extraction from forests (Davidar et al., 2008; Laurance et al., 2002). Moreover, rural patterns of forest use and forest-based livelihoods can be directly or indirectly shaped by consumer demands in urban centres in a growing economy with increasing connections to larger markets (Rudel et al., 2009; Shackleton et al., 2011). Thus, in many developing nations, proximity to urban centres can influence forest loss by regulating market demand for forest goods or via changes in patterns of land- and forest-use (DeFries et al., 2010; Madhusudan, 2005). Besides altering patterns of forest-based livelihoods, economic development is accompanied by increased construction of infrastructures such as roads, canals, and powerlines, which often lead to forest loss and negatively impact biodiversity (Laurance et al., 2014, 2009).

In addition, administrative factors such as local governance and legal protection status (henceforth, protected areas) regulate forest-cover change (Andam et al., 2008). Local resource use and infrastructure development are often subject to greater oversight within protected areas (Barber et al., 2014; Bruner et al., 2001). However, national and local motivation to protect, which affects whether protected areas successfully retain forest cover, can change with developmental trajectories influenced by international markets, national resource base, and changing economic opportunities (Bradshaw et al., 2015; Rudel, 2007). Thus, evaluating the efficacy of protected areas in retaining forest cover in a Biodiversity Hotspot in relation to demographic and development factors could provide one benchmark of whether legal protection is meeting its objectives (Roy and Srivastava, 2012). Moreover, establishing baseline forest cover and assessing ongoing correlates of forest loss can aid long-term monitoring of changes in forest cover across large spatial scales.

Across large landscapes, baseline forest cover can be established and trends in forest cover change monitored using readily available satellite imagery of high quality and resolution (Margono et al., 2014; Rudel et al., 2005). Remotely sensed data offer a powerful tool to link patterns of forest loss to its potential drivers across large landscapes that are often impossible to survey physically in entirety (Hansen et al., 2013, 2010; Kurz, 2010; Margono et al., 2014). Furthermore, demographic and administrative factors linked to forest loss can vary with spatial scale and region across large landscapes (Margono et al., 2014). For example, development trajectories and implementation of conservation laws can differ between local governance units such as states and provinces, leading to scale-dependence in drivers of forest cover change (Nolte et al., 2013). In this regard as well, remotely sensed data can be analyzed at multiple spatial extents to link landscape assessments better with necessary policy interventions.

In this study, we analyzed landscape-scale correlates of forest loss in the Western Ghats of India—among the most threatened of global Biodiversity Hotspots (Myers et al., 2000) (Fig. 1). Recently designated a UNESCO World Heritage Site, it holds viable populations of endangered wild mammals such as tiger (*Panthera tigris*), Asian elephant (*Elephas maximus*), Asiatic wild dog (*Cuon alpinus*) and gaur (*Bos gaurus*). The Western Ghats also contains unique habitats such as the montane Shola-grassland ecosystems (Jose et al., 1994) and wet evergreen forests with high endemism for plants (56%), amphibians (78%), and reptiles (62%) (Gunawardene et al., 2007; Myers et al., 2000). Simultaneously, the region has high human population densities averaging 350 people/km^2 (Cincotta et al., 2000), good development indices, historically intensive agriculture, and a relatively small extent of area under strict protection compared to global targets (Cincotta et al., 2000; Sloan et al., 2014).

Large dams and agriculture were major causes of forest loss in the Western Ghats from 1950 to 1990 (Jha et al., 1995), but the rate of forest loss has slowed since 1990 (Reddy et al., 2016). Reduced forest loss could be driven by changing economic paradigms since 1990, which slowed agricultural expansion and increased migration of rural populations to cities, potentially lowering population pressures on forest. However, India's economic liberalization since 1994 fueled the development of roads and highways in rural and forested areas, which often required clearing forests (Bawa et al., 2007). Changing developmental paradigms and accompanying demographics could increase or decrease net forest loss and influence spatial patterns in drivers of forest loss (Rudel et al., 2009), but remain unexamined for the Western Ghats. Hence, we examined the following questions:

1. What are the recent trends in forest loss (from 2000 CE) in the Western Ghats, a populous Biodiversity Hotspot experiencing economic development and infrastructure expansion?
2. How does forest loss correlate with demographic, biophysical and administrative factors across a Biodiversity Hotspot? Specifically, does protection status, greater distance from roads and towns, and lower human population densities decrease forest loss?
3. Do correlates of forest loss vary with spatial extent of analysis?

We expected decadal forest loss to be higher in more populous areas and that shorter distances to roads and towns would be associated with greater forest loss. Importantly, we expected that the effect of population and distances to road and town would be modified by protection status—protected (wildlife sanctuaries and national parks) versus non-protected areas.

2. Materials and methods

2.1. Data collection

We quantified annual rates of deforestation using the Global Forest Change (GFC, version 1.6) forest loss dataset—a high-resolution global map compiled from Landsat ETM+ images, in which forest loss is defined as stand-replacement disturbance, or a change from forest to non-forest (Hansen et al., 2013). Using this dataset, we calculated the number of 30 × 30 m pixels deforested per km^2 for each year from 2000 to 2016 (89,681 total pixels).

To assess factors associated with forest loss, we compiled biophysical, demographic, administrative, socio-economic and landscape data from multiple sources (Table S1). We used slope, elevation, and distances to rivers and lake as biophysical predictors because forest loss can decrease on steeper slopes, higher elevations, and farther from water sources, all of which influence human settlements and agriculture and thus mediate forest loss (Green et al., 2013). In addition, we used mean annual rainfall—obtained from the BIOCLIM dataset (Hijmans et al., 2005)—which explains the most variation in species composition of Western Ghats forests (Krishnadas et al., 2016). We calculated elevation and slope from ASTER GDEM satellite data (Table S1) and created rasters of landscape variables for distance to the nearest lakes and rivers. As demographic indicators, we used local human populations and distances to roads and towns—proxies for market linkage and economic development (Green et al., 2013)—expecting higher forest loss in more populous areas and closer to roads and towns. We used decadal census data collected in 2001 and 2011 (Table 1) to generate