ESTIMATING THE IMPACT OF FOREST USE ON BIODIVERSITY IN PROTECTED AREAS OF DEVELOPING TROPICAL REGIONS

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Summary: In many developing tropical regions, especially indigenous people are often deprived of their traditional land use rights due to the establishment of protected areas. This conservation practice jeopardizes people's livelihoods and ultimately counteracts conservation efforts by provoking illegal use of natural resources. Thus, approaches that consider local livelihood needs in conservation planning are of high importance. In this regard, methods to quantify human impact on conservation-relevant biodiversity features, e.g., species richness, are required to objectively evaluate the effectiveness of current management practices and to facilitate tradeoffs between land use and nature conservation. We introduce an approach that draws on the degree of human-induced forest fragmentation as a proxy for land use intensity. Quantitative information on forest fragmentation was obtained by applying landscape metrics on satellite imagery. We analyzed relations between this proxy and vascular plant species data from an Indian protected area. In our case, species richness on a local scale was only marginally affected by forest fragmentation. However, ongoing land use throughout the reserve resulted in distinct alterations of species composition and promotion of biological invasion.


Keywords: Forest fragmentation, indigenous people, land use, landscape metrics, protected area, species composition, species richness, conservation

1 Introduction

Especially in developing tropical regions, loss of forest biodiversity associated with intense human land use occurs at an alarming rate (Southworth et al. 2004). Ever since this trend was observed, protection of biodiversity has become a major goal in nature conservation. However, many indigenous people in developing tropical regions still rely on forest resources to cover their livelihood needs, which makes the establishment and management of protected areas a difficult task (Chapin 2004; Madhusudan 2003; Brockington et al. 2008). Conservation efforts often disregard local people's rights, thereby threatening their very existence (Upadhyay and Kothari 2001) and provoking illegal use (Nagendra et al. 2006). These issues have been entering conservation discussions with the effect that more emphasis is put on natural resource-use rights of people living in and around protected areas (Redford and Sanderson 2000).

Hence, the objective quantification of the impact of different land use intensities on forest biodiversity or conservation-relevant biodiversity features, e.g., species richness and composition, becomes necessary in order to estimate management effectiveness and threat status (Bleier et al. 2006). This task further includes the identification of adequate tradeoffs between sustainable land use and conservation (Karanth et al. 2006). Cost-effective and practi-
Among the threats to the survival of species diversity (Peres and Michalski 2006). Thus, it is close at hand to assume that forests in tropical regions are exposed to varying scales of human-induced habitat disturbance. Some studies treat the effects of both forest fragmentation (mostly patch characteristics) and disturbance as independent predictors of forest biodiversity features (e.g., Guirado et al. 2007; Michalski et al. 2007), even though they emphasize that effects of human impact and fragmentation cannot be separated.

We therefore draw on an approach that is less affected by these problems, easy to implement, cost-effective, and provides quick access to relevant information. This approach relies on the mere degree of forest fragmentation as a proxy for land use intensity. It is based on the two assumptions that (1) intensified land use in forested areas increases forest fragmentation (Abdullah and Nakagoshi 2007) whereas (2) forest fragmentation facilitates the accessibility to forests. This facilitated accessibility, in turn, supports further use of forest fragments (Peres and Michalski 2006). To quantify the twofold human impact of fragmentation and forest use on forest ecosystems, we related biodiversity features to their landscape context. The landscape context was quantified through landscape metrics, which were calculated in circular areas around each sample point. We subsequently related fragmentation (indicating land use intensity) to vascular plant species richness and vascular plant species composition.

In this study we hypothesized that the degree of forest fragmentation is (a) related to plant species richness, (b) to plant species composition, and (c) to the occurrence of invasive species. We considered the chosen vegetation characteristics as easy-to-quantify aspects of biodiversity that can also serve as indirect measures for other biodiversity features (e.g., Duelli and Obrist 1998; Axmacher et al. 2009).

2 Study site

The study was conducted in summer 2007 in the lowland areas of the Satkosia Gorge Wildlife Sanctuary, Orissa, India (20° N, 85° E, Fig. 1). Within the sanctuary, there are 35 villages (often subdivided into smaller hamlets) with approximately 14,000 inhabitants. The age of the villages within the sanctuary is about 100 years (S. Pradhan, personal communication). Another 80 villages are located in the surrounding buffer zone. Twenty-five percent of the population in this area belongs to Scheduled Castes and Scheduled Tribes, represent-
Sixty percent of the local population lives below the Indian poverty line (Pradhan 2007). Agricultural land is scarce and the unemployment rate is very high due to insufficient infrastructure and very remote job opportunities. Therefore there is a strong dependence on the surrounding forests for timber, non-timber forest products, forage, and as grazing grounds for cattle (S. Pradhan, personal communication). Natural and degraded forest, interspersed with villages and agricultural fields predominate in the sanctuary. Outside its boundary, the land is exposed to intense use; forested areas are reduced to patches of various sizes.

Since the establishment of the sanctuary in 1976, conservation management prohibits the use of any kinds of forest goods for human consumption, fuelling people’s resentment towards the park management and provoking unregulated illegal extractions (Pradhan 2007). Satkosia Gorge Wildlife Sanctuary is thus a prime example of the competing claims of strict conservation versus sustainable use. A quantitative analysis of human impact and plant species diversity to facilitate the development of a sustainable conservation approach is of high importance.

3 Methods

Outline and sampling design

Figure 2 illustrates the methodological concept of the study. All analyses were based on a random vegetation sample (n = 58), covering a gradient of forest fragmentation. In the context of this study, we defined forest fragmentation as any pattern of forest perforation or dissection.

In order to minimize environmental effects that may exert further influence on plant species occurrences apart from land use (e.g., slope and exposure), we restricted possible sample locations to plain areas (slope < 15%). These areas were identified from a digital elevation model.
Locations of forested areas were taken from a remotely sensed forest map based on imagery from 1997; the current satellite image ordered for the analysis was not available for the development of the sampling design.

Species data

At each sample location, we recorded information on all vascular plant species based on a nested design (Fig. 3a). Tree species abundance was quantified within 300 m², further differentiated in a regenerating and established stage, following Ochoa-Gaona et al. (2004). Information on abundances of shrub species and tall herbs was recorded within a sample of 30 m². Finally, in the herb layer, we collected information on small herbs and grasses, as well as herbaceous climbers in four subsamples of 1 m² each nested within the tree plot. Invasive species were identified in the list of occurring species.

From these records, overall species counts and species counts for separate plant groups were used as a measure for plant species richness.

Overall species composition and species composition of the different plant groups separately were subjected to Isometric feature mapping (Isomap, Tenenbaum et al. 2000) to extract gradients in species composition. In contrast to more well-established ordination methods, Isomap features the ability to cope with linear and non-linear species response curves without the requirement of a priori assumptions (Mahecha et al. 2007). Axes with an explained variance of less than 15% were not considered meaningful and were thus dismissed.

Fragmentation data

Corresponding information on forest fragmentation at the sampling locations was derived from a recent panchromatic SPOT satellite image (spatial resolution 5 m, acquisition date January 25, 2007) which had been previously classified in forested and non-forested areas. Classification accuracy was assessed by calculating the Kappa coefficient (Cohen 1960) between the classified SPOT image and a SPOT image of the same date with 2.5 m spatial resolution. For this reason, 100 reference points were randomly distributed across the study area. A Kappa coefficient of $k = 0.92$ indicated very high classification accuracy. The higher resolution SPOT image was not found to be suitable for the classification; the employed unsupervised pixel-based classification approach led to less accurate classification results due to shade effects more prominent than in the SPOT image of 5 m resolution.

For the computation of forest fragmentation with landscape metrics, we used FRAGSTATS 3.3 (McGarigal et al. 2002). Landscape metrics were calculated in circular areas, centered on each of the 58 sample locations. For these areas, three different
radii (150, 250, and 350 m, Fig. 3b) were chosen in order to approximate the scale at which fragmentation has strongest explanatory power (see also Winfree et al. 2007). We used five landscape metrics to calculate forest fragmentation: (1) percentage of area covered by forest (PLAND), (2) total edge length between forested and non-forested area (TE), (3) number of patches (NP), (4) landscape division index (DIVISION), and (5) contagion index (CONTAG). For details on these metrics, we refer to McGarigal et al. (2002). The choice of landscape metrics was based on a tradeoff between their intuitive interpretability, their suitability in correlation analyses, as well as their wide acceptance and application in studies on forest fragmentation.

**Analysis**

Gradients in species composition, as represented by the derived Isomap axes, were correlated with fragmentation to quantify the impact of this land use proxy on species composition. Analogous correlation analyses were implemented for species counts per plot to quantify the impact of land use intensity on species richness. Finally, quantitative occurrences of the aggressive invasive shrub *Chromolaena odorata* (L.) R. King & H. Robins were correlated with fragmentation to estimate possible impacts of land use intensity on the species’ invasive potential in the sanctuary. Correlations were implemented in the R statistical environment (R DEVELOPMENT CORE TEAM 2008); further, the Isomap implementation of the vegan package (Oksanen et al. 2008) was employed.

Since the risk of Type I errors (i.e., a relationship is assumed which is not valid in reality) generally increases with the number of tests of significance, the significances of all correlations were Bonferroni corrected to minimize this possibility.

4 Results

Within all sample plots, we recorded 310 vascular plant species. Out of these, 76 were tree species, 56 were shrubs or tall herbs, 51 were identified as herbaceous climbers, and 127 species as small herbs or grasses.

The relationship between vegetation parameters and fragmentation measures was only marginally affected by the different radii used for the derivation of landscape metrics. For simplicity’s sake, we therefore limit our depiction of results to the radius of 250 m.

In correlation analyses of fragmentation with species counts, significant relationships could only
to be established for two plant groups; the tree species richness turned out to be only marginally related to the results of landscape metrics, indicating a tendency of lower tree species richness with increasing land use intensity ($r^2$ range: 0.11* to 0.25*, * Bonferroni-corrected $p \leq 0.05$, Fig. 4a). In the climber layer, a barely observable species decline in the presence of land use was noted ($r^2 = 0.10*$).

The individual correlation of quantitative occurrences of the invasive species *C. odorata* with the degree of forest fragmentation was significant for results of three landscape metrics ($r^2 = 0.16*$, 0.23*, and 0.24*, Fig. 4b).

Correlations of species composition with fragmentation were usually significant (Tab. 1). These results indicated a pronounced qualitative change in species composition (see Fig. 4c for an example), especially for the layer of regenerating trees, for the shrub layer, and overall plant species composition.

5 Discussion

Variables derived with landscape metrics have often been proposed as biodiversity indicators (e.g., Moser et al. 2002). Moreover, fragmentation is easily quantifiable, e.g., by applying the free software FRAGSTATS which makes this approach inexpensive in terms of software requirements. In our study, we used high spatial resolution panchromatic SPOT imagery. The acquisition of satellite imagery is usually accompanied by considerable costs. However, aerial photographs – probably the most common and affordable remote sensing data – may be just as useful as long as they allow accurate forest classification. The approach, hence, represents an empirical method for a cost-effective and practicable quantification of land use impacts on biodiversity in developing tropical regions. Its application as monitoring strategy may also be possible.

In this study, we do not consider fragmentation as a driver apart from, but rather associated with other effects of land use, e.g., facilitated access to remaining forest patches as a result of forest fragmentation. We thus refrain from interpreting the observed effects as an outcome of fragmentation alone and restrict our conclusions to an overall effect of land use with forest fragmentation as a proxy. Ecological information on plant species were taken from Saxena and Brahma (1994, 1995a, b, 1996) unless otherwise indicated.

In the analyses of species richness, we found weak but still significant signs of depletion in the tree layer (Fig. 4a) and in the layer of herbaceous climbers. For the tree layer, this species loss may be attributed to selective logging and the obstruction of regeneration through alterations in microclimatic conditions, as well as browsing damage. The decrease in climber species indicated a decline of forest species in more fragmented forest areas. In fact, many of the encountered climber species in these areas, e.g., *Atylosia scarabaeoides* (L.) Benth., *Hemidesmus indicus* (L.) Benth., or *Ichnocarpus frutescens* (L.) R. Br. were xerophytes. However, even if we established weak negative tendencies for these two groups, the findings do not support the often stated severe reduction of species richness due to human-induced forest fragmentation (see Fahrig 2003 for a review). Thus, hypothesis (a), a relationship between fragmentation and species richness could not be supported.

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![Fig. 4: Exemplary correlations for the radius of 250 m. Landscape metrics used for the respective correlations were DIVISION (a), PLAN D (b), and TE (c).](image-url)
Overall species composition, as well as species composition of different groups, was more affected by human land use. Thus, forest fragmentation increased between-site diversity and led to higher species richness on the landscape level. This finding contradicts findings of earlier studies in which within-site diversity was often increased (McKinney 2002), whereas landscape and between-site diversity was found to decrease in the presence of land use (McKinney 2004).

In this study, the tree composition represented an exception from our general findings, since it was scarcely related to fragmentation. Yet, trees are long-lived and arduous species, possibly responding with certain time-lags to new landscape configurations (Tilman et al. 1994). Thus, the risk of eventual species disappearance due to already changed environmental conditions, now unfavorable for reproduction, cannot be dismissed. This argument is supported by a closer examination of the successive generation in the tree layer, featuring distinct changes. These changes were primarily ascribed to the emergence of more drought-tolerant species like, e.g., Emblica officinalis Gaert., Diospyros melanoxylon Roxb., or Casearia elliptica Willd. In the shrub layer we also found a clear change in species composition towards species assemblages adapted to drier conditions. Since shrub species exhibit a shorter lifespan than trees, often with faster dispersal rates, drought-tolerant species like, e.g., Woodfordia fruticosa (L.) Kurz, Grewia birsuta Vahl, or Cipadessa baccifera (Roxb.) Miq. may colonize fragmented forests in comparatively little time.

In fact, we found abundances of the aggressive invasive shrub *C. odorata* to be correlated with the degree of fragmentation, giving evidence for human land use favoring its dispersal (hypothesis c). The increase of common and often invasive species through the reduction of habitats for native and rare species is generally seen as major threat to the local uniqueness (Mooney and Cleland 2001) with land use as a major driver (McKinney 2004).

Doddamani et al. (1999) state that the degree of infestation by *C. odorata* is low in thick forests where light is the limiting factor. This observation is supported by the present study, where specimens of *C. odorata* were found in almost every plot, but of very different habitus, height and quantity, depending on the degree of fragmentation and the light regime. *C. odorata* exhibits fast dispersal rates, offers a high regeneration capacity in the presence of trampling (Doddamani et al. 1999), and is known to be inedible for domestic animals (Swaminath and Shivana 1999). Thus, *C. odorata* by itself may already be a good indicator of forest use.

Occurences of another invasive shrub, *Lantana camara* L. var. aculeata, visually increased with fragmentation. However, rare occurrences in sample plots did not allow for statistical analysis. Both invasive species are known to change ecosystems drastically by hampering the germination of native species (Muniappan and Viraktamath 1993; Reddy 1999).
Significant correlations of herbs and grasses with fragmentation were largely attributed to an increase in grass species. Possible reasons may be changes in microclimatic conditions, positive selection through cattle grazing, and comparatively fast dispersal rates in an environment marked by disturbance. For climbers we found moderate correlations with fragmentation. This relation was ascribed to the already stated observed change of climber species composition into more drought-tolerant species assemblages. Thus, a relationship between plant species composition and fragmentation as postulated in hypothesis (b) was supported.

6 Conclusions and implications for the study site

By applying very simple means, our study revealed that stable plant species richness existed across the forest fragmentation gradient in the Satkosia Gorge Wildlife Sanctuary. At the same time, plant species composition changed perceptibly towards more drought-tolerant species assemblages which may be attributed to changes in microclimatic conditions due to forest thinning. This was accompanied by increasing numbers of the widespread invasive species *C. odorata*. Local village communities in the sanctuary, however, remain highly dependent on forest resources for their subsistence needs. The current management policy which completely prohibits human land use provokes illegal extraction. This illegal use is uncontrollable and has alarming consequences for natural plant species composition. Thus, alternative strategies are needed that make land use manageable and that are accepted and supported by local people. Without this prerequisite, the survival of the natural plant species diversity cannot be guaranteed.

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