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

Ulrike Faude, Hannes Feilhauer and Sebastian Schmidtlein

With 4 figures and 1 table
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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.

Zusammenfassung: Die Einrichtung von Schutzgebieten führt in tropischen Entwicklungsregionen oft zu Spannungen, da vielerorts traditionelle Landnutzungsformen eingeschränkt werden. Strenge Schutzauflagen entziehen nicht nur der indigenen Bevölkerung die Lebensgrundlage, sondern wirken auch dem eigentlichen Schutzgedanken entgegen, da sie eine illegale und damit unkontrollierte Nutzung der natürlichen Ressourcen herausfordern. Zur Entwicklung von alternativen Schutzkonzepten werden Methoden benötigt, die objektiv den menschlichen Einfluss auf schutzwürdige Aspekte der Biodiversität erfassen. In der vorliegenden Studie wird am Beispiel eines indischen Schutzgebietes ein derartiger Ansatz vorgestellt, der über die als Indikator verwendete anthropogen hervorgerufene Waldfragmentierung Rückschlüsse auf die Auswirkungen der tatsächlich vorliegenden Landnutzungsintensität erlaubt. Der Grad der Fragmentierung wurde quantitativ aus einem Satellitenbild bestimmt und in Bezug zu flächenbezogenen Aspekten der Biodiversität (Artenreichtum, Artenzusammensetzung und Auftreten invasiver Arten) gesetzt. Während sich der Artenreichtum entlang des Fragmentierungsgradienten kaum änderte, wurden mit steigender Fragmentierung deutliche Änderungen der Artenzusammensetzung sowie ein zunehmendes Auftreten invasiver Arten beobachtet.

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 (Upadhaya 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 (Bleher 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-

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cable methods are of great concern (Salafsky and Margoluis 1999).

Land use intensity within protected areas is subject to spatial variation. Possible reasons for this variation have been addressed in several studies (e.g., Nagendra et al. 2006; Robbins et al. 2007). However at the site level, it is generally very difficult to obtain reliable data on land use intensity and therefore its actual influence on biodiversity. The reasons are manifold; one major constraint is the widespread reluctance of local stakeholders to communicate their often illegal actions. Some researchers confront this problem by aiming at the direct quantification of land use intensity in the field (e.g., Bleher et al. 2006) and subsequently relate it to biodiversity features. Land use impacts on forest biodiversity may however not always be obvious; be it due to the general inconspicuousness of some impacts, seasonal dynamics, or past land use no longer visible. These uncertainties may bias established relationships considerably. In other studies, forest areas are subjected to a classification according to a presumed state of degradation (e.g., Devi and Behera 2003). This approach may however imply an undue generalization of various real life conditions, i.e., small-scale variability in forest use.

Today, fragmentation and habitat loss are recognized as the greatest threats to biodiversity (Solé et al. 2004). Following classical equilibrium theory of island biogeography (MacArthur and Wilson 1967), fragments have often been considered as islands in a hostile environment (Haila 2002). Therefore, species persistence in remnant forest patches has been mainly related to patch size and isolation (e.g., Lienert 2004; Vasconcelos et al. 2006). This approach is deeply criticized, however, due to the oversimplifying assumptions that are not relevant in most real-life situations concerned with terrestrial habitat islands (Gotelli and Graves 1996, 222f.; Haila 2002).

In developing tropical regions, ongoing landscape change and fragmentation through expansion of human land use are of major concern to future sustainability (Laurance 1999). Evidence of further use of forest fragments is ubiquitous. The canopy cover is often punctured by selective logging (Nascimento and Laurence 2004; Echeverría et al. 2007) and large trees die off due to the increasing frequency of human-induced forest fires (Barlow et al. 2003). This creation of 'inner edges' leads to a change in the microclimate and to the establishment of early successional plants (Echeverría et al. 2007). Extraction of non-timber forest products is seen as additional threat for 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-

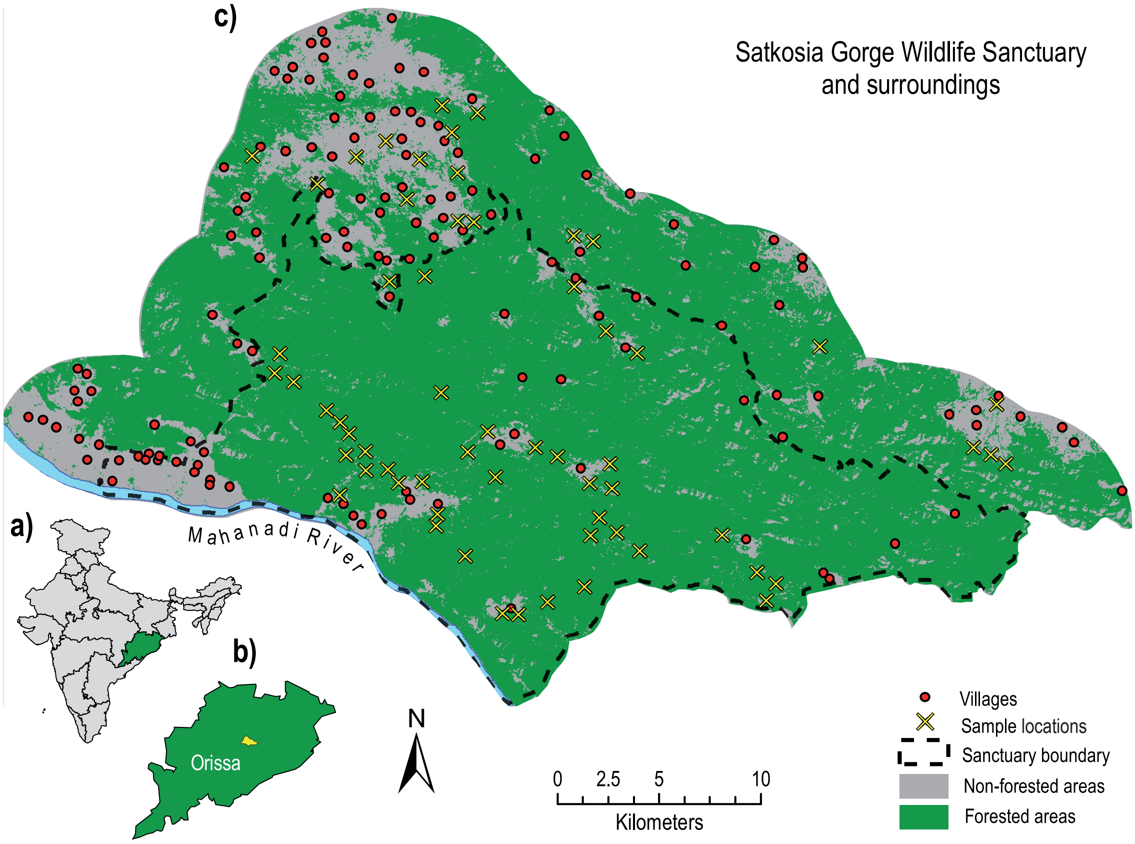

Fig. 1: the study area is located in central Orissa, India. (a) indicates the situation of Orissa at the Bay of Bengal, surrounded by the states Andhra Pradesh, Chhattisgarh, Jharkandh, and West Bengal (clockwise). (b) depicts the location of the study area in central Orissa, and (c) shows its full extent with the sanctuary core area and the buffer zone of five kilometers width. Sample locations randomly distributed across plain areas are drawn as crosses, villages as circles.

ing the poorest groups of Indian society. 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.

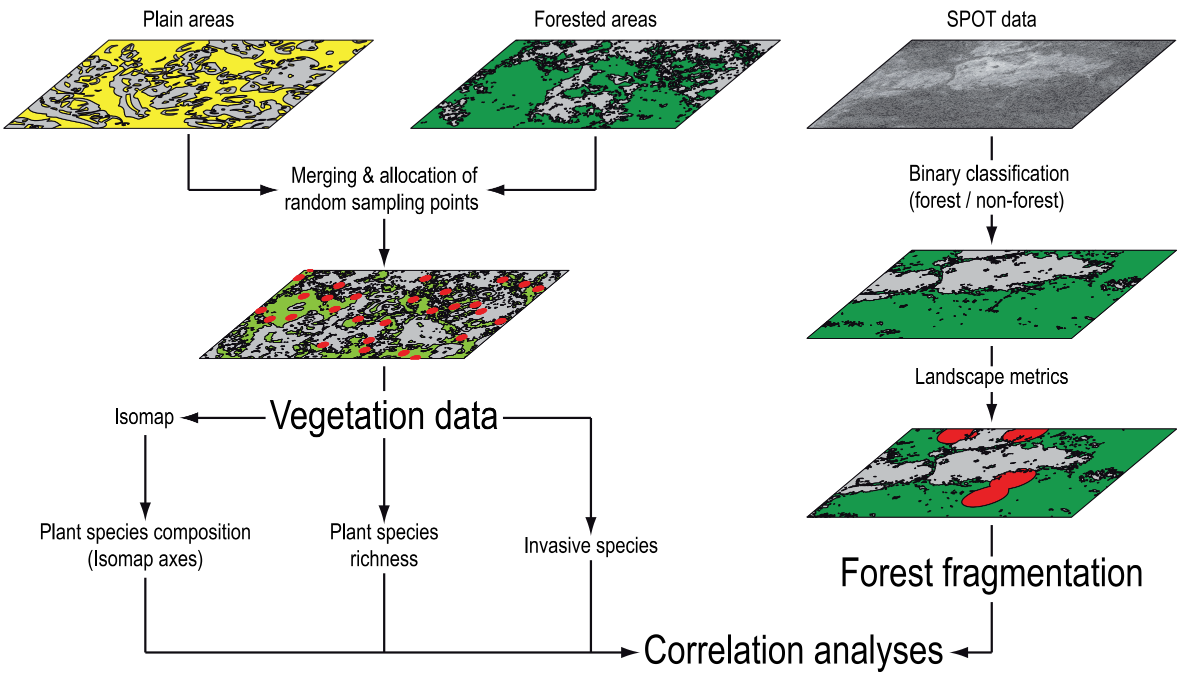

Fig. 2: Flowchart of the analyses.

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

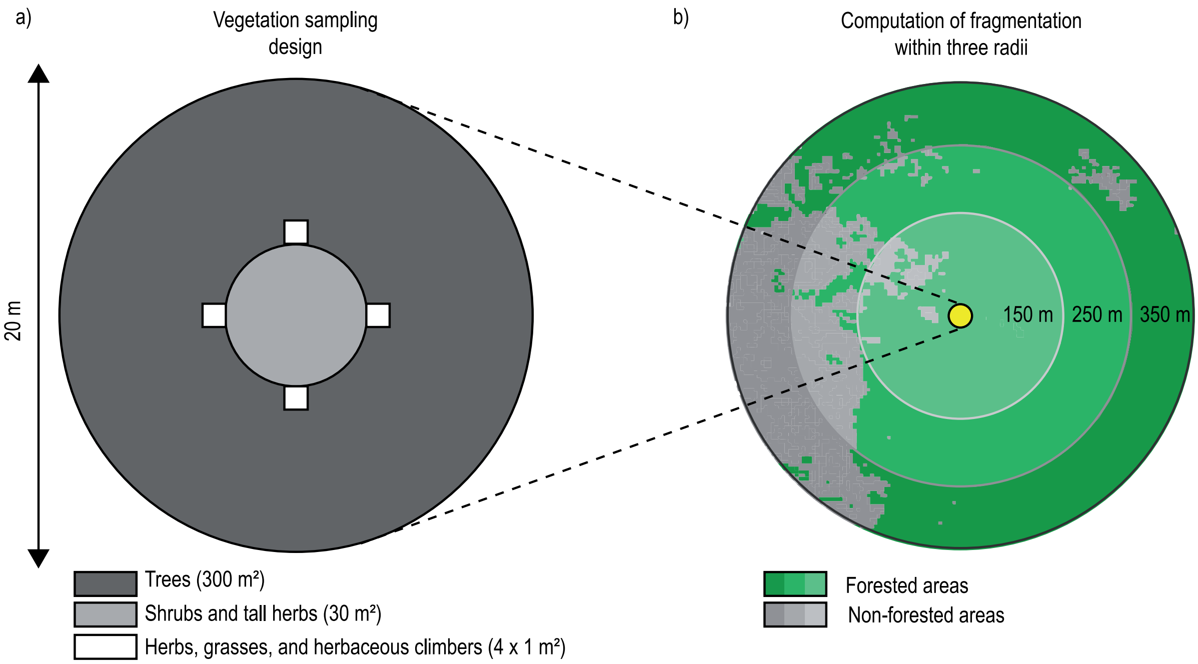

Fig. 3: a) Illustrates the design for recording the vegetation sample (*n* = 58), b) shows the three radii in which fragmentation around each vegetation sample location (in yellow) was calculated.

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 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 Brahman (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 frustescens* (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.

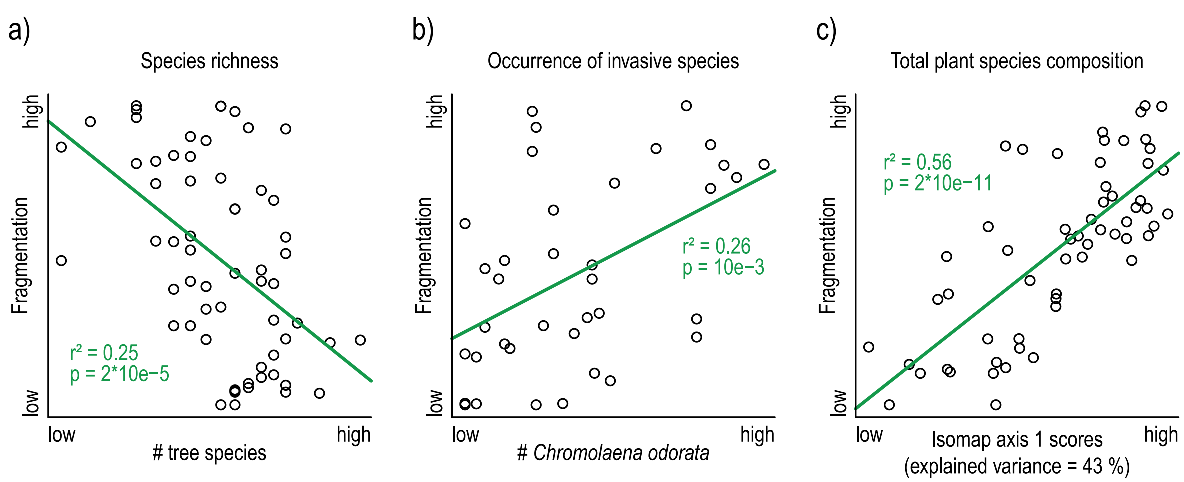

Fig. 4: Exemplary correlations for the radius of 250 m. Landscape metrics used for the respective correlations were DIVISION (a), PLAND (b), and TE (c).

Table 1: significant results ($p \leq 0.05$, Bonferroni corrected) of correlations between vegetation gradients as expressed by Isomap axes and fragmentation calculated in a radius of 250 m.

	Vegetation gradient [f]	Variance [%] [g]	Significant correlations [r²]				
			a	b	c	d	e
All species	main	43	0.45	0.49	0.45	0.39	0.56
All trees	main	50	0.1	-	-	-	-
Regenerating trees	main	58	0.18	0.1	-	-	0.09
Regenerating trees	second	19	0.3	0.37	0.37	0.32	0.39
Shrubs	main	61	0.41	0.48	0.22	0.51	0.34
Herbs	main	44	0.12	-	0.18	0.12	0.13
Herbaceous climbers	main	72	-	-	0.16	-	0.09

[a] Contagion index (CONTAG)
[b] Landscape division index (DIVISION)
[c] Number of patches (NP)
[d] Percentage of area covered by forest (PLAND)
[e] Total edge length between forested and non-forested areas (TE)
[f] Hierarchy of vegetation gradients as derived by Isomap axes
[g] Proportion of floristic variance explained by the respective Isomap axis

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 hirsuta* 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.

Occurrences 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 perceivably 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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References

Abdullah, S. A. and Nakagoshi, N. (2007): Forest fragmentation and its correlation to human land use change in the state of Selangor, peninsular Malaysia. In: Forest Ecology and Management 241, 39–48. DOI: 10.1016/j.foreco.2006.12.016

Axmacher, J. C.; Brehm, G.; Hemp, A.; Tünte, H.; Lyaruu, H. V. M.; Müller-Hohenstein, K. and Fiedler, K. (2009): Determinants of diversity in afrotropical herbivorous insects (Lepidoptera: Geometridae): plant diversity, vegetation structure or abiotic factors? In: Journal of Biogeography 36, 337–349. DOI: 10.1111/j.1365-2699.2008.01997.x

Barlow, J.; Peres, C. A.; Lagan, B. O. and Haugaasan, T. (2003): Large tree mortality and the decline of forest biomass following Amazonian wildfires. In: Ecology Letters 6, 6–8. DOI: 10.1046/j.1461-0248.2003.00394.x

Bleher, B.; Uster, D. and Bergsdorf, T. (2006): Assessment of threat status and management effectiveness in Kakamega Forest, Kenya. In: Biodiversity and Conservation 15, 1159–1177. DOI: 10.1007/s10531-004-3509-3

Brockington, D.; Duffy, R. and Igoe, J. (2008): Nature unbound: conservation capitalism and the future of protected areas. London.

Chapin, M. (2004): A challenge to conservationists. In: World Watch 17, 17–31.

Cohen, J. (1960): A coefficient of agreement for nominal scales. In: Educational and Psychological Measurement 20, 37–46. DOI: 10.1177/001316446002000104

Devi, U. and Behera, N. (2003): Assessment of plant diversity in response to forest degradation in a tropical dry deciduous forest of Eastern Ghats in Orissa. In: Journal of Tropical Forest Science 15, 147–163.

Doddamani, M. P; Mummigatti, U. V.; Nadagoudar, B. S. and Chetti, M. B. (1999): *Chromolaena* in Karntataka: problems and prospects. In: Sankaran, K. V.; Murphy, S. T. and Evans, H. C. (eds.): Alien weeds in moist tropical zones: banes and benefits. Peechi, 42–45.

Duelli, P. and Obrist, M. K. (1998): In search for the best correlates for local organismal biodiversity in cultivated areas. In: Biodiversity and Conservation 7, 297–309. DOI: 10.1023/A:1008873510817

Echeverría, C.; Newton, A. C.; Lara, A.; Benayas, J. M. R. and Coomes, D. A. (2007): Impacts of forest fragmentation on species composition and forest structure in the temperate landscape of southern Chile. In: Global Ecology and Biogeography 16, 426–439. DOI: 10.1111/j.1466-8238.2007.00311.x

Fahrig, L. (2003): Effects of habitat fragmentation on biodiversity. In: Annual Review of Ecology, Evolution, and Systematics 34, 487–515. DOI: 10.1146/annurev.ecolsys.34.011802.132419

Gotelli, N. J. and Graves, G. R. (1996): Null models in ecology. Washington.

Guirado, M.; Pino, J. and Rodà, F. (2007): Comparing the role of site disturbance and landscape properties on understory species richness in fragmented periurban Mediterranean forests. In: Landscape Ecology 22, 117–129. DOI: 10.1007/s10980-006-9009-y

Haila, Y. (2002): A conceptual genealogy of fragmentation research: from island biogeography to landscape ecology. In: Ecological Applications 12, 321–334.

Karanth, K. K.; Curran, L. M. and Reuning-Scherer, J. D. (2006): Village size and forest disturbance in Bhadra Wildlife Sanctuary, Western Ghats, India. In: Biological Conservation 128, 147–157.

Laurance, W. F. (1999): Reflections on the tropical deforestation crisis. In: Biological Conservation 91, 109–117. DOI: 10.1016/S0006-3207(99)00088-9

Lienert, J. (2004): Habitat fragmentation effects on fitness of plant populations – a review. In: Journal of Nature Conservation 12, 53–72. DOI: 10.1016/j.jnc.2003.07.002

MacArthur, R. H. and Wilson, E. O. (1967): The theory of island biogeography. Princeton.

Madhusudan, M. D. (2003): Living amidst large wildlife: livestock and crop depredation by large mammals in the interior villages Bhadra Tiger Reserve, South India. In: Environmental Management 31, 466–475.

Mahecha, M. D.; Martínez, A.; Lischeid, G. and Beck, E. (2007): Nonlinear dimensionality reduction: alternative ordination approaches for extracting and visualizing biodiversity patterns in tropical montane forest vegetation data. In: Ecological Informatics 2, 138–149. DOI: 10.1016/j.ecoinf.2007.05.002

McGarigal. K.; Cushman, S. A.; Neel, M. C. and Ene, E. (2002): FRAGSTATS: Spatial pattern analysis program for categorical maps. Amherst. http://www.umass.edu/landeco/research/fragstats/fragstats.html. (20-01-2010).

McKinney, M. L. (2002): Do human activities raise species richness? Contrasting patterns in United States plants and fishes. In: Global Ecology and Biogeography 11, 343–348. DOI: 10.1046/j.1466-822X.2002.00293.x

– (2004): Measuring floristic homogenization by non-native plants in North America. In: Global Ecology and Biogeography 13, 47–53. DOI: 10.1111/j.1466-882X.2004.00059.x

Michalski, F.; Nishi, I. and Peres, C. A. (2007): Disturbance mediated drift in tree functional groups in Amazonian forest fragments. In: Biotropica 39, 691–701. DOI: 10.1111/j.1744-7429.2007.00318.x

Mooney, H. A. and Cleland, E. E. (2001): The evolutionary impact of invasive species. In: Proceedings of the National Academy of Sciences of the United States of America 98, 5446–5451. DOI: 10.1073/pnas.091093398

Moser, D.; Zechmeister, H. G.; Plutzar, C.; Sauberer, N.; Wrbka, T. and Grabherr, G. (2002): Landscape patch shape complexity as an effective measure for plant species richness in rural landscapes. In: Landscape Ecology 17, 657–669. DOI: 10.1023/A:1021513729205

Muniappan, R. and Viraktamath, C. A. (1993): Invasive alien weeds in the Western Ghats. In: Current Science 64, 555–557.

Nagendra, H.; Pareeth, S. and Ghate, R. (2006): People within parks – forest villages, land-cover change and landscape fragmentation in the Tadoba Andhari Tiger Reserve, India. In: Applied Geography 26, 96–112. DOI: 10.1016/j.apgeog.2005.11.002

Nascimento, H. E. M. and Laurance, W. F. (2004): Biomass dynamics in Amazonian forest fragments. In: Ecological Applications 14 Suppl., 127–138. DOI: 10.1890/01-6003

Ochoa-Gaona, S.; González-Espinosa, M.; Meave, J. A. and Sorani-Dal, B. V. (2004): Effect of forest fragmentation on the woody flora of the highlands of Chiapas, Mexico. In: Biodiversity and Conservation 13, 867–884. DOI: 10.1023/B:BIOC.0000014457.57151.17

Oksanen, J.; Kindt, R.; Legendre, P.; O'Hara, B.; Simpson, G. L.; Solymos, P.; Stevens, M. H. H. and Wagner, H. (2008): Vegan: community ecology package. http://vegan.r-forge.r-project.org (20-01-2010)

Peres, C. and Michalski, F. (2006): Synergistic effects of habitat disturbance and hunting in Amazonian forest fragments. In: Laurance W. F. and Peres, C. (eds.): Emerging threats to tropical forests. Chicago, 105–126.

Pradhan, S. K. (2007): Conservation and communities of Satkosia biotope. In: e-planet 5, 1–5.

R DEVELOPMENT CORE TEAM (2008): R: a language and environment for statistical computing. Vienna, Austria. http://www.R-project.org (01-25-2010)

Reddy, M. M. (1999): *Lantana* infestation in Karnataka: an overview. In: Sankaran, K. V.; Murphy, S. T. and Evans, H. C. (eds): Alien weeds in moist tropical zones: banes and benefits. Peechi, 64–66.

Redford, K. H. and Sanderson, S. E. (2000): Extracting humans from nature. In: Conservation Biology 14, 1362–1364. DOI: 10.1046/j.1523-1739.2000.00135.x

Robbins, F.; Chhangani, A. K.; Rice, J.; Trigosa, E. and Mohnot, S. M. (2007): Enforcement authority and vegetation change at Kumbhalgarh Wildlife Sanctuary, Rajasthan, India. In: Environmental Management 40, 365–378. DOI: 10.1007/s00267-006-0187-9

Salafsky, N. and Margolius, R. (1999): Threat reduction assessment: a practical and cost-effective approach to evaluating conservation and development projects. In: Conservation Biology 13, 830–841. DOI: 10.1046/j.1523-1739.1999.98183.x

Saxena, H. O. and Brahman, M. (1994): The flora of Orissa. Ranunculaceae to Fabaceae. Vol. 1. Bhubaneshwar.

– (1995a): The flora of Orissa. Rosaceae to Martyniaceae. Vol.2. Bhubaneshwar

– (1995b): The flora of Orissa. Acanthaceae to Commelinaceae. Vol.3. Bhubaneshwar.

– (1996): The flora of Orissa. Flagellariaceae to Poaceae, Gymnosperms and Pteridophyta. Vol.4. Bhubaneshwar.

Solé, R. V.; Alonso, D. and Saldaña, J. (2004): Habitat fragmentation and biodiversity collapse in neutral communities. In: Ecological Complexity 1, 65–75. DOI: 10.1016/j.ecocom.2003.12.003

Southworth, J.; Munroe, D. and Nagendra, H. (2004) Land cover change and landscape fragmentation – comparing the utility of continuous and discrete analyses for western Honduras region. In: Agriculture, Ecosystems and Environment 101, 185–205. DOI: 10.1016/j.agee.2003.09.011

Swaminath, M. H. and Shivanna, M. (1999): The ecological impact of *Chromolaena odorata* in the Western Ghats forests of Karnataka and the management strategies to minimize the impact. In: Sankaran, K. V.; Murphy, S. T. and Evans, H. C. (eds.): Alien weeds in moist tropical zones: banes and benefits. Peechi, 112–114.

Tenenbaum, J. B.; de Silva, V. and Langford, J. C. (2000): A global geometric framework for nonlinear dimensionality reduction. In: Science 290, 2319–2323. DOI: 10.1126/science.290.5500.2319

Tilman, D.; May, R. M.; Lehman, C. L. and Nowak, M. A. (1994): Habitat destruction and the extinction debt. In: Nature 371, 65–66. DOI: 10.1038/371065a0

Upadhaya, S. and Kothari, A. (2001): National parks and sanctuaries in India – a guide to legal provision. Allahabad.

Vasconcelos, H. L.; Vilhena, J. M. S.; Magnusson, E. and Albernaz, A. L. K. M. (2006): Long-term effects of forest fragmentation on Amazonian communities. In: Journal of Biogeography 33, 1348–1356. DOI: 10.1111/j.1365-2699.2006.01516.x

Winfree, R.; Griswood, T. and Kremen, C. (2007): Effect of human disturbance on bee communities in a forested ecosystem. In: Conservation Biology 21, 213–223. DOI: 10.1111/j.1523-1739.2006.00574.x

Authors

Dipl.-Geogr. Ulrike Faude
Dipl.-Geoökol. Hannes Feilhauer
Prof. Dr. Sebastian Schmidtlein
Department of Geography
University of Bonn
Meckenheimer Allee 166
53115 Bonn
ulrike.faude@giub.uni-bonn.de
hannes@geographie.uni-bonn.de
s.schmidtlein@uni-bonn.de