Measuring and Mapping Threats to a Wildlife Sanctuary in Southern India

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Measuring and Mapping Threats to a Wildlife Sanctuary in Southern India

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Abstract: *Although conservation and management of tropical ecosystems requires that we understand the threats to these areas, there are no standardized methods to quantify threats to ecosystems. We used a geographic information system-based protocol with several physical and socioeconomic attributes to assess the threats to a protected area, a wildlife sanctuary in southern India. Physical attributes included threats from major and minor roads and the accessibility of an area (given as inverse of the slope of the area), and socioeconomic attributes included the number of human settlements and human, cattle, and sheep populations. We divided the sanctuary into 30-ha grids, and for each grid we computed three threat categories: (1) settlement-associated threat from humans, cattle, and sheep; (2) development-associated threat resulting from major and minor roads; and (3) accessibility-related threat caused by the steepness of the terrain. Combining all three threats, we derived a composite threat index for each grid and mapped five levels of threats in the sanctuary. We collected data on human activities, tree species richness, and diversity in the transects laid in areas corresponding to these five threat levels. Although the threat levels of the transects were strongly correlated with the human-related disturbance activities, the composite threat indices of the transects were negatively correlated with tree species richness, indicating that the threat values we derived served as a good surrogate of the actual threat experienced by the sanctuary. With appropriate modifications, the protocol developed here can be applied to other ecosystems as well.*

Key Words: Biligiri Rangaswamy Temple Sanctuary, disturbance index, threat map, Western Ghats

Medición y Mapeo de Amenazas a un Santuario de Vida Silvestre en el Sur de India

Resumen: *La conservación y manejo de ecosistemas tropicales requiere que entendamos las amenazas a esas áreas. Sin embargo, no hay métodos estandarizados para cuantificar las amenazas a los ecosistemas. Utilizamos un protocolo basado en SIG con varios atributos físicos y socioeconómicos para evaluar las amenazas a un área protegida, un santuario de vida silvestre en el sur de India. Los atributos físicos incluyeron amenazas de caminos mayores y menores y accesibilidad de un área (como el inverso de la pendiente del área), y los atributos socioeconómicos incluyeron el número de asentamientos humanos y las poblaciones humanas, de ganado y ovejas. Dividimos al santuario en parcelas de 30 ha, y en cada parcela computamos tres categorías de amenaza: (1) amenaza de humanos, ganado y ovejas asociada con asentamientos, (2) amenaza asociada con desarrollo debido a caminos mayores y menores y (3) amenaza relacionada con accesibilidad debido a la pendiente del terreno. Combinando las tres amenazas, derivamos un índice compuesto de amenaza para cada parcela y mapeamos cinco niveles de amenaza en el santuario. Recolectamos datos sobre actividades humanas, riqueza y diversidad de especies de aves en los transectos ubicados en*

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áreas correspondientes a estos cinco niveles de amenaza. Aunque los niveles de amenaza en los transectos estuvieron fuertemente correlacionados con actividades de perturbación humana, los índices compuestos de amenaza estuvieron correlacionados negativamente con la riqueza de especies de árboles lo que indica que los valores de amenaza que derivamos fueron buen sustituto de la amenazas que hay en el santuario. Con las modificaciones apropiadas, el protocolo desarrollado puede ser aplicado en otros ecosistemas.

Palabras Clave: Ghats Occidentales, índice de perturbación, mapa de amenazas, Santuario Templo Biligiri Rangaswamy

Introduction

In southern Asia, as in many other parts of the tropics, increasing demand by human populations has greatly threatened the forests and the resources associated with them (Lugo 1995; Hegde et al. 1996; Murali et al. 1996). For instance, between 1990 and 2000, the largest percent decrease in forest area occurred in Africa, South America, and Asia (Food and Agricultural Organization [FAO] 2001). In India alone it is estimated that approximately 50 million people depend directly on the forests for their livelihood (Hegde et al. 1996). It is feared that continuing dependence on the forest could lead to a substantial loss of forest area in the country. Partly to rein in such loss and to insulate forest from human pressures, protected areas (PAs) have been established worldwide. Despite the establishment of the legislative PA network, more than 99% of the world's protected areas may be experiencing serious threats. The most severe threats to PAs are poaching, encroachment, agriculture, ranching, urban development, illegal and legal logging, and collection of nontimber forest products (World Bank 1999; World Wide Fund for Nature [WWF] 2004). In India there are 533 PAs of various sizes (median, 200 km^2; mean, 430 km^2) covering 5.2% of land area. Sixty-five percent of these PAs are inhabited by indigenous communities (Kothari et al. 1989) that depend almost exclusively on PAs for their livelihood.

Unless urgent attempts are made to reduce the threats, protected areas will succumb to increasing human pressures. Unfortunately most of the threats arising from anthropogenic activities in the protected areas are not easily quantifiable because they are very dynamic and heterogeneous. Effective conservation of protected areas, however, demands that we evaluate the threats and accordingly formulate appropriate management plans to mitigate them (Lugo 1995). There are hardly any standardized methodologies to evaluate the threats that protected areas face. We propose a protocol for assessing and mapping threats for a protected area, a wildlife sanctuary, in southern India. We devised a composite threat index that combines several physical and socioeconomic attributes and developed threat maps of the protected area. The threat index and the map reflect several empirical measures of disturbance and loss of biodiversity occurring in the protected area. Such assessment and mapping of threats could offer a valuable tool with which to manage threats and mitigate forest loss in protected areas.

Methods

Study Site

The Biligiri Rangaswamy Temple (BRT) Wildlife Sanctuary (540 km^2, 77°–77°16′ E and 11° 47′–12°09′N) is in Karnataka in southern India (Fig. 1). A wide range of climatic and elevational variations within the BRT sanctuary have resulted in a highly heterogeneous landscape with various vegetation types: scrub, moist and dry deciduous forest, riparian areas, evergreen forest, *sholas,* and grasslands (Ramesh 1989; Ganeshaiah & Uma Shaanker 1998; Murali et al. 1998*a,* 1998*b*). The sanctuary has a highly undulating terrain with flatter areas in the periphery. About 6000 indigenous people, *Soligas*, live in 57 settlements in and around the sanctuary. Because of the high density of large and charismatic mammals, this area was declared a wildlife sanctuary in 1973. Consequently, the relatively nomadic tribal people were allotted land for cultivation (*Podus*) within the sanctuary. These people also depend on the forest for a variety of nontimber forest products (NTFPs). About 60% of their total cash income is derived from forest products. The communities supplement their cash income with daily wages made by working in coffee plantations located inside the sanctuary (Hegde et. al. 1996). Details of the sanctuary's biogeography, history, management regime, and ecology are given elsewhere (Ganeshaiah & Uma Shaanker 1999; Aravind et al. 2001; Krishnaswamy et al. 2004).

Identifying Threats to the Sanctuary

Among various threats to the sanctuary, we identified three broad categories that are likely to affect the structure, diversity, and health of the forest. "Settlement-related threats" (agriculture, dependence on forest products, and grazing) include farming by Soligas; small and large coffee plantations owned by Soligas and others, with the associated human activities; human settlements in the forest; harvesting of NTFPs; collection of fuel wood; and grazing by sheep and cattle owned by the residents living in and around the sanctuary (Murali et al. 1996). There

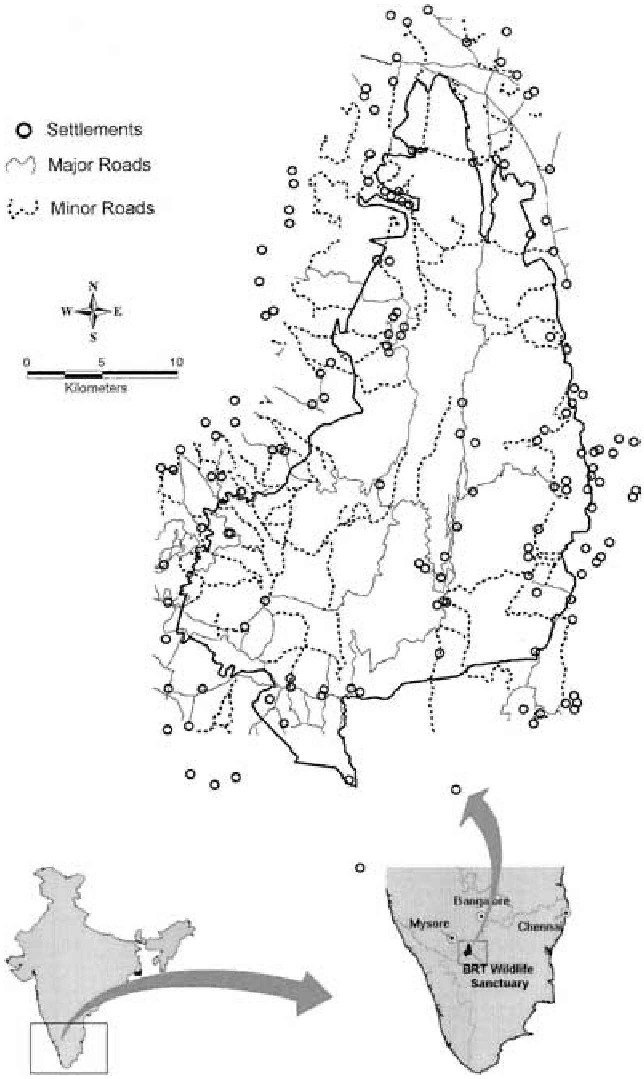

Figure 1. Location of settlements and major and minor roads in Biligiri Rangaswamy Temple (BRT) Wildlife Sanctuary. Inset shows the location of BRT in India.

is a high level of grazing within the sanctuary limits, especially in the peripheral flat areas. "Topography-related threats" influence the accessibility of the areas for harvesting and grazing (Ganeshaiah 1998). The landscape of the sanctuary is undulating and hence has a varied terrain. Harvesting of fuel wood and other immediate needs of the people are met within a radius of 3 km around settlements (K.N.G., personal observation), although the NTFPs are likely to be harvested from areas beyond this radius. Even grazing by sheep and cattle is limited to a radius of 3 km around the settlements (Murali et al. 1996). "Development-related threats" include the wide network of major and minor roads that crisscross the sanctuary, facilitating harvesting, grazing, and occasional poaching by the people (Menon & Bawa 1997).

We considered components of the three threat categories important to varying degrees and incorporated them accordingly in the calculation of the threat values. Even though agriculture substantially alters the structure of the forest, we did not delineate its effect from that of settlements for two reasons. First, farming is restricted to the areas around the settlements (Murali et al. 1998*b*; Ganeshaiah et al. 2000); hence, the threat value computed using the settlements effectively captures the impact of agriculture as well. Second, legally, the agricultural land is not owned by the residents. In this sense the farming area is temporally and spatially dynamic, although it is always concentrated around settlements. Therefore, it was easier to use settlements as a surrogate for farming.

Computation of Threat Values

We digitized the BRT wildlife sanctuary boundary from Survey of India toposheets (scale 1:50,000) and divided the sanctuary into 2294 grids of 30 ha ($\sim$550 $\times$550 m). A 30-ha grid was used as basic unit of analysis because it corresponds to the working and management grid size being followed by the forest department. Based on the field survey and topographic maps, we mapped all the settlements within BRT sanctuary and within a 3-km buffer zone around the sanctuary. To each settlement point on the geographic information system (GIS) layer, we overlaid the data on human, cattle, and sheep populations. We obtained digital maps of the four different vegetation types from Menon and Bawa (1997) and overlaid them on the 30-ha grid map of the sanctuary.

SETTLEMENT-RELATED THREATS

We assumed that the threat on a grid increases with densities of human, cattle, and sheep in and around that grid. Our earlier work shows that the intensity of NTFP harvesting decreases with distance from the settlements. This is because the opportunity cost of harvesting increases as a person moves away from the settlements. Further, we also found that normalized difference vegetation index (NDVI), an index of greenness (and of forest cover) increases asymptotically with the distance from the settlement (Ganeshaiah & Uma Shaanker 1999). Therefore, we assumed that threat decreases inversely with distance between the settlement and the grid, and in this sense we are replacing space (distance) for time sensu Pickett (1989). We computed three components of settlement-related threats as follows:

$$\text{threat from humans} = \sum_{i=1}^{n} P_i/D_i,$$

$$\text{threat from cattle grazing} = \sum_{i=1}^{n} C_i/D_i, \text{ and}$$

$$\text{threat from sheep grazing} = \sum_{i=1}^{n} S_i/D_i,$$

where n is the number of settlements within a radius of 3 km around the grid; P_i, C_i, and S_i are the human, cattle, and sheep populations, respectively, in the i^{th} settlement; and D_i is the distance of the i^{th} settlement from the grid. Because settlements were polygons, the center of the grid seldom coincided with the center of the settlement; thus, D_i was never zero. These three threat components were independently normalized by dividing the values of all grids by the maximum value within each component and then averaging the normalized values to arrive at disturbance index 1 (D1).

TOPOGRAPHY-RELATED THREATS

Based on interviews and our personal observations during harvesting of NTFPs by residents, we found that harvesters more frequently use forests with a flat terrain because of the relative ease of accessibility. We therefore used slope as a surrogate for accessibility and computed the threat value of that area. We computed two categories of slopes: (1) point slope, the slope of the focal grid; and (2) approach slope, the average of slopes of the eight grids surrounding the focal grid. These two slope values were separately normalized by computing the ratio of the minimum among all the grid slopes to the slope value of the grid and subsequently averaging this ratio for each grid to represent disturbance index 2 (D2).

DEVELOPMENT-RELATED THREATS

The sanctuary is crisscrossed with roads that connect settlements in the periphery and those within the sanctuary, the Karnataka Forest Department's (KFD) establishments, and game roads (Menon & Bawa 1997). Roads are of two types, major roads (metaled or tarred roads) and minor roads (unmetaled roads connecting major roads and foot paths). We digitized these roads and identified their numbers within a radius of 3 km around each grid (Fig. 1). Threat values resulting from roads were computed as follows:

$$\text{threat from minor roads, dm} = \sum_{i=1}^{I} 1/\text{dm}_i \text{ and}$$

$$\text{threat from major roads, dM} = \sum_{i=1}^{N} 1/\text{dM}_i,$$

where dm_i is distance from the grid to the ith minor road, dM_i is distance from the grid to the ith major road, and I and N are numbers of minor and major roads within a 3-km radius around the grid. The values thus computed (dm and dM) were normalized by dividing them by the maximum value within each category. We assumed that major roads offered more access to the forest than minor roads. Therefore, disturbance index 3 (D3) was computed as

$$\text{D3} = (2 * \text{dM} + \text{dm})/2.$$

COMPOSITE THREAT INDEX

Among the three disturbance indices, the human-settlement related threat (D1) is the most detrimental, followed by the slope factor, and then the developmental factor. The roads considered for D3 often offered protection in extinguishing fire, preventing illegal poaching, and facilitating routine patrolling for the forest guards. Thus, their contribution to the total threat was considered relatively less and weighted less. Accordingly, the composite threat index (CTI) was derived as

$$\text{CTI} = (3\text{D1} + 2\text{D2} + \text{D3})/3.$$

Mapping and Evaluating the Threat Index

We classified the values of CTI and its three components into five threat levels each and developed thematic maps for these threat levels (Fig. 2). The five threat levels of CTI are hereafter referred to as T1 through T5 in decreasing order of threat to the grids. Whether or not these maps represent the threat was evaluated in two different ways: evaluation with each vegetation type and evaluation within the entire sanctuary.

The BRT sanctuary has four major vegetation types: evergreen, moist deciduous, dry deciduous, and scrub forest. Because the impact of the threats and the threat-related activities could be different in each of these vegetation types, we evaluated the relationship between CTI and other disturbance parameters and the impact of threats on the tree species diversity separately for each vegetation type. We overlaid the thematic map of CTI with the vegetation types. Within each vegetation type, we identified the areas of T1 to T5 and laid two transects of 600 × 20 m within each threat level. Thus, we laid a total of 10 transects in each vegetation type. Within each transect, we collected data on cut and broken stems and number of dung pads. Cut and broken stems are good indicators of disturbance in BRT (Murali et al. 1996; Ganeshaiah et al. 1998). The data on number of cut and broken stems was expressed as a proportion of the total stems, and the number of dung pads was normalized with respect to the maximum in any one transect. From the cut and broken stems and dung pad data, we computed the average of the cut and broken stems and the normalized dung value (ACBD) for each transect. We also recorded a set of human-related disturbance activities in each transect, assigned weightings based on intensity of the activity, and then computed total disturbance activity index. Table 1 provides the details of activities and the weightings assigned for each activity.

For each transect we recorded tree species and number of individuals with >10 cm diameter at breast height and computed species richness and Shannon diversity index following Magurran (1988). Latitude and longitude for each transect in different vegetation types were taken with a Scout Master GPS (Trimble, Sunnydale, California) in acculock mode and then superimposed on the 30-ha

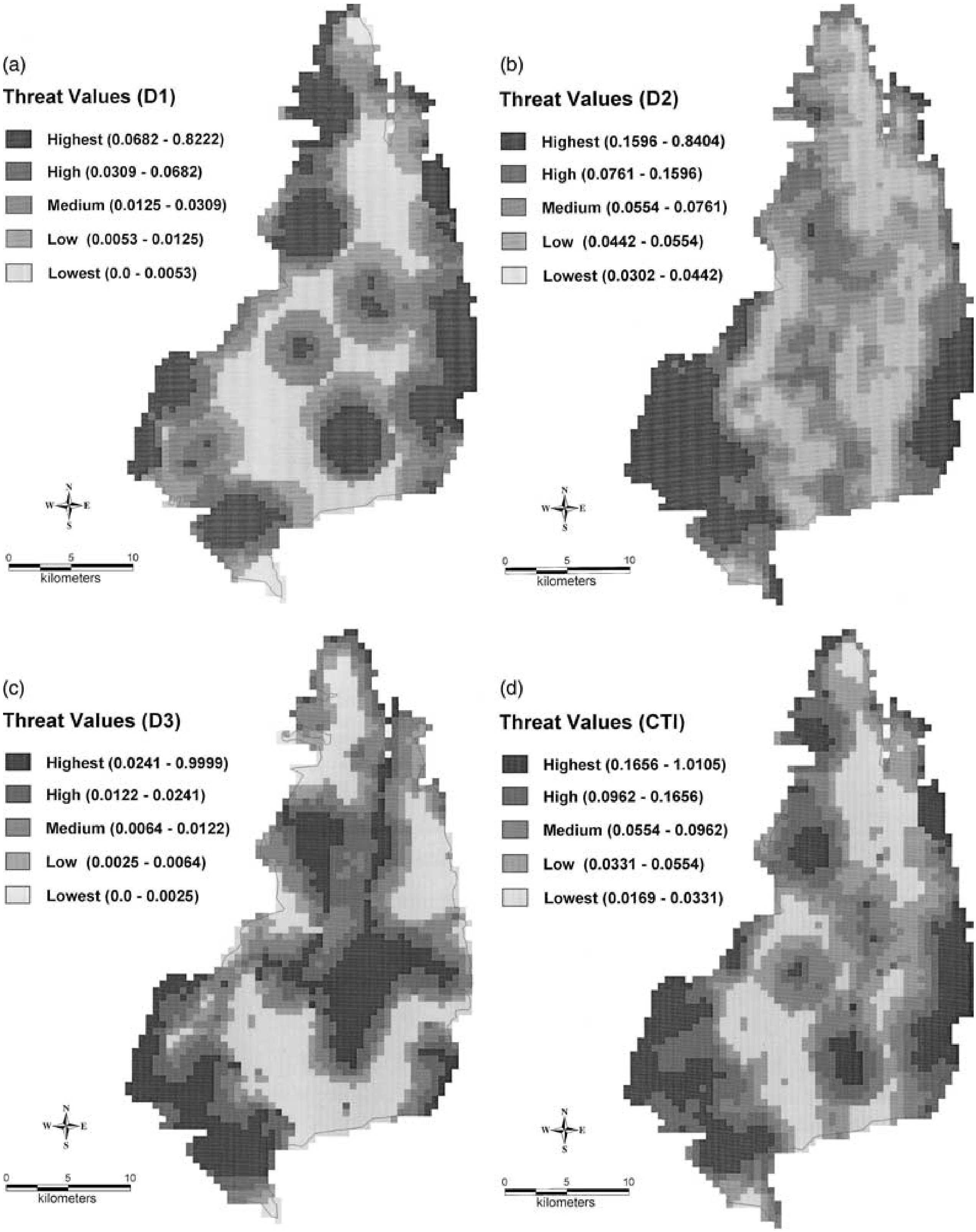

Figure 2. Threat maps of the Biligiri Rangaswamy Temple (BRT) Wildlife Sanctuary depicting the three threat indices: (a) D1, the disturbance induced by the settlement-related activities; (b) D2, topography-related access to the grids and the consequent threats; (c) D3, development-related threats; and (d) composite threat index values. The five categories in each map refer to the five qualitative levels of threat identified. The five threat levels corresponding to composite threat index were used in the study for identifying the transects.

Table 1. Disturbance activities in the transects laid in areas of a wildlife sanctuary with different threat levels[a] (qualitative levels T1–T5; Fig. 2) and of different vegetation types.

	Vegetation type																				
	evergreen					*moist deciduous*					*dry deciduous*					*scrub jungle*					*Weight assigned*
Disturbance	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	T1	T2	T3	T4	T5	
Agriculture	+	−	−	−	−	+	−	−	−	−	+	−	−	−	−	+	−	−	−	−	3
NTFP collection	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	2
Grazing	+	+	−	−	−	+	+	+	−	−	+	+	+	−	−	+	+	+	−	−	2
Fire	+	−	+	−	−	+	+	+	+	−	+	−	+	+	+	+	−	−	−	−	2
Wood for house construction	−	+	+	−	−	−	+	+	−	−	−	+	+	+	+	−	+	+	+	+	2
Firewood collection	+	+	−	−	−	+	+	+	−	−	+	+	+	−	−	+	+	+	−	−	2
Hunting	−	+	+	?	?	−	+	?	?	?	−	+	+	?	?	−	+	+	+	+	1
Invasive weeds[b]	+	+	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	2
Total disturbance activity index[c]	13	11	7	2	2	13	14	11	6	4	13	12	14	8	6	13	12	12	8	8	

[a] *Threat levels (disturbance) correspond to the classes in Fig 2: T1 is the highest threat and T5 the lowest. Question mark (?) indicates data not available.*
[b] *Includes* Lantana *and* Eupatorium. *The intensity of invasion varies between disturbance levels and between vegetation types.*
[c] *Sum of the weights assigned to the activities in a threat level recorded in the transect.*

grids. Because the 600-m-long transects on the ground corresponded to more than one grid on the threat map, we computed the average of the composite threat indices of the grids corresponding to each transect and correlated these values with the tree species richness and diversity parameters of the transects.

Tree species richness values for about 134 points were available for entire sanctuary from earlier studies (Murali et al. 1998). From these data sets, we derived tree species richness for each grid of the threat map by a linear extrapolation technique in Vertical Mapper 3 (Northwood Geoscience Ltd., Nepan, Ontario, Canada). We then correlated these with the corresponding CTI values.

Results

Threat Values and Their Distribution in the Sanctuary

The distribution of the three threat indices (D1, D2, and D3) and the CTI values CTI were highly positively skewed (Fig. 3). Most parts of the sanctuary, then, were relatively safe, but a few of the grids were highly threatened. Among the three threat types, D3 (road-related threats) values were much more positively skewed than others, suggesting that the network of roads in BRT is sparse and causes relatively less threat than the other two categories. The human-settlement related threats (D1) appear to be more serious in the sanctuary because relatively more grids had higher values of D1 than of D2 and D3 (Fig. 3).

Highly threatened areas were located in the periphery (Fig. 2a-d). Nevertheless the central core area was also highly vulnerable because of the coffee plantations and associated human-induced disturbance. Further, human-induced threat was also high in the southeastern edge, where Tibetan refugees have established their settlements. The distribution pattern of the CTI in the sanctuary was not affected by the fact that the D1, D2, and D3 were weighed differently. The spatial pattern did not change when the CTI values computed by giving equal weights for the three threat types were mapped. The D1 and D2 threat types showed similar patterns of distribution in the sanctuary and were strongly correlated with CTI in all the vegetation types and in the entire sanctuary (Table 2).

The threat resulting from human settlements (D1) was significantly positively correlated with slope-related threats (D2; $r = 0.472$, $p < 0.01$) and development-related threats (D3; $r = 0.246$, $p < 0.01$). Slope-related threat (D2) was also significantly positively correlated with development-related threats (D3; $r = 0.319$, $p<$

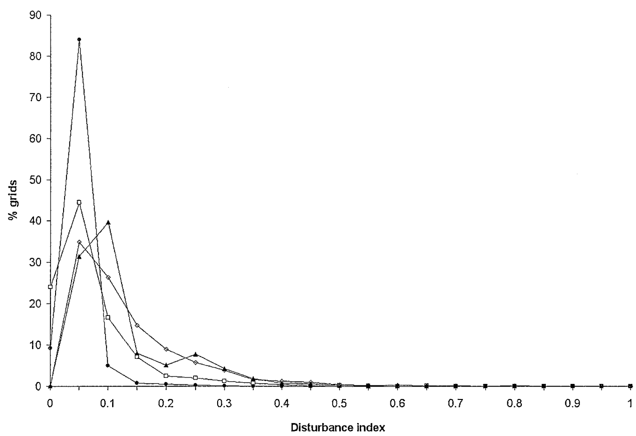

Figure 3. Frequency distribution of the three threat indices (open squares, settlement-related threat, D1; closed triangles, topography-related threat, D2; closed circles, development-related threat, D3) and of the composite threat index (CTI, open diamond) for the entire sanctuary.

Table 2. Association (Spearman's rank correlation) among the three threat indices (D1, D2, and D3), the composite threat index (CTI), and the tree species richness of the grids for different vegetation types and for the entire sanctuary.[a]

Threat category[b]	*Area*	*D1*	*D2*	*D3*	*CTI*	*SR*	n
D1	entire sanctuary	1.000	0.472**	0.246**	0.875**	−0.271**	2294
	scrub jungle	1.000	0.295**	0.038	0.823**	−0.189**	606
	dry deciduous	1.000	0.184**	0.415**	0.734**	−0.243**	371
	moist deciduous	1.000	0.495**	0.466**	0.879**	−0.043	633
	evergreen	1.000	0.116**	0.167**	0.877**	0.237**	568
D2	entire sanctuary		1.000	0.319**	0.767**	−0.392**	2294
	scrub jungle		1.000	0.571**	0.702**	−0.049	606
	dry deciduous		1.000	0.267**	0.753**	−0.178**	371
	moist deciduous		1.000	0.390**	0.752**	0.118**	633
	evergreen		1.000	0.102	0.381**	0.042	568
D3	entire sanctuary			1.000	0.401**	0.113*	2294
	scrub jungle			1.000	0.356**	−0.081*	606
	dry deciduous			1.000	0.436**	−0.313**	371
	moist deciduous			1.000	0.627**	0.157**	633
	evergreen			1.000	0.393**	0.504**	568
CTI	entire sanctuary				1.000	−0.337**	2294
	scrub jungle				1.000	−0.151**	606
	dry deciduous				1.000	−0.299**	371
	moist deciduous				1.000	−0.002	633
	evergreen				1.000	0.323**	568

[a]*Probability:* *<0.05, ** <0.01.
[b]*Definitions: D1, settlement-related threat; D2, grazing-related threat; D3, topography-related threat. CTI is a composite threat index derived from D1, D2, and D3.*

0.01; Table 2). The correlations among the three threat types were similar in all three vegetation types and in the entire sanctuary (Table 2).

Threat Levels, CTI, and Disturbance Activities

The average CTI values of grids corresponding to transects showed strong correlation with the proportion of cut and broken stems ($r = 0.634, p < 0.01$) and the number of dung pads ($r = 0.763, p < 0.01$) in the transects (Table 3). The disturbance activity index (DAI), a composite of a range of disturbance activities in the transects, increased significantly with the qualitative levels of threats (T5, low threat, to T1, high threat; Table 3) derived from CTI (Fig. 4; $r = -0.82; p < 0.05$). Thus, the threat indices derived reflect the real pressures to the sanctuary.

Threat Values and Tree Diversity

Tree diversity of an area was significantly affected by threats. Specific results supported this finding. First, all three types of threats and CTI were significantly negatively correlated with the tree species richness of the grids in all the vegetation types and also in the entire sanctuary except in moist deciduous forest (Table 2). Second, the average composite threat index (ACTI) of the grids corresponding to the transects was weakly negatively correlated with tree species richness ($r = -0.429, p = 0.059$; Table 3). Third, tree species richness and Shannon diversity of transects were significantly negatively correlated with ACBD (species richness: $r = -0.76, p < 0.05$ and Shannon diversity: $r = -0.46, p < 0.05$; Table 3).

Discussion

We have outlined a methodology for identifying sensitive and threatened areas of a sanctuary. Based on several physical and socioeconomic parameters, and using GIS tools, we showed that threat maps can be developed that

Table 3. Association (Spearman's rank correlation) among the average composite threat index (ACTI) and disturbance parameters in the transects.

Attribute[a]	*CBP*	*ND*	*ACBD*	*ACTI*	*Tree species richness*	*Tree Shannon diversity*	n
CBP	1.000	0.893**	0.639**	0.641**	0.250	−0.05	20
ND		1.000	0.727**	0.762**	−0.440	−0.130	20
ACBD			1.000	0.742**	−0.760**	−0.460*	20
ACTI[b]				1.000	−0.429	−0.177	20

[a]*Disturbance parameters: CBP, proportion of cut and broken stems; ND, normalized dung pads; ACBD, average CBP and ND in the selected 20 transects. Probability:* *<0.05, **<0.01.
[b]*Average composite threat index of the grids.*

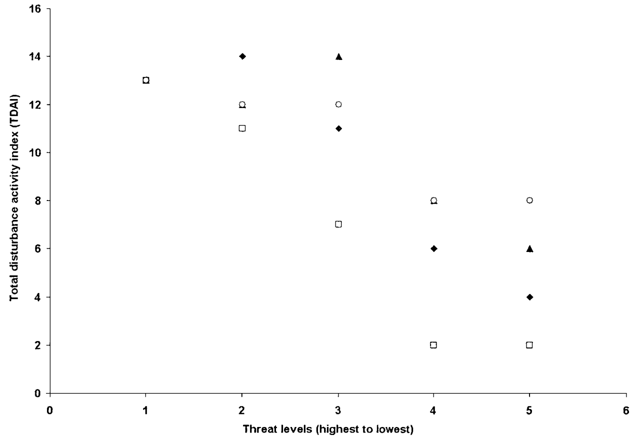

Figure 4. Relationship between threat levels (Table 1 and Fig. 2) and total disturbance activity index (TDAI; Table 1) of transects in the sanctuary. Points refer to transects from evergreen (open squares), moist deciduous (closed diamonds), dry deciduous (closed triangles), and scrub jungle (open circles).

represent the actual human-induced disturbance levels in the protected areas. At BRT sanctuary, threats were distributed along the edges of the sanctuary and in the core areas where the plantations are located. Along the periphery, the highly threatened areas were characterized by activities such as intensive farming, NTFP harvesting, grazing, and occurrence of invasive weeds. The existing roads did not seem to constitute severe threats.

In the core of the sanctuary, zones with plantations and relatively high human population densities were the most vulnerable. Because the plantations are located in the core, the resulting disturbance is more serious for the health of the sanctuary because plantations affect the continuity of important ecological activities such as pollination, dispersal, and animal movement.

The CTI values were negatively correlated with tree species richness in the entire sanctuary irrespective of the vegetation type (Table 2). Similarly, the average threat values of the transects were negatively correlated with their tree species richness. Thus, the human-induced threats within and around the sanctuary appear to have significantly affected the vegetation composition and structure. Such changes in forest composition and structure may result from farming; plantations, which fragment the forest; grazing; wood collection; and NTFP harvesting, which results in thinning of the forest. Together, these activities affect the regeneration of natural species, encourage invasion by weeds such as *Lantana camara* and *Chromolaena odorata (= Eupatorium odoratum)* in turn affecting forest structure and composition.

Based on the threat components identified, we suggest the following mitigation measures to maintain the health of the ecosystem of the BRT sanctuary.

(1) Do not extend the license period for plantations.
(2) Encourage forest dwellers who are willing to move and settle outside the sanctuary. As an alternative, encourage agroforestry such that the forest dwellers derive their needs from within their agroecosystems and reduce their dependence on the forest.
(3) Protect the flat areas located in the periphery of the sanctuary.
(4) Establish "invisible" barriers along the edges of the sanctuary in the form of stringent regulations that minimize the impact of villagers from outside the sanctuary and their activities in the forest. This can only be done by creating alternate sources for their needs and by educating them about the importance of the forest for their agriculture.
(5) Regulate the farming areas within the sanctuary to avoid the tragedy of commons syndrome (Hardin 1968).

Although the above suggestions are specific to the BRT wildlife sanctuary, our methodology is not location-specific and can be used for any protected area and other forest ecosystems. The protocol demands minimal groundwork and promises a cost-effective procedure for formulating strategies in tropical countries such as Africa, Southeast Asia, and Latin America, where resources are highly constrained. Development of such a threat map for any sanctuary would help identify mitigation strategies, as has been done for BRT wildlife sanctuary.

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