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Mammal indicator species for protected areas and managed forests in a landscape conservation area of northern India

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Abstract There is a realization that managed forests and other natural areas in the landscape matrix can and must make significant contributions to biodiversity conservation. Often, however, there are no consistent baseline vegetation or wildlife data for assessing the status of biodiversity elements across protected and managed areas for conservation planning, nor is there a rapid and efficient means to acquire those data. We used a unified vegetation classification and simple animal sampling design to describe the patterns of abundance of selected mammals as indicator, or characteristic, species in different vegetation types and protected areas vs. managed forest units in the Terai Conservation Area (TCA) in northern Uttar Pradesh state, India. We quantified the relative abundance of 15

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mammals of conservation concern from dung counts in vegetation sampling plots within 122 sample patches in 13 vegetation types and 4 management units. Assemblages of species differed both among vegetation types and among management units. Species assemblages in the two protected areas differed strongly from those in two managed forests. Grasslands in protected areas were the most species diverse among vegetation types and had several indicator species. Protected forests were dominated by chital *(Axis axis)* and nilgai *(Boselaphus tragocamelus)* in a second species group. A third species group in open grasslands and savannas in managed forests was characterized by cattle *(Bos taurus)* and Indian hare *(Lepus nigricollis).* Protected areas clearly are the core conservation area of the TCA for their relatively high habitat value and species diversity, and their protected status minimizes human disturbance. Impacts of human use are high in managed forests, indicating their compromised value for biodiversity conservation. Our simple assessment methodology gives managers a simple way to assess the status of important mammals across landscape conservation units.

Keywords Grasslands · India · Indicator species · Managed forests · Monitoring · Protected areas · Sal forest

Introduction

Large reserves and corridors in reserve networks long have been considered the keystone biodiversity conservation strategy (e.g., Noss and Harris 1986; Noss and Cooperrider 1994). Yet, there is the realization that managed forests and other semi-natural areas in the landscape matrix can and must make significant contributions to biodiversity conservation (Everett and Lehmkuhl 1996; Reid 1996; Salwasser et al. 1996; Sawarkar 2005; Franklin and Lindenmayer 2009). Several issues hinder the integration of protected areas and managed forests into a cohesive conservation unit (Everett and Lehmkuhl 1996; Sawarkar 2005). First, goals, objectives, and consequent practices may differ. Second, there often is no consistent baseline vegetation or wildlife data for assessing the status and contribution of biodiversity elements across allocations and the impacts of different management objectives: hence, no basis for effective conservation planning. Although coarse-filter approaches that conserve general vegetation communities or animal habitats are vital, fine-filter baseline data on species of concern are vital for effective conservation planning and management (Hunter et al. 1988; Haufler et al. 1996; Lambeck 1997; Lindenmayer et al. 2002). We address the second issue in this paper.

India has a well-established network of protected areas and managed forests that are managed by state forest departments under different administrative divisions in collaboration with the national Indian Forest Service. Forest reserves for sustainable extraction of wood and forage were established across India during the late 1800s and early 1900s, and the Indian Forest Service was established to develop a core of professional foresters (Saxena 2002). During the last half of the twentieth century an impressive network of protected areas as national parks and wildlife sanctuaries was carved from managed forest reserves, and that protected area network continues to grow (Rodgers et al. 2000). Currently, 21 % of India is classified as forested (FSI 2003), but only 24% of the forested land is in protected areas (MoEF 2008). Under the mandate of the Biological Diversity Act of 2002 foresters have begun to develop landscape-scale strategies for integrating biodiversity and social issues in management plans that encompass protected areas, managed forests, and matrix (De 2001; Sawarkar 2005). Yet, the lack of consistent baseline assessments of habitats and species across administrative units hinders that integration (Sawarkar 2005).

Pilot projects in four diverse Indian ecosystems assessed the issues and developed landscape-scale strategies for integrating protected and managed forests into formal conservation areas (Mathur et al. 2002; Lehmkuhl et al. 2006). One of those pilot projects focused on the remaining Terai forests and grasslands in the premier protected areas and managed forests of northern Uttar Pradesh (U.P.) state (Kumar et al. 2002). The Terai is a biodiversity-rich area of forests and tall grasslands in the alluvial floodplains of the Ganga River that extends east-west at the base of the Himalaya through southern Nepal and the northern Indian states of Uttarakhand, UP., Bihar, and West Bengal (Mathur 2000). It is part of the Terai-Bhabhar biogeographic sub-division of the Upper Gangetic biotic province in the Gangetic Plains biogeographic zone (Rodgers et al. 2000).

In the past, the Terai ecosystem was a continuous belt of tropical moist deciduous forests interspersed with tall wet grasslands and numerous swamps (Mathur 2000). It is kramanayake et al. 2004). This area now is highly fragmented by densely populated and rich agricultural land, and is one of the most affected ecosystems of India (Rodgers et al.

Nevertheless, remnant portions of the Terai region in Uttarakhand, UP., Bihar, and West Bengal plus similar habitats in the Brahmaputra River valley of Assam state, remain as complex and dynamic natural ecosystems and are a biodiversity-rich region in India. These protected areas and adjacent managed forests are international conservation strongholds for several threatened or endangered species, most notably tiger *(Panthera tigris tigris),* greater one-homed rhinoceros *(Rhinoceros unicomis),* Asian elephant *(Elephas maximus),* Asian wild buffalo *(Bubalus bubalis),* swamp deer *(Rucervus duvaucelii duvaucelii),* pygmy hog *(Porcula salvania),* hispid hare *(Caprolagus hispidus),* and Bengal florican *(Hubaropsis bengalensis).* Historically, the diversity and biomass of large herbivores in an intact Terai ecosystem equaled or exceeded many of the famous wildlife areas of East Africa (Lehmkuhl 1994).

The Terai Conservation Area (TCA) designated by Kumar et al. (2002) in northern U.P. has two core protected areas, Dudwa National Park and Kishanpur Wildlife Sanctuary, two managed forest units (North and South Kheri Forest Divisions), and the intervening agricultural matrix. In addition to encompassing varied environments, the constituent units are under different management objectives, administration, and levels of human disturbance. Human disturbance varies from little to none, except tourist use, in national parks, to some allowable grazing and produce collection in wildlife sanctuaries, to timber harvest, silvicultural operations, and grazing in managed forests. Wildlife habitat relationships might vary not only with vegetation types, or habitat, but with management allocation and the corresponding amount of human use (De 2001). No common vegetation classification scheme existed for both protected areas and managed forests, and there was no common process or methodology for rapid wildlife assessments and monitoring. If landscape conservation areas like the TCA are to be successful in the critical integration of the matrix and protected areas (Prugh et al. 2008; Franklin and Lindenmayer 2009). then rapid and efficient collection and analysis of baseline data on vegetation condition and animal distribution and habitat use across units is critical for further planning efforts, including coarse- and fine-filter approaches (e.g., focal species) (Lambeck 1997; Lindenmayer et al.

Our goal was to develop a rapid field assessment and data analysis methodology that could be integrated with standard timber, or vegetation, inventory procedures to quantify baseline wildlife habitat relationships among management allocations and determine how allocations uniquely contribute to or hinder conservation of wildlife species. Our primary objective was to describe the patterns of abundance of selected mammals of management concern as indicator, i.e. characteristic, species in different vegetation types and management allocations (i.e., protected areas vs. managed forest units) of the TCA with different management and disturbance histories. We hypothesized that mammal occurrence would be most strongly affected by vegetation type, and that management allocation (protected vs. managed) and associated levels of human disturbance would have a modifying affect on occurrence.

Materials and methods

Study area

The TCA covers 7,900 km^2 between latitude N 27°49' and 28°43' and longitude E 80°01' and 81°18' in Lakhimpur Kheri, Pilibhit, Shahjahanpur and Bhairach districts of D.P. state (Fig. 1). The protected areas of Dudwa National Park (DNP, 680 km^2) and Kishanpur Wildlife Sanctuary (KWLS, 203 km^2), and managed forests (MFs) of North Kheri and South Kheri Forest Divisions (NKFD, 318 km^2, and SKFD, 415 km^2) occur within a matrix of private agricultural and government revenue lands. The forests in DNP are well protected and were last worked for timber production 30 years ago, while timber management of forests in KWLS stopped about 15 years ago (De 200l). Forests in NKFD and SKFD are still being worked conservatively for timber production and are under high biotic pressure for subsistence grazing, fuelwood collection, and other uses.

The TCA is on the flat alluvial flood plains of the Subeli, Mohana and Sharda Rivers. The elevation ranges from 143 to 183 m. The soils of the TCA are a recent alluvial formation of the Gangetic Plains (Singh 1965). Different forests in TCA cover 73% of the

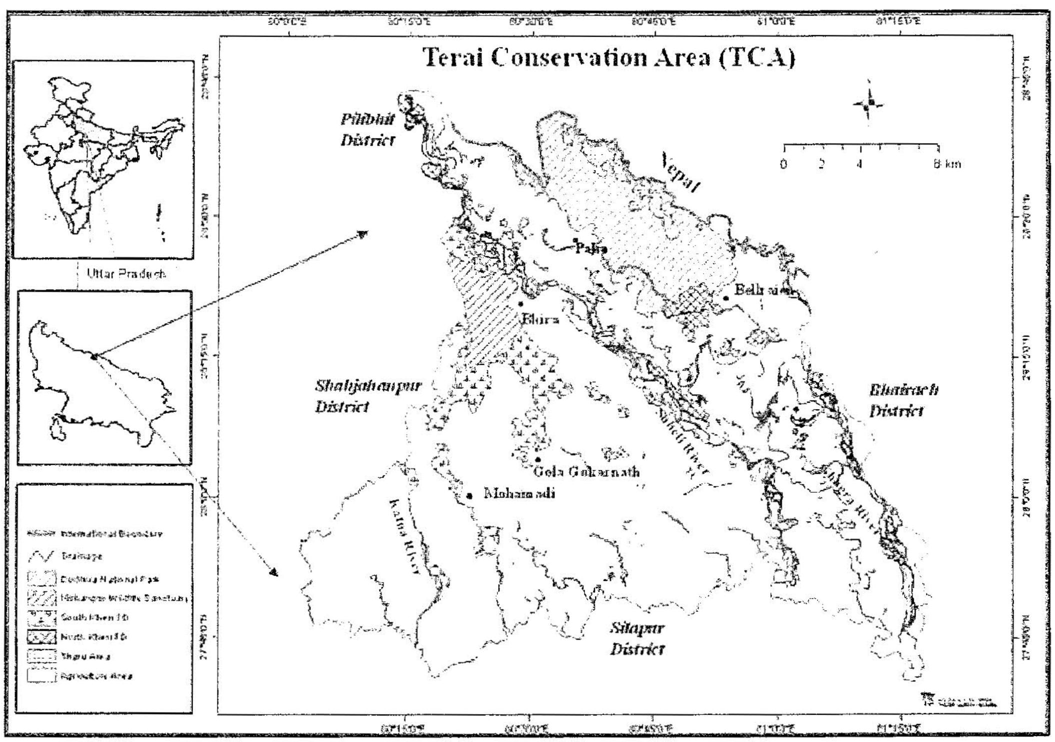

Fig. 1 Location of study area in the Terai Conservation Area of northern Uttar Pradesh, India

non-agricultural areas (Table 1). Sal *(Shorea robusta)* forests account for 45% of the forested area, with most in the protected DNP and managed SKFD units. Moist mixed deciduous forest, tropical semi-evergreen, and seasonal swamp forests occupy 12.4% of the area. Early-seral *Acacia/Dalbergia* and *Tamarix* communities occupy 8.4% of the young floodplain terraces. Dry upland and wet lowland grasslands occur on 13% of the natural areas, primarily in DNP. Plantations of primarily eucalyptus occur on 7.7% of the area, mostly in SKFD. A detailed description of vegetation in the TCA can be found in Kumar et al. (2002).

The climate of the study area is a tropical monsoon type and experiences three distinct seasons: cool-dry winter (mid-October to mid-March), hot-dry summer (mid-March to mid-June), and warm-wet monsoon (mid-June to mid-October). The month of January is the coldest with mean maximum temperature of 20°C and mean minimum temperature of 9°C. The months of May and June are hottest with the mean maximum temperature rising up to 43°C. Annual rainfall is about 150 cm (De 2001).

Sampling design

We stratified sampling of non-wetland vegetation patches by natural vegetation types, management unit, and patch size. Thirteen vegetation types (9 forest types, *Tamarix* scrub, dry upland and wet lowland grasslands, and plantations of varying ages) were identified from a vegetation map based on the classification of IR 1B LISS II satellite images (Table 1) (Kumar et al. 2002). Patches of varying sizes in each vegetation type and management unit were delineated. We allocated samples within vegetation types to ensure representative samples of different patch sizes in each of the four management units (Table 1). In the case of varying types of S. *robusta* forest, large, medium, and small patches were >2000 ha, 1000-2000 ha and <1000 ha area, respectively. In other categories of forests and grasslands, large, medium, and small patches were >500 ha, 100-500 ha, and <100 ha area, respectively. Altogether, we sampled 122 patches in 13 vegetation types (Table 1).

We sub-sampled each sample patch with 20 m x 20 m quadrats laid out along transects. The size of the quadrat was based on species-area curves (Mueller-Dombois and Ellenberg 1974) to meet vegetation sampling objectives (Kumar et al. 2002). In general, a minimum of 10 quadrats was used to sample the smallest forest patches (~50 ha). Quadrats were distributed at 200-m intervals within patches along transects of varying length (2-3.5 km) to systematically cover the patch. Vegetation was measured at each plot and is reported elsewhere (Kumar et al. 2002). The presence of wildlife dung for each species was recorded in the subsample quadrats. Sampling occurred during November 1997 to February 2001. A total of 1,967 vegetation quadrats were subsampled in the 122 sample patches.

We calculated an index of animal abundance as the percentage frequency of occurrence of a species in each sample patch as the number of subsample quadrats with old or fresh dung divided by the total number of quadrats. We recorded data for 15 mammals of conservation or management concern: tiger *(Panthera tigris tigris),* sloth bear *(Melursus ursinus),* honey badger *(Mellivora capensis),* elephant *(Elephas maximus),* nilgai *(Boselaphus tragoeamelus),* sambar *(Rusa unicolor),* swamp deer *(Rucervus duvaucelii duvaueelii),* chital *(Axis axis),* barking deer *(Muntiacus muntjak),* blackbuck *(Antelope cervicapra),* hog deer *(Axis porcinus),* wild boar *(Sus scrofa),* Indian hare *(Lepus nigricollis),* hispid hare *(Caprolagus hispidus),* and cattle *(Bos taurus).* Tiger, elephant, and hispid hare are Endangered, sloth bear and swamp deer are Vulnerable, blackbuck is Near

Table 1 Area and percentage of vegetation types in management units and the number of sample patches in the four management units of the Terai Conservation Area, Uttar Pradesh, India

Vegetation type	DNP				KWLS				NKFD				SKFD				Study area		
	km^2	% type	% unit	*n*	km^2	% type	% unit	*n*	km^2	% type	% unit	*n*	km^2	% type	% unit	*n*	km^2	% unit	*n*
Grassland																			
Dry grassland	43	77.3	6.3	5	1	2.5	0.7	3	2	3.0	0.5	1	10	17.2	2.3	2	56	3.2	11
Wet grassland	82	49.3	12.0	6	30	18.1	14.8	2	35	20.9	10.9	3	19	11.7	4.7	2	166	9.6	13
Subtotal	125	56.4	18.3	11	31	14.2	15.5	5	37	16.4	11.4	4	29	13.2	7.0	4	222	12.8	24
Forests																			
Acacia/Dalbergia	9	7.9	1.4	2	–	–	–	–	80	67.3	25.2	5	30	24.8	7.1	2	119	6.9	6
Tamarix scrub	–	–	–	–	3	9.9	1.2	2	8	30.8	2.4	2	15	59.3	3.6	2	25	1.5	9
Plantations	34	25.5	5.0	7	12	8.9	5.8	3	3	2.5	1.1	2	84	63.1	20.1	6	132	7.7	18
Moist mixed deciduous	58	36.3	8.5	4	8	5.2	4.1	2	75	47.0	23.7	5	19	11.6	4.5	2	160	9.3	13
Tropical semi-evergreen	11	100.0	1.6	2	–	–	–	–	–	–	–	–	–	–	–	–	11	0.6	2
Seasonal swamp	21	47.5	3.0	3	6	14.6	3.1	2	6	13.2	1.7	1	11	24.5	2.6	4	43	2.5	10
Shorea open	176	50.5	25.9	4	49	13.9	23.8	2	7	2.0	2.2	1	117	33.6	28.2	7	348	20.2	14
Shorea moderate	130	46.0	19.0	5	57	20.1	27.9	3	–	–	–	–	95	33.8	23.0	4	281	16.3	12
Shorea dense	91	100.0	13.4	6	–	–	–	–	–	–	–	–	–	–	–	–	91	5.3	6
Shorea mixed	10	59.2	1.5	2	7	40.8	3.5	2	–	–	–	–	–	–	–	–	17	1.0	4
Chandar *Shorea*	–	–	–	–	22	77.6	10.9	2	–	–	–	–	6	1.5	1.5	2	29	1.7	4
Subtotal	539	42.9	79.3	35	163	13.0	80.3	18	179	14.2	56.3	16	376	29.9	90.6	29	1,257	73.0	98
Wetlands[a]																			
Swamps	6	44.7	0.8		2	12.2	0.7		5	43.1	1.6		0	0.8	0.0		12	0.7	
Rivers	10	19.6	1.5		3	5.6	1.4		34	68.3	10.8		3	6.5	0.7		50	2.9	
Sandy Banks	1	0.7	0.1		4	5.8	2.1		63	84.3	19.8		7	9.2	1.6		75	4.3	
Total	680		100.0	46	203		100.0	23	318		100.0	20	415		100.0	33	1,726	100.0	122

Management units are the Protected Areas of Dudwa National Park (DNP) and Kishanpur Wildlife Sanctuary (KWLS), and the managed forests of the North Kheri Forest Division (NKFD) and the South Kheri Forest Division (SKFD)

[a] Wetlands were not sampled, but their areas given here for a complete description of the study area

Threatened, and honey badger is at Lower Risk on the IUCN Red List (IUCN 2009), and all are accorded Schedule I (highest) protection under the Wildlife (Protection) Act of India (WPA) (MoEF 1972). Nilgai, sambar, chital, barking deer, hog deer, and wild boar are all IUCN Lower Risk species with Schedule III (lowest) protection under the WPA; but, these species have critical management importance as either a WPA Schedule I species (honey badger), or as primary prey species of the tiger (De 2001). Cattle are of interest because their occurrence impacts native wild ungulate species through potential competition and human disturbance (De 200l). Indian hares are important prey for avian and small mammalian carnivores and a likely indicator species in scrubby disturbed habitats. Species taxonomy followed Wilson and Reeder (2005).

Data analysis

We used non-parametric methods for analysis of ecological communities to examine the relationships between relative animal abundance, vegetation type, management unit, and patch size. Typical methods for modeling resource use by individual species, such as general linear models (Manly et al. 2002) or occupancy modeling (MacKenzie et al. 2006), were problematic because the sampling design included many empty cells (e.g., not all vegetation types were found in every management unit), the data included many zero values (i.e., animals not found in a vegetation type or management unit), and data for species had messy frequency distributions. Those types of data are well suited for community analysis methods (McCune and Grace 2002). All analysis was done with PCORD software (McCune and Mefford 1999).

We used Multi-Response Permutation Procedures (MRPP) to test the hypothesis of no difference in species composition among groups, i.e., among vegetation types and among management units (Zimmerman et al. 1985; Biondini et al. 1988). An A statistic measured the grouping "effect size", or distinctiveness of groups, on a scale of 0-1. Values of $A > 0.3$ are considered fairly high. Monte Carlo permutations calculated probabilities for differences between groups.

A primary method for summarizing relative abundance data was Indicator Species Analysis (ISA), which identified indicator, or characteristic, species found mostly in a single type and present in the majority of the sites belonging to a group (Dufrene and Legendre 1997). ISA combined information on both species relative abundance and relative frequency across sample patches to estimate indicator values for each species in each group (i.e., vegetation type, management unit, patch size). The maximum indicator value of an item within cover types was tested for statistical significance against the random expectation calculated by Monte Carlo permutation.

We also used two-way cluster analysis of species and sample patches to graphically examine relationships among species and sample units representing different vegetation types and management units (McCune and Mefford 1999). Data were represented in a two-way dendrogram with species as columns and samples as rows. Relative abundance for species in each sample was coded by a grey-scale gradient, with black indicating 100% relative abundance in the sample patch. Management unit status was examined by manipulating the topology of the dendrogram to group sample patches (McCune and Mefford 1999). Outlines were drawn around the 3 main groups that were evident in the cluster dendrogram as defined by a 50% cutoff in information remaining in the sample dataset.

We accepted a significance level of $P < 0.10$ for all statistical analyses. Although less conservative than $P < 0.05$, we considered $x = 0.10$ to be an acceptable chance of Type I error for ecological field studies that also allowed for reduced Type II error and was well within the bounds of statistical convention (Zar 1999). A significant difference is implied where a difference among means is reported in the text for a priori comparisons.

Results

Dung of the selected mammal species was present in about 50% of the 1,967 subsample quadrats in 122 sample patches. Assemblages of species differed both among vegetation types ($A = 0.231$, $P < 0.001$) and among management units ($A = 0.125$, $P < 0.001$). Based on the relative size of A statistics, vegetation type had a nearly 2x stronger effect on species occurrence compared to management unit. Species assemblages in the protected areas of DNP and KWLS differed somewhat in composition ($A = 0.010$, $P = 0.103$) (Table 2, Fig. 2). Chital and hog deer were important indicator species in both protected areas, but DNP had a much stronger diversity of grassland species compared to KWLS. Nilgai were commonly found with chital in forests of both protected areas (Fig. 2).

The collective assemblage of species in both protected areas differed strongly from that of the managed forests of NKFD and SKFD ($A < 0.09$, $P < 0.001$), primarily in the absence of cattle and Indian hare (Fig. 2). Species composition in the two managed forest units themselves differed ($A = 0.069$, $P < 0.001$), mostly in the presence of wild boar and Indian hare (Fig. 2). Species composition was not affected by the size of patch that was sampled ($A = 0.002$, $P = 0.556$); but swamp deer, sloth bear, and hispid hare were indicator species of large sample patches ($P < 0.051$).

Three obvious and sensible patterns of species clustering among vegetation types and management units were evident at the 50% value of information remaining (Table 2, Fig. 2). The dry upland grasslands and wet lowland grasslands were the most species diverse among vegetation types and had several indicator (characteristic) species (Table 2, top section of Fig. 2). Hog deer, swamp deer, hispid hare, and honey badger were grassland indicator species. Wild boar and sloth bear also had their highest indicator values in the combined grassland types. These grassland species were most indicative of protected areas, mostly DNP where 56% of the grassland occurred. Chital also were relatively abundant in grasslands, but also were abundant in protected forests.

A second group dominated by chital and nilgai described an assemblage of species in forests of protected areas (middle group of Fig. 2). No species was a specific indicator of a particular forest type. However, chital a generalist using both grasslands and forests, tended to be most abundant in closed-canopy sal forest (Table 2). Nilgai was a forest-dependent species that favored open-canopy sal and other forests. Barking deer reached their highest abundance in closed-canopy sal forests of DNP.

A third species group characterized the mammal assemblage wherever cattle were present in most managed forests and some grasslands (Table 2, bottom group of Fig. 2). Grasslands, *Tamarix* scrub on fresh riverbed alluvium, open *Acaci/Dalbergia* savanna on secondary river terraces, plantations, and open or moderate-canopy sal forest were typical vegetation types in managed forest areas that were used by this group. Indian hare and wild boar were other indicator species that seemed compatible with cattle grazing. Nilgai also was associated with this species group, mostly where cattle were found in open sal and other forests.

Tiger used a broad array of vegetation types and management units, but was not significantly characteristic of any vegetation type or management unit (Table 2, Fig. 2). Elephant sign likewise was not associated with any particular vegetation type, but was

Table 2 Indicator values of ungulate and mammalian carnivore species in vegetation types and management units in the Terai Conservation Area, Uttar Pradesh

Common name (code)	Vegetation types													Mgmt. units			
	Dry grassland (Grass)	Wet grassland (Grass)	*Tamarix* scrub (Tam)	*Acacia/ Dalbergia* (Kha)	Plantation (Pla)	Mixed decid. forest Mix)	Trop. semi-evergreen (TSE)	Seasonal swamp forest (SSw)	*Shorea* open (Sao)	*Shorea* moderate (Sam)	*Shorea* closed (Sac)	*Shorea* chander (Sah)	*Shorea* mixed (Sax)	Dudwa National Park (DP)	Kishanpur Sanctuary (KS)	N. Kheri Division (ND)	S. Kheri ivision (SD)
Chital (CH)	11	5		1	3	1	12	5	4	11	11	8	11	39	**41**		4
Hog deer (HD)	**32**	30	4	1										13	**15**		
Swamp deer (SD)	24	**34**												**19**	3		
Wild boar (WB)	9	18								9				1		**12**	1
Sloth bear (SB)	5	14								1				**15**			
Hispid hare (HH)	14	15		5										**24**			
Honey badger (HB)	**31**			2										**11**			
Tiger (TI)		3	7				14	5		1	2			6	6		4
Elephant (EL)	3	6	11							2	1			**14**	3		
Barking deer (BD)										5	15	16	5	**14**	1		1
Nilgai (NI)		1		3	9	4	17	6	13	7			16	17	4	10	22
Sambar (SA)									7					2			
Blackbuck (BB)					11												6
Indian hare (IH)	3	8	**35**	3											2	**26**	2
Cattle (CA)	5	6	21	**25**	3	3		2	2			4		1	1	**60**	21

Table 2 continued

Common name (code)	Vegetation types													Mgmt. units			
	Dry grassland (Grass)	Wet grassland (Grass)	*Tamarix* scrub (Tam)	*Acacia*/ *Dalbergia* (Kha)	Plantation (Pla)	Mixed decid. forest Mix)	Trop. semi-evergreen (TSE)	Seasonal swamp forest (SSw)	*Shorea* open (Sao)	*Shorea* moderate (Sam)	*Shorea* closed (Sac)	*Shorea* chander (Sah)	*Shorea* mixed (Sax)	Dudwa National Park (DP)	Kishanpur Sanctuary (KS)	N. Kheri Division (ND)	S. Kheri ivision (SD)
Total species	10	11	5	7	4	3	3	4	4	7	4	3	3	13	9	4	8
Mean richness[a]	3.9	4.4	3.0	2.3	1.8	1.4	2.5	2.4	2.5	3.2	2.2	2.0	2.0				
Mean diversity[b]	1.13	1.20	0.87	0.68	0.47	0.27	0.82	0.77	0.69	0.88	0.37	0.62	0.57				
Rank diversity	2	1	4	8	11	13	5	6	7	3	12	9	10				

Indicator values are the per cent of perfect indication = (relative abundance × relative frequency) × 100. Abundance was measured as frequency occurrence of dung in sample patches. Bold values are significantly different than chance ($P \leq 0.10$) based on Monte Carlo simulations. Species are sorted by habitat affinity

[a] Species richness = mean number of species encountered in sample patches

[b] Shannon diversity index = −sum (P_i*ln(P_i))

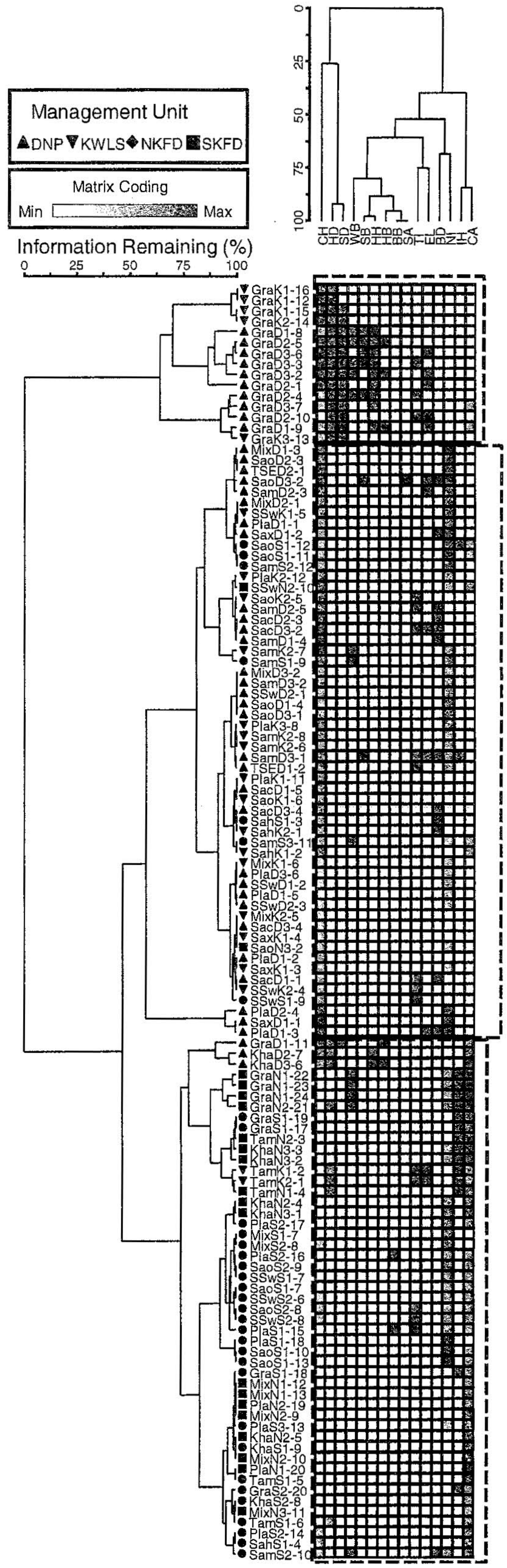

Fig. 2 Two-way dendrogram of species (columns) and sample patches for 13 vegetation types and 4 management units in the Terai Conservation Area, Uttar Pradesh, India. Relative abundance for species in each sample was quantified as the percentage of subplots with dung counts in a sample patch, and is coded by a grey-scale gradient with black indicating 100% relative abundance and light grey indicating low abundance in the indicated sample patch. Outlines were drawn around the 3 main groups that were evident in the cluster dendrogram and defined by a 50% cutoff in information remaining in the sample dataset. Row labels are a combination of vegetation code (see Table 2) and plot number

mostly found in open grassland and *Tamarix* scrub vegetation (Table 2). Unlike tiger, however, elephant sign was highly characteristic of the protected area DNP.

DNP had by far the most indicator species (Table 2). Swamp deer, sloth bear, hispid hare, honey badger, elephant, and barking deer were strong indicator species of the DNP protected area. Chital and hog deer were indicator species for KWLS. Collectively these eight species characterized the protected areas. Indicator species of the managed forest areas were cattle, Indian hare, and wild boar. Nilgai also had high indicator values in managed forests, but similar to values in DNP.

Discussion

We found support for our hypothesis that vegetation has a primary influence over important mammal species distributions, and that management allocation and its varied level of human disturbance also was important. DNP was clearly the core conservation area of the TCA for its relatively high species diversity and high indicator values for many species, and its protected status that minimizes human disturbance. Much of that intrinsic value can be ascribed to the grassland communities, which have been long recognized as local biodiversity hot spots (Bell and Oliver 1992; Lehmkuhl 1994; Mathur et al. 203) and are the primary reason many of these areas have been protected in south Asia (Rodgers et al. 2000). Hog deer (Dhungel and O'Gara 1991; Timmins et al. 2008), swamp deer (Duckworth et al. 2008), and hispid hare (Oliver 1980; Maheswaran and Smith 2008) are well recognized obligate grassland species and are of important conservation concern in this area (Rodgers et al. 2000).

Grasslands also were important habitat for wild boar, sloth bear, and honey badger, but only the later two were characteristic of DNP. Sloth bear is a creature of mixed deciduous forests, scrub and grassland (Joshi et al.(1995); Menon 2003), and the apparent protection from humans, for whom sloth bear are both aggressive and dangerous, made DNP a stronghold area. Joshi et al. (1995) also found grasslands to be the primary habitat for sloth bears in the similar Chitwan National Park, Nepal. The honey badger is an uncommon, but widespread and little studied species in India, that uses a variety of open scrubby and forested habitats (Prater 1971; Menon 2.003), and is most abundant in the semi-arid regions of northwestern India (Hussain 1999), which includes the study area. Based on our data, honey badgers in the TCA find dry grasslands to be their primary habitat, perhaps because of the open structure and relatively sandy soils for easy digging while foraging or making dens (Prater 1971). Wild boar are a common species in grassland and open habitats, and are persistent crop raiders (Prater (1971); they were most characteristic of wet grasslands in NKFD, possibly because the pattern of small constituent forest patches in the NKFD set in the agricultural matrix afforded ample opportunity for shelter and food. Elephant abundance was relatively high in the grasslands of DNP, where it was characteristically found as an indicator species.

Grasslands, mostly wet grasslands, comprised ~ 16% of the KWLS and were also likely a strong factor in the diversity of species in KWLS, despite KWLS being the smallest unit in the TCA. Protected area status and contiguity of area likely were other important factors in the diversity of detected species in the KWLS. Both KWLS and DNP are single contiguous blocks of habitats with strict protective enforcement denying human access; whereas, the managed NKFD and SKFD units are comprised of many small (NKFD) to medium-large subunits imbedded as fragments in the agricultural matrix, so have high human activity as a result of easy human access, permitted access for grazing and other uses, and active timber management programs (Kumar et al. 2002).

The impact of human disturbance was perhaps best seen in the distribution of chital across the TCA vegetation types and management units. Chital were found very broadly across the grassland, and semi-evergreen and sal forest vegetation types, as others have observed in the Terai (Dinerstein 1979; Mishra 1982; Moe and Wegge 1994), but almost exclusively in the protected areas of the TCA. The size of the unit had little to do with chital presence as shown by a strong indicator value in KWLS, which was the smallest unit. The relatively large blocks of sal forest with low edge in SKFD compared to NKFD may have contributed to relatively higher use of SKFD compared to NKFD among the managed forest units.

Menon (2003) describes poaching and cattle grazing as the chief conservation threats to chital. That chital are sensitive to human use and the presence of cattle is supported by the near absence of chital in managed forest units, where cattle was among the strongest indicators species. In addition to harassment, competition for forage with cattle could also be having an impact. If managers were able to control human use or cattle grazing in managed forest units, then chital populations might be expected to increase and provide abundant prey for tiger. That would benefit tiger conservation, and may reduce depredation on cattle and incidents of attacks on humans.

Nilgai was the second most common and widespread ungulate after chital. In contrast to chital, nilgai were a predominantly open forest animal that was found in both protected area and managed forest units. In nearby (~75 km) and similar Bardia National Park, Nepal, chital was the most abundant ungulate and together with nilgai constituted the major wild herbivore biomass (Dinerstein 1980). The presence of cattle seemed to have very little influence on occurrence of nilgai, and the species is known to be well suited to open patchy forests in disturbed landscapes (Khan 1994, 1995; Bagchi et al. 2003; Menon 2003). The high abundance of cattle in *Acacia/Dolbergia* forest, *Tamarix* scrub, and upland and lowland grasslands can be attributed to the availability of forage, water, and proximity to village areas.

Tiger sign was found broadly in the protected areas and in the NKFD managed forests, but the indicator value was not significantly high in anyone unit. Correlations of tiger indicator values and the 2 major prey species, chital and nilgai, showed some interesting patterns that managers should note. Tiger, chital, and nilgai sign were highest in the relatively uncommon tropical semi-evergreen forest, which is found along stream and pond riparian areas only in DNP, where it makes up only 1.6% of the area. The presence of free water, and productive rich and moist soils (Kumar et al. 2002) make this an attractive vegetation type for the two major ungulate prey species of tiger, hence also for the tiger. Because of the relatively small area of this type, only two plots were observed, so results should be considered tentative. However, the more heavily sampled seasonal swamp forest ($n = 10$), which is similar to semi-evergreen forest (Kumar et al. 2002), had patterns of abundance of chital, nilgai, and tiger similar to semi-evergreen forest. Tiger sign was also relatively abundant in *Tamarix* scrub, where the likely prey species was cattle based on indicator values and the absence of other prey species.

This research was an initial step in documenting patterns of wildlife occurrence across the disparate units of the TCA in conjunction with vegetation sampling. The wildlife occurrence data were collected as secondary data to the primary vegetation sampling (Kumar et al. 2002); as such, the wildlife data had limitations on the type of analysis that could be performed. As opposed to conventional dung counts in plots or strips to estimate dung or animal density (reviewed by Marques et al. 2001), we recorded simple presence or absence of dung in subplots, then indexed abundance in sample patches as the percentage of subplots with dung. Analysis was similar to what could be done with the vegetation percentage cover data using community ecology techniques (McCune and Grace 2002). Our methodology was simple but effective in quantifying patterns of relative occurrence among vegetation types and management units. It could easily be incorporated in the comprehensive field inventories that are standard practice in managed forests (Sawarkar 2005). We were unable, however, to estimate the density of animals, or the specific time period or season to which our data applied.

Recent efforts to prepare a Tiger Conservation Plan for the National Tiger Conservation Authority (India) have resulted in a consistent and rigorous methodology to map vegetation and quantify and monitor patterns of tiger and prey distributions across protected area and managed forest conservation units (Gopal et al. 2007). The comprehensive methodology includes mark-recapture and occupancy methods to document the distribution and numbers of tigers and other carnivores, and line-transect and pellet-count methods to quantify abundance of large tiger prey (Jhala and Qureshi 2005; Gopal et al. 2007). To date, regional scale patterns of occurrence in forested areas have been reported (Jhala et al. 2008). Our results provide TCA managers with smaller patch-scale data for local vegetation types and management status that provides a fine-scale view of wildlife distribution patterns.

We believe the ecological scope of the research results is not limited just area of the TCA, but applies certainly to the 15 protected areas and their surrounding managed forests, and managed forests in general, with similar habitats and species in the Indian and Nepalese Terai at the base of the Himalayas. This region is an internationally recognized biodiversity hot spot with many recognized endangered habitats and species, chief among them the tiger (Wikramanayake et al. 2004). The implications of human use and cattle in managed forests (and protected areas too) and the associated exclusion of chital has implications throughout peninsular India where chital are probably the most abundant primary prey of endangered tigers (Jhala et al. 2008).

Complete faunal inventories are difficult, time-consuming and costly (Lawton et al. 1998), therefore monitoring of the status of all species operationally is impossible for most natural resource managers (Baldi 2003). Many managers and researchers want to identify practical indicator or focal species (Lambeck 1997) that can be monitored efficiently and extrapolated reliably to understand the impacts of management. Our results provide a starting point for selecting which species to monitor. In a push for monitoring efficiency, however, it should not be forgotten that little is known about the distribution, population status, ecology, and effects of management of the large number of less conspicuous plant and animal species that make up the bulk of biodiversity in the TCA (Hore and Uniyal 2008b). These species form the base of the intricate food webs and ecosystems that support the well-known species on which management typically is focused and should be considered for monitoring patterns of biodiversity (Hore and Uniyal 2008a).

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