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Village size and forest disturbance in Bhadra Wildlife Sanctuary, Western Ghats, India

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ABSTRACT

Habitat fragmentation, land cover change and biodiversity loss are often associated with village communities in protected areas, but the extent and intensity of such impacts are often inadequately assessed. We record resource use and depletion by human inhabitants by conducting ecological surveys in six villages and social surveys in all 13 villages of varying sizes in India's Bhadra Wildlife Sanctuary (492 km^2). We examined the occurrence of 10 regionally-specific ecological indicators that encompassed several aspects of human activities. Thirty transects with 180 total sampling locations recorded the occurrence of these specific habitat disturbance variables. High correlations between the variables led to the use of principal component analysis to derive an effective summary index that reflected disturbance intensity and determined village ecological impacts spatially. A generalized linear model was fit to determine the rate at which disturbance decreases as we move away from village centers. Our model indicates that village size class, distance from the village and proximity to other villages were significant predictors of the disturbance index. The index distinguished each village's spatially explicit ecological impact. We estimated that an average area of 23.7 km^2 of the forest surrounding the six focal villages was altered by human activities. These six villages have directly impacted 8–10% of this protected area.

1. Introduction

Protected areas (PAs) cover about 5% of the total land area in India and support ca. 4.5 million people (Kothari et al., 1989). Small PA size (mean area < 300 km^2) and enclosure by densely populated areas (>300 people/km^2) make PAs in India vulnerable to human and domestic livestock populations, and the associated environmental impacts (Karanth, 2002; Rodgers et al., 2003). Although threats to Indian parks are much like those within Africa and the Americas, higher human population densities may have more immediate and severe consequences in India (Brandon, 1998; Neumann, 1998; Brashares et al., 2001; Ferraro, 2002; Peres, 2002; Oates, 2002). In many Asian PAs, human pressures continue to threaten wildlife survival, habitat protection and biological diversity (Karanth, 2002; Müller and Zeller, 2002; Peh et al., 2005). Yet it is neither ethically right nor often administratively or politically feasible to disregard the legitimacy of people's claims to living in PAs. The current debate within the conservation community centers on natural resource use rights of human settlements and village communities found in and around PAs (Agrawal and Gibson, 1999; Redford and Sanderson, 2000; Schwartzman et al., 2000a,b; Brechin et al., 2002; Terborgh, 2002; Wilshusen et al., 2002; Tutin, 2002; Colchester, 2004).

Biodiversity loss, habitat fragmentation and land cover changes are occurring across many Indian PAs (Gadgil and Guha, 1992; Kothari et al., 1995). Human livelihood activities of livestock grazing, agriculture, hunting, fishing, and collection

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of timber, fuel wood and non-timber forest products (NTFPs) have altered land cover and introduced new land uses in many Indian PAs (Murali et al., 1996; Somanathan and Borges, 2000; Rahmani, 2003). Grazing of domestic livestock has decreased food resources for wild herbivores (increased crop raiding incidences), shifted nutrient dynamics (increased soil erosion and compaction) and changed overall plant composition (Sekhar, 1998; Middleton, 2003). Grazing has led to local extinctions or emigration of animals dependent on specific vegetation cover (Madhusudan and Mishra, 2003), and increased transmission of diseases and parasites to wild herbivores (Rahmani, 2003). Fuel wood and NTFP collection of assorted plant parts has directly affected food availability for several species dependent on these resources and indirectly affected plant survival, regeneration and recruitment patterns (Murali et al., 1996; Somanathan and Borges, 2000). Importantly, rapid and extensive market expansion or change in access typically has led to over-harvesting of these products. These human activities have had concomitant effects on ecological interactions and ecosystem functioning (Robinson, 1993).

Discerning impacts of resident human populations is critical for park management and rural livelihoods (Salafsky and Wollenberg, 2000; Sanderson et al., 2002; Nepstad et al., 2002; Liu et al., 2003). This involves determining how human-dominated ecosystems function and ecological implications of human activities (specifically about the type, intensity and spatial extent of disturbance). Therefore, methods and tools that can quantify human induced forest disturbance are especially important if we aim to develop buffer zones, manage human activities while forest communities continue to live in and around PAs and derive livelihoods dependent on forest products, fuel wood and livestock grazing.

Our goal was to determine the extent of forest disturbance around six villages in India's Bhadra Wildlife Sanctuary (BWS). We examined resource use by human inhabitants of six villages with varying household sizes in the park. When this study was conducted (July–September 2002), 11 of the 13 villages were participating in a voluntary relocation project (Karanth, in review). This voluntary relocation of 419 of the 457 households (and their livestock) from the reserve with full compensation, housing and infrastructure provided additional impetus to determine the spatial extent of forest disturbance around the villages. This study provides information for park managers about areas of the reserve affected by human activities and where subsequent recovery and regeneration efforts should be directed.

1.1. Study Site

Bhadra Wildlife Sanctuary (75°15′ to 75°50′E and 13°25′ to 13°50′N) is a protected area covering 492 km^2 in India's Western Ghats, a region delineated as a biodiversity hotspot (Fig. 1, Myers et al., 2000). Vegetation comprises of wet evergreen forests and moist deciduous forests that are dominated by bamboo. The forest canopy is comprised of many valuable timber species such as *Tectona grandis*, *Terminalia tomentosa*, *Terminalia paniculata*, and *Lagerstromia lancelota* (Karanth,

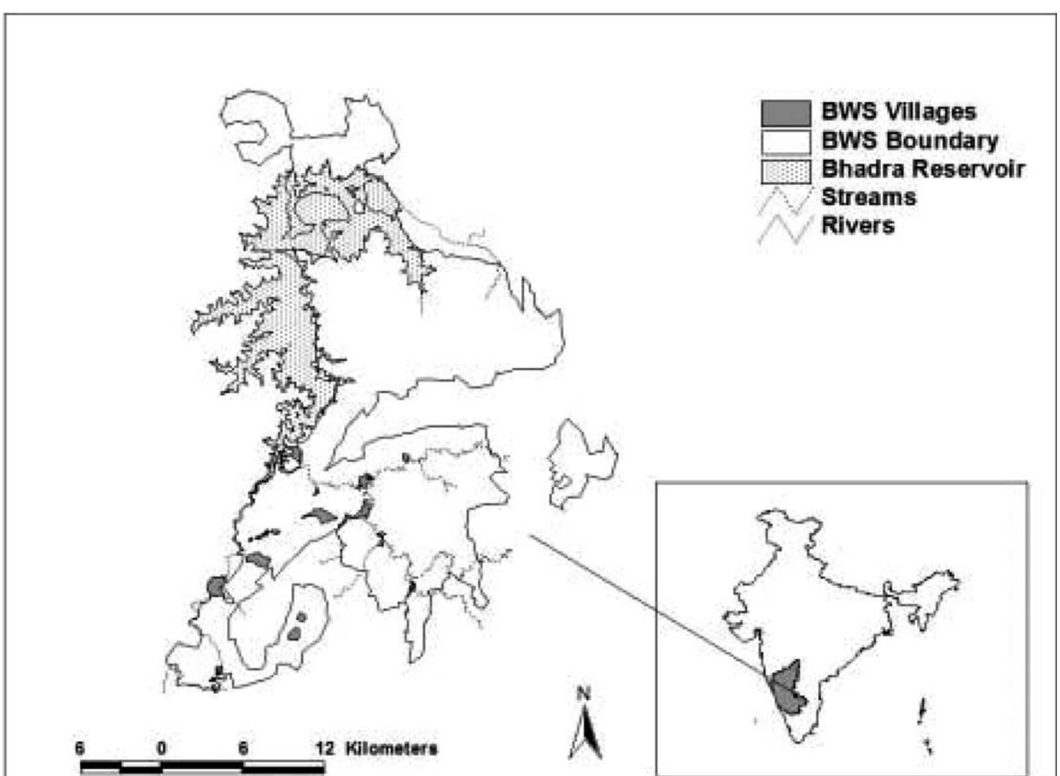


Fig. 1 – Study region location. Bhadra Wildlife Sanctuary is a protected area in Western Ghats, India (area is 492 km^2, 75°15′ to 75°50′E and 13°25′ to 13°50′N).

1982). The mid-canopy is comprised of species such as *Kydia calycina*, *Dillenia pentagyna*, *Gmelina arborea* and *Randia* spp. (Karanth, 1982). The understory is dominated by bamboo, especially *Bambusa arundineacea* and *Dendrocalamus strictus* (Karanth, 2003). Low-lying valleys contain swampy grasslands occupied by village settlements and rice-agriculture (Karanth, 1982; Karanth, 2003). The total number of individuals inhabiting the park across 13 villages till recently was ca. 4000 (8.1 people/km^2, includes adults and children, Karanth, 2003). Households across all villages harvested wildlife, grazed livestock, and collected firewood, timber and forest products. Severe human wildlife conflicts (crop raiding, property loss, livestock predation) also occurred frequently within this park (Karanth, 1982; Karanth, 2003). Although some households in these villages had legal status, the majority did not have legal status. Construction of a major irrigation reservoir in the 1970s isolated these villages, and park protection provisions have limited infrastructure development within the reserve. The villages in BWS did not have electricity and often did not have running water. During the monsoons, several bridges and roads would be washed away leaving many villages temporarily isolated. Primary, middle and high schools did exist but were very rudimentary with few facilities and teachers were present irregularly. There was no hospital or functional primary health center within or near the park. Given this context, families from these villages sought voluntarily to relocate outside the reserve if their socio-economic needs were met (Karanth, 2003; Karanth, in review).

2. Methods

2.1. Village society composition and demographics

A household level semi-structured social survey was conducted by Karanth in the local languages Kannada and Tulu in all 13 villages in Bhadra Wildlife Sanctuary as well as the two relocation sites (M.C Halli and Kelaguru). This paper examines 6 of 13 villages that were selected for both social and ecological surveys. The small villages of Karvani, Kesave and Muthodi had ⩽30 households, while the mid-sized villages of Hebbe and Hipla had a total of ca. 60 households. Madla had 127 households and represents the largest village in the socio-ecological sample. The survey compiled demographic data and questioned households through semi-structured interviews on livelihood activities such as collection of firewood and NTFP's, livestock grazing, fishing and hunting, along with wildlife crop raiding and livestock predation that they experienced. The survey was conducted during the relocation process, with some families interviewed in their original villages and most were interviewed at the relocation villages. A total of 196 out of 319 households (61.4%) were interviewed from July to August 2002 in the six focal villages (Table 1). Repeated attempts were made to interview all households in all the villages, but the transitional period prevented us from interviewing those families that were temporarily absent in either the original or new relocation villages when we visited and subsequently unavailable for interviews.

Table 1 – Household social survey (conducted in the local languages Kannada and Tulu) results from six selected villages in Bhadra Wildlife Sanctuary, India from July 2002 to September 2002

Village name	Karvani	Kesave	Muthodi	Hebbe	Hipla	Madla
Total number of households	15.0	26.0	29.0	60.0	62.0	127.0
Percentage of households interviewed	60.0	42.3	69.0	56.7	62.9	65.4
Percentage of male head of household	88.9	63.6	85.0	82.4	87.2	81.9
Percentage of household born in village	55.6	72.7	50.0	76.5	66.7	66.3
Average household size	4.3	6.1	3.9	5.0	4.5	4.3
Average yrs household has lived in the village	43.9	44.3	38.7	45.6	42.6	42.9
Religion- Hindu	100.0	100.0	100.0	97.1	82.4	96.4
Caste composition						
Shetty	100.0	81.8	30.0	0.0	35.9	1.3
Gowda	0.0	0.0	25.0	67.7	23.1	60.0
S.C	0.0	0.0	25.0	5.9	20.5	35.0
Other	0.0	18.2	20.0	26.5	20.5	3.8
Percentage of households with agriculture as primary income	77.8	100.0	35.0	64.7	82.1	86.8
Percentage of households with wage labor as primary income	22.2	0.0	40.0	26.5	7.6	12.1
Percentage of households with legal land rights	11.1	72.7	30.0	61.8	71.8	75.6
Percentage of households with encroached land/landless	88.9	27.3	70.0	29.4	17.9	48.2
Percentage of people additionally renting land	55.6	54.6	20.0	47.1	43.6	42.2
Average number of years households farming	33.6	43.6	31.7	36.0	31.4	28.3
Average size of land owned/encroached in acres	3.28	3.83	2.29	4.58	2.9	3.19
Average distance from home to field in km	0.22	0	0.33	0.47	0.38	0.62
Percentage of households using fire wood from the forest	100	100	100	100	100	100
Average distance walked to gather wood in km	0.66	0.68	0.85	0.54	0.83	0.93
Average bundles of firewood per households per week	4.89	5.27	5.42	5.55	5.15	5.81
Total firewood bundles per village per week in kgs	2190	4110	4710	9990	9570	22140
Average number of cattle per household	12	7	2	9	9	8
Total number of cattle present in village	173	182	55	524	545	1021
Percentage of livestock grazing in the forest	100	100	100	100	100	94.2

Sample survey questionnaire available upon request.

2.2. Ecological survey

Empirical field data on ecological indicators of forest use and disturbance were collected along thirty transects (five transects per village) that began at random starting points at the edge of each village and radiated outwards. Transect starting points and compass directions were determined with a random number generator. Each transect was 1 km in length and on each transect, ecological data were collected at six sampling points measured 200 m apart. Using a geographical information system (GIS; Arc View 3.2), sectors were drawn on map of BWS around the six focal villages. We aimed to exclude areas of possible overlap and maximize distance between villages to isolate each individual village's forest disturbance. The global positioning system location of each point was recorded. Results from a pilot study (conducted in June 2002) indicated that 1 km was an appropriate transect length. This initial survey also identified suitable habitat variables to be measured along these transects. The choice of transect length was also corroborated by our social surveys where mean distance walked (once per week) by people to gather firewood and other forest products is <1 km (range 0.54–0.93 km, mean distance = 0.75 km, Table 1). We surveyed 30 sampling locations around each village and obtained a total of 180 sampling points for all six villages (Fig. 2).

At each point (15 m radius), the following habitat disturbance variables were measured: cut stems, cut bamboo, lopped trees, tree notches, fire intensity, exotic weeds visible and easily documented signs of human induced disturbance activity in the forest. These variables encompass all of the visible signs of disturbance seen around these villages. Cut stems refer to residual tree stumps from felling for wood, and cut bamboo refer to residual meristems of bamboo following extraction. Lopped trees are trees with branches that were cut for fuel wood although the main bole remains intact and alive. Tree notches represent cuts in trees as a result of attempts to remove the stems and/extract gum and other plant products. The fire occurrence variable identified signs of human fires that burnt individual trees or forest patches. Cattle and human trails were clearly distinguishable paths through vegetation that result from frequent human and livestock use (highly compact soil with little or no ground cover). Exotic weeds are transported by humans and invade through human alterations of habitat. The presence/absence and coverage extent of exotic weeds such as *Mimosa pudica*, *Lantana* spp., and *Euphatorium* spp. were noted. At each location, the spatial extent of understorey cover was examined along with regeneration of the four most common species of bamboo in BWS namely *Bambusa arundinaecea*, *Dendrocalamus strictus*, *Oxytenthera monostigma*, and *Ochlandra travancorica*. Data for the habitat variables were ranked in classes as absent, low, medium and high and subsequently represented on a numerical scale between 0 and 3. These classes allowed us to group the variables based on the intensity and extent of disturbance. For example, cut stems were classified as absent when no stems were effected, as low when 1–5 stems were effected, as medium when 6–10 stems were effected and high when >10 stems were effected at each point location (15 m radius). The objective of the ecological survey was to quantify the degree of forest disturbance from village livelihood activities.

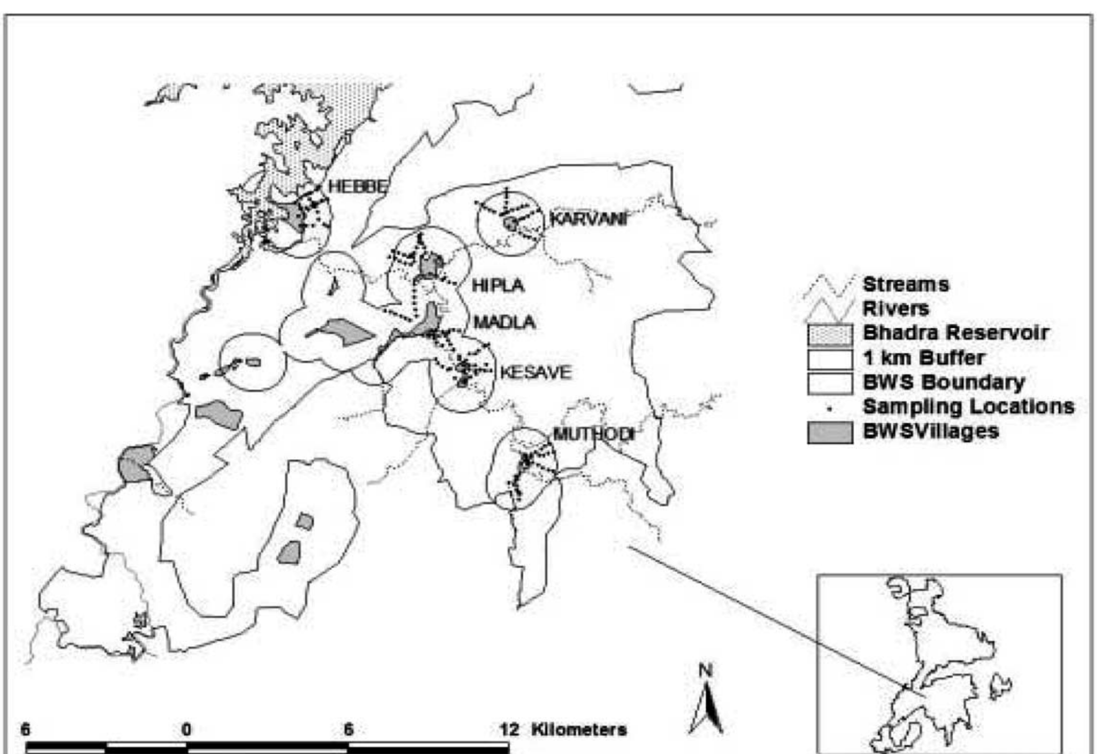


Fig. 2 – GPS sampling locations around selected villages in Bhadra Wildlife Sanctuary, India. Thirty transects (length 1 km) with 180 total sampling locations recorded the occurrence of these specific habitat disturbance variables.

2.3. Analyses

Data points were converted from decimal degrees to UTM coordinate system (with distances measured in meters). The proximity of some of the villages resulted in overlapping regions that were accessed by more than one village. Therefore, any overlapping points were re-assigned to villages based on shortest euclidean distance to the centroid of each of the six selected villages and two other nearby villages. As a result, the original 30 data points per village were redistributed and between 27 and 32 points were assigned to each of the villages. The correlation matrix among disturbance variables suggested substantial inter-relationships among many of the measured variables (Table 2). Because the habitat disturbance variables were all highly correlated with each other, principal component analysis was used to derive a habitat disturbance summary index that could be used to determine village ecological impacts spatially. Because correlation between abundance of cattle trails and human trails was 0.98, only measurements of human trails were included in PCA computations. Eigenvalue analysis suggested that a single principal component be retained as a measure of habitat disturbance. This principal component was rescaled to assume values between 0 and 3, the same scale as the original disturbance variables (roughly corresponding to disturbance of none, low, medium, high). To examine relationships between the PCA composite disturbance index and village size, villages were divided into four size classes based on the total number of households in each village (the mean number of people living in each household was similar across villages; Table 1). The choice of four size classes was based on preliminary non-parametric density estimates that suggest that disturbance varies within each of the resulting village size classes (Class 1, Karvani with 15 households; Class 2 Kesave and Muthodi with ca. 30 households; Class 3 Hipla and Hebbe with ca. 60 households; Class 4 Madla with ca. 120 households). These density estimates indicated that a second order polynomial regression model be used to model decreasing disturbance as a function of distance from the edge of each village: separate polynomials were fit for each size class. The goal in fitting a parametric model was to allow for the estimation of disturbance at various distances around the villages directly surveyed in this study.

3. Results

The social survey conducted by Karanth determined that fuel wood and non-timber forest products (NTFPs) were collected extensively and used often by households in all these villages. Firewood collected per household was similar across villages. Average distance walked to collect firewood varied among villages and ranged from 0.54 km in Hebbe to 0.93 km in Madla. Firewood consumption was estimated from 2190 kg/week in Karvani to 22,140 kg/week in Madla. The unrestricted access to and availability of several fuel wood species around these villages is expected to affect the standing biomass around each village, as corroborated by the many cut stems and lopped trees observed along transects. Livestock (mainly cattle) ownership differed among villages, but 94–100% of the animals grazed in the forest (Karanth, 2003).

NTFPs were collected extensively and three species were sold in urban markets- namely seegakai (*Acacia concinna*), soap nut (*Sapindus emarginatus*), and wate huli (*Artocarpus lacoocha*) (Karanth, 2003). Seegakai was collected in large quantities (from 500 kg in Karvani to 46,600 kg in Madla) and sold in markets (net income generated is US$113 and $9393, respectively). Similarly, soap nut collection varied from 20 kg in Karvani to 11,200 kg in Madla with resulting net incomes per village of US$1 to $2061, respectively. These species were harvested regularly by households that located trees in the forest adjoining their village. The non-market NTFPs collected were bamboo (all four local species, especially *Bambusa arundineacea*, *Oxytenthera* spp., *Ochlandra travancorica* and *Dendrocalamus strictus*), savige (*Sterculia villosa*), gooseberry (*Emblica offcinalis*), several wild fruits (jack fruit-*Artocarpus* heterophyllus, mango-*Mangifera indica*, tamarind-*Tamarindus indicus*, jamun-*Syzygium cumini*, and citrus species), wild mushrooms and honey. The percentage of households interviewed per village that were involved in collecting these NTFPs is shown in Fig. 3.

3.1. Principal component analysis (PCA)

The first principal component (PC1) explained 56% of the variability in the 10 habitat disturbance variables. Subsequent components each explained less than 10% of overall disturbance variability. A scree plot of eigenvalues plotted against principal component number suggested that only the first

Table 2 – Correlation matrix for 10 habitat disturbance variables measured during transects in Bhadra Wildlife Sanctuary, India

	Fire intensity	Cut stems	Cut bamboo	Tree notches	Exposed soil	Exotic weeds	Human trails	Understorey cover	Bamboo regeneration
Cut stems	0.60								
Cut bamboo	0.50	0.59							
Tree notches	0.54	0.67	0.53						
Exposed soil	0.37	0.57	0.36	0.42					
Exotic weeds	0.14	0.26	0.27	0.28	0.16				
Human trails	0.45	0.75	0.66	0.62	0.62	0.39			
Understory cover	−0.24	−0.52	−0.33	−0.38	−0.63	−0.03	−0.51		
Bamboo regeneration	−0.31	−0.56	−0.47	−0.43	−0.52	−0.34	−0.66	0.56	
Lopped trees	0.45	0.73	0.53	0.69	0.52	0.32	0.66	−0.47	−0.48

See text for description of variable assessment methods.

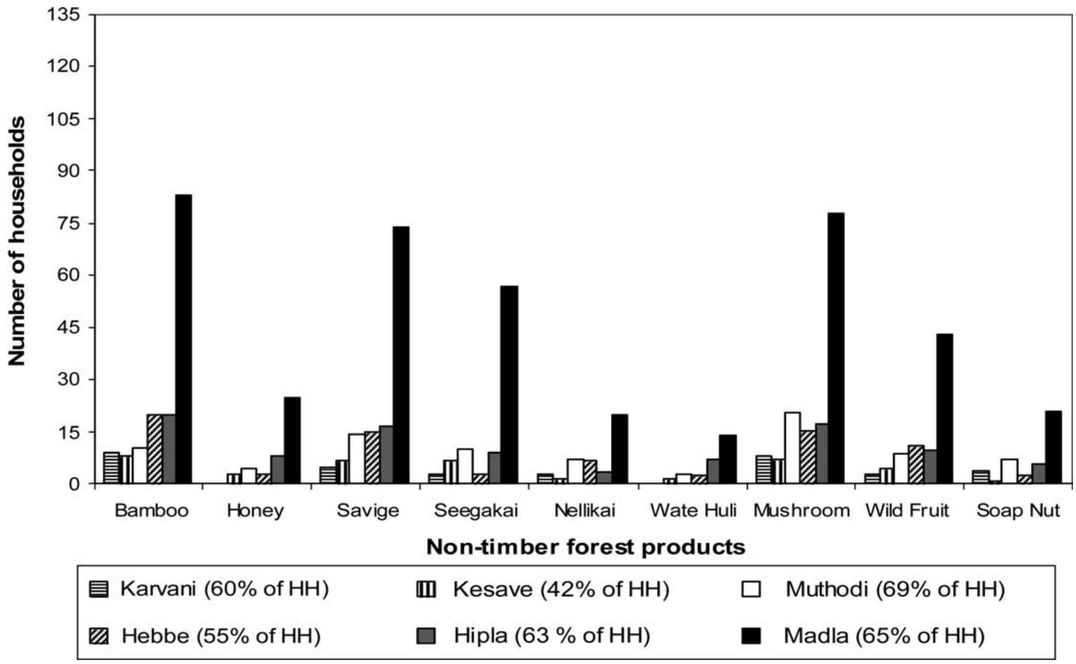


Fig. 3 – Non-timber forest products collected by interviewed households in focal villages of Bhadra Wildlife Sanctuary, India. The percentage of households respondents interviewed in each village shown after village name. HH refers to households.

principal component be retained. The loadings on the first principal component divided the variables into two major groups. The first group had eight negative habitat disturbance variables (which had positive loadings) capturing negative effects of human activities in the region. The second group contained two positive habitat disturbance variables (with negative loadings) that represent recovery and regeneration (Table 3). Principal component coefficients were of relatively similar magnitude for all disturbance variables (only exotic weeds appeared to be less influential, Table 3). This suggested that the various manifestations of disturbance around the villages occurred consistently together.

3.2. *Principal component scores and distance to village edge*

Scores for the first principal component were calculated for each sampling location. For ease of interpretation, scores were rescaled to the same 0–3 scale used for the original disturbance variables (disturbance values of none, low, medium, and high). The first principal component score was plotted against the shortest euclidean distance to the edge of the closest village. Plots of the disturbance index versus distance were drawn for each of the four village size classes (Figs. 4a–4d). Non-parametric regression splines suggested a quadratic relationship between disturbance index and distance from village edge for each size class. Other measures of village natural resource use (e.g. heads of cattle, firewood bundles and non-timber forest products collected) were also modeled as a function of distance from village edge, but were all highly correlated with village size.

The smaller villages (Karvani, Kesave and Muthodi in Figs. 4a and 4b) had lower disturbance levels compared to medium villages (Hebbe and Hipla in Fig. 4c) and large village (Madla in Fig. 4d). We found that as distance from village centroid increased disturbance decreased and overlap regions were most disturbed. For class sizes 1, 2 and 4 forest disturbance decreased as we moved away from the village (Fig. 4d). Although most points in size class 2 showed a similar downward trend, four points showed an upward trend, indicating that disturbance was increasing rather than decreasing as we moved away from these villages. These points were very close to other villages in the area (especially the largest village Madla) and therefore, were probably impacted more severely due to increased access and use by multiple villages (Fig. 4b). Four points beyond 1200 m were measured on a transect originating at Kesave, but during reclassification were re-assigned to Muthodi. For locations that were close to or between two or more villages, forest disturbance at that location was influenced by several villages. Our correlation matrix showed that all the variables were correlated with each other (Table 2).This suggested that

Table 3 – Standardized loadings on the first principal components used to derive the forest disturbance around villages

Variable	First principle component
Fire intensity	0.22
Cut stems	0.34
Cut bamboo	0.35
Tree notches	0.31
Exposed soil	0.29
Exotic weeds	0.14
Human trails	0.46
Understory cover	−0.21
Bamboo regeneration	−0.37
Lopped trees	0.33

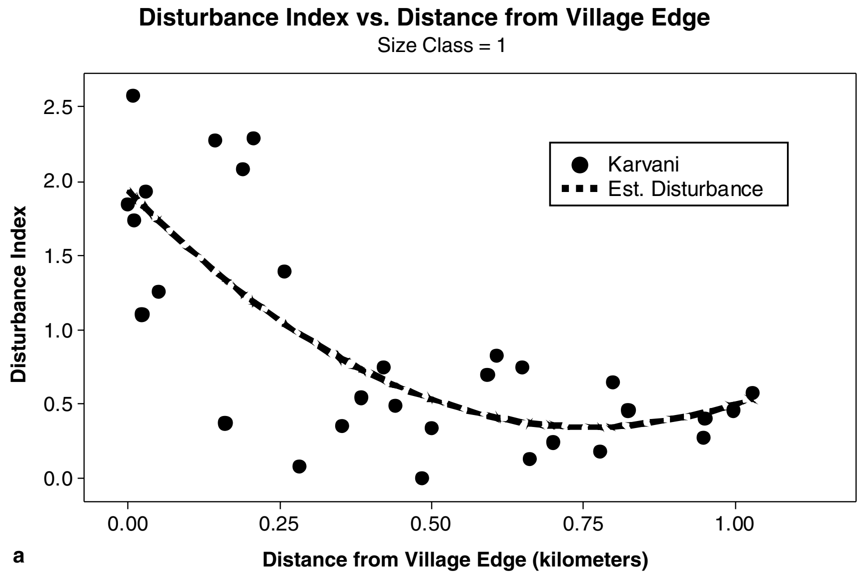


Fig. 4a – Scores for the first principal components are calculated for each sampling location and used to derive a disturbance index. The disturbance index scores are rescaled to the original scale used to measure the 10 ecological variables (values of none, low, medium, and high). This first principal component score is plotted against the shortest euclidean distance (in km) to the edge of the closest village for each of the four size classes. Rescaled PCA scores versus distance from village edge for Karvani (15 total households).

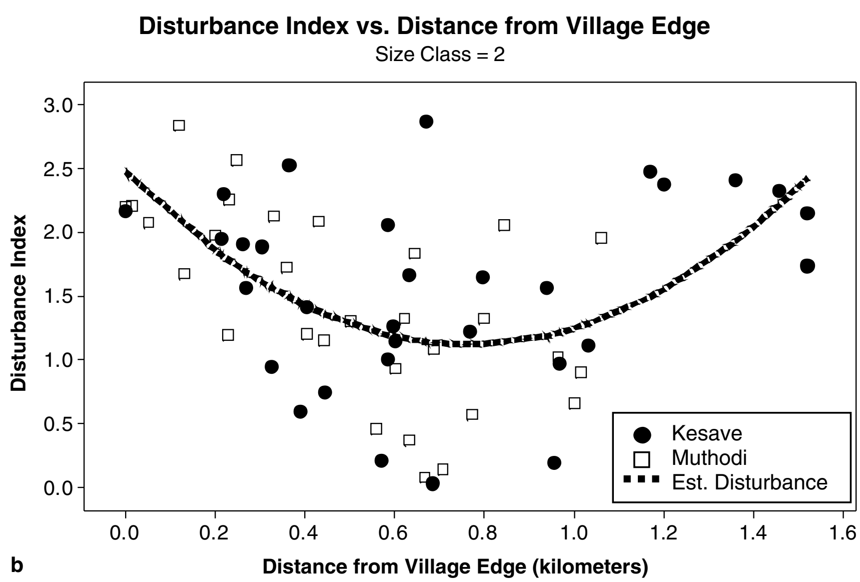
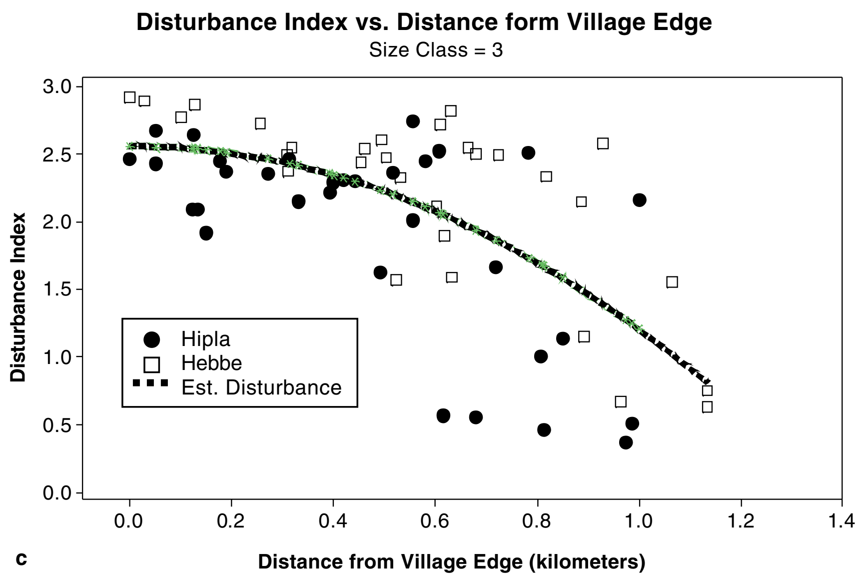


Fig. 4b – Scores for the first principal components are calculated for each sampling location and used to derive a disturbance index. The disturbance index scores are rescaled to the original scale used to measure the 10 ecological variables (values of none, low, medium, and high). This first principal component score is plotted against the shortest euclidean distance (in km) to the edge of the closest village for each of the four size classes. Rescaled PCA scores versus distance from village edge for Kesave and Muthodi (26 and 29 total households).

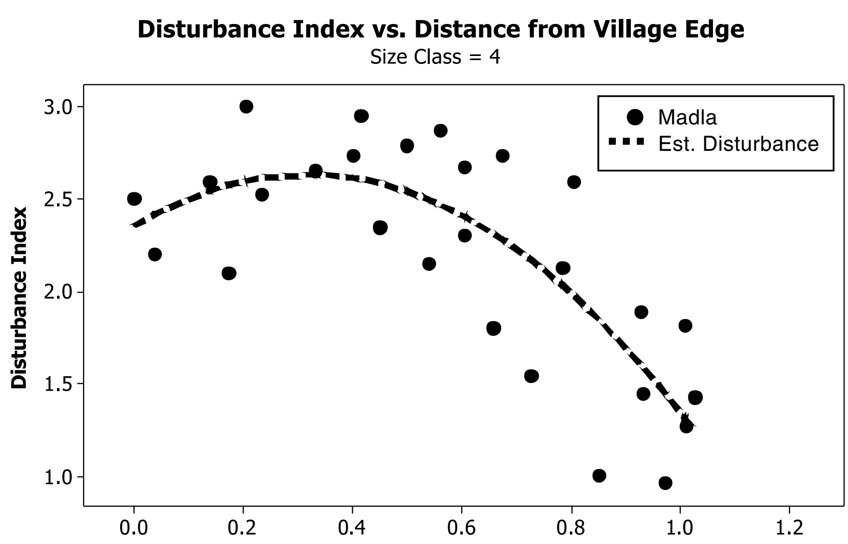
future studies should simply measure overall disturbance in particular locations.

For the small villages of Karvani and Kesave, declines in disturbance scores occurred close to the village (0–400 m) and leveled off by 550 and 700 m, respectively. For Muthodi, disturbance declines began at 400 m and continued up to 1100 m. For mid-sized villages of Hipla and Hebbe, disturbance remained high until 750 and 1000 m, respectively after which disturbance declined. Hebbe village was located next to the Bhadra reservoir, which probably concentrated forest disturbance to one side of the village. For the largest village, Madla, the disturbance declined after 800 m.



c

Fig. 4c – Scores for the first principal components are calculated for each sampling location and used to derive a disturbance index. The disturbance index scores are rescaled to the original scale used to measure the 10 ecological variables (values of none, low, medium, and high). This first principal component score is plotted against the shortest euclidean distance (in km) to the edge of the closest village for each of the four size classes. Rescaled PCA scores versus distance from village edge for Hebbe and Hipla (60 and 62 total households).



d

Fig. 4d – Scores for the first principal components are calculated for each sampling location and used to derive a disturbance index. The disturbance index scores are rescaled to the original scale used to measure the 10 ecological variables (values of none, low, medium, and high). This first principal component score is plotted against the shortest euclidean distance (in km) to the edge of the closest village for each of the four size classes. Rescaled PCA scores versus distance from village for edge Madla (127 households).

Our generalized linear model indicated that village size class and quadratic functions of distance, along with the interactions between distance and village size class were significant predictors of the principal components disturbance index. Analysis of residuals indicated that this model was an adequate fit to the data (Tables 4a and 4b, Fig. 5). The Generalized Linear Model was used to estimate disturbance index scores for various radii around each of the six selected villages. We also came up with a reasonable range of estimated disturbance areas based on the GLM. These areas should be interpreted as the estimated area around a village such that the average disturbance in the area was greater than 2, the disturbance threshold level 2 was indicative of medium to high disturbance. The minimum and maximum are 95%

Table 4a – Analysis of variance for scaled PCA (using adjusted SS for tests)

Source	DF	Seq SS	Adj SS	Adj MS	*F*	*P*
Size class	3	36.0455	1.5628	0.5209	1.72	0.165
Edge distance (meters)	1	17.2215	2.6909	2.6909	8.88	0.003
Edge distance Sq (meter sq)	1	9.0573	0.0732	0.0732	0.24	0.624
Size class * edge dist (meters)	3	2.2111	7.5417	2.5139	8.29	0.000
Size class * edge dist Sq (meters sq)	3	10.3587	10.3587	3.4529	11.39	0.000
Error	168	50.9350	50.9350	0.3032		
Total	179	125.8292				

S = 0.550622; R-Sq = 59.52%; R-Sq (adjusted) = 56.87%.

Table 4b – Generalized linear model based on first principal component score and four village size classes predicting forest habitat disturbance in Bhadra Wildlife Sanctuary

	Quadratic function			
Term	Coefficient	SE coefficient	*T*	*P*
Constant	2.3295	0.1201	19.39	0.000
Edge distance (m)	−1.4758	0.4954	−2.98	0.003
Edge distance squared	0.2198	0.4472	0.49	0.624
Edge distance (m) * village class				
1	−2.6995	0.9114	−2.96	0.003
2	−2.0468	0.6567	−3.12	0.002
3	1.5108	0.7475	2.02	0.045
Edge distance squared * village class				
1	2.5166	0.8826	2.85	0.005
2	2.0743	0.5313	3.90	0.000
3	−1.6050	0.6694	−2.40	0.018

limits on the area such that the average disturbance in the area was greater than 2. In BWS, the six villages intensively used an average area of 23.7 km^2 of the reserve (Table 5). For the smaller villages disturbance decreased sharply and hence we expect the spatial extent of forest disturbance will be restricted for Karvani, Kesave and Muthodi villages. However, for the larger villages, the steep declines in disturbance did not occur in the 1 km transect. Therefore, in addition to the 23.7 km^2 of intensive use, we expect additional usage and more extensive disturbance impact for the medium and large villages. In BWS, the total disturbed area around the six villages was expected to be between 17 and 29 km^2 in addition to the spatial extent of the villages themselves (Table 5). The total area (spatial extent and estimated disturbance area) of forest impacted around the six focal villages in BWS was estimated to be 41–52 km^2 (average 46.63 km^2, Table 5). We estimated that at least 8–10% of the park was intensely affected by human activities of these six villages within the park.

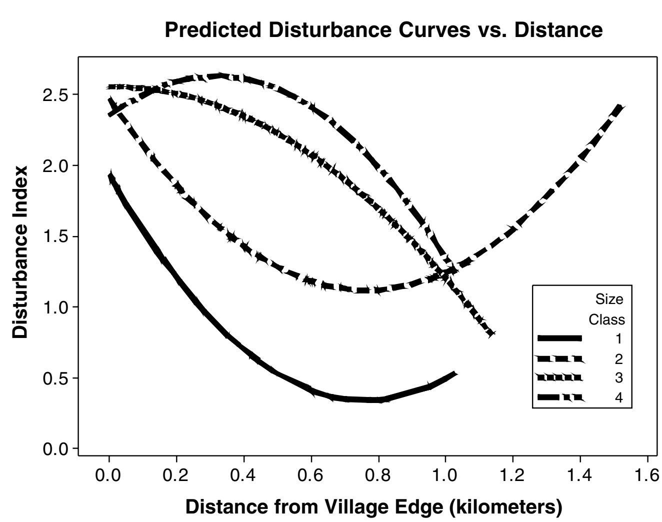


Fig. 5 – Predicted forest disturbance based on generalized linear model for four village size classes. The generalized linear model indicates that village size class and quadratic functions of distance, along with the interactions between distance and village size class are significant predictors of the principle components disturbance index (Table 4a). Residual analysis indicates that this model fits a quadratic curve within each village class size (Table 4b). Other measures of village usage (e.g. heads of cattle, firewood bundles and non-timber forest products collected) were also modeled, but all were cross-correlated with village size. The numbers 1–4 represent village size classes for the six focal villages.

Table 5 – Estimated forest disturbance around six villages in Bhadra Wildlife Sanctuary (km^2)

Study villages	# Of households	Village spatial extent in km^2	Average area disturbance >2	Minimum area disturbance >2	Maximum area disturbance >2	Estimated total area in km^2
Karvani	15	1.62	0.00	0.00	0.20	1.62
Kesave	26	2.01	0.80	0.00	1.40	2.81
Muthodi	29	1.30	0.60	0.00	1.20	1.90
Hebbe	60	5.41	6.40	4.90	7.60	11.81
Hipla	62	4.77	6.10	4.70	7.20	10.87
Madla	127	7.82	9.80	7.90	11.30	17.62
Total	319	22.93	23.70	17.50	28.90	46.63

Note: a disturbance level of 2 was used as a threshold to indicate medium to high disturbance. This was the estimated area around a village such that the average disturbance in the area was >2. The minimum and maximum are 95% limits on the area such that the average disturbance in the area was >2.

4. Discussion

Three major factors appeared to influence forest disturbance around each village in BWS: village size (# households), distance from village and proximity to other villages. Smaller villages had declines in disturbance beginning at $\leqslant$400 m, resulting in a smaller spatial extent of forest disturbance around them compared to larger villages. Medium and the large village had higher disturbance levels with declines in disturbance beginning $\geqslant$800 m. Additionally, overlap regions (areas accessible to two or more villages) had higher disturbance levels. High correlations among the variables required the use of PCA to develop an effective habitat disturbance index. We developed a preliminary assessment of forest disturbance around the six selected villages in BWS.

Fuel wood and NTFPs were major natural subsidies for these village households. Their availability, unrestricted access, ease of extraction and in some cases market prices rendered them vulnerable to over exploitation. The social survey identified some of the species directly affected by human livelihood activities in BWS. The ecological survey provided evidence about the nature and extent of damage to the forest that surrounded these villages. Extensive grazing of livestock can be expected to have affected the quality of palatable forage available to wild herbivores and increased soil compaction especially along human and cattle trails. Human activities in the park probably have had serious affects on survival, regeneration and recruitment of above mentioned species and several others that remain undocumented. Estimates from this study provide an initial step towards facilitating regeneration and recovery efforts targeted at specific locations within the reserve and towards specific species.

A concurrent development in BWS was a voluntary village relocation program implemented during 2001–2003 that resulted in 11 of the 13 villages leaving the park (Karanth, in review). The results from the ecological and social surveys will allow park officials to focus in recovery and regeneration efforts on a ca. 46 km^2 area around those villages. Our study indicated that forest disturbance effects were related to village size, with smaller villages having relatively restricted forest disturbance areas compared to larger villages. For larger villages, the chosen transect length of 1 km was unable to capture all disturbance around the villages and forest use impacts continued beyond this distance (personal observation, Karanth, 2002). All of these villages were located in low lying areas of the park and were often in close proximity to rivers and streams (Figs. 1 and 2). The vegetation types surrounding these villages were similar: moist and dry deciduous forests and bamboo forests (Figs. 1 and 2). Therefore, we could expect such alterations of natural habitats to affect terrestrial species that live in these habitats.

Our approach uses information gathered from social and ecological surveys to gain a more comprehensive understanding about effects that human livelihood activities have on forests. Examining human induced ecological disturbance in PAs that have forest-dependent agrarian communities living in them (Asia and Africa), as well as extractive and indigenous reserves (South America) is important for long term conservation. Disturbance indices can be developed relatively easily by using region or site-specific ecological indicators, wildlife species and signs of human natural resource use. This study highlighted the importance of estimating the intensity and spatial extent of anthropogenic disturbance before we attempt to improve ecosystem recovery or restore ecological dynamics. Moreover, these spatial effects and landscape level changes can be incorporated into remote sensing analyses and long-term management plans to monitor changes in the size and intensity of human disturbance or habitat degradation. In many cases such as the one presented here, we anticipate that such impacts from subsistence economies to be highly concentrated in both time and space. To protect and maintain biological diversity in regions that also support village communities and their livelihood needs, we need to obtain accurate estimates of the spatial extent of human ecological impacts so that we can focus and improve efficiency of park management efforts.

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REFERENCES

Agrawal, A., Gibson, C., 1999. Enchantment and disenchantment: the role of community in natural resource conservation. World Development 27, 629–649.

Brandon, K., 1998. Comparing Cases: a review of findings. In: Brandon, K., Redford, K.H., Sanderson, S.E. (Eds.), Parks in Peril: People, Politics, and Protected Areas. Island Press, Washington, DC, pp. 375–414.

Brashares, J.S., Arcese, P., Sam, M.K., 2001. Human demography and reserve size predict wildlife extinction in West Africa. Proc. R. Soc. Lond 268, 2473–2478.

Brechin, S.R., Wilshusen, P., Fortwangler, C.L., West, P.C., 2002. Beyond the square wheel: toward a more comprehensive understanding of biodiversity conservation as a social and political process. Soc. Nat. Resources 15, 41–64.

Colchester, M., 2004. Conservation policy and indigenous peoples. Environ. Sci. Policy 7, 145–153.

Ferraro, P.J., 2002. The local costs of establishing protected areas in low-income nations: Ranomafana National Park, Madagascar. Ecol. Economics 43, 261–275.

Gadgil, M., Guha, R., 1992. This Fissured Land. An Ecological History of India. Oxford University Press, New Delhi.

Karanth, K. Voluntary village relocation in Bhadra Wildlife Sanctuary: Addressing People's Needs. Economic and Political Weekly, in review.

Karanth, K.K., 2003. Forest use and human-wildlife conflicts in Bhadra Wildlife Sanctuary, India. Tropical Resources Bull. 22, 48–58. Yale University.

Karanth, K.U., 1982. Bhadra wildlife sanctuary and its endangered ecosystem. J. Bombay Nat. History 79, 79–86.

Karanth, K.U., 2002. Nagarahole: limits and opportunities in wildlife conservation. In: Terborgh, J., van Schiak, C., Davenport, L., Rao, M. (Eds.), Making Parks Work: Strategies for Preserving Tropical Nature. Island Press, Washington, DC, pp. 189–202.

Kothari, A., Suri, S., Singh, N., 1995. People and protected areas: rethinking conservation in India. Ecologist 25, 188–194.

Kothari, A., Pande, P., Singh, S., Variava, D., 1989. Management of National Parks and Sanctuaries in India: A Status Report. Indian Institute of Public Administration, New Delhi.

Liu, J., Daily, G.C., Erhlich, P., Luck, G.W., 2003. Effects of household dynamics on resource consumption and biodiversity. Nature 421, 530–533.

Madhusudan, M.D., Mishra, C., 2003. Why big, fierce animals are threatened: conserving large mammals in densely populated landscapes. In: Saberwal, V., Rangarajan, M. (Eds.), Battles Over Nature: Science and Politics of Conservation. Permanent Black, New Delhi, pp. 31–55.

Middleton, B., 2003. Ecology and objective based management: case study of the Keoladeo National Park, Bharatpur, Rajasthan. In: Saberwal, V., Rangarajan, M. (Eds.), Battles Over Nature: Science and Politics of Conservation. Permanent Black, New Delhi, pp. 86–116.

Müller, D., Zeller, M., 2002. Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. Agricul. Economics 27, 333–354.

Murali, K.S., Shankar, U., Uma Shanker, R., Ganeshaiah, K.N., Bawa, K.S., 1996. Extraction of non-timber forest products in the forests of Biligiri Rangan Hills, India. 2. Impact of NTFP extraction on regeneration, population structure, and species composition. Economic Botany 50, 252–269.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Nepstad, D., McGrath, D., Alencar, A., Barros, A.C., Carvalho, G., Santill, M., Diaz, M.delC.V., 2002. Frontier governance in Amazonia. Science 295, 629–630.

Neumann, R.P., 1998. Conservation versus custom: state seizure of natural resource control. In: Neumann, R.P. (Ed.), Imposing Wilderness: Struggles over Livelihood and Nature Preservation in Africa. University of California Press, Berkeley, pp. 97–121.

Oates, J.F., 2002. West Africa:tropical forests on the brink. In: Terborgh, J., van Schiak, C., Davenport, L., Rao, M. (Eds.), Making Parks Work: Strategies for Preserving Tropical Nature. Island Press, Washington, DC, pp. 57–75.

Peh, K.S.H., Jong, J.de, Sodhi, N.S., Lim, S.L.H., Yap, C.A.M., 2005. Lowland rainforest avifauna and human disturbance: persistence of primary forest birds in selectively logged forests and mixed-rural habitats of southern peninsular Malaysia. Biol. Conserv. 123, 489–505.

Peres, C.A., 2002. Expanding conservation area networks in the last wilderness frontiers: the case of Brazilian Amazonia. In: Terborgh, J., van Schiak, C., Davenport, L., Rao, M. (Eds.), Making Parks Work: Strategies for Preserving Tropical Nature. Island Press, Washington, DC, pp. 137–148.

Rahmani, A., 2003. Conservation outside protected areas. In: Saberwal, V., Rangarajan, M. (Eds.), Battles Over Nature: Science and Politics of Conservation. Permanent Black, New Delhi, pp. 117–138.

Redford, K.H., Sanderson, S.E., 2000. Extracting humans from nature. Conserv. Biol. 14, 1368–1370.

Robinson, J.G., 1993. The limits to caring: sustainable living and the loss of biodiversity. Conserv. Biol. 7, 20–28.

Rodgers, A., Hartley, D., Bashir, S., 2003. Community approaches to conservation: some comparisons from Africa and India. In: Saberwal, V., Rangarajan, M. (Eds.), Battles Over Nature: Science and Politics of Conservation. Permanent Black, New Delhi, pp. 324–382.

Salafsky, N., Wollenberg, L., 2000. Linking livelihoods and conservation: a conceptual framework for assessing the integration of human needs and biodiversity. World Development 28, 1421–1438.

Sanderson, E.W., Jaiteh, M., Levy, M.A., Redford, K.H., Wannebo, A.V., Woolmer, G., 2002. The human footprint and the last of the wild. BioScience 52, 891–904.

Schwartzman, S., Moreira, A., Nepstad, D., 2000a. Rethinking tropical forest conservation: perils in parks. Conserv. Biol. 14, 1351–1357.

Schwartzman, S., Moreira, A., Nepstad, D., 2000b. Arguing tropical forest conservation: people versus parks. Conserv. Biol. 14, 1371–1374.

Sekhar, N.U., 1998. Crop and livestock depredation caused by wild animals in protected areas: the case of Sariska Tiger Reserve, Rajasthan, India. Environ. Conserv. 25, 160–171.

Somanathan, H., Borges, R.M., 2000. Influence of exploitation on population structure, plant spacing and reproductive success in dioecious tree species within a fragmented cloud forest in India. Biol. Conserv. 94, 243–256.

Terborgh, J., 2002. Overcoming impediments to conservation. In: Terborgh, J., van Schiak, C., Davenport, L., Rao, M. (Eds.), Making Parks Work: Strategies for Preserving Tropical Nature. Island Press, Washington, DC, pp. 243–249.

Tutin, C.E.G., 2002. Parks in the Congo Basin: can conservation and development be reconciled? In: Terborgh, J., van Schiak, C., Davenport, L., Rao, M. (Eds.), Making Parks Work: Strategies for Preserving Tropical Nature. Island Press, Washington, DC, pp. 76–85.

Wilshusen, P., Brechin, S.R., Fortwangler, C., West, P.C., 2002. Reinventing a square wheel: critique of a resurgent protection paradigm in international biodiversity conservation. Soc. Nat. Resources 15, 17–40.