RELATIVE UNGULATE ABUNDANCE IN A FRAGMENTED LANDSCAPE: IMPLICATIONS FOR TIGER CONSERVATION

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This is to certify that I have examined this copy of a doctoral thesis by

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PREFACE

The tiger, *Panthera tigris* is a large and wide ranging carnivore that occupies a wide range of habitats in Asia. It is certainly one of the most striking flagship species in the world and consistently draws much attention to a wide diversity of conservation issues. Long term viability of tiger populations in many range countries is uncertain despite millions of dollars worth of investments in conservation by various organizations. Degradation, fragmentation, and loss of habitat as well as poaching of tigers and their prey base are the main threats in tiger conservation. Conservation has to be extended beyond the boundaries of parks and reserves to ensure long term sustainable existence of this wide ranging species. Landscape scale of conservation with partnership involving local, national, regional, and international stakeholders may possibly meet this goal. Recognizing this challenge His Majesty's Government of Nepal initiated the Terai Arc Landscape Conservation Project (TAL) in 2001, with support from the World Wildlife Fund. This long term project aims to reestablish a network of 11 protected areas in India and Nepal to promote long term conservation of large mammals, including the tiger. Restoration of habitats and coordination among stakeholders has already been started on the ground. While in the field conducting my dissertation research I had several opportunities to participate and lead coordination meetings with stakeholder and bilateral meetings between conservation officials of India and Nepal.

My first encounter of a tiger in the wild was on an evening in Basanta Forest in 1986 during my regular patrolling ventures as a young forest officer in the far western district of Kailali. Later after joining the Department of National Parks and Wildlife Conservation, I had several opportunities to see tiger in the wild in parks and reserves of the lowlands, the Terai. The fear and excitement of my encounters with tigers always intrigued me with questions about the future of this charismatic animal in Nepal, particularly in relation to availability of suitable habitat, poaching pressure on its prey, and increased human pressure on the forests.

While working with my adviser, Dr. James L.D. Smith, at the University of Minnesota for my Ph.D., I accepted an opportunity to assess the Terai landscape of Nepal for tiger conservation. It was exciting work to generate baseline conservation information needed to develop management strategies for innovative and ambitious projects like

TAL. I also had professional commitments to the Department of National Parks and Wildlife Conservation and Department of Forest in Nepal, to help them with landscape wide information. I benefited from this professional affiliation to seek support from the field officials to carry out this large scale task.

I have organized this thesis into three separate chapters. All chapters, although related to each other, have their own abstract, introduction, study area, methods, results, discussion, and literature cited sections. Chapter 1 describes the distribution and abundance of tiger prey species, develops a tiger prey abundance model, and designs a monitoring technique for tiger prey. Chapter 2 develops a vegetation classification using satellite imagery and identifies priority conservation areas based on land cover configuration. It also established the role of vegetation in connectivity between tiger populations. Finally, Chapter 3 describes a study of pellet group decay rates for three important tiger prey species and discusses the relevance of the results for monitoring efforts to estimate ungulate abundance.

ABSTRACT

Degradation and fragmentation of habitats in the southern lowlands (Terai) of Nepal have restricted many wide ranging large mammals into small and isolated protected areas. Information, important for developing conservation strategies and evaluating management interventions, is not available for the Terai landscape. This study: (1) determined distribution and abundance of tiger prey species in the Terai, (2) classified vegetation using satellite imagery and used the results to identify priority areas for conservation, and (3) determined decay rates of pellet groups produced by important tiger prey species. Habitat variables and ungulate pellet groups were measured in 10 m^2 circular plots spaced 25 m apart along 625 m straight line transects. A hybrid approach was used for vegetation classification of five satellite scenes. Pellet decay rates were determined by monitoring cohorts of pellet groups from every month for a year. Poisson regression analysis was used to develop a model to predict ungulate abundance. Finally, a grid cell approach was undertaken to create a prey abundance map for the Terai using geographical information system (GIS).

A total of 772 transects distributed in various forest management systems were surveyed for ungulate pellet groups in the forested landscape of the Terai. Medium sized prey species (0.6±0.04) were more abundant than small (0.04±0.01) and large (0.14±0.02) prey. Prey abundance was higher in protected areas but similar in forests outside protected areas. Human disturbance and livestock grazing had a negative effect on ungulate abundance. Floodplains with riverine forest and grasslands were rich in ungulates; this type of habitat was scarce outside protected areas. The model predicted prey abundance accurately in different habitat types across the landscape.

This study provides information on distribution and abundance of ungulates and their link to habitat characteristics at a landscape scale. Additionally, it developed and tested a monitoring strategy to evaluate management interventions, primarily restoration of degraded lands in partnership with local communities across the Terai. Nepal's national forests, although experiencing different levels of degradation, have tremendous conservation potential to ensure long term viability of large mammals (e.g. tigers) if restored and integrated into landscape level conservation plans across the Terai.

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Distribution and Abundance of Tiger Prey Species in Relation to Habitat Variables: A Landscape Scale Model

ABSTRACT

The large scale conversion of forests into agricultural land beginning early 1950s restricted distribution of many wildlife species into small and isolated parks and reserves leading to their uncertain population viability. Recognizing this threat, an innovative conservation project, the Terai Arc Landscape Conservation Project (TAL), was initiated in 2001 to restore the ecological integrity of the forest landscape of the Terai. TAL aims to link the region's 11 parks and reserves in India and Nepal through restoration and management of habitats. It is important to monitor and analyze landscape changes and evaluate their impacts on tiger prey species. Landscape wide information on tiger prey distribution and abundance in Nepal is currently not available. The purpose of this study was to (1) determine distribution and abundance of tiger prey species, (2) develop a tiger prey abundance model in the Terai landscape in relation to habitat variables, and (3) design a monitoring system for tiger prey. Pellet groups and dung of wild and domestic ungulates and habitat variables were measured along a 625 m long straight line transect containing 10 m^2 circular plots at an interval of 25 m. A total of 772 transects (measuring a linear distance of 550 km and containing 22,026 plots) were surveyed for pellet groups and other habitat variables across the 13,500 km^2 forest landscape in the Nepalese Terai. Medium sized tiger prey species (0.6 ± 0.04) were more abundant than small (0.04 ±0.01) and large (0.14 ± 0.02) sized prey species. Vegetation types (G^2_7 = 119.03, p = 0.00), surface ruggedness (G^2_2 = 11.01, p = 0.00) and distance from water source (G^2_1 = 26.3, p = 0.00) had significant effects on pellet group abundance. Low lying areas with grasslands and riverine forest habitats that are uncommon outside protected areas, supported the highest abundance of ungulates. A prey abundance map was generated using geographic information system (GIS) analysis based on a model developed by using Poisson regression analysis. Existing forest outside protected areas presents a great potential to link tiger populations in protected areas and increase regional population viability. This study contributes to the goals of TAL by providing information on

distribution and abundance of ungulate species and their linkage to habitat characteristics. It provides a monitoring strategy to evaluate management interventions, primarily restoration of degraded lands that benefit both local communities and wildlife.

INTRODUCTION

The southern lowland along the foothills of the Himalayas, locally known as the Terai of Nepal, is one of the premier hot spots for large mammal conservation in Asia. Tigers (*Panthera tigris*) once ranged widely across the grassland and forests of the Terai. Until a half century ago, this habitat was indirectly preserved because risk of malaria was high and the government supported a deliberate policy of maintaining a natural barrier of thick forest all along the southern border with India as a strategic defense against invasion from the British Empire. This policy restricted large-scale agricultural development and human settlements in the Terai (Gurung 1983; Mishra & Jefferies 1991). In 1954, the ecology of the Terai began to change significantly; malaria eradication was initiated and the subsequent influx of human population from the hills led to extensive conversion of forest into agricultural land, bringing a dramatic change in the entire Terai landscape. Populations of large mammals, including tigers plummeted severely as their habitat became increasingly restricted and fragmented by the growing needs of a rapidly increasing human population.

The government, alarmed by the loss of wildlands, established the National Parks and Wildlife Conservation Act of 1973. Starting with Royal Chitwan National Park, several parks and reserves in the Terai were established to protect some of the remaining tiger and rhinoceros (*Rhinoceros unicornis*) habitat. However, increased human pressure and subsequent degradation of critical forest habitat outside protected areas continued unabated. As a result, large carnivores, such as tigers became restricted into small and isolated parks and reserves surrounded by a matrix of other competing land use. Currently, wildlife conservation in forests outside protected areas (national forest) is virtually nonexistent; very few tigers occur in this habitat because the degraded landscape, increased human activities, and hunting pressure have widely reduced the tiger prey base below a level needed to support resident breeding tigers.

Since the policy change in the 1950s, the Terai (covering about 23% of the country's total land area) has become the most densely populated region of Nepal. It now holds nearly 50% of Nepal's population of 23.2 million (CBS 2001). Encroachment, degradation, and subsequent conversion of forest into cultivation, although at a lower scale compared to the past, are still going on. At present, approximately 43% of the Terai landscape (15,692 km^2) remains under forest cover of different quality ranging from heavily degraded to intact forest (HMG/Nepal 2001). Protected areas constitute 18% of the Terai forest. They are rapidly becoming the last refuge for tigers and other large mammal populations owing to increased human pressure on the national forests. Expansion of protected areas or bringing more forestlands under strict protection is no longer a feasible option due to the heavy dependence of people on forest resources for their livelihood. This situation makes conservation of large carnivores more challenging than ever for conservation biologists because these animals require large areas of habitat (Noss et al. 1996).

Landscape Conservation

Due to small size, the relatively isolated existing protected areas do not ensure the long term viability of tiger populations (Smith et al. 1987; Dinerstein & Wikramanayake 1993; Smith et al. 1998; Ahearn et al. 2001). Existing forest outside protected areas presents a great potential to link tiger populations in protected areas and increase regional population viability. If these lands are managed under an ecosystem management framework that favors restoring connectivity, tiger populations will have a higher probability of long term survival. Because the majority of potential tiger habitat is in multiple-use national forest outside protected areas (see Chapter 2) conservation measures need to be undertaken beyond the boundaries of parks and reserves (Ahearn et al. 2001). Restoring degraded habitat and expanding the land base and connectivity will re-establish the past metapopualtion structure of linked population centers that is critical to long term survival of tigers.

Smith et al. (1998) advocated shifting to a landscape-wide conservation approach for long term conservation of large mammals (e.g., tiger, elephant, rhino) that promoted Terai wide management. In 2001, His Majesty's Government of Nepal (HMG), with support from World Wildlife Fund (WWF), initiated the Terai Arc Landscape Conservation Project (TAL), a revolutionary step to restore the ecological integrity of the central Himalayan lowland forest landscape. The TAL encompasses a landscape mosaic of about 49,500 km^2 extending from the Bagmati River in eastern Nepal to the Yamuna River in western India. TAL aims to linking the region's 11 parks and reserves into a network of protected areas through a well established framework that integrates programs in adaptive management and participation by communities and other stakeholders.

As management is undertaken to restore forest integrity across the Terai, it is important to monitor and analyze landscape changes and evaluate the impact of these changes on tiger prey species. Better understanding of prey distribution and abundance in relation to human activities will in turn facilitate development of management strategies. Improving habitats to encourage prey abundance is crucial for maintaining larger more connected tiger populations. Tiger density is positively related to prey abundance particularly wild ungulates (Smith 1984; Karanth & Stith 1999; Sunquist et al. 1999). Thus, information on habitat quality, as measured by prey abundance, is critical for guiding tiger conservation action from local management interventions to regional conservation planning in the focal landscape (WWF 2002). Establishing protected areas is not enough for tiger conservation because protected areas in Nepal and across most of the tiger range do not support population of tigers of adequate size to ensure long term viability (Smith et al. 1998; Smith et al. 1999). In many parts of the tiger's range, ungulate assemblages with no large or medium sized prey (cervids or bovids) support low tiger density and reproduction rate declines in an impoverished habitat with low prey base (Karanth & Stith 1999). Decline in prey base as a result of habitat degradation and widespread poaching has limited areas that can support tigers. A primary objective of TAL is to restore the ecological integrity of the Terai forests that consequently increases the prey base in these forests. Periodical monitoring of tiger habitat is therefore, necessary to prioritize areas for conservation interventions and assess the effectiveness of management efforts. Moreover, a threshold of prey abundance that indicates poor or good quality habitat and ultimately reflects potential for presence of breeding tigers is important for developing necessary conservation action (Smith et al. 1998; Smith et al. 1999).

In Nepal, fragmentation of habitat has divided tigers into three separate populations (Chitwan, Bardia, and Suklaphanta tiger populations) with very limited opportunities for interaction between and among these isolated units (Smith et al. 1998). A fourth population occurs in Basanta forest with source population centered at Dudwa National Park in India (Shrestha unpubl. data). Tiger population in Trijuga forest, near Koshi Tappu Wildlife Reserve was recently extirpated. Tiger numbers declined across the Terai forest in the 1970s (Smith 1993) and tigers were last recorded in Trijuga in 1994 (Smith pers. comm.). Since tigers were extirpated from Trijuga, there have been no records of tigers from east of Bagmati River. For example, no tiger sign was observed between the Bagmati River and Trijuga forest (linear distance 155 km) during repeated surveys between 1999 and 2004 (Gurung 2002).

Sambar deer (*Cervus unicolor*), swamp deer (*C. duvauceli*), Chital (*Axis axis*), hog deer (*A. porcinus*), barking deer (*Muntiacus muntjak*), wild boar (*Sus scrofa*), gaur bison (*Bos gaurus*), and sometimes langur (*Semnopithecus entellus*) comprise the main prey species for tigers in Nepal. Although blue bull (*Boselaphus tragocamelus*) and four-horned antelope (*Tetracerus quadricornis*) are also eaten periodically, their distribution is very limited. Domestic livestock are occasionally preyed upon in fringe habitats. Quantitative studies on the tiger prey base in Nepal have been limited to protected areas (Seidensticker 1976; Dinerstein 1980; Mishra 1982; Smith 1984; Dhungel & O'Gara 1991; Stoen & Wegge 1996; Smith et al. 1999).

Information on prey abundance in national forests is virtually non-existent. Furthermore, very little information on landscape wide abundance and densities of tiger prey species is available even in the protected areas. Therefore, understanding distribution and abundance of tiger prey species is fundamental to implementation of the Terai wide conservation plan that seeks to increase the land base supporting tigers. The objectives of this study are to (1) determine distribution and abundance of tiger prey species, (2) analyze prey abundance in relation to habitat variables, and (3) design a monitoring system for tiger prey.

STUDY AREA

The study was conducted across the lowlands of Nepal between 26^0 27’ N to 29^0 05’ N latitude and 80^0 06’ E to 88^0 03’ E longitude covering an aerial distance of about 850 km and an area of approximately 13,500 km^2. It included 3 ecological zones on the southern flank of the Himalayas: Siwalik Range (Churiya), inner Terai composed of “dun” valleys, and the outer Terai. The lowland ecosystem lies along the northern border of the Gangetic Plain and covers 27% of the total land area of Nepal (Anon 1994). The elevation ranges from 60 m to >1000 m. “Duns” are elongated valleys enclosed between Siwaliks and Midhills ranges. Together with the dun valleys, the Terai is characterized by rich alluvial habitat with tall grasslands. It is one of the biodiversity “hotspots” in Asia that supports the world’s highest density of tigers (Smith et al. 1998).

The Siwaliks are comparatively dry and fragile with permeable geophysical structure and few permanent water sources except the large rivers that cut through this range. Most of the streams and rivers remain dry during the dry season. They surge into heavy flood level during the monsoon rainfall due to rapid run off. Lack of water in the dry season has restricted human settlement and similarly wildlife abundance is low. At the foot of the Siwaliks is a boulder and gravel zone with a porous surface, the “Bhabhar”, where water flows underground to reappear at the surface on the southern Terai. At the southern fringe of the “Bhabhar” zone, bordering India, is the northern extension of the Gangetic Plain that forms a low flat land with rich alluvial soil and high water table. The soil is characterized by the most fertile alluvial and sandy soil formed by the flood plain effect of constantly meandering river systems. The rivers originating in the trans-Himalayas culminate with tributaries before passing on to the Terai where they widen, fanning out into braided channels and forming large floodplains. Several lesser rivers drain through the Terai. Many small streams are intermittent that hold water only during the monsoon.

The climate is subtropical and highly influenced by the monsoon. Most of the precipitation occurs in 4 months of the year (June – September). October – March is cool and dry. April – May is hot and experiences some pre-monsoon showers. The mean annual precipitation is 2000 mm (HMG/Nepal 2001). The western Terai is relatively dryer as it usually receives less rainfall and the monsoon is shorter than in the east. A brief winter rain occurs in December-January. The west Nepal receives more winter rain than the east. The annual average temperature ranges from 10^{o}C to 40^{o}C (HMG/Nepal 2001).

The natural vegetation in the study area is broadly comprised of a mosaic of dry and moist deciduous forest, scrub, and alluvial grasslands. The vegetation in the Siwaliks corresponds to Dobremez's (1976) upper tropical level, Stainton's (1972) tropical and sub-tropical hill sal forest, and the north tropical dry deciduous forest as described by Champion and Seth (1968). Considering both biogeographic and conservation values, the study area corresponds to three eco-regions as proposed by Wikramanayake et al. (2001): (1) Upper Gangetic Plains moist deciduous forest, (2) Terai-Duar savanna and grasslands, and (3) Himalayan sub-tropical broadleaf forest. The Terai-Duar savanna and grasslands is listed among the 200 globally important areas, due to its large mammal assemblage (Wikramanayake et al. 2001). Vegetation in the Terai is characterized by subtropical moist deciduous forest with tall grassland that is similar to the North Indian Moist Deciduous Forest subtype of Champion & Seth (1968). The "sal" (*Shorea robusta*) forest is an ecologically characteristic climax vegetation of the Terai (Stainton 1972; Dobremez 1976). Natural and physical forces such as floods, fires, erosion, and soil aridity attributes to a continually changing mosaic of grasslands, mixed deciduous, dry-thorny and riverine forests in various stages of succession in the Terai.

The Siwaliks contain dominant mature sal forest on dry, deeply eroded upper hill slopes, and Chir pine (*Pinus roxburghii*) along the ridge tops above 800 m. Some areas have thorny scrub forest with stunted sal, *Anogeissus latifolia*, *Buchanania latifolia, Diospyros tomentosa, Bassia latifolia, Schleichera oleosa, Carissa carandas* and a palm species (*Phoenix acaulis*) forming the understory (Anon 1995). The sloping upland benches that lie between the Siwaliks and the Terai are composed of open sal forest with tall grass understory. Sandy river courses dissect sal and mixed deciduous forests along the broad, sandy river courses that drain the hills. The southernmost flood plain is composed of a dynamic interspersion of riverine forests, tall grasses, and broad, sandy riverbanks. Sal forest is dominant intermixed with *Terminalia tomentosa*, *T. bellerica*, *T.*

chebula, Dillenia pentagyna, Careya arborea, Semecarpus anacardium. Riverine forest is composed of *Dalbergia sissoo*, *Acacia catechu*, *Trewia nudiflora*, *Ehretia laevis*, *Bombax ceiba, Ficus spp*. The floodplains are characterized by grassland composed of *Saccharum spontanium, S. bengalensis, Narenga porphyrocoma, Imperata cylindrical, Themeda villosa*, etc. Outside the protected areas most of the rich alluvial land that can support high diversity of vegetation and diverse fauna has already been cultivated. Only a few alluvial lands containing grassland are found in the national forest outside the protected area. As a result most wild lands outside protected areas contain only small patches of grasslands and are dominated by sal and mixed deciduous forest habitats.

Synergistic effects of forest fire, grass cutting, and grazing by livestock control the prominence of understory and low vegetation particularly during the dry period (January – April) and the visibility is extensive. With the onset of the monsoon the ground cover reappears and the rapid growth decreases visibility significantly.

In the lowlands, wildlife habitat is interspersed in a mosaic of settlement and intensive cultivation. Habitat fragmentation in Nepal that began in the late 1950s shifted the once widespread forest matrix to the current stepping stone structure composed of a series of gradually shrinking forest habitat islands spanning the length of the Terai. Despite the overall decline in forest cover, the diverse vegetation juxtaposition of the Terai with mosaic of grassland and forest still support the incomparable large mammal assemblage. The prominent species are tiger (*Panthera tigris*), sloth bear (*Ursus ursinus*), gaur (*Bos gaurus*) greater one-horned rhinoceros (*Rhinoceros unicornis*), and Asian elephant (*Elephas maximus*). The ecosystem also supports a high diversity of ungulates (Seidensticker 1976; Stoen & Wegge 1996) that are important tiger prey species such as sambar, chital, hog deer, barking deer, wild boar, and common langur. Isolated populations of blue bull, four-horned antelope, swamp deer, gaur bison are found.

METHODS

Indices of population abundance are frequently used to assess population status and change for many wildlife species that are difficult to census (Eberhardt & Simmons 1987). For example, pellet-group counts are widely used to estimate the abundance of ungulate species (Bennett et al. 1940; Eberhardt & Van Etten 1956; Neff 1968; Bailey & Putnam 1981; Plumptre & Harris 1995; Barnes et al. 1997; Komers 1997; Vernes 1999; Barnes 2001; Krebs et al. 2001; Marques et al. 2001; Walsh et al. 2001; Barnes 2002) and their habitat use (Collins & Urness 1984; Loft & Kie 1988; Edge & Marcum 1989; Harkonen & Heikkila 1999) despite some controversies (Van Etten & Bennett 1965; Collins & Urness 1981, 1984; Fuller 1991; Fuller 1992; White 1992). Following are general arguments for using the pellet count method at a landscape level study: 1) the technique is relatively simple and low in cost, 2) a strong correlation exists between estimates from the pellet group counts and other methods (White 1992; Barnes 2001), and 3) in contrast to distance sampling, this method is appropriate for a wide variety of open and high density forest environment, particularly in terms of detection probability. In an open environment of national forest, deer flee at greater distances than can be observed and in a dense forest and tall grassland of parks and reserves, the detection probability is extremely low. Although a more accurate form of counting pellets can be conducted using the 'clearance plot' method, limited resources and need to survey a large number of plots across the landscape makes the standing crop method of pellet count preferable (Plumptre & Harris 1995; Marques et al. 2001). The clearance plot method requires a first visit to the site to clear all existing pellets from the plot and a return visit to estimate pellet deposition after clearing whereas the standing crop method derives an estimate on the first visit.

To assess prey abundance, I used a technique modified from the works of several investigators (Wegge 1976; Freddy & Bowden 1983; Smith 1984; Smith et al. 1998). This approach is used to compare prey densities among sites and years. Pellet group data were collected exclusively during the dry season (February-April). Sampling was carried out in 1997, 1999, 2000 and 2003.

Transects were selected by systematic sampling across the Terai using 1:25,000 topo map grids. Points were selected prior to going to the field and the geographical coordinates of the selected points were uploaded in a GPS for navigating to the sampling site. After arriving at the site, a random compass direction was selected at the starting point of the transect. Each transect or sampling unit (SU) was a 625 m long straight line transect with 25 circular plots spaced 25 m apart. Each plot was 10 m^2 in size (Wegge 1976; Smith 1984). Such pellet counts in a series of small sized plots along a line transect is considered efficient in terms of its power and time required (Neff 1968). The SU was designed to include variability within a deer's home range and between sites. A 10 m^2 plot was chosen because large plots are difficult to survey in dense vegetation and hard to count accurately.

Each sampling team consisted of one person who measured the distance between plots by pacing along a fixed bearing, one recorder, and one person who raked the plot. A transect was initiated when one person paced off 25 m along the randomly chosen bearing. A roble pole was held vertically at the center of a plot and viewed from the starting point to determine horizontal cover by observing how many of four-red and white bands (30.5 cm each) were visible. After recording horizontal cover, the recorder documented human related disturbance (e.g. cutting of trees, lopping of branches) in a semi-circle as he walked to the next plot. For each plot, a starting point was established and then a pole 1.785 m long was slowly swung 360^o as the plot is surveyed. Two persons carefully and lightly raked the litter to observe and count all pellet groups within the plot. At the beginning of every season, survey teams used a double observer method (Nichols et al. 2000) to test individual ability to recognize and count pellet groups. The goal was not to estimate missed pellet groups, but to ensure everyone had approximately the same skill level. At least two people counted every plot. Throughout the survey season, the person holding the pole served as an informal second observer as the other observer called out each pellet group detected. Detection probability was assumed to be 100% because plots were small and searched carefully. Although older pellet groups were fewer in number, all groups were counted equally. Pellets spread out in a line occur when an animal moves while defecating. These were classified as a single group. Number of tree seedlings and livestock dung were also recorded for each plot in the transect. A generalized description of the entire transect included canopy cover, habitat quality, ruggedness of the surface, protected status, and vegetation type (Table 1).

Pellet groups were classified by prey size class. The small prey class included barking deer and four-horned antelope; the medium sized class contained chital, and hog deer; the large prey class consisted of sambar deer, swamp deer, and blue bull. Four other classes of droppings were also classified: primates (*Semnopithecus entellus* and *Macaca mulatta*), forest bovid such as gaur, wild pig, and domestic livestock (*Bos taurus* and *Bubalus bubalis*). Gaur dung data were not used in analysis because of their restricted distribution in one park. They comprise of a very small fraction in the wild ungulate composition of the Terai landscape. In addition to the data collected at each 10 m^2 plot, animal sign were also recorded along the transect line and in the vicinity while the field crew walked to the starting point. Track observations were recorded as simple presence or absence. Each team sampled 2-4 transects/day depending on the field conditions and distance they needed to walk to the sampling site.

Survey Design and Rules

Sampling was conducted during the dry period of the year, the first in February-May 1999 and the second in February-March 2000. An additional 28 transects were surveyed by J.L.D. Smith and A. Joshi (unpubl. data) in 1997 and 37 by B. Gurung (unpubl. data) in 2003. At the beginning all team members worked together to standardize the field procedures. Transects for sample plots were selected systematically with random start with some pre-determined sampling rules:

a) plots were located at least 1-2 km inside the forest from the edge
b) the gap between transects was between 1-5 km
c) ridge tops and barren areas in hilly terrain were generally avoided
d) a pellet group consisted of $\geq$5 pellets spread out close together and having similar size, shape, texture, and color (Freddy & Bowden 1983), and
e) a best estimate of the number of pellet groups were made based on age of pellets, color, sheen, and level of degradation of pellets.

f) A transect within 500 m of another transect from the previous year was considered a replicate.

Tigers has been reported breeding at 3000 m with occasional occurrence above 4000 m in Bhutan (McDougal 1998). However, for the past 40 years in Nepal, tigers have not been observed at higher elevations due to the lack of large blocks of forest cover, low prey abundance, and high human density (McDougal pers. comm.). Therefore, few samples were taken at higher elevations in the study area.

The survey period during the dry season that extended from February through April was ideal considering the pellet deterioration rate. A study of pellet group deterioration rates (Chapter 3) demonstrated that pellet studies need to be conducted after the monsoon because pellets disappear rapidly once the rains begin. Pellets begin to accumulate in October and pellet groups from October remained largely intact through our survey season which extended to April. The survey season was divided into 2 week intervals starting 1 February and the number of pellet groups in the transect was multiplied by an adjustment factor to incorporate time that pellets accumulated in previous months and their decay rate (Chapter 3). I assumed that there was no difference in defecation and decay rates of pellet groups across the Terai landscape during the same season of the year. Periodical ground fires occur during the dry period and are common across the Terai forest; it is possible that some pellet groups were burnt and were not recorded in our study. However, ground fires progress very rapidly and generally pellets are still intact and recognizable after a fire has passed through an area (Wiles 1980).

Building the Environmental Variable Database

Ten environmental variables were chosen because of their possible effect on prey abundance at a landscape scale (Table 1). Most variables were quantified while surveying for the pellet groups in the field. Vegetation cover type was obtained from two sources. The dominant vegetation type was assigned to the entire transect during the field surveys. These data were compared to a remote sensing vegetation cover classification (Chapter 2) by overlaying the transect points on the classified LANDSAT 7 Enhanced Thematic Mapper Plus (ETM+) image layer. Discrepancies were examined, and in most cases, the transect was assigned the class obtained during ground surveys. Ruggedness values for transects were assigned by comparing the field data with that from the elevation contour layer. Distance from forest edge and distance from nearest water source for transects were generated by using the respective vector layers. Forest canopy cover, horizontal cover, human disturbance, livestock dung, habitat quality, and protected status of each of the transects were assigned during the survey. Protected status was assigned to the following classes: 1) protected areas (included national parks and wildlife reserves managed strictly for maintaining a natural state and biodiversity conservation); 2) buffer zones (forest areas adjacent to protected areas managed to create a land base for wildlife and for sustainable use of forest resources with participation from local communities); and 3) national forest lands (subject to extractive management and have considerable anthropogenic pressure for resource extraction). International boundaries and major highways were delineated by screen digitization of LANDSAT 7 ETM+ scenes of 2001.

Data Analysis

A Kolmogorov-Smirnov Goodness-of-Fit test indicated that all the variables were not normally distributed. Therefore, I used non-parametric statistics such as Kruskal-Wallis and Mann-Whitney tests to examine the relationship of mean number of pellet groups to individual independent variables. SPSS (Release 11.0, SPSS Inc., 1989-2001) was used for statistical analysis and Arc statistical program (Arc 1.06, rev July 2004;(Cook & Weisberg 1999) was used for Poisson regression analysis of the pellet group count data.

Modeling and Validation

The number of pellet groups per unit area observed is a discrete random variable taking values on the positive integers. The baseline model for counted data is the Poisson distribution, (Agresti 1996), with probability mass function

$$Pr(y_i = r) = (exp^{-\mu i}\ \mu_i^{\ r})/r!, \ \ r = 0, 1, 2, \ldots\ldots..$$

Poisson regression adds additional structure to the problem by assuming that the mean for the i^{th} pellet group μ_i depends on a number of biotic and abiotic predictors, say x_1, $x_2,...,x_k$. The most common Poisson regression model uses the log-link function, and assumes that

$$\mu_i = \alpha + \beta_1 x_1 + \ldots\ldots + \beta_k x_k)$$

Standard statistical software is available for estimating the intercept and partial slopes β_j. The β_j have a straightforward interpretation: increasing a predictor x_j by one unit will multiply the mean by $\exp(\beta_j)$.

A severe limitation of the Poisson model is that it assumes that the location of pellet groups within the landscape is purely at random; no spatial correlation is allowed. When there is “clumping” of groups, meaning that the presence of one group makes the presence of more groups more likely, the Poisson model will not be appropriate. This will be reflected in the failure of the assumption that the mean and variance of the counts, adjusted for the predictors, will be approximately equal, but rather we will observe over-dispersion, in which the variance is considerably larger than the mean. This is diagnosed by very large values of the goodness-of-fit statistics, either the likelihood ratio G^2 or Pearson's Chi-square, for the fit of a Poisson regression.

An alternative model that allows for clumping or over-dispersion is based on the negative binomial distribution, which is a mixture of Poisson distributions with a Gamma distribution (Breslow 1984; White & Bennetts 1996). This model assumes that the conditional mean of a count y_i given the predictors,

$$E(y_i \mid x_1,...x_k, \lambda_i) = \lambda_i$$

as before, but the λ_i are themselves random,

$$\lambda_i \sim \text{Gamma}(\mu_i , 1 / ø)$$

where ø can be thought of as a “clumpiness” parameter. Thus two transects with the same values for the predictors can have different expected number of groups, depending on the λ_i. This is one way of correcting for the variability caused by not including other unmeasured variables in the model. The mean and variance of the y_i given the predictors but averaging over the λ_i is

$$E(y_i) = \mu_i$$

$$\text{Var}(y_i) = \mu_i (1 + ø\, \mu_i)$$

which can account for extra variation if $ø > 0$.

Because of the presence of clear over-dispersion in the data, the negative binomial approach was used, using an Arc add-on by Scrucca (2000). To assess the ability of the model to predict prey abundance, a cross-validation approach was used, in which the data were split into two parts at random. Half the data were used to fit models, and the remaining half to compare predictions to the observed values to assess goodness of fit (Harrell 2001).

Spatial Analysis

I took a parsimonious approach (McCullagh & Nelder 1989; Burnham & Anderson 1992) to my data analysis and used only 4 variables: distance from forest edge, distance from nearest water source, vegetation types, and ruggedness for spatial modeling because these explained most of the variance in prey distribution. I did not use the protected status data in the model despite its significance in explaining the variability in prey abundance because it created a sharp boundary of prey distribution between protected areas and adjacent forest. Based on the field observations, this predicted hard edge is not true; there is, instead a gradual decline in prey across park boundaries where forest cover extends beyond the border of the park.

Spatial analysis was done with ERDAS IMAGINE 8.7 (Leica Geosystems GIS & Mapping LLC 1991-2003), ArcGIS 8.3 (Environmental Systems Research Institute 1999-2002), and ArcView 3.3 (ESRI 1999-2002). I delineated my study area by creating a polygon south of the first ridge line of the Siwaliks except in the parks and reserves which included both sides of the Siwalik ridge line. Settlements within the polygon were masked out. I created grid polygons of 250 m x 250 m size for the entire Terai and later clipped to cover the study area (Fig. 1). All GIS coverage and grids were projected to UTM Zone 44 and WGS 84.

A vector layer of ruggedness was delineated based on elevation contour and soil characteristics (Fig. 2). I clipped the vegetation image file with the shape file of my study area (Fig. 3). Both vegetation and ruggedness layers were converted into a grid coverage corresponding to the fishnet grid polygon size (250 m x 250 m) of the study area. Grid values of each of these theme layers were extracted to the gird polygons. A vector layer of all water sources (seasonal and perennial) such as stream, river, lakes and ponds was created (Fig. 4). Distances from forest edge (in km), and water source (in km) for each of the fishnet grid polygons were generated using the corresponding coverage.

I used GIS modeling to predict prey abundance in the Terai landscape. Predicted prey abundance for each fishnet grid polygon was calculated using the regression coefficients from the best model fit for corresponding environmental variables (Table 1) that were significant in explaining the variability in prey abundance. The prey abundance values of the fishnet polygons were then converted into grid coverage to give it a continuous appearance.

RESULTS

Transect Surveys and Pellet Group Abundance

A total of 772 transects (22,026 plots) was surveyed to estimate abundance of ungulates from pellet groups throughout the 13,500 km^2 forest landscape in the Nepalese lowlands (Fig. 5). I surveyed 234 transects in protected areas, 151 in buffer zones and 387 in national forests. In 1999, 336 transects were randomly selected and surveyed from western Nepal 630 km eastward to Mahottari District east of Parsa Wildlife Reserve (Fig. 5). In 2000 the Terai was again randomly surveyed from the western border approximately 800 km eastward to Jhapa District., An additional 28 and 37 transects were surveyed in 1997 and 2003. The transects of the entire study covered a linear distance of 550 km.

Pellet group abundance varied across land ownership, vegetation types and ruggedness. Pellets were more abundant in protected areas than in national forests and buffer zones (Krusakll-Wallis $H_2 = 288.135$, $p < 0.001$). However, pellet group abundance was similar in national forests and buffer zone forests (Mann-Whitney $U = 26694$, $p = 0.12$; Fig. 6). Vegetation cover types had a significant effect on pellet group abundance (Kruskall-Wallis $H_7 = 157.6$; $p < 0.001$). Low density sal forests and degraded scrub forests offer very little forage and cover; hence, these forest types had the lowest number of pellet groups (Fig. 7 and Table 2). Low lying areas, particularly flood plains with grasslands and riverine forests (characterized by rich alluvial soil and abundant water sources) were preferred habitat; this was indicated by high numbers of pellet groups. Pellet group abundance varied significantly at different ruggedness levels (Kruskall-Wallis $H_2 = 36.4$; $p<0.001$). Forests in the Bhabhar zone (medium ruggedness) at the foothills of Siwaliks had low pellet groups compared to both higher and lower ruggedness levels. This zone of moderate ruggedness has porous, dry soil, which supported low abundance of forage plants in the shrub layer. The soil in this zone was so porous that surface water was extremely scarce (Fig. 8). Interestingly, horizontal cover did not have any effect on pellet group abundance (Fig. 9). Habitat quality, an index of both biotic and abiotic factors at the site of the transect, had significant effect on the abundance of pellet groups (Kruskall-Wallis H_4= 298.53; $p<0.001$). Intact forest habitat had more pellets than other categories of habitat quality (Fig. 10). Levels of human disturbance attributed to cutting, lopping, and other resource use in the forest had a significant negative effect on the prey abundance (Kruskall-Wallis H_4 = 166.03; $p<0.001$). However, at higher levels of human disturbance above a threshold, the effect was more or less constant. Finally, abundance of wild ungulate pellet groups was higher in low grazing areas as indicated by livestock dung (Fig. 11). Distribution of livestock dung and that of wild ungulates were negatively associated (Fig. 12).

Tiger Prey Distribution and Abundance

Based on comparison of number of pellet groups Chital, a medium sized tiger prey species, was dominant among the ungulates in the Terai landscape (Fig. 14). Sambar was an important prey species in protected areas (12%) but much less common in national forests (3%) (Table 3). Wild pig, four-horned antelope, blue bull, langur/monkey, and livestock were more abundant in national forests and buffer zones than in protected areas. Swamp deer and hog deer were recorded only in protected areas. The distribution of blue bull was very restricted; this species was found only in the dry scrub forest. Domestic livestock (e.g. cow, water buffalo) contributed 26% to the total ungulate composition outside protected areas (Fig. 14). Sambar and barking deer were more abundant at higher elevations with rugged terrain than in lower elevations (Table 3).

Medium sized prey species (0.6 ± 0.04) were more abundant than small (0.04 ± 0.01) and large (0.14 ± 0.02) sized species. This difference is primarily due to higher abundance of Chital and their ubiquitous distribution. Gaur dung was recorded only from the Chitwan Complex and therefore, was excluded from the analysis considering its small contribution to the ungulate composition of the Terai. No gaur dung was found in the Trijuga forest where the species was recorded in the past.

Prediction Model of Prey Abundance

Variables such as vegetation cover type, distance from water, and surface ruggedness significantly explained the variability in number of pellet groups and hence were good predictors of prey abundance. The forest cover in the study area was composed of a total of 184,445 grid cells (Fig. 1). Distance from water ($G^2_1 = 26.3$, $p = 0.00$), vegetation types ($G^2_7 = 119.03$, $p = 0.00$), and surface ruggedness ($G^2_2 = 11.01$, $p = 0.00$) were significant (Table 4) in explaining the variability in prey abundance in the Terai landscape. In contrast, distance from forest edge was not significant ($G^2_1 = 1.35$, $p = 0.25$)

Distance from water source and ruggedness were negatively associated with prey abundance and the vegetation cover types showed a ranked but positive association (Table 4). The best model fit indicated that alluvial flat surface (Ruggedness = 1; Fig. 2), grassland and riverine forest (Fig. 3), and closeness to water source (Fig. 4) supported the high prey abundance (Fig. 15). Ruggedness category 2, foothills of Siwaliks (the Bhabhar zone) with scarce water source and forage had the lowest prey abundance.

Model Assessment

Evaluation of the model after treatment with overdispersion indicated that the model accurately predicted prey abundance in the Terai landscape. The model agrees closely to the mean number of pellet groups indicating fit of the Poisson regression model (Fig. 13). However, there was a strong evidence of overdispersion ($G^2_{761} = 13870.34$, $p = 0$). Treatment with extra-Poisson variance resulted an adequate fit of the model ($G^2_{761} = 586.88$, $p = 0.99$).

Cross validation test suggested that the model adequately predicted the prey abundance ($G^2_{385} = 284.5$, $p = 0.99$). Further support of the model was a mean deviance value that was close to 1 (0.74) and the extra-variation parameter ($ø = 1.216$) (Table 4) remained the same in both cross validation model and the model fit that used the entire data set.

DISCUSSION

The primary goal of the TAL Project is landscape conservation and one of the major target species is the tiger. In addition to meeting the resource needs of local people, community forestry and other management programs and activities in Nepal are typically implemented with an objective of increasing the land base and connectivity of tiger habitat. However, monitoring to measure the effects of such conservation interventions on tigers is difficult. Direct monitoring of tiger numbers is one way to measure management success; however, it is difficult to detect if actual changes in tiger numbers have occurred. Fortunately there is a well established positive correlation between tiger density and prey abundance (Smith 1984; Karanth & Stith 1999; Sunquist et al. 1999). Results from this study provide baseline information on abundance of tiger prey species for the Terai landscape in Nepal. A major focus of TAL is to target potential habitat restrictions or "bottlenecks" (Chapter 2) where increasing habitat connectivity is a priority. In key high priority areas, periodical monitoring of my georeferenced transects will help assess population changes in tiger prey species resulting from management interventions. The methodology is simple and does not require highly skilled field technicians. The method is practical and can be done by teams of forest guards and game scouts managed by rangers, District Forest Officers and Wildlife Conservation Officers. It is a powerful technique for monitoring trends of ungulate populations at both landscape and local scales, but it requires a strong management team to implement this monitoring system because a large number of government and citizen staff are needed to collect the data. Quality control and data management are critical to monitoring at this geographic scale.

An equally important issue is to determine the level of change in prey abundance that managers want to detect. Once this level of change is identified then sampling intensity can be set to assure that there is statistical power to detect the level of change that is appropriate. Unfortunately there are no clear biological criteria for determining the level of change that is important. This information can only be derived from radio telemetry studies of tigers living or temporarily using these low prey abundance areas.

Modeling Prey Abundance

This study also examined the contribution of various environmental variables to prey abundance. Using an overdispersed Poisson regression model I generated a prey abundance surface for the Terai, which may be useful for landscape wide management, particularly in evaluating priority areas where habitat restoration is being carried out under TAL (Chapter 2). Within these high priority areas the prey abundance surface can help to evaluate potential prey abundance response to specific management targets.

The prey surface model has a high variance (over dispersion) primarily at higher ungulate density; fortunately I am more interested in how the model fits at lower prey density where the model is stronger. At low density prey managers need to be able to predict whether national forest lands have adequate prey to function as dispersal corridors or breeding habitat for tigers. The next step in evaluating the role of national forests in conserving tigers is to combine the prey abundance model with an object oriented tiger model (OOTM) (Ahearn et al. 2001) based on tiger demographics (Smith & McDougal 1991), predation rates (Chundawat et al. 1999), and current distribution of tigers in the Terai (Gurung, 2002). The OOTM model (Ahearn et al. 2001) developed a conceptual framework for modeling tiger survival and reproduction in Nepalese national forests where wild prey density is low and livestock compete with wild ungulates for forage. This OOTM examined tiger response to varied stocking rates of domestic and wild prey, different grazing practices and human response to livestock depredation. It is logical to next merge the OOTM and the prey abundance models to predict tiger carrying capacity within different components of the landscape.

As a first stage of linking a prey abundance model with a tiger behavioral model it might be practical to model tiger distribution and abundance within one of the identified high priority areas for habitat restoration. Before this modeling can take place, however, a better understanding of human responses to livestock depredation is needed. Furthermore, it is important to recognize that these models do not take into account tiger and deer poaching. Poaching of unknown magnitude does occur in the Nepalese lowlands. Nevertheless, even without information on poaching, the model of tiger prey abundance offers a starting point for evaluating the response of tigers to current and proposed habitat improvement projects being undertaken as a part of the TAL ecoregional project.

Model Evaluation

Count data on biological populations generally exhibit clumping distribution; this is attributed to the complexity of habitat structure and patchiness. In addition to non-normal distribution, such data also present high variability across treatments. Clumped distribution is better modeled by overdispersion considering $Var(y_i) > \mu_i$ in the data compared to a Poisson distribution. Negative binomial distribution or gamma distribution (Breslow 1984; White & Bennetts 1996) gives a better model fit for such data. The extra-variation parameter $ø = 1.216$ in my model fit accommodates for the overdispersion of pellet group distribution in the data.

Validation of a model is necessary to determine whether it is an acceptable representation of the real system for its intended use under the specified conditions (Rykiel 1996). In general, a model can be considered to adequately represent the real system if its output corresponds to observations. A model can achieve some of the objectives even without validation, e.g., improving understanding of the role of ecological or environmental variables in prey abundance. However, it is important to know how much confidence can be placed on inferences of the model results while mimicking real world situations. Reliability of a model to justify its use for decision-making depends on its validity. The main objective of my model was to predict relative prey abundance in the Terai landscape, which it is able to do.

Habitat Management

My study indicates that high quality habitat such as grassland and riverine forests support high ungulate biomass that in turn supports a high density of tigers that is consistent to previous studies by smith et al. (1999). For example, a recent study in RCNP in 2002 found that one female with 4 sub-adult cubs living completely within riverine forest and grassland habitat had a home range of < 17.5 km^2. Given that the subadult tigers were, on average, as large as their mother, the density of tigers in this female's range was one tiger per 3.5 km^2 (Smith, unpubl. data 2001). Therefore, tiger density in these habitats may be 2-3 times higher than that in pure upland sal forest habitat. Grassland and riverine habitats are very scarce outside protected areas because they occur on the most fertile land and are the easiest habitat for settlers to convert to agricultural land. However, restoration of these vegetation cover types in potential corridors may be critical to encourage adequate prey abundance needed to make structural corridors function as dispersal corridors. Establishing community forest plantations with a mixture of trees and grasslands can provide fodder and fuel wood for local human population and also create tiger habitat similar to natural riverine forests and grasslands.

A paradigm shift in national forest management is needed to expand forest resource management to incorporate intensive habitat management described above. There are a few areas in the TAL landscape where strong intervention is required to recreate habitat that has been lost. However there are many areas where community forestry on degraded land and forest restoration efforts has increased habitat connectivity among population centers. A majority of the land area requiring management interventions in the TAL is within national forest lands. A gradual shift in land management is occurring in these areas as TAL conservation partners and local people are increasingly focusing on plantation forestry and habitat restoration. Another management technique that needs to be investigated is selective logging on a sustainable yield basis. Under the correct prescriptions, logging does not hinder ungulate populations. To the contrary, opening up the canopy is likely to induce growth of grassland and other ground level forage that in turn has a positive effect on prey population densities. A third management option to increase natural prey abundance is to reduce livestock grazing pressure on natural forest lands. My study indicates that there is a negative association between abundance of wild ungulate pellet groups and that of livestock dung. Any reduction of livestock is a major undertaking. In 1998/99, the livestock population in the Terai was estimated at 3.7 million cattle and buffalo and 2 million goats and sheep (Sharma et al. 2001). The present system of uncontrolled livestock grazing in the national forest exerts a significant pressure on national forest lands and has created strong competition for forage between wild ungulates and livestock. The result is prey depletion across much of Nepal’s national forest lands.

Control of livestock grazing has been a policy in community managed forest lands and buffer zones, however, grazing pressure is still very high throughout the national forest. In the past, higher numbers of livestock, regardless of their productivity, used to be considered an indicator of social status in rural areas. However, the huge numbers of unproductive livestock are becoming increasingly a burden to farmers. They are finding it less profitable to take good care of these unproductive livestock. Often cattle are allowed to roam unattended for several days in the forest. Many farmers would prefer to get rid of unproductive cattle and primarily keep water buffalo that produce more milk. Furthermore, water buffalo, when cross bred with improved milk producing stock, are almost always shifted from free grazing to stall feeding water buffalo. Nepal is a Hindu Kingdom and killing of cattle or selling them to the slaughterhouse in India is illegal. A system needs to be devised to reduce the number of unproductive livestock and encourage farmers on stall feeding. Currently local and international NGOs have started cross breeding programs by providing high quality water buffalo bulls to local communities as a means to reduce grazing pressure in the forest, but there has been no prior effort to target specific areas within the landscape to achieve increased connectivity. In the early stages of TAL, most habitat management has focused on community forestry. It is now time to use information on forest cover and condition, and prey abundance, to select areas where cattle reduction and cross breeding water buffalo could be used to improve the quality and connectivity of tiger habitat.

Sal forest, in general, occur on poorer, dryer soils. Soil in the sal forest at higher elevations, and at the base of the rugged foothills, is extremely porous. These areas are characterized by bouldery “Bhabar” soils where water in streams flow under the surface of the soil. Scarcity of water and dry habitat provides little forage for either domestic or wild prey. Even low levels of cattle grazing in these habitats reduce cover and forage for wild ungulates. Reducing grazing in these areas not only will increase natural prey populations but will also improve ground cover and watershed management.

Joint management with local villagers and education about the negative relationship between excessive use of the forest and the environmental catastrophes are essential to bring about an effective conservation in these habitats. In time, as trust between the Department of Forest and local villagers increase, it may be possible to designate zones in the Bhabhar as no grazing areas. Existing legislative policy for Siwaliks and Bhabhar forests to be managed under protected forest management system needs to be strengthened and implemented on the ground.

Abundance of medium sized prey species (e.g. Chital, wild pig) at some locations in national forests and the patchy distribution of tigers recorded during 1999-2004 (Gurung 2002) substantiate the potential of national forests to support tiger populations (Karanth & Stith 1999). Conservation and restoration of degraded areas will increase the carrying capacity of the forest to support ungulates. In time, increased prey will undoubtedly increase tiger numbers. If tigers do increase there bound to be increased tiger-human conflicts. Livestock populations in national forests have been a supplement to tiger prey base. Currently, tigers from protected areas overflow into national forests during dispersal in an attempt to establish a territory. These tigers prey upon livestock periodically when there is an inadequate supply of natural prey base. There are also increased incidences of man-eating by tigers in the fringe areas of protected areas in recent years. Tigers, killing livestock, are at high risk of being poisoned by villagers or eventually become man-eaters.

Similar prey abundance in national forests and buffer zones, as indicated by the results, is likely to change over the years as a result of better conservation and protection in buffer zones. Once suitable habitat is established, its adjacency to protected areas will help colonize and replenish wildlife population. This phenomenon has already been demonstrated in the Baghmara and other community forests around Royal Chitwan and Royal Bardia National Parks. In about four years of protection and restoration wild animals such as rhino and tigers along with several ungulate species have recolonized the restored habitats.

Connectivity and Corridors

Existing legislative policy recognizes the fragility of Siwaliks and recommends the entire range for protection forest management. This forest, running parallel to the foothills across the Terai, carries high potential for tiger conservation specially, for re-establishment of connectivity where there is a strong break in the lowland forest. The area is dry and not suitable for farming. Appropriate management in this area will support a good prey base to support tiger dispersal. At present, a significant portion of tiger habitat is outside the protected area network. Therefore, national forests present a potential area to support tiger populations and link the network of protected areas. In terms of tiger conservation, an index of relative importance for conservation has to be developed for zoning of the national forest management plan.

Potential effectiveness of land use should also be assessed. Some economists and land use planners have advocated conversion of Terai forest into agricultural land more efficient (Ghimire 1992) at increasing food production than keeping it under forest cover. Furthermore, their assertion is that keeping the current state of degraded forests in the Terai translates into loss of billions of tons of food. However, most economists that want to convert Terai forest to agriculture undervalue the ecosystem services and biodiversity richness found in the Terai. Such values are often taken for granted and not evaluated in economic terms. Moreover, the livelihood of Nepalese households is still intimately tied to the use of forest resources. The goal of TAL is to ensure long term ecosystem health of the landscape which is a more sustainable strategy to help the local people and the environment than conversion of degraded forests to cropland. This study contributes to the goals of TAL by providing information on distribution and abundance of ungulate species and their linkage to habitat characteristics. Additionally, it provides a monitoring strategy to evaluate management interventions, primarily restoration of degraded lands in partnership with local communities across the Terai.

LITERATURE CITED

Agresti, A. 1996. An introduction to categorical data analysis. John Wiley & Sons, Inc, New York.

Ahearn, S. C., J. L. D. Smith, A. R. Joshi, and J. Ding. 2001. TIGMOD: an individual-based spatially explicit model for simulating tiger/human interaction in multiple use forests. Ecological Modelling **140**:81-97.

Anon 1994. Deforestation in the Terai districts 1978/89 - 1990/91. Forest Resources Inventory and Survey Project. Publication No. 60. Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Anon 1995. Biodiversity profile of Terai and Siwalik physiographic zones. Biodiversity Profile Project Publication No. 12. Department of National Parks and Wildlife Conservation, Ministry of Forests and Soil Conservation, HMG of Nepal, Kathmandu.

Bailey, R. E., and R. J. Putnam. 1981. Estimation of fallow deer (Dama dama) populations from faecal accumulation. Journal of Applied Ecology **18**:697-702.

Barnes, R. F. W. 2001. How reliable are dung counts for estimating elephant numbers? African Journal of Ecology 39(1): 1-9. 2001.

Barnes, R. F. W. 2002. The problem of precision and trend detection posed by small elephant populations in West Africa. African Journal of Ecology **40**:179-185.

Barnes, R. F. W., K. Beardsley, F. Michelmore, K. L. Barnes, M. P. T. Alers, and A. Blom. 1997. Estimating forest elephant numbers with dung counts and a geographic information system. Journal of Wildlife Management **61**:1384-1393.

Bennett, L. J., P. F. English, and R. McCain. 1940. A study of deer populations by use of pellet-group counts. Journal of Wildlife Management **4**:398-403.

Breslow, N. E. 1984. Extra-Poisson variation in log-linear models. Applied Statistics **33**:38-44.

Burnham, K. P., and D. R. Anderson. 1992. Data-based selection of an appropriate biological model: the key to modern data analysis. Pages 16-30 in D. R. McCullough, and R. H. Barrett, editors. Wildlife 2001: populations. Elsevier Applied Science, New York, New York, USA.

CBS. 2001. Preliminary results of population census 2001. Central Bureau of Statistics, Kathmandu, Nepal.

Champion, H. G., and S. K. Seth 1968. A revised survey of the forest types of India. Government of India, Manager of Publications, Delhi, India.

Chundawat, R. S., G. N, and J. A. J. T. 1999. Tigers in Panna: preliminary results from an Indian tropical dry forest. Pages 123-129 in J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the tiger. tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom.

Collins, W. B., and P. J. Urness. 1981. Habitat preferences of mule deer as rated by pellet-group distribution. Journal of Wildlife Management **45**:969-972.

Collins, W. B., and P. J. Urness. 1984. The pellet group census techniques as an indicator of relative habitat use: response to Leopold et al. Wildlife Society Bulletin **12**:327.

Cook, R. D., and S. Weisberg 1999. Applied regression including computing and graphics. John Wiley & Sons, Inc.

Dhungel, S. K., and B. W. O'Gara 1991. Ecology of the hog deer in Royal Chitwan National Park, Nepal. Wildlife Monograph No. 119. Wildlife Society, Bethesda, MD.

Dinerstein, E. 1980. An ecological survey of the Royal Karnali-Bardia Wildlfie Reserve, Nepal. Part III: ungulate populations. Biological Conservation **18**:5-38.

Dinerstein, E., and E. D. Wikramanayake. 1993. Beyond "hotspots": how to prioritize investments to conserve biodiversity in the Indo-Pacific region. Conservation Biology **7**:53-65.

Dobremez, J. F. 1976. Le Nepal ecologie et biogeography. Editions du Centre Nationale de la Recherche Scientifique, Paris, France.

Eberhardt, L., and R. C. Van Etten. 1956. Evaluation of the pellet group count as a deer census method. Journal of Wildlife Management **20**:70-74.

Eberhardt, L. L., and M. A. Simmons. 1987. Calibrating population indices by double sampling. Journal of Wildlife Management **51**:665-675.

Edge, W. D., and C. L. Marcum. 1989. Determining elk distribution with pellet-group and telemetry techniques. Journal of Wildlife Management **53**:621-624.

Freddy, D. J., and D. C. Bowden. 1983. Sampling mule deer pellet-group densities in Juniper-Pinyon woodland. Journal of Wildlife Management **47**:476-485.

Fuller, T. K. 1991. Do pellet counts index white-tailed deer numbers and population change? Journal of Wildlife Management **55**:393-396.

Fuller, T. K. 1992. Do pellet counts index white-tailed deer numbers and population change?:A reply. Journal of Wildlife Management **56**:613.

Ghimire, K. B. 1992. Forest or farm? The politics of poverty and land hunger in Nepal. Oxford University Press, Delhi.

Gurung, B. 2002. Mapping the meta-population structure of tigers throughout Nepal by establishing a tiger monitoring network of "Village Rangers". Page 52. Fisheries, Wildlife and Conservation Biology. University of Minnesota, St. Paul.

Gurung, K. K. 1983. Heart of the Jungle: the wildlife of Chitwan, Nepal. Andre Deutsch Limited in association with Tiger Tops Nepal, Kathmandu, Nepal.

Harkonen, S., and R. Heikkila. 1999. Use of pellet group counts in determining density and habitat use of moose Alces alces in Finland. Wildlife Biology **5**:233-239.

Harrell, F. E. 2001. Regression modeling strategies. Springer-Verlag, New York.

HMG/Nepal 2001. Statistical year book of Nepal. His Majesty's Government, National Planning Commission Secretariat, Central Bureau of Statistics, Kathmandu, Nepal.

Karanth, K. U., and B. M. Stith. 1999. Prey depletion as a critical determinant of tiger population viability. Pages 100-113 in J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the tiger: tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom.

Komers, P. E. B., Peter N. M. 1997. Dung pellets used to identify the distribution and density of dik-dik. African Journal of Ecology 35(2): 124-132. 1997.

Krebs, C. J., R. Boonstra, V. Nams, M. O'Donoghue, K. E. Hodges, and S. Boutin. 2001. Estimating snowshoe hare population density from pellet plots: a further evaluation. Canadian Journal of Zoology **79**:1-4.

Loft, E. R., and J. G. Kie. 1988. Comparison of pellet-group and radio triangulation methods for assessing deer habitat use. Journal of Wildlife Management **52**:524-527.

Marques, F. F. C., S. T. Buckland, D. Goffin, C. E. Dixon, D. L. Borchers, B. A. Mayle, and A. J. Peace. 2001. Estimating deer abundance from line transect surveys of dung: sika deer in southern Scotland. Journal of Applied Ecology **38**:349-363.

McCullagh, P., and J. A. Nelder 1989. Generalized linear models. Chapman and Hall, New York, New York, USA.

McDougal, C., and K. Tshering 1998. Tiger conservation strategy for the kingdom of Bhutan. Nature Conservation Section, Foretry Services Division, Ministry of Agriculture/WWF.

Mishra, H. R. 1982. The ecology and behaviour of chital (Axis axis) in the Royal Chitwan National Park, Nepal. Ph. D. thesis. University of Edinburgh.

Mishra, H. R., and M. Jefferies 1991. Royal Chitwan National Park wildlife heritage of Nepal. The Mountaineers, Seattle, Washington, USA.

Neff, D. J. 1968. The pellet-group count technique for big game trend, census, and distribution: a reveiw. Journal of Wildlife Management **32**:597-614.

Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon, and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. Auk **117**:393-408.

Noss, R. F., H. B. Quigley, M. G. Hornocker, T. Merrill, and P. C. Paquet. 1996. Conservation biology and carnivore conservation in the Rocky Mountains. Conservation Biology **10**:949-963.

Plumptre, A. J., and S. Harris. 1995. Estimating the biomass of large mammalian herbivores in a tropical montane forest: a method of faecal counting that avoids assuming a 'steady state' system. Journal of Applied Ecology 32(1): 111-120, 1995.

Rykiel, E. J. J. 1996. Testing ecological models: the meaning of validation. Ecological Modelling **90**:229-244.

Scrucca, L. 2000. Fitting extra-poisson variation in Poisson Regression Models using Arc. Web source: http://www.stat.umn.edu/arc/addons.html:1-3.

Seidensticker, J. 1976. Ungulate populations in Chitwan Valley, Nepal. Biological Conservation **10**:183-210.

Sharma, H. B., R. P. Gautam, and S. Vaidya 2001. District development profile of Nepal: a development database for Nepal. Informal Sector Research and Study Center, Kathmandu, Nepal.

Smith, J. L. D. 1984. Dispersal communication, and conservation strategies for the tiger (Panthera tigris) in Royal Chitwan National Park, Nepal. Page 155. Ph. D. Thesis. University of Minnesota, St. Paul, Minnesota, USA.

Smith, J. L. D. 1993. The role of dispersal in structuring the Chitwan tiger population. Behaviour **124**:165-195.

Smith, J. L. D., S. C. Ahearn, and C. McDougal. 1998. Landscape analysis of tiger distribution and habitat quality in Nepal. Conservation Biology **12**:1338-1346.

Smith, J. L. D., and C. McDougal. 1991. The contribution of variance in lifetime reproduction to effective population size in tigers. Conservation Biology **5**:484-490.

Smith, J. L. D., C. McDougal, S. C. Ahearn, A. Joshi, and K. Conforti. 1999. Metapopulation structure of tigers in Nepal. Pages 176-189 in J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the tiger: tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom.

Smith, J. L. D., C. McDougal, and E. Sunquist Melvin. 1987. Female land tenure system in tigers. Pages 97-109 in R. Tilson, and U. S. Seal, editors. Tigers of the World: the biology, biopolitics, management, and conservation of an endangered species. Noyes Publications, Park Ridge, New Jersey.

Stainton, J. D. A. 1972. Forest of Nepal. John Murray, London.

Stoen, O. G., and P. Wegge. 1996. Prey selection and prey removal by tiger (Panthera tigris) during the dry season in lowland Nepal. Mammalia **60**:363-373.

Sunquist, M., K. U. Karanth, and F. Sunquist. 1999. Ecology, behaviour and resilience of the tiger and its conservation needs. Pages 5-18 in J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the tiger: tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom.

Van Etten, R. C., and C. L. J. Bennett. 1965. Some sources of error in using pellet-group counts for censusing deer. Journal of Wildlife Management **29**:723-729.

Vernes, K. 1999. Pellet counts to estimate density of a rainforest kangaroo. Wildlife Society Bulletin **27**:991-996.

Walsh, P. D., L. J. T. White, C. Mbina, D. Idiata, Y. Mihindou, F. Maisels, and M. Thibault. 2001. Estimates of forest elephant abundance: projecting the relationship between precision and effort. Journal of Applied Ecology **38**:217-228.

Wegge, P. 1976. Terai Shikar Reserves: survey reports and management proposals. FAO Project Nepal Field Document No. 4, Kathmandu, Nepal.

White, G. C. 1992. Do pellet counts index white-tailed deer numbers and population chnage?: A comment. Journal of Wildlife Management **56**:611-612.

White, G. C., and R. E. Bennetts. 1996. Analysis of frequency count data using the negative binomial distribution. Ecology **77**:2549-2557.

Wikramanayake, E. D., E. Dinerstein, C. Loucks, D. Olson, J. Morrison, J. Lamoreux, M. McKnight, and P. Hedao 2001. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press, Washington, D.C.

Wiles, G. J. 1980. Faeces deterioration rates of four wild ungulates in Thailand. Natural History Bulletin of Siam Society **28**.

WWF 2002. Conserving tigers in the wild: A WWF framework and strategy for action 2002-2010. Species Programme, WWF International, Gland.

Table 1. Environmental variables used in analysis

1. Vegetation types
    a. Dry Sal forest (DS)
    b. High density Sal forest (HS)
    c. Low density Sal forest (LS)
    d. High density mixed forest (HM)
    e. Low density mixed forest (LM)
    f. Riverine forest (RF)
    g. Grassland (GS)
    h. Degraded scrub forest
2. Ruggedness index
    a. Flat alluvial soil and below 200 m (1)
    b. Dry soil surface with low water table and between 200-300m (2)
    c. Hilly terrain and > 300m (3)
3. Distance from nearest water source (in km)
4. Distance from forest edge (in km)
5. Forest canopy cover (in percent)
6. Horizontal cover index
7. Human disturbance index (number of cutting of trees and lopping of branches)
8. Livestock dung (number)
9. Habitat quality index (subjective scoring)
    a. Intact
    b. Fairly Intact
    c. Degraded
    d. Moderately Degraded
    e. Severely degraded
10. Protected status
    a. Parks and reserves (PA)
    b. Buffer zone (BZ)
    c. National forest (NF)

Table 2: Pellet group abundance (# of pellet groups/plot) of tiger prey species in different vegetation types

Species	Dry Sal Forest (t = 112 p = 2813)	High Density Sal Forest (t = 244 p = 7071	Low Density Sal Forest (t = 136 p = 3980)	High Density Mixed Forest (t = 67 p = 1773)	Low Density Mixed Forest (t = 114 p = 3579)	Riverine Forest (t = 42 p = 1186)	Grassland (t = 32 p = 884)	Degraded Forest (t = 25 p = 740)
Sambar	0.1 ± 0.02	0.1 ± 0.01	0.04 ± 0.01	0.1 ± 0.04	0.05 ± 0.02	0.28 ± 0.06	0.3 ± 0.12	0.01 ± 0.01
Chital	0.29 ± 0.05	0.55 ± 0.05	0.26 ± 0.04	0.79 ± 0.16	0.39 ± 0.07	2.24 ± 0.3	2.77 ± 0.39	0.16 ± 0.07
Wild pig	0.06 ± 0.01	0.06 ± 0.00	0.05 ± 0.01	0.07 ± 0.01	0.05 ± 0.01	0.10 ± 0.02	0.07 ± 0.01	0.02 ± 0.0
Swamp deer	0	0.002 ± 0.00	0	0.01 ± 0.02	0	0.1 ± 0.06	1.18 ± 0.38	0
Blue bull	0.01 ± 0.01	0.01 ± 0.00	0.01 ± 0.00	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01
Barking deer	0.04 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.05 ± 0.02	0.03 ± 0.01	0.08 ± 0.02	0.04 ± 0.01	0.002 ± 0.00
Four-horned antelope	0.03 ± 0.02	0.001 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.04 ± 0.03	0	0	0
Hog deer	0	0.001 ± 0.00	0	0.001± 0.00	0.003 ± 0.00	0.01 ± 0.00	0.3 ± 0.09	0
Langur/Macaque	0.07 ± 0.01	0.08 ± 0.01	0.06 ± 0.01	0.13 ± 0.02	0.07 ± 0.01	0.06 ± 0.02	0.03 ± 0.02	0.06 ± 0.02
Cow/Buffalo	0.08 ± 0.01	0.07 ± 0.01	0.13 ± 0.01	0.11 ± 0.02	0.21 ± 0.03	0.19 ± 0.07	0.3 ± 0.13	0.28 ± 0.05
Wild ungulates	0.6 ± 0.08	0.84 ± 0.06	0.45 ± 0.04	1.18 ± 0.2	0.65 ± 0.09	2.88 ± 0.36	4.7 ± 0.64	0.26 ± 0.08
All prey species (including cattle)	0.68 ± 0.08	0.90 ± 0.06	0.57 ± 0.05	1.29 ± 0.2	0.86 ± 0.09	3.07 ± 0.34	5.01 ± 0.6	0.55 ± 0.09

(t = number of transect, p = number of plots, and values are average number of pellets in transects ± standard deviation)

Table 3. Pelllet group abundance (# of pellet groups/plot) of tiger prey species in the Terai landscape and management units

Species	Landscape (t = 772 p = 22026)	Protected Area (t = 222 p = 6200)	Buffer Zone (t = 151 p = 4444)	National Forest (t = 399 p = 11382)	Landscape (t = 772 p = 22026)	Rugged ness		
						Low (t = 441 p = 12988	Medium (t = 285 p = 7881)	High (t = 46 p = 1157)
Sambar	0.1 ± 0.01	0.28 ± 0.03	0.04 ± 0.01	0.01 ± 0.00	0.1 ± 0.01	0.09 ± 0.01	0.09 ± 0.02	0.24 ± 0.06
Chital	0.63 ± 0.04	1.53 ± 0.12	0.29 ± 0.04	0.22 ± 0.02	0.63 ± 0.04	0.82 ± 0.06	0.38 ± 0.04	0.36 ± 0.1
Wild pig	0.06 ± 0.00	0.08 ± 0.01	0.06 ± 0.01	0.05 ± 0.00	0.06 ± 0.00	0.06 ± 0.00	0.05 ± 0.00	0.06 ± 0.01
Swamp deer	0.06 ± 0.02	0.19 ± 0.06	0	0	0.06 ± 0.02	0.1 ± 0.03	0	0
Blue bull	0.01 ± 0.00	0.07 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.002± 0.00
Barking deer	0.04 ± 0.03	0.07 ± 0.01	0.03 ± 0.01	0.02 ± 0.00	0.04 ± 0.03	0.04 ± 0.01	0.03 ± 0.00	0.07 ± 0.02
Four-horned antelope	0.01 ± 0.01	0.02 ± 0.02	0.002 ± 0.00	0..01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.001± 0.00
Hog deer	0.01 ± 0.00	0.05 ± 0.01	0.001 ± 0.00	0	0.01 ± 0.00	0.02 ± 0.01	0	0
Langur/Macaque	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.09 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.06 ± 0.01	0.12 ± 0.04
Cow/Buffalo	0.13 ± 0.01	0.07 ± 0.02	0.13 ± 0.02	0.16 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	0.05 ± 0.01
Wild ungulates	0.99 ± 0.06	2.27 ± 0.15	0.5 ± 0.05	0.41 ± 0.02	0.99 ± 0.06	1.24 ± 0.1	0.63 ± 0.05	0.85 ± 0.16
All prey species (including cattle)	1.12 ± 0.06	2.34 ± 0.15	0.63 ± 0.05	0.56 ± 0.03	1.12 ± 0.06	1.37 ± 0.1	0.76 ± 0.05	0.90 ± 0.15

(t = number of transect, p = number of plots, and values are average number of pellet groups in plot ± standard error)

Table 4. Poisson regression model built with pellet group numbers per transect

					Goodness-of-fit[b]			
Variable	Symbol	β	SE	p[a]	χ^2	Deviance	df	p[c]
General model	Constant	2.3426	0.2558	0.000	760.96	582.21	761	
Water	Water	-0.2952	0.0627	0.000		24.593	1	0.000
Habitat	DS	0.7008	0.2641	0.008		114.04	7	0.000
	HDS	0.9790	0.2529	0.000				
	LDS	0.4732	0.2601	0.069				
	HDM	1.2341	0.2803	0.000				
	LDM	0.8217	0.2636	0.002				
	RIV	2.0706	0.3041	0.000				
	GRS	2.5827	0.3168	0.000				
	DEG	0						
Ruggedness	1	0				10.025	2	0.007
	2	-0.2847	0.0908	0.002				
	3	-0.0993	0.1859	0.5934				
Extra variation[d]	1.271							

[a] Significance level of the coefficient for the Wald statistic
[b] Pearson χ^2 and Deviance divided by the degrees of freedom are often used to detect overdispersion or underdispersion of the general model. It should be approximately one to meet the assumption of equal variance and mean for Poission distribution
[c] Significance value of each predictors on its role in explaining the variability of the response variable
[d] Value useful for cross validation of the model

DS = dry sal forest; HDS = high density forest; LDS = low density forest; HDM = high density mixed forest; LDM = low density mixed forest; RIV = riverine forest; GRS = grasslands; DEG = degraded forest

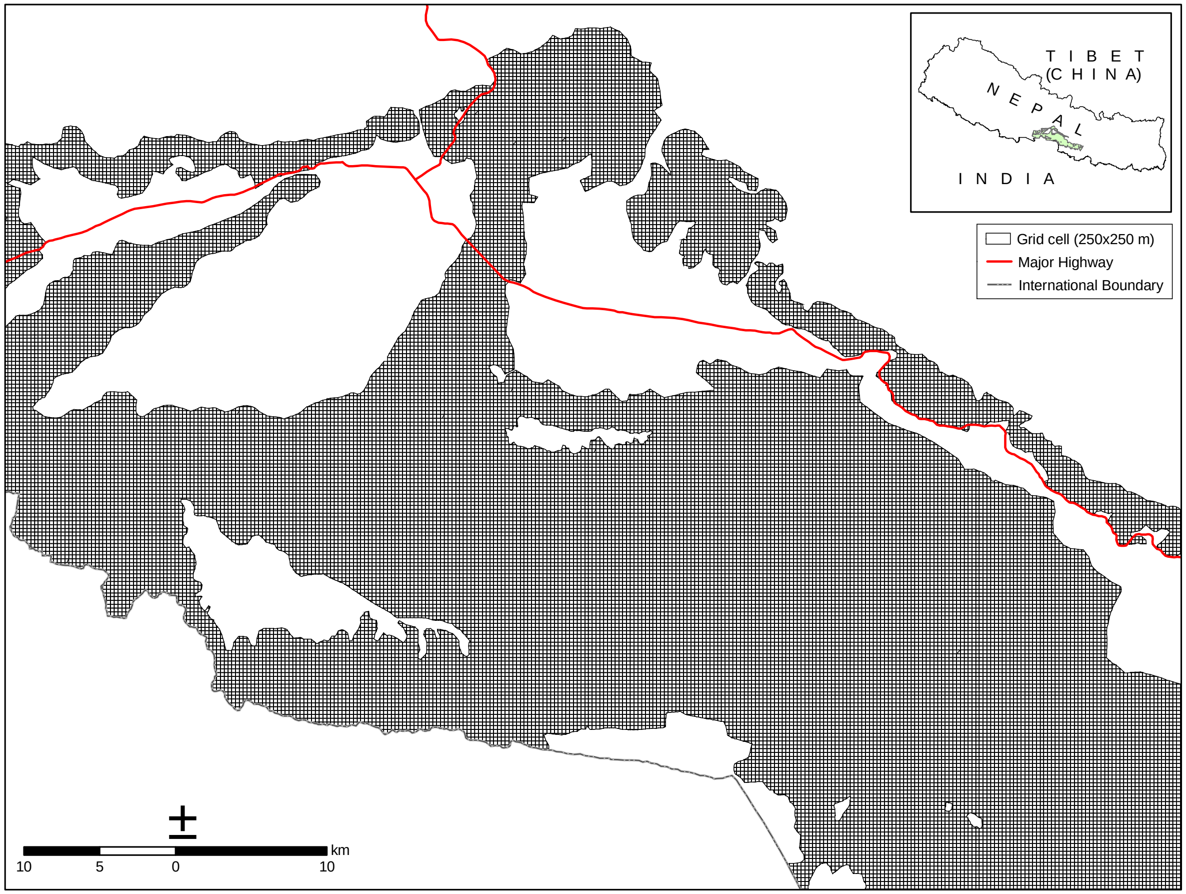


Figure 1. Forest landscape in the Terai in grids of 250 m x 250 m. (zoom-in view example of Chitwan)

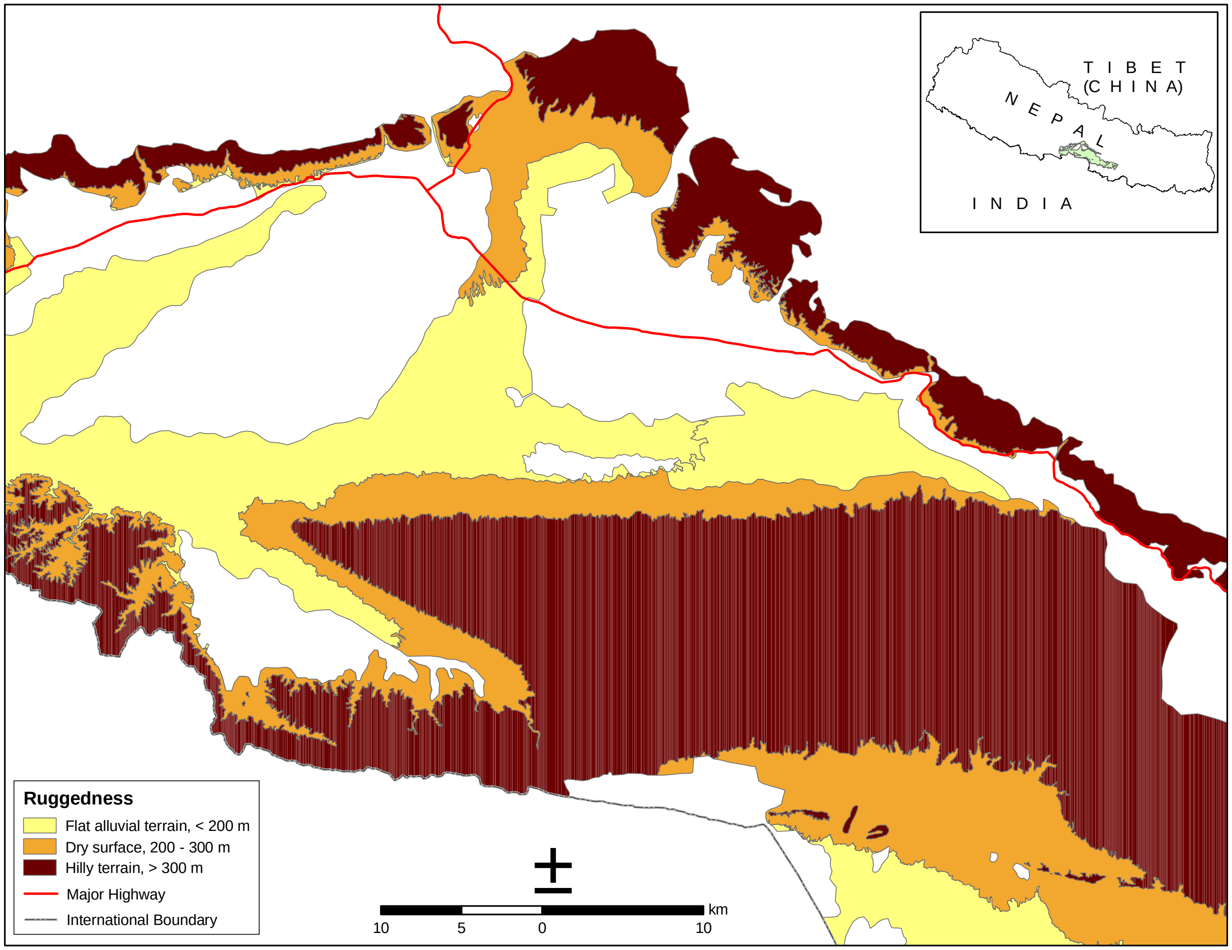


Figure 2. Ruggedness levels assigned to the Terai landscape (zoom-in view example of Chitwan)

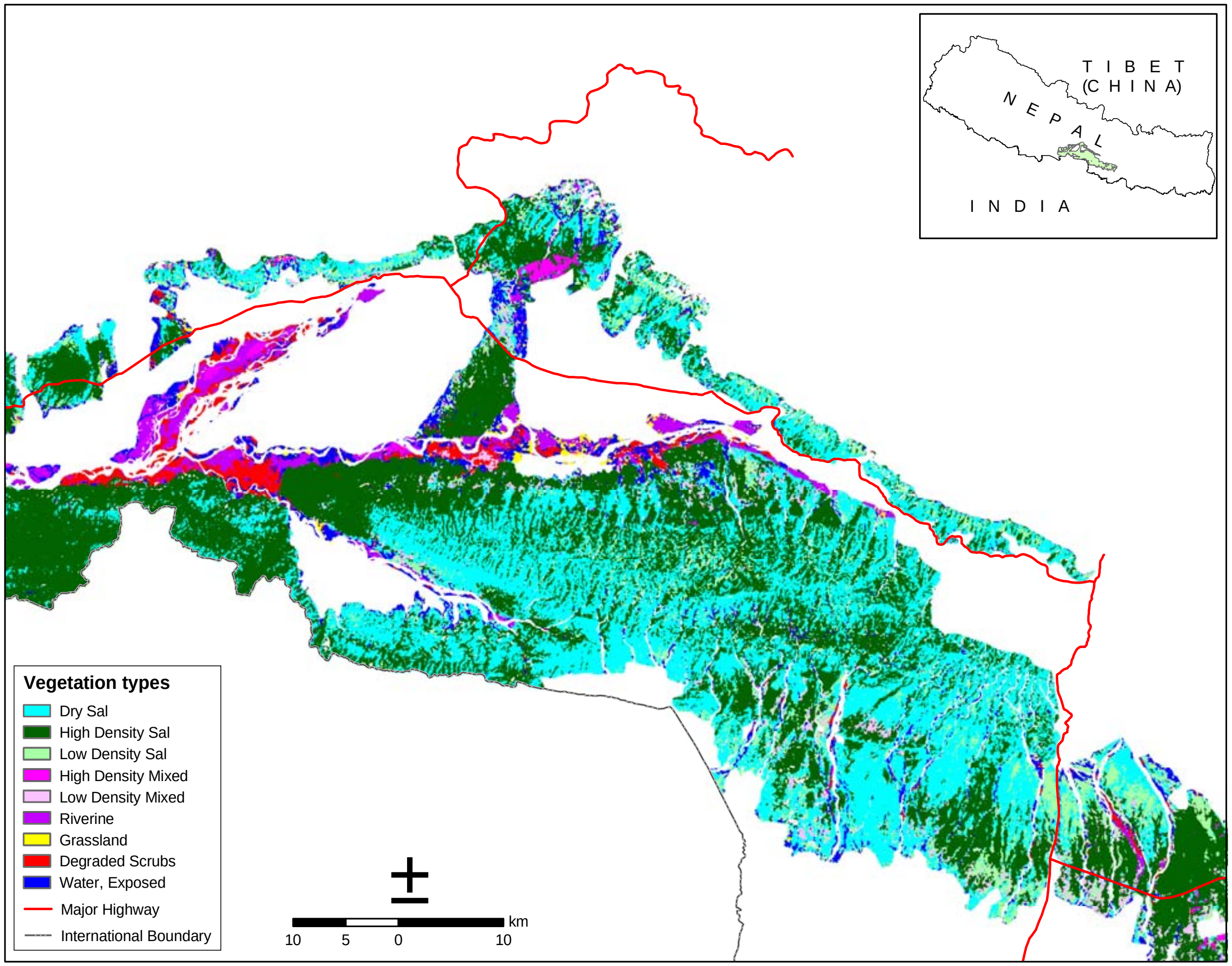


Figure 3. Vegetation cover types in the Terai (zoom-in view example of Chitwan)

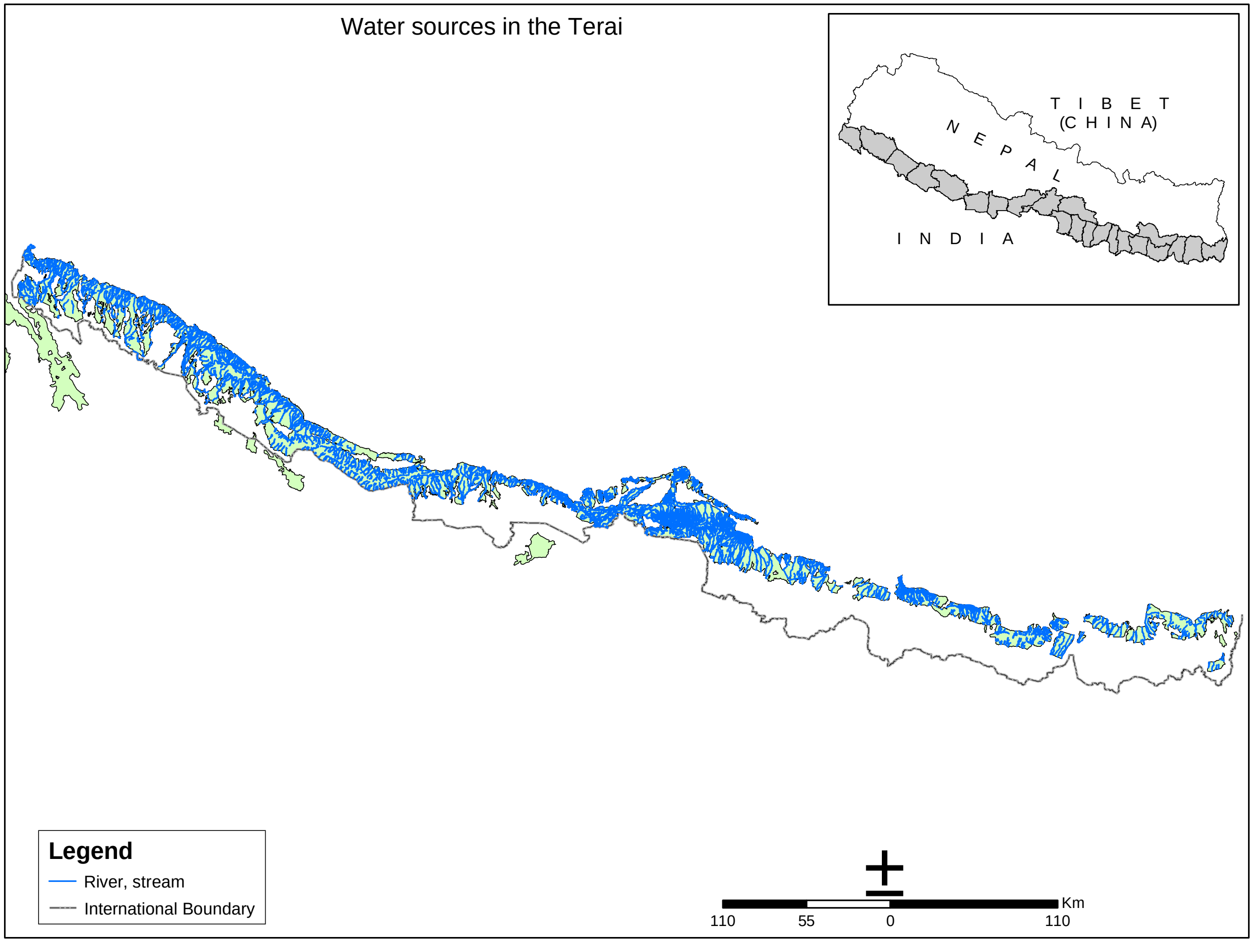


Figure 4. Distribution of water source (streams and rivers) in the Terai

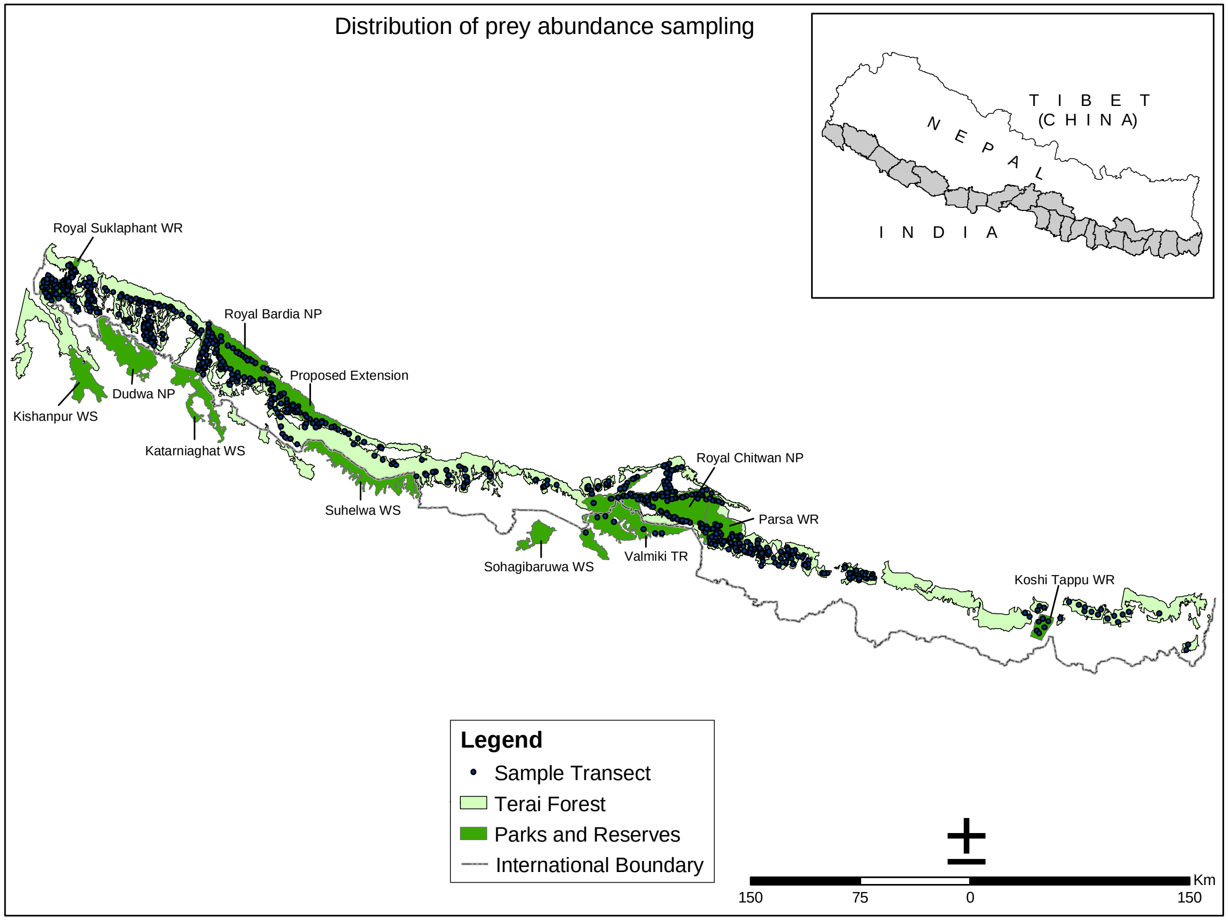


Figure5. Sampling distribution for prey abundance study in the Terai

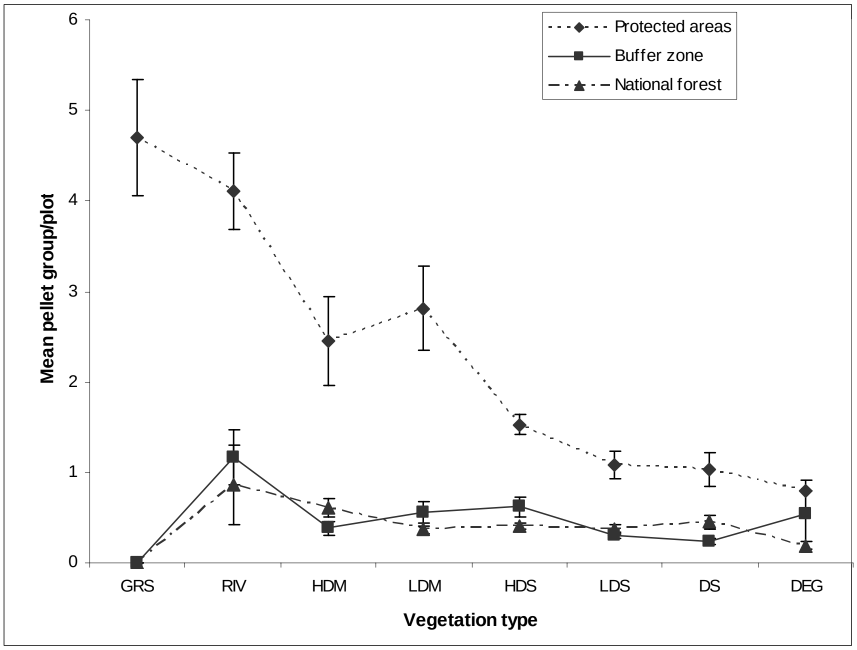


Figure 6. Distribution of pellet groups (± SE) in different vegetation types and forest management categories; (GRS = grassland, RIV = riverine forest, HDM = high density mixed forest, HDS = high density sal forest, LDM = low density mixed forest, LDS = low density sal forest, DS = dry sal forest, DEG = degraded forest)

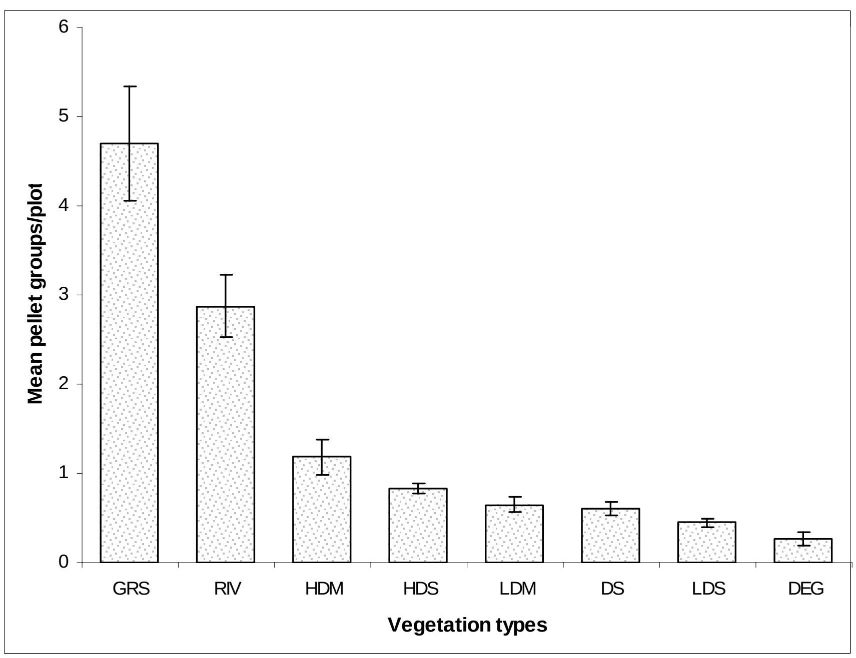


Figure 7. Distribution of pellet groups (± SE) in different vegetation types; (GRS = grassland, RIV = riverine forest, HDM = high density mixed forest, HDS = high density sal forest, LDM = low density mixed forest, LDS = low density sal forest, DS = dry sal forest, DEG = degraded forest)

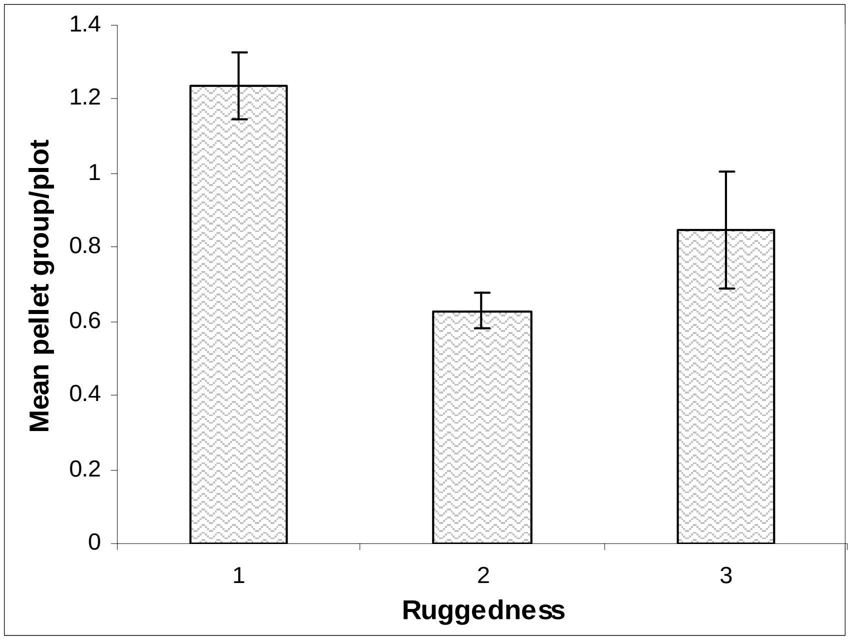


Figure 8. Pellet group abundance (± SE) in different ruggedness levels

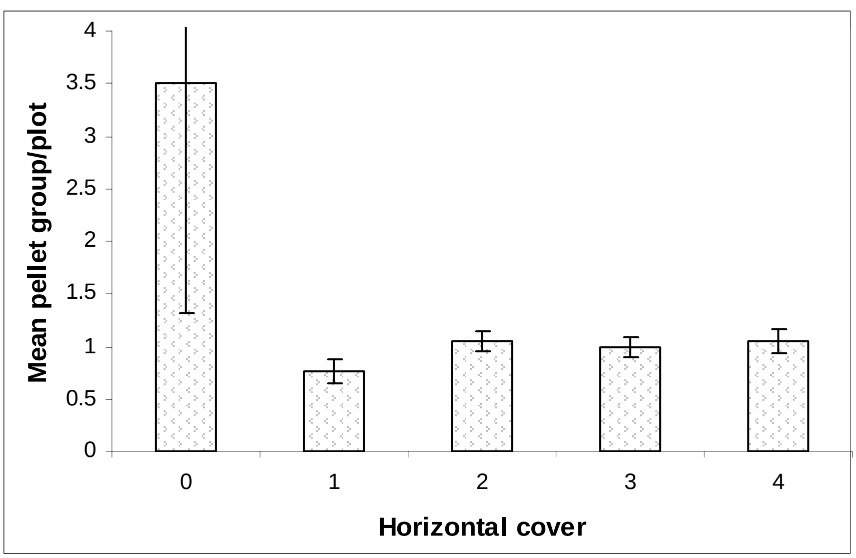


Figure 9. Pellet group abundance (± SE) in different horizontal cover categories

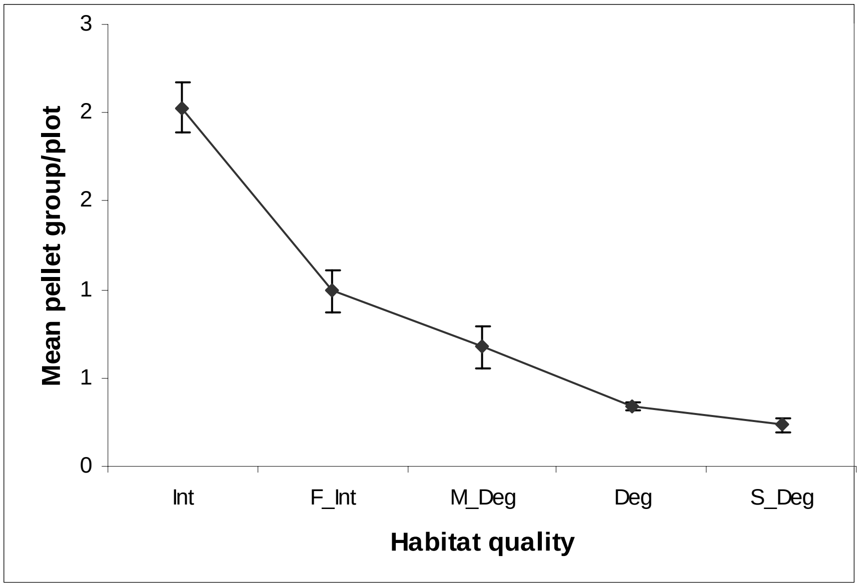


Figure 10. Pellet group abundance (± SE) in different habitat quality. (Int = intact, F_Int = fairly intact, M_deg = moderately degraded, Deg = degraded, S_Deg = severely degraded)

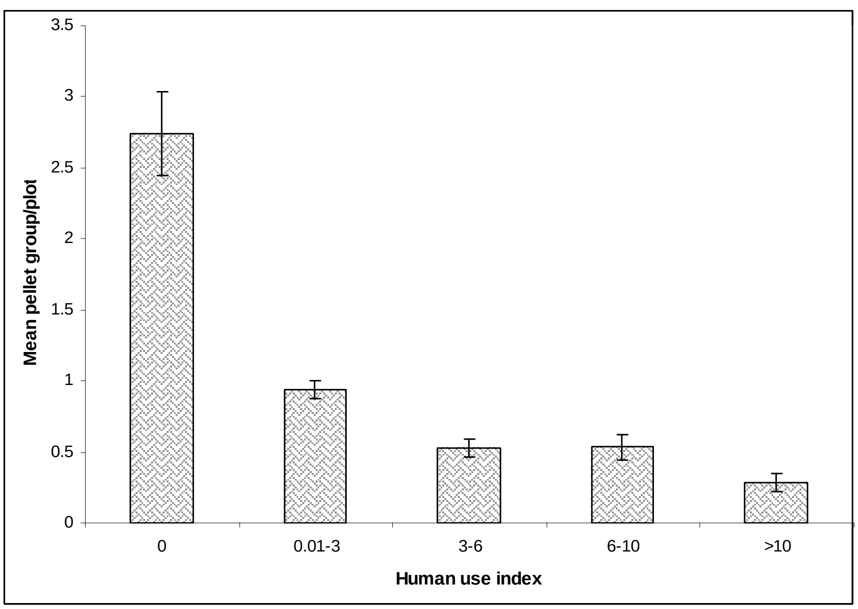


Figure 11. Mean pellet group abundance (± SE) at different level of human disturbances

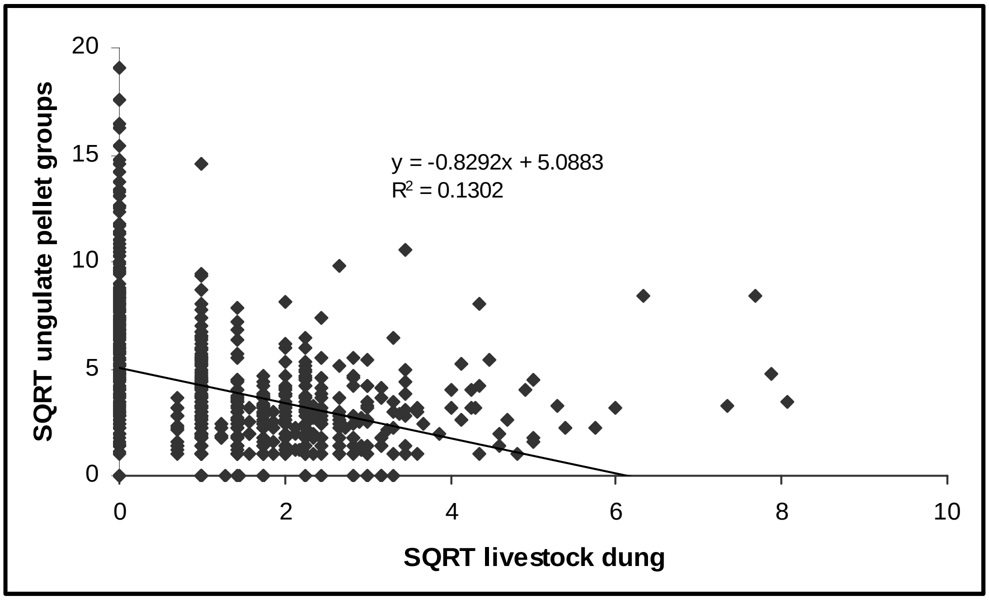


Figure 12. Distribution pattern of wild ungulate pellet groups and livestock dung

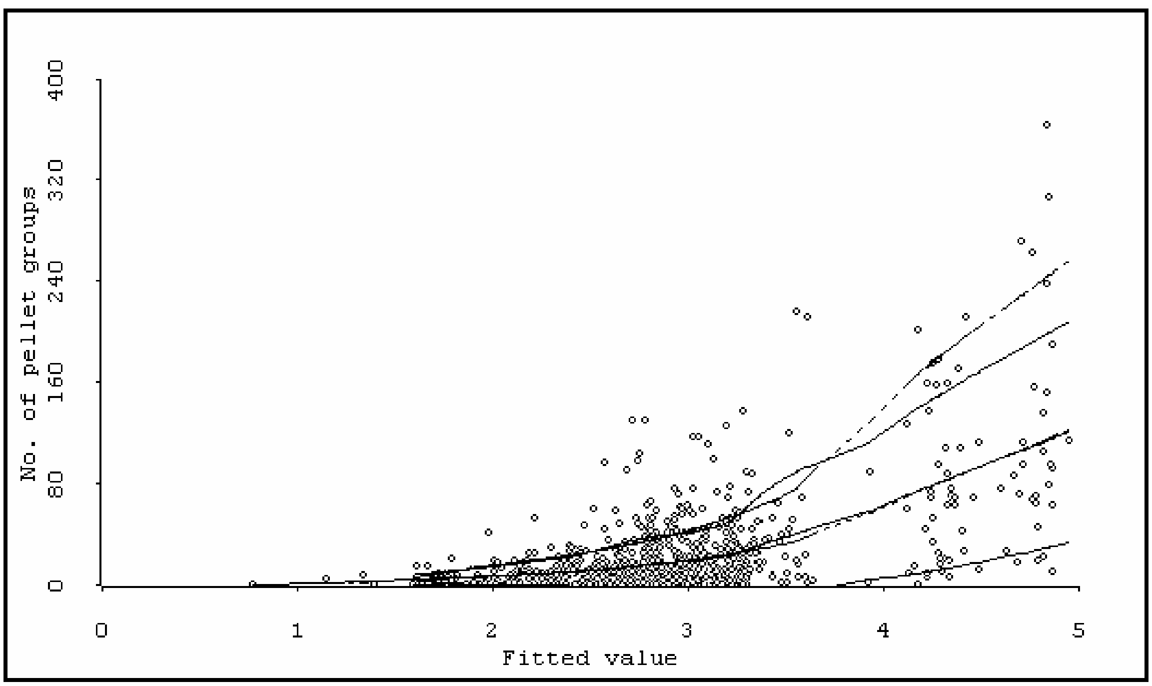


Figure 13. The mean functions from the data (solid line) and model (dashed line) matched very well. The variance function from the model, however, appeared to give variances that are a bit too large for the higher number of pellet groups.

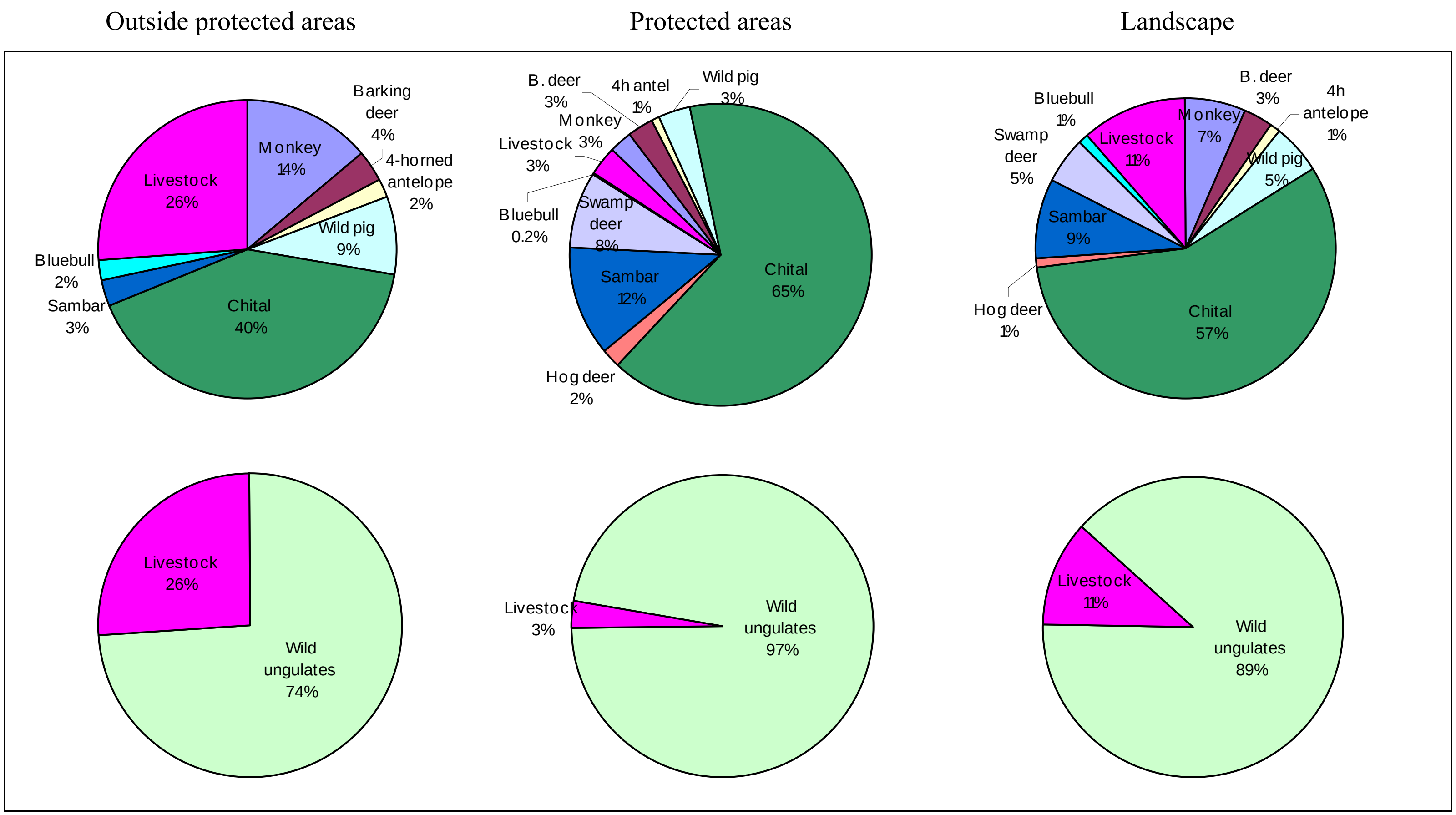


Figure 14. Ungulate species composition in the Terai

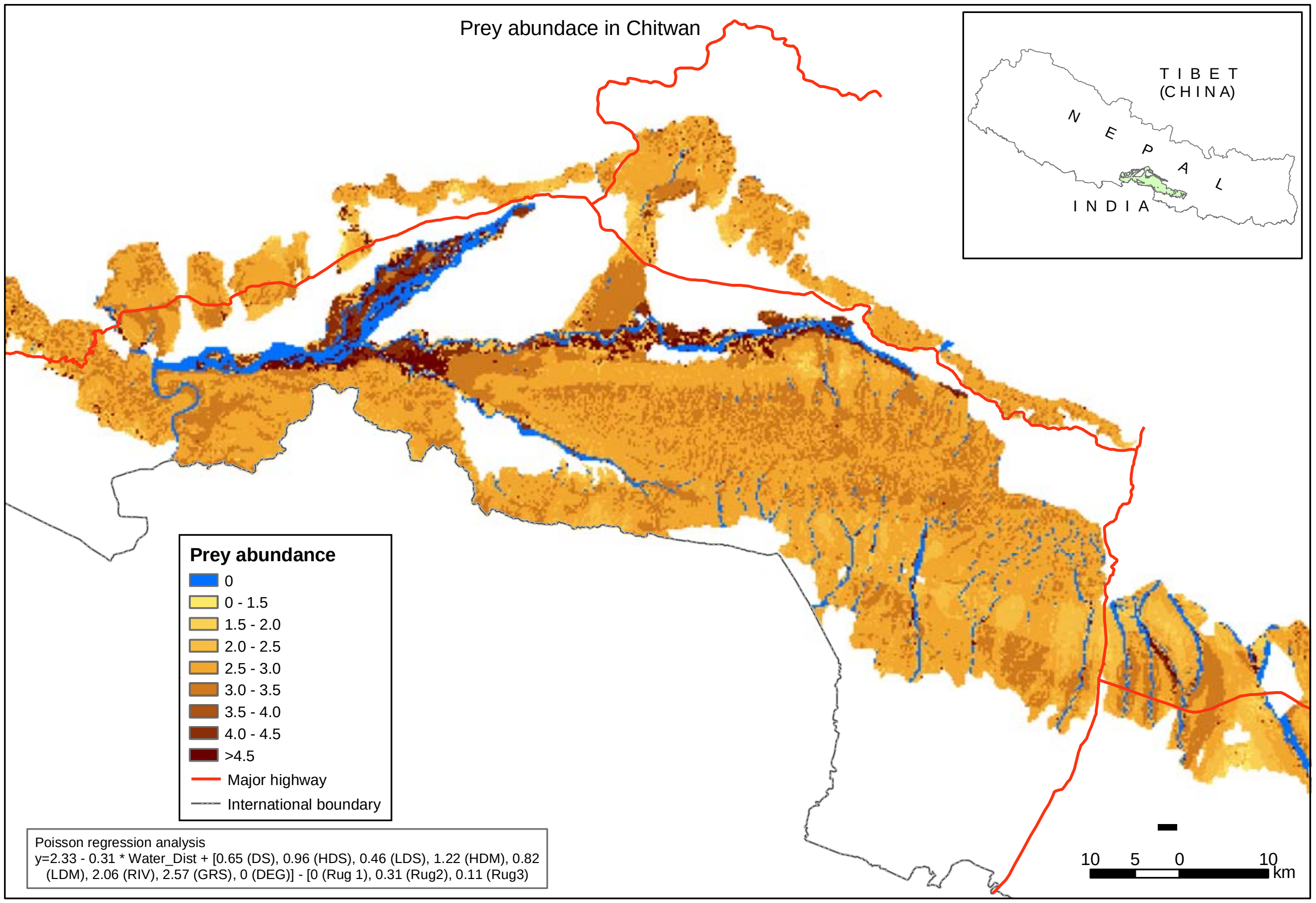


Figure 15. Tiger prey abundance in the Terai landscape (a zoom-in view of Chitwan)

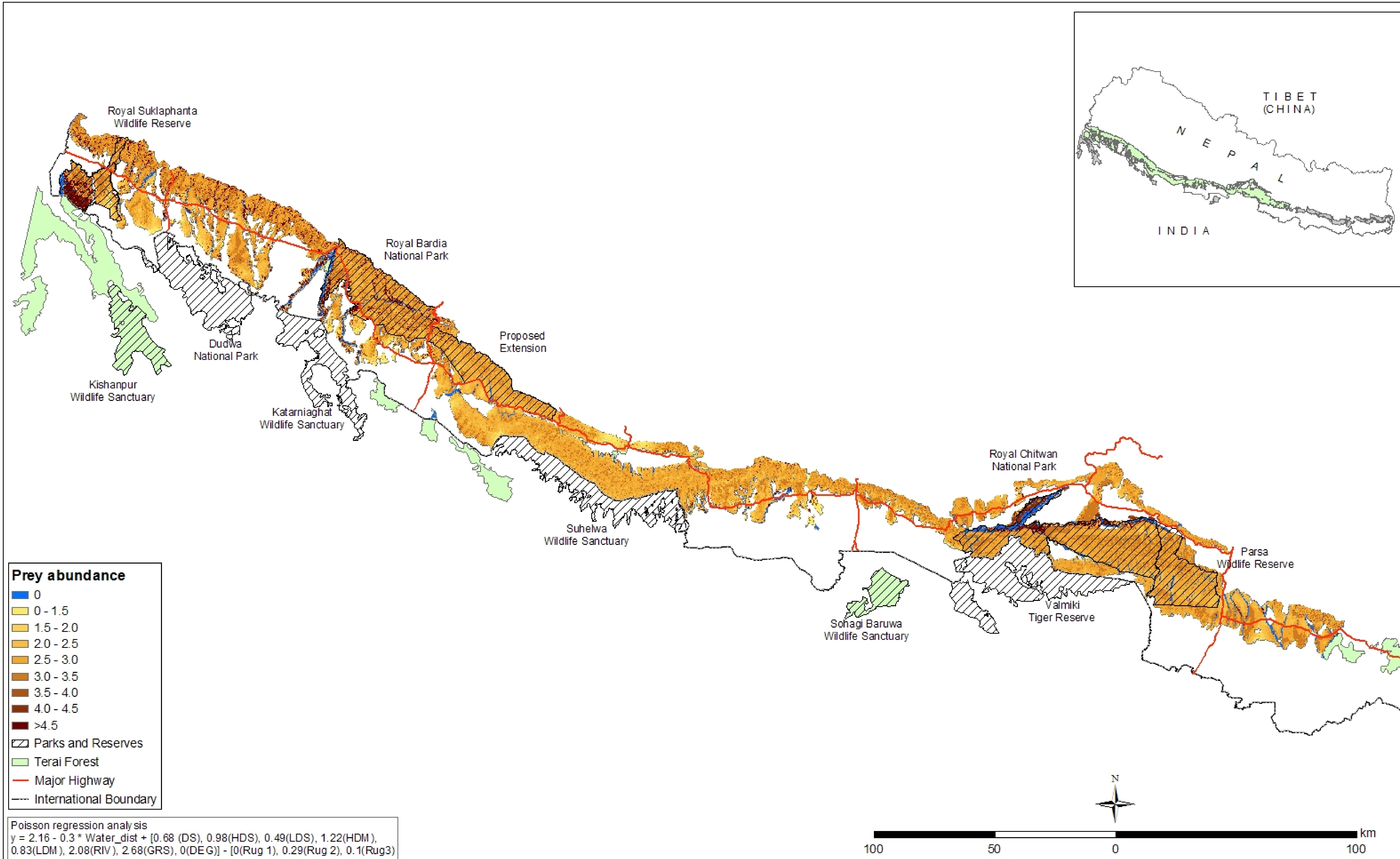


Figure 16. Tiger prey abundance in the lowlands Terai of Nepal

Vegetation Cover Classification of the Southern Lowlands (Terai) of Nepal: Identifying Priority Areas for Conservation

ABSTRACT

Landscape conservation is necessary for long term conservation of many wide ranging large mammals such as tigers (*Panthera tigris)* and other large mammals. Effective conservation strategies at the scale of eco-regional conservation programs require spatial planning that is most conveniently organized in a geographical information system (GIS). Land cover maps, particularly vegetation maps and land configuration, is fundamental to developing a conservation strategy. Satellite remote sensing technology offers a significant amount of information for landscape conservation at low cost for mapping landscape patterns and monitoring change detection. A vegetation cover map that is useful for biodiversity planning is not available for the southern lowlands (Terai) of Nepal. The purpose of this study was to classify vegetation using satellite imagery and use the results to identify priority areas for conservation in the Terai. Vegetation classification of five LANDSAT ETM+ scenes were done using a hybrid approach that included both unsupervised and supervised classification algorithms. Sal forest (58%) is the dominant vegetation cover type in the Terai. Riverine forest and grasslands (12%) were primarily restricted to protected areas. The overall thematic accuracy of classification was 82.2%. Seven conservation priority areas were identified based on their role in connectivity. This classification provides baseline spatial information for landscape conservation and future vegetation monitoring and change detection that occur in response to on-going conservation and management interventions.

INTRODUCTION

The southern lowlands, or Terai of Nepal, is a mosaic of dry and moist deciduous forest interspersed with tall grasslands. It is one of the premier habitats in Asia for large mammals such as tiger (*Panthera tigris*), greater-one-horned rhinoceros (*Rhinoceros unicornis*), Asian elephant (*Elephas maximus*), sloth bear (*Melursus ursinus*), and many ungulate species [e.g. chital (*Axis axis*), sambar (*Cervus unicolor*)]. Extensive conversion of forests into agricultural land beginning in the early 1950s brought about a dramatic change in the entire Terai landscape. It is estimated that between 1954 to 1985 about 104,000 ha of forest were cleared under a human settlement program (HMG/Nepal 1988). The pace of deforestation accelerated during the last six years of this period; about 22,700 ha were legally converted to non-forest land between 1979 and 1985. Approximately the same amount of forest was lost to illegal squatters. At present, the Terai covers about 23% of the total land area of Nepal and it is the most densely populated region supporting nearly 50% of the country's 23.2 million people (CBS 2001). High human density occurs because the Terai is the most important land in the country for agricultural production due to high fertility of the soils. In addition, the region has comparatively better infrastructure (e.g. roads and communications) than in the mountainous regions. Dependency of people on forest resources for their livelihood has also put extensive pressure on the remaining forest. Forest quality continues to be degraded, particularly in national forests, but in a few places community forestry projects and forest restoration are increasing forest integrity on a local basis.

Conversion and degradation of forests in the Terai have had adverse effects on many wide-ranging large mammals (e.g. tigers, rhinos, and elephants) in Nepal. Pressure from immigration into the lowlands from the middle hills and the growing human population continue to place heavy demands on forest resources. Impacts of change in land use extend far beyond the boundaries of converted land. For example, loss of connectivity and corridors has divided populations of large mammals into small units that are under increased threat of reduced long term viability. The need for re-establishment of connectivity and landscape scale of conservation is widely recognized (Beier 1993; Seidensticker et al. 1999; Johnsingh & Negi 2003). Effective conservation at this scale necessitates working together with stakeholders to seek a balance between maintaining the natural state of land area and resource needs of local people. To address this issue, His Majesty's Government of Nepal with the support of the World Wildlife Fund (WWF) and other stakeholders (including the University of Minnesota) initiated the Terai Arc Landscape Conservation Project (TAL) in 2001. TAL is a Terai-wide landscape conservation program. This is a long term initiative with a goal of linking 11 trans-border protected areas between Nepal and India to support eco-regional conservation and specifically to maintain a viable population of large mammals. It encompasses a matrix of about 49,500 km^2 that includes both forested and non-forested areas in Nepal and India. Broad success of community forestry in Nepal provides an opportunity for restoration and management of existing forest to increase their quality. This effort is being undertaken in a participatory framework with local, national, and international stakeholders.

Effective conservation strategies at the scale of eco-regional conservation programs like TAL require spatial planning that is most conveniently organized in a geographical information system (GIS). The base map for such a spatial information system is a cover map of the study area. It is almost impossible to acquire such information purely on the basis of field assessment. Satellite remote sensing technology offers a tremendous wealth of information on biophysical characteristics of large areas and is a suitable solution for mapping landscape patterns and processes at a relatively low cost (Pedroni 2003; Lo & Choi 2004). A land cover classification and condition data layer is a basic data layer for biological analysis and is useful for a variety of land management needs that can best be generated through remote sensing data. Combining this data layer with other economic, social, and ecological data provides the basis for landscape scale analysis and planning. The purpose of this study was to classify vegetation using satellite imagery and use the results to identify priority areas for conservation in Nepal's southern lowlands.

Background to Vegetation Classification

Determining land cover classes from remote sensing data is based on the different reflectance properties of vegetation types and other land features. The process of classifying cover can be easy if classes have dissimilar reflectance such as water and bare ground or forest and grasslands, but it can be quite difficult when very different cover types have the same reflectance properties such as corn fields and tall grass. Because the goal is to minimize within-plant association variance, while maximizing between-plant association variance, higher resolution is not inherently better. It is important to seek the scale of spectral wavelengths that facilitate discriminating vegetation cover types.

Spectral response of vegetation varies depending on a complex mixture of vegetation factors such as leaf surface, area, and structure, phenological state, canopy structure, as well as ground surface structure, understory components, stand density, and crown size (Treitz et al. 1992; Fuller et al. 1997; Nagendra 2001). The LANDSAT 7 Enhanced Thematic Mapper Plus (ETM+) data presents the best combination of spatial resolution and spectral information for land cover classification. The data have eight spectral bands with different spatial resolutions: panchromatic (band 8) has a spatial resolution of 15 m, thermal (band 6) has a resolution of 60 m; visible (bands 1, 2, 3), near infrared (band 4), middle infrared (band 5), and far infrared (band 7) bands have 30 m resolution. There is strong reflectance of vegetation in the visible red (0.63 to 0.69 μm), near-infrared (0.77 to 0.9 μm), middle-infrared (1.55 to 1.75 μm), and thermal band (10.4 to 12.5 μm) portion of the spectrum. Between class separability of vegetation cover is enhanced by the variable sensitivity of vegetation to spectral response in the red spectrum due to chlorophyll concentration and that in the near-infrared spectrum due to leaf area index (ratio of the total area of all leaves on a plant to the area of ground covered by the plant) and green vegetation density. In general, greater canopy closure reflects greater amount of near-infrared energy (Jensen 1996). Hence, red and near-infrared bands are considered well suited for vegetation type discrimination as they contain > 90% of the information relating to vegetation (Baret & Guyot 1991; Bannari et al. 1995).

Some radiometric bands are problematic during image interpretation and when mosaicking 2 adjacent scenes from different dates because they are more affected by atmospheric noise arising from absorption and scattering due to gases and aerosols. The net atmospheric effect is positive at shorter wavelengths (<0.7 μm) where scattering in the atmosphere is dominant whereas it is negative at longer wavelengths (>1.0 μm) where absorption in the atmosphere is predominant (Myneni & Arsrar 1994; Campbell 1996). The visible blue band (0.45-0.52 μm) and the visible green band (0.52-0.60 μm) in the electromagnetic spectrum of an image are likely to have greater atmospheric noise and lower vegetation spectral response (Campbell 1996). Hence, effective ability of these bands to discriminate species or vegetation cover type is poor.

A land cover map for the Terai that is useful for biodiversity planning is not available in Nepal. Previous forest cover maps primarily focused on forest stand and harvest. Furthermore, an updated map that incorporates recent changes in landscape configuration is critical to planning a conservation strategy for TAL because land use and land cover has changed significantly in the past decade. In addition to cover classification, remotely sensed data also provide a "bird's eye view" on landscape configuration revealing gaps and corridors that are crucial conduits for movement of animals between populations. Information on landscape geometry (e.g. corridor width, shape, topological relationships) are fundamental to developing an overall conservation strategy for landscape conservation like TAL and for identifying specific priority areas. For species level analysis and conservation planning, cover maps based on remote sensing are useful for developing models that predict species distribution patterns (see Chapter 1). I analyzed five multi-spectral LANDSAT 7 ETM+ scenes from 2001 to create a land cover and forest quality classification of the Nepalese lowlands and used this product to identify priority areas for immediate conservation actions in the Terai.

STUDY AREA

The focus of this study was the forested area in the southern lowlands of Nepal. The coverage of the 5 LANDSAT 7 ETM+ scenes extended from the country's western border to Morang District in eastern Nepal. It covered an aerial east-west distance of about 800 km and an area of approximately 13,500 km^2. The study included 3 ecological zones on the southern flank of the Himalayas: Siwalik Range, inner Terai composed of "dun" valleys, and the outer Terai. This lowland ecosystem lies along the northern border of the Gangetic Plain and covers 27% of the total land area of Nepal (Anon 1994). Elevation ranges from 60 to >1000 m. The inner Terai "duns" are elongated valleys enclosed between the Siwalik and Mahabharat mountain ranges. In the outer Terai, and the inner dun valleys, rich alluvial habitat characterized by tall grasses was once widespread but is now localized. These grasslands support the world's highest density of tigers.

The Siwaliks are comparatively dry and fragile and contain permeable geophysical structure and few permanent water sources except the large rivers that cut through this range. Most of the streams and rivers are seasonal. At the foot of the Siwaliks is a porous zone of boulders and gravel called the "Bhabhar". In this region, water flows underground to reappear at the surface 5-10 km south in the Terai where the Bhabhar transitions to the alluvial Gangetic plain. In the dry season surface water does not flow or is very limited in the Bhabhar; lack of water restricts human settlements in this porous outwash zone. The Gangetic Plain is low flat land characterized by rich alluvial soil and a high water table.

The natural vegetation in the study area broadly comprises of a mosaic of dry and moist deciduous forest, scrub and alluvial grasslands. The vegetation in the Siwaliks corresponds to upper tropical level described by (Dobremez 1976), the tropical and sub-tropical hill sal (*Shorea robusta*) forest noted by (Stainton 1972), and the north tropical dry deciduous forest identified by (Champion & Seth 1968). Considering both biogeographic and conservation values, the study area corresponded to three eco-regions proposed by (Wikramanayake et al. 2001) : (1) Upper Gangetic Plains moist deciduous forest, (2) Terai-Duar savanna and grasslands, and (3) Himalayan sub-tropical broadleaf forest. The Terai-Duar savanna and grasslands are listed among the 200 globally important areas, due to the co-occurring large mammal assemblage. Vegetation in the Terai is characterized by subtropical moist deciduous forest with tall grassland that is similar to the North Indian Moist Deciduous Forest subtype of Champion & Seth (1968). The sal forest is the ecologically characteristic climax vegetation of the Terai (Stainton 1972; Dobremez 1976). Natural and physical forces such as floods, fires, erosion, and soil aridity contribute to a continually changing mosaic of grasslands, mixed deciduous, dry-thorny and riverine forests in various stages of succession in the Terai.

The Siwalik Range contains dominant mature sal forest on dry, deeply eroded upper hill slopes, and Chir pine (*Pinus roxburghii*) along the ridge tops above 800 m. Some areas have thorny scrub forest with stunted sal, *Anogeissus latifolia*, *Buchanania latifolia, Diospyros tomentosa, Bassia latifolia, Schleichera oleosa, Carissa carandas* and a palm species (*Phoenix acaulis*) forming the understory. The sloping upland benches that lie between the Siwaliks and the Terai are composed of open sal forest with tall grass understory. Sandy river courses dissect the sal and mixed deciduous forest along the broad, sandy river courses that drain the hills. The southernmost flood plain is composed of a dynamic interspersion of riverine forests, tall grasses, and broad, sandy riverbanks. Sal forest is dominant intermixed with Terminalia tomentosa, T. bellerica, T. chebula, Dillenia pentagyna, Careya arborea, Semecarpus anacardium. Riverine forest is composed of *Dalbergia sissoo*, *Acacia catechu*, *Trewia nudiflora*, Ehretia laevis, Bombax ceiba, Ficus spp. The floodplains are characterized by grassland composed of Saccharum spontanium, S. bengalensis, Narenga porphyrocoma, Imperata cylindrical, Themeda villosa, etc. Outside the protected areas most of the rich alluvial land that can support high diversity of vegetation and diverse fauna have already been cultivated.

MATERIALS AND METHODS

Five LANDSAT 7 ETM+ scenes with systematic level of correction (L1G) were used for mapping vegetation cover classification of Nepal's Terai because this imagery provides high resolution image information of the Earth's surface, has more radiometric data and an appropriate resolution for large scale analysis. All the scenes contained less than 10% cloud cover and were from February-March 2001 except one which was from Feb 2000 (Fig. 1). The data acquired were a level-1G product which was geometrically (systematically) corrected. I verified that the geometrically rectified product was accurate to approximately 30 m resolution.

Image Processing

I used ERDAS IMAGINE 8.7 (Leica Geosystems GIS & Mapping LLC 1991-2003), for image processing and ArcGIS 8.3 (Environmental Systems Research Institute 1999-2002), ArcView 3.3 (ESRI 1999-2002) for final map preparation. All five scenes which are referred to as 1 to 5 from west to east (Fig. 1) were clipped to include only the southern lowlands of the Terai because this study focused on areas supporting large mammal populations.

Classification consisted of a multiple step process (Fig. 2). For the initial unsupervised classification, no image processing was done and all bands were used without radiometric calibration. This first step revealed general patterns of variation and allowed me to identify potential problems where vegetation classes were difficult to separate.

Radiometric calibration was done subsequently to alleviate the external variations to increase the clarity and sharpness of the image that enhanced the spectral features of vegetation cover (Pons & Solé-Sugrañes 1994). Normalization of noise arising from atmospheric effect and illumination was done by converting the digital number (DN) to at-satellite radiance units using the information in the header file such as MIN and MAX Radiance values that accompanied the image (Markham & Barker 1986; Richards & Jia 1999; Huang et al. 2001; Chander & Markham 2003). The following equation was used for the radiance unit conversion:

L_λ = "gain" * QCAL + "offset"

which is also expressed as:

$L_\lambda = ((LMAX_\lambda - LMIN_\lambda)/(QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN_\lambda$

Where,

L_λ = Spectral radiance at the sensor's aperture in $W/(m^2.sr.\mu m)$

"gain" = Rescaled gain (the data product "gain" contained in the Level 1 product header or ancillary data record) in $W/(m^2.sr.\mu m)$

"offset" = Rescaled bias (the data product "offset" contained in the Level 1 product header or ancillary data record) in $W/(m^2.sr.\mu m)$

QCAL = quantized calibrated pixel value in DN

$LMAX_\lambda$ = maximum detected spectral radiance for the scene that is scaled to QCALMAX in $W/(m^2.sr.\mu m)$

$LMIN_\lambda$ = minimum detected spectral radiance for the scene that is scaled to QCALMIN in $W/(m^2.sr.\mu m)$

QCALMAX = maximum quantized calibrated pixel value (DN=255) corresponding to $LMAX_\lambda$

QCALMIN = minimum quantized calibrated pixel value (DN=1) corresponding to $LMIN_\lambda$

For the final round of vegetation cover classification, optimum bands (“feature selection”) that enhanced the clarity of the scene and between-class separability were selected (Nagendra 2001). The Landsat 7 ETM+ bands 3 (Red), 4 (NIR), 5 (MIR), and 7 (FIR) in each scene were selected for the classification because of the strong reflectance of vegetation in these bands (Guerschman et al. 2003). Converting to radiance and eliminating bands also helped calibrate adjacent images by reducing atmospheric caused differences between scenes. For the final stage of supervised classification, human settlements and agricultural lands were masked out to avoid problem in discriminating grasslands and agricultural crops. For example, crops (e.g. wheat), fallow land, and grasslands at the forest edge had similar spectral responses.

Classification Process

For effective use of my vegetation cover map in developing a conservation strategy for the Terai landscape, it is important to define cover classes that will be meaningful for management. For example, the number of classes must be useful for conservation while at the same time provide the details sought by foresters and botanists by taking into account the inverse relationship between the “categorical” resolution (number of vegetation cover types) and the accuracy of classifications. I established a classification scheme that identified 9 vegetation cover classes (Table 1) that were familiar to Nepalese foresters and ecologists (Stainton 1972; HMG/Nepal 2002) and subsequently combined some classes to simplify the classification and increase its usefulness for conservation planning. I used a hybrid approach to classification by combining unsupervised and supervised classifications. This multi-step classification approach required extensive ‘ground truth’ efforts and ancillary data for correct identification of feature classes. My approach also takes into account a certain level of spectral variability between classes and within classes as it shares some characteristics of both the per-pixel and per-parcel classification.

Classification was a three stage process. At the first stage, unsupervised classification with ISODATA (Iterative Self-Organizing Data Analysis) algorithm was performed on scenes 1 and 5 to group pixels with similar spectral response into unique clusters of 60 different classes. I selected these two scenes because I had ancillary data and expert ground knowledge for these areas. Homogeneous clusters corresponding to a specific land use/land cover types were assigned appropriate vegetation cover classes based on ancillary data from aerial photographs, topographic maps, and expert ground knowledge. Clusters that contained mixed cover classes were extracted from the raw data and were re-classified with the same unsupervised algorithm into 10 or more classes to discriminate into specific cover types. Color composite images helped identify different vegetation cover types. They were assigned appropriate classes by swiping them on top of the raw scene. Next they were recoded and union overlayed on the main classified image. This process was repeated with other classes until I got a satisfactory classified map. Clusters of homogeneous reflectance were merged into 9 vegetation cover and 4 non-vegetation classes that were defined at the beginning of the study. Spectral signatures of each of the 13 classes from these two classified scenes were generated in the overlapping zone with the adjacent scenes 2 and 3. These signatures were compared to signatures from the same geographical locations in the unclassified adjacent scenes (2 and 3) and used to transform the data for the entire unclassified scenes. Using the transformed spectral signature the scenes were classified with supervised maximum likelihood algorithm.

In preparation for the second step, ground verification, samples for each class that represented homogeneous examples of these known land cover types were identified in each classified scenes and their coordinates were recorded. Samples were selected across the scene to include variability. Ground verification was carried out during March-April 2003 (same time frame when scenes were captured) for training sites. A notebook computer connected to a GPS was used to navigate to the ground training sites. Canopy cover, basal area, average height and composition of three strata (upper canopy, middle, and shrub vegetation) that characterized the class type were recorded. Ground vegetation, species composition, and percent cover were also estimated. In addition, at each site digital photos in the four cardinal directions were taken for reference during classification. Three discrete samples at 50 m interval were measured at each site for a total of 586 samples.

In the third stage of classification, cultivated lands and human settlements were masked out from each of the scenes because of the similar spectral response of crop and grassland. This masking removed the confusion and enhanced better classification of natural vegetation cover. From the training data set, 50% were randomly selected to create spectral signatures for each of the classes on each scene for classification; the remaining 50% were left for evaluation of the classification. Supervised classifications were performed using the maximum likelihood decision rule. This widely accepted algorithm for image classification basically assigns land cover categories to pixels with similar spectral values (Jensen 1996). Classes that contained mixed vegetation cover type based on ground truthing were extracted and reclassified into 5-10 classes by unsupervised ISODATA classification procedure. The resulting classes were assigned appropriate vegetation classes, recoded, and then incorporated into the main classified map. This procedure helped define different species assemblages and density based on features such as canopy, basal area, and vegetation classes (Table 1). For example, class category that had a canopy cover of 60 % or greater and 10 m^2 or greater basal area was classified as high density forest in respective cover type.

Geographical stratification of certain areas was done based on ancillary *a priori* data, that helped define misclassified areas to give it a meaningful class feature (Jensen 1996). Classes that could not be discriminated into different groups from extraction and reclassification but could clearly be reclassified by ancillary data (e.g. elevation or other spatial contexts) were stratified by masking them out and recoding them to the appropriate classes. For example, riverine forest on alluvial floodplains along the major rivers and mixed plantation forest in scene 4 were stratified and recoded accordingly to give them the right cover types. Stratification proved to be a simple but effective tool that can improve the classification accuracy.

Finally, all the classified scenes were projected to UTM zone 44 and WGS 84. They were mosaicked to give it a continuous scene and to make adjustments of frame edges and to eliminate geometric and radiometric seams. The salt-and-pepper appearance of vegetation cover map as a result of the pixel by pixel classification taking into account spectral variability during the classification procedure was resampled by using a 3 x 3 majority smoothing filter (Fig. 3).

Evaluation Process

A quantitative evaluation of classification accuracy is very important if remote sensing derived land use/land cover map are to be useful (Congalton 1991; Fitzgerald & Lees 1994; Janssen & Wel 1994; Lillesand & Kiefer 1994; Jensen 1996; Stehman 1997). The classification error matrix or contingency table summarizes the classification accuracy of each category by comparing the remote-sensing derived classification results with corresponding reference test information collected from the ground. The test data for the classification evaluation were independent of training samples. To obtain an adequate sample of test data I used the remaining 50% randomly selected ground control points (293 points) that were not used for classification and 772 transect locations where I previously recorded vegetation types during the tiger prey surveys. For non-vegetation classes (e.g. water, exposed surface) the test samples were taken from the false color composite (FCC) of the Landsat 7 ETM+ image of the study area and the ground knowledge base. The water bodies were clearly shown in dark blue color in the FCC image, while the exposed surface was light colored. The sample size of the test data was established based on what is statistically sound and what is practically attainable. As a good rule of thumb, a minimum of 75 to 100 samples for each land cover category is usually recommended to produce an error matrix for a landscape classification (Congalton 1991). A cluster-based sampling was done for accuracy assessment because the final map was resampled for spatial smoothing (3 x 3).

An error matrix was generated by listing the known cover types from the ground (in columns) versus the pixels actually classified into vegetation cover types (in rows). The classification was tested for its overall accuracy, user’s accuracy (error of commission), producer’s accuracy (error of omission), and Kappa statistics. The overall accuracy was calculated by dividing the sum of the major diagonal axis (i.e., number correctly classified pixels) by the total number of pixels included in the evaluation process. Producer’s accuracy was calculated by dividing the number of correctly classified pixel in each category (on the major diagonal) by the number of test set pixels used for that category (column total). This figure evaluates how well the test set pixels of the given cover type were classified. Likewise, user's accuracy was computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category (row total). This figure tests the probability of a pixel classified into a given cover type actually corresponds to the cover type on the ground.

Identification of Priority Areas for Conservation

Priority areas were identified based on geometry and spatial organization of land cover types. I looked for the following land characteristics favorable for corridors: natural forest cover wide enough to facilitate dispersal, connectivity and the nature of adjacent areas, particularly proximity to human activities (Innes & Koch 1998). Forest cover area, distance between two major habitat patches and forest quality were also assessed in these potential corridors to provide base line data to prioritize conservation efforts.

RESULTS

Vegetation cover classification maps were prepared at two levels, detailed and generalized, targeting different level of users. Detailed classification that includes 9 vegetation cover classes (Fig. 3) is targeted to research such as modeling tiger, elephant and ungulate distribution and for detailed site specific management plans or forest management plans. Sal forest (58%) at various density levels and surface ruggedness is the dominant vegetation cover type in the Terai (Table 2). Riverine forest occupies the smallest area (1.3%) in the landscape. Tall and short grasslands together comprise only 9% of the vegetation cover. Coverage of tall grassland is very small (2%) and is primarily restricted to protected areas. Degraded scrub forest is a substantial land cover type and it occurs only as a result of human activities. Scrub forest characteristically occurs at the forest edge.

Generalized classification identified high density (good) forest, low density (low to moderately degraded) forest, degraded forest, short grass (over grazed areas), and tall grass vegetation (Fig. 4). This classification is important for large scale conservation planning such as identifying priority areas and for communicating to local stakeholders and policy makers. Half (50%) of all forest types in the generalized classification system were High Density Forest Cover (Table 2).

Accuracy Assessment

The two final vegetation cover maps were compared with reference test data for vegetation classes from the ground and with FCC for other non-vegetation classes. Based on the overall accuracies, the hybrid classification was better than the simple ISODATA clustering. The overall thematic accuracy of the detailed classification was 82.2% (Table 3). The producer's and user's accuracy for low density sal forest was low. The overall thematic accuracy of generalized classification improved a little compared to that of detail classification (Table 4).

There are more errors of commission than omission in the degraded scrub class. They were primarily closely mixed with low density mixed forest class. The shrub and sparse canopy trees may give such reflectance to the sensor. This resulted in significant commission errors (77.54%) and made this class less accurate.

Radiometric correction helped discriminate spectral features of different vegetation cover classes with 89% overall accuracy. The overall accuracy of the thematic map improved to some extent when different class categories were collapsed. This implies that detailed classifications, although important to land managers, are likely to have lower accuracy.

Priority Areas

There were a number of large forest blocks in western Nepal. However, these were often only tenuously connected to each other by narrow forest corridors where forest lands were also highly degraded. Narrower corridors of highly degraded forest are qualitatively stronger barriers for movement and dispersal of tigers. Although I do not have quantitative data on the parameters that make corridors functional as dispersal habitat, it is still important to identify areas with the lowest probability of serving as dispersal corridors. Seven priority areas were identified as potential corridor habitat based on their importance in establishing connectivity between habitat blocks (Fig. 5).

1. **Bandrekhal-Godavari**

   This corridor is located at the foot hills of the Himalayas in far western Nepal (Fig. 5). Settlement and agricultural fields extend to the hills with highly degraded forest. The smallest gap of agricultural land separating forest cover was 380 m wide. The forest cover width at the narrowest end along the hilly slope was 1368 m. Land area south of this corridor is already converted into agricultural land and is the only existing link with forest cover that connects wildlife populations between Royal Suklaphanta Wildlife Reserve (RSWR) and Royal Bardia National Park (RBNP). This gap appears to be a strong dispersal barrier for tiger populations at present. Forest cover is composed of degraded quality with predominance of low density sal (17.6%), low density mixed (21%) and scrubs (14%) (Table 5). The narrow forest cover extends for a linear distance of 6 km. Reestablishment of connectivity in this bottleneck area is possible through restoration of foothills and hill slopes in partnership of local communities.

2. **Basanta North**

   This bottleneck area is on either side of the east-west highway in far western Nepal (Fig. 5). The forest near the main east-west highway is very narrow due to settlement on either side of the forest. The width of forest cover in this area ranges from 1.65 to 2.01 km and is under intensive human pressure. This corridor is composed mainly of scrub and stunted tree species favored by the dry soil and human activities. This area is a bottleneck for tiger populations occupying Basanta-Dudwa, RBNP and RSWR. Restoration of the forest in the bottleneck region and the foothills of the Siwaliks can re-connect these populations. Low density and degraded forest (43.8%) contribute to the bulk of the forest cover type (Table 5). The narrow width of forest cover extends 4.5 km along a north south direction. Elephants regularly use this corridor during their migration between these parks (Velde 1997).

3. **Basanta South**

There is a very tenuous link of forest cover between Basanta forest and Dudwa National Park (DNP) in India along the international boundary in far western Nepal (Fig. 5). Through the Basanta forest this connectivity continues to the Siwalik foothills that are subsequently linked to RSWR in the west and RBNP in the east. The width of the corridor under scrub and riverine forest together with river bed on either side of the international border ranges from 800 m to 1150 m. The north-south length of this corridor is about 5 km. Settlement and agriculture on both side of the Nepal-India international border have narrowed this corridor at least several decades ago. The forest type in Basanta South is predominantly low density forest (54%). Fragmented patches of riverine forest and grasslands (8%) (Table 5) along the river that runs alongside the international boundary sustain heavy cattle grazing pressure from adjacent settlements. Despite the tenuous corridor between Basanta South and DNP, the continuous existence of a small tiger population in Basanta forest since 1986 (Shrestha unpubl. data) indicates tigers disperse between these two habitat patches. Viability of this apparent sink population of tigers in Basanta solely depends on the continuous supply of individuals from the source population in Dudwa NP. Wild elephants have also been known to use this corridor as a migratory pathway between Dudwa, Bardia, and Suklaphanta. Grasslands at the edge or in the interior part of the forest are generally overgrazed by domestic livestock. Re-establishing the connectivity between DNP and Basanta forest requires extensive community restoration on both sides of the international border.

4. **Bardia_Katarniaghat**

This north-south corridor is about 9 km long and connects RBNP with Katarniaghat Wildlife Sanctuary in India. It runs along a major river system and is under extensive pressure from livestock grazing from nearby human settlements. Degraded scrub (19%) and low density mixed forest (23%) is predominant but this corridor also has isolated patches of riverine forest

(1.3%) and grasslands (19%) (Table 5). In this corridor, forest cover and river bed habitat varies from 1 to 3 km wide. Field studies (Gurung 2002) indicated that the corridor is currently used by tigers and rhinos. The characteristic dry soil in much of the area in this corridor presents a challenge in restoration. However, reducing grazing pressure and some enrichment plantation in cooperation with local communities would help restore the connectivity.

5. **Shamshergunj**

This corridor is the connecting link for wildlife populations between RBNP and Suhelwa WS in India. In this corridor, the narrowest width of forest cover combined with river bed habitat is 3.35 km wide. Forest cover is under heavy pressure from cattle grazing. In addition, dry soil structure and rugged terrain of the foothills of the Siwaliks also affects forest cover. Low density mixed forest (27%) with some scattered sal (18%) and degraded scrub (9%) are the dominant forest types (Table 5). Human settlements along the river present barriers to dispersal and other movement of wild animals. Forest land adjacent to Shamshergunj corridor is known tiger breeding habitat. Breeding was validated in 2001 when the tracks of the female with cubs were discovered (Shrestha and Gurung pers. observ). Dry soil with deep ravines is the characteristic of the area and supports dry scrub vegetation type. However, patches of lush green forest in the gullies is also present. Reducing grazing pressure and collaborating with local communities to encourage them for restoration and forest management is likely to enhance the habitat quality.

6. **Butwal**

This gap creates a strong dispersal barrier between the Chitwan population and the western Nepal tiger population that is centered in Bardia. The narrowest corridor width is 500 m wide; it is bisected by the steep slopes of the gorge through which the Tinau River flows. The city of Butwal and the gorge create a strong break in the narrow forest corridor. The 20 km forest strip running along the Siwaliks to the west of Butwal is degraded owing to dry soil structure, rugged hilly slopes and human pressure. There has not been tiger sign recorded in this strip of forest west of Butwal in the past 10 years (J.L.D. Smith pers. comm.). Community forestry practices and government plantation forests south-east of Butwal City has demonstrated success in restoration of some of the areas. Therefore, high density sal forest comprise of 35% in this area (Table 5). Local communities have been gradually reviving the hill slopes west of the City along the highway. Further increase in community forestry programs and reducing human pressure on the forest for firewood, timber, and grazing are necessary. Encroachment to the north-east of the City needs to be controlled.

7. **Bagmati River**

   Habitat east and west of the Bagmati River is highly degraded owing to agricultural lands that extend to the Siwalik hills. Forest habitat exists on the hill slopes, but it is highly fragmented and of poor quality. Agriculture in this area, therefore, creates a strong barrier that has limited tiger dispersal between Chitwan complex and the eastern part of the country. Tigers were recorded east of this barrier as recently as 1994 (Smith pers. comm.). Since then, however, no tiger sign has been observed east of this barrier indicating extirpation of tigers from this area. Community forests in some areas in the eastern Terai and Siwaliks has been successful in restoring some habitats, however, it requires an extensive restoration programs to allow dispersal of tiger, if any, east of Bagmati River.

DISCUSSION

Classification and Analysis

Radiometric calibration and selection of spectral bands that carry most of the vegetation information helped discriminate spectral features of different vegetation cover types. Eliminating bands 1 and 2 reduced atmospheric attenuation among different scenes. Response from green biomass in the near infrared (band 4) portion of the electromagenetic spectrum varied in response to foliage content or LAI (Leaf area index) and was useful in differentiating species and vegetation associations (Taylor 1993;

Lillesand & Kiefer 1994; Jensen 1996). This classification was primarily focused on discriminating between sal and other species in the canopy vegetation type. Spectral properties of parcels of sal forest were distinct probably because of leaf biochemistry (thick and leathery). Presence of multiple vegetation strata in a forest had a higher spectral reflectance due to higher LAI this elevating it into high density category. For example, areas with dense sal seedlings/saplings with scattered canopy of sal trees were categorized as high density sal forest because of high LAI. Vegetation cover type with multi-layered structure is susceptible to problems of canopy overlap, often leading to confusion in interpretation (Nagendra 2001). There were several cases in our study where high density sal saplings, with or without canopy cover, had spectral characters similar to that of high density sal forest. They were assigned high density sal forest (Table 1). Similar cases occurred with high and low density mixed forests that had a dense regeneration layer of saplings. This commission of error of combining high density sal and high density of regenerating sal saplings is not a major problem from the conservation point of view because high density sal sapling cover requires no management action. This cover type is in the process of becoming high density sal forest. Several other confounding variables (e.g. differences in canopy structure, soil type and moisture, stand density, and ground cover) made the between-cover type separability more challenging and may have contributed to misidentification and error in classification (Treitz et al. 1992; Price 1994; Fuller et al. 1997).

Pixels containing mixtures or transition states in vegetation dynamics results in a confusing radiometric boundary between some vegetation classes due to similar spectral response (Pons & Solé-Sugrañes 1994). For example, some pixels classified as tall grass can also contain some shrubby vegetation that has similar spectral reflectance. For example, an association of *Woodfordia fruticosa* and *Coelobrookia oppositifoia* along river banks outside protected areas was usually misclassified as tall grass. Both are shrub species with long branches originating from a main stem at the base and with smaller leaves producing a reflection similar to grass. Furthermore, this association may contain clusters of grass species such as *Saccharum spontaneum*. A similar confusion occurred in the classification of short grassland and agricultural crops or fallow land. I separated short grass from agriculture by masking out human settlements and agricultural lands based on visual interpretation of aerial photographs. A third problem area was the classification of riverine forest as mixed deciduous forest. Its proper classification presented a challenge even with several extraction and reclassification attempts. However, forest stands in the alluvial floodplain along the river (low elevation with proximity to water) with low human disturbance is unmistakably riverine forest. Other ancillary data in addition to visual interpretation and aerial photographs are very important in vegetation cover classification. Errors of commission can be corrected by stratified classification with extensive ancillary and ground level information. I separated some confusing vegetation classes by geographical stratification using on-screen digitizing of the area of interest (AOI) to separate miss-classified areas and re-recoded them to assign an appropriate class.

In summary, my classification is simple and does not include an elaborate species classification. Therefore, using a single date LANDSAT 7 ETM+ image served well enough for the current purpose of classifying vegetation into broad categories of sal forest, mixed deciduous hardwood forest, and grassland. However, multi-date imagery could have assisted in separating communities of similar species based on phonological differences among species and communities (Shriever & Congalton 1993). In a heterogeneous forest, as the number of classes or species to be differentiated increases, the accuracy level decreases even with multi-date image. Thus, justification for the added effort and expense of using multi-date images largely depends on the categorical resolution needed, the degree of spectral similarity among vegetation classes and the accuracy level requirement (Nagendra 2001).

Implications of Vegetation Classification for Transboundary Conservation

This updated and accurate vegetation cover classification of the Terai is an important component of a spatial database. This spatial layer, together with other spatial data layers (e.g. land use, human demographic structure, livestock population, local socio-economics, community forest distribution, point information on biodiversity) can serve as a powerful tool for developing a conservation strategy and planning site specific management across the landscape. This base vegetation map is also important for evaluating management interventions. For example, effectiveness of forest restoration, community forestry, and programs to reduce livestock grazing can be evaluated by remote sensing change detection. Vegetation monitoring at high priority areas by change detection in vegetation cover and forest configuration is a rigorous unbiased monitoring tool (Innes & Koch 1998; Nagendra & Gadgil 1999)

Under the umbrella of TAL, project conservation organizations in Nepal and India are working together to restore degraded areas and establish connectivity to ensure long term survival of tigers and other large mammals. Restoration of priority areas will establish connectivity among many trans-boundary protected areas. This classification covered only Nepal's southern lowlands (Terai); a joint conservation workshop between the authorities of Nepal and India is needed to extend forest classification to the portion of TAL that belongs to India. Standardizing classification will facilitate management in trans-border areas where issues related to habitat restoration (e.g. improving connectivity and metapopulation structure of wildlife populations) are important.

Monitoring changes in priority areas is an important task for which satellite remote sensing is well suited. Data used in this classification are from 2001. Since that time, management efforts to establish community plantations and restore natural forests have been undertaken in key areas. For example, the corridor that connects Basanta forest to Dudwa National Park has been widened by establishing a community forest. Areas restored prior to 2001 also are present. Restoration of existing forest or establishing the structural and vegetation components of a corridor with plantation occurs rapidly. These restored areas and ongoing restoration are not well documented but can serve as test sites for developing change detection algorithms. In addition to identifying priority areas, products from this study will be used to help establish effective biodiversity conservation strategies and provide land cover data for elephant, tiger, and tiger prey abundance modeling of the TAL landscape.

LITERATURE CITED

Anon 1994. Deforestation in the Terai Districts 1978/89 - 1990/91. Forest Resources Inventory and Survey Project. Publication No. 60. Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Bannari, A., D. Morin, F. Bonn, and A. R. Huete. 1995. A review of vegetation indices. Remote Sensing Reviews **13**:95-120.

Baret, F., and G. Guyot. 1991. Potentials and limits of vegetation indices for LAI and APAR assessment. Remote Sensing of Environment **35**:161-173.

Beier, P. 1993. Determining minimum habitat areas and habitat corridors for cougars. Conservation Biology **7**:94-108.

Campbell, J. B. 1996. Introduction to remote sensing. The Guilford Press, New York.

CBS. 2001. Preliminary Results of Population Census 2001. Central Bureau of Statistics, Kathmandu, Nepal.

Champion, H. G., and S. K. Seth 1968. A revised survey of the forest types of India. Government of India, Manager of Publications, Delhi, India.

Chander, G., and B. Markham. 2003. Revised Landsat 5 TM radiometric calibration procedures and post-calibration dynamic ranges. SAIC/EDC/USGS.

Congalton, R. G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sensing of Environment **37**:35-46.

Dobremez, J. F. 1976. Le Nepal Ecologie et Biogeography. Editions du Centre Nationale de la Recherche Scientifique, Paris, France.

Fitzgerald, R. W., and B. G. Lees. 1994. Assessing the classification accuracy of multisource remote sensing data. Pages 362-368. Remote Sensing of Environment.

Fuller, D. O., S. D. Prince, and W. L. Astle. 1997. The influence of canopy strata on remotely sensed observations of savanna-woodlands. International Journal of Remote Sensing **18**:2985-3009.

Guerschman, J. P., J. M. Paruelo, C. Di Bella, M. C. Giallorenzi, and F. Pacin. 2003. Land cover classification in the Argentine Pampas using multi-temporal Landsat TM data. International Journal of Remote Sensing **24**:3381-3402.

HMG/Nepal. 1988. Master plan for forestry sector Nepal: Main report. Master Plan for Forestry Sector Project of His Majesty's Government of Nepal, Asian Development Bank, FINNIDA, Kathmandu, Nepal.

HMG/Nepal 2002. Forest and Vegetation Types of Nepal. TISC Document Series No. 105. Ministry of Forests and Soil Conservation, Department of Forest, HMGN/Nepal, Natural Resource Management Sector Assistance Programme (NARMSAP), Tree Improvement and Silvicuture Component.

Huang, C., L. Yang, C. Homer, B. Wylie, J. Vogelman, and T. DeFelice. 2001. At-Satellite reflectance: a first order normalization of Landsat 7 ETM+ images. Raytheon ITSS, EROS Data Center, Sioux Falls, SD.

Innes, J. L., and B. Koch. 1998. Forest biodiversity and its assessment by remote sensing. Global Ecology and Biogeography Letters **7**:397-419.

Janssen, L. L. F., and F. J. M. v. d. Wel. 1994. Acuracy assessment of Satellite derived land-cover data: a review. Photogrammetric Engineering & Remote Sensing **60**:419-426.

Jensen, J. R. 1996. Introductory digital image processing: a remote sensing perspective. Prentice Hall, Upper Saddle River, New Jersey.

Johnsingh, A. J. T., and A. S. Negi. 2003. Status of tiger and leopard in Rajaji-Corbett Conservation Unit, northern India. Biological Conservation **111**:385-393.

Lillesand, T. M., and R. W. Kiefer 1994. Remote sensing and image interpretation. John Wiley & Sons, Inc., New York.

Lo, C. P., and J. Choi. 2004. A hybrid approach to urban land use/cover mapping using Landsat 7 Enhanced Thematic Mapper Plus (ETMz) images. International Journal of Remote Sensing **25**:2687-2700.

Markham, B. L., and J. L. Barker. 1986. Landsat MSS and TM post-calibration dynamic ranges, exoatmospheric reflectance and at-satellite temperatures. EOSAT Landsat Technical Notes **1**:3-8.

Myneni, R. B., and G. Arsrar. 1994. Atmospheric effects and spectral vegetation indices. Remote Sensing of Environment **47**:390-402.

Nagendra, H. 2001. Using remote sensing to assess biodiversity. International Journal of Remote Sensing **22**:2377-2400.

Nagendra, H., and M. Gadgil. 1999. Satellite imagery as a tool for monitoring species diversity: an assessment. The Journal of Applied Ecology **36**:388-397.

Pedroni, L. 2003. Improved classification of Landsat Thematic Mapper data using modified prior probabilities in large and complex landscapes. Pages 91-113. International Journal of Remote Sensing.

Pons, X., and L. Solé-Sugrañes. 1994. A simple radiometric correction model to improve automatic mapping of vegetation from multispectral satellite data. Remote Sensing of Environment **48**:191-204.

Price, J. C. 1994. How unique are spectral signatures? Remote Sensing of Environment **49**:181-186.

Richards, J. A., and X. Jia 1999. Remote sensing digital image analysis: an introduction. Springer-Verlag, New York.

Seidensticker, J., P. Jackson, and S. Christie, editors. 1999. Riding the tiger: tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom.

Shriever, J. R., and R. G. Congalton. 1993. Evaluating seasonal variability as an aid to cover type mapping from Landsat Thematic Mapper data in the Northeast. Photogrammetric Engineering & Remote Sensing **61**:322-327.

Stainton, J. D. A. 1972. Forest of Nepal. John Murray, London.

Stehman, S. V. 1997. Selecting and interpreting measures of thematic classification accuracy. Remote Sensing of Environment **62**:77-89.

Taylor, J. E. 1993. Factors causing variation in reflectance measurements from Bracken in Eastern Australia. Remote Sensing of Environment **43**:217-229.

Treitz, P. M., P. J. Howarth, R. C. Suffling, and P. Smith. 1992. Application of detailed ground information to vegetation mapping with high spatial resolution digital imagery. Remote Sensing of Environment **42**:65-82.

Velde, P. T. 1997. A status report of Nepal's elephant population. Unpublished report. Page 50.

Wikramanayake, E. D., E. Dinerstein, C. Loucks, D. Olson, J. Morrison, J. Lamoreux, M. McKnight, and P. Hedao 2001. Terrestrial ecoregions of the Indo-Pacific: a conservation assessment. Island Press, Washington, D.C.

Table 1. Vegetation classification schemes and basic parameters of classification

No.	Cover type	Definition
1	Dry Sal Forest (DS)	Approximately >60% canopy in Bhabar or Siwaliks with some understory. Some areas in the Bhabar may contain dry grass on the ground layer. This cover type is typical and grows in areas with low water table. Composition: *Shorea robusta, Anogeissus latifolia, Lagerstroemia parviflora, Adina cordifolia, Cedrela toona, Albizzia lebbeck, Buchnania latifolia, Diospyros melanoxylon, Hymenodyction spp., Lannea coromandelica, Phylanthus emblica,* etc.
2	High Density Sal Forest (HS)	Sal forest with >60% canopy cover and >10 m^2 basal area. Usually, different layers of understory vegetation increase the Leaf Area Index (LAI). High density sal saplings also occur in this category; they have high reflectance due to higher LAI. They are normally distributed in low lying areas but small patches may occur in the Siwaliks. Composition: *Shorea robusta, Terminalia tomentosa, T. chebula, T. bellerica, Duabanga grandiflora, Lagerstroemia parviflora, Dillenia pentagyna, Careya arborea, Semecarpus anacardium*
3	Low Density Sal Forest (LS)	Sal species dominant but <60% canopy and <10 m^2 basal area with sparse understory layers. Generally has sparsely distributed sal trees with scrub in the ground layer. Composition: *Shorea robusta, Lagerstroemia parviflora, Holarhenna antidysenterica, Mallotus philippensis*
4	High Density Mixed Forest (HM)	Forest with mixed species composition >60% canopy and >10 m^2 basal area were categorized in this class. Sal constituted a small percentage in the overall composition in this cover type. *Terminalia tomentosa, Shorea robusta, Adina cordifolia, Syzigium operculatum, Albizzia sps., Ficus sps, Cedrela toona, Dysoxylon spp. Mitragyna parviflora*, etc.
5	Low Density Mixed Forest (LM)	Mixed species composition with sparse trees (<60% canopy and <10 m^2 basal area) and some scrub. *Anogeissus latifolia, Holarhenna antidysenterica*.
6	Riverine Forest (RF)	Forest along the flood plain composed of *Trewia nudiflora, Dalbergia sissoo, Acacia catechu, Baombax ceiba, Ehretia laevis, Gmelina arborea, Bombax ceiba, Maesa sps., Clerodendron viscosum, Coelobrookia oppositifilia, Murraya koenigii*, etc. SPACING
7	Short Grassland (SG)	Heavily grazed areas with very short grass ground cover.
8	Tall Grassland (TG)	Areas dominant with tall grassland and no soil exposure. Primarily found in protected areas. *Composition: Narenga porphyrocoma, Themeda arundinacea, T. villosa, Phragmites karka, Imperata cylindrica, Saccharum spp*, etc.
9	Degraded Scrub (DG)	Degraded scrubby area with very sparse trees. Primarily composed of *Lantana camara, Croton roxburghii, Holarhenna antidysenterica, Clerodendron viscosum, Carissa carandas.*

Table 1. Vegetation classification schemes and basic parameters of classification (contd..)

No.	Cover type	Definition
Non-forest class		
10	Water Body	All areas of open water including streams, rivers, lakes, and reservoirs.
11	Exposed Surface	Surface with no ground vegetation, sand banks along river, fallow land with no vegetation.
12	Cloud	There were very few clouds in scene 4, otherwise all other scenes were cloud free.
13	Shadow	Created due to sun angle or angle of the sensors when the image was taken. It is found primarily in the hilly terrain
Generalized vegetation classification		
1	High Density Forest (HD)	Includes DS, HS, HM, and Riverine forests
2	Low Density Forest (LD)	Includes LS, LM
3	Other Classes	As above

Table 2. Estimated area of vegetation cover types in the Terai

Detailed Classification			**Generalized Classification**		
Vegetation cover type	**Area (ha)**	**%**	**Vegetation cover type**	**Area (ha)**	**%**
Dry sal	349,646	17	High density forest	1,023,444	50
High density sal	476,268	23			
High density mixed	170,324	8			
Riverine	27,206	1			
Low density sal	368,271	18	Low density forest	591,665	29
Low density mixed	223,394	11			
Degraded scrub	255,719	13	Degraded scrub	255,719	13
Short grassland	139,672	7	Short grassland	139,672	7
Tall grassland	50,352	2	Tall grassland	50,352	2

Table 3. Error matrix of the detailed vegetation cover classification.

		Columns: Reference Test Data												
		DS	HS	LS	HM	LM	RF	SG	TG	DG	WA	EX	Sum	U.Acc (%)
Rows: Classified Data	DS	90	4	8	5	7	0	0	0	5	0	0	119	75.63
	HS	7	129	18	7	2	0	0	0	0	0	0	163	79.14
	LS	4	14	96	5	9	0	0	0	2	0	0	130	73.85
	HM	1	4	2	90	6	5	0	2	4	0	0	114	78.95
	LM	1	5	7	5	94	4	0	4	1	0	0	121	77.69
	RF	0	0	0	5	2	67	0	3	5	0	0	82	81.71
	SG	0	0	0	0	2	0	92	7	3	0	0	104	88.46
	TG	0	0	0	2	1	4	0	85	1	0	0	93	91.40
	DG	0	1	8	1	11	2	0	17	98	0	0	138	71.01
	WA	0	0	0	0	0	0	0	0	0	112	1	113	99.12
	EX	0	0	0	0	0	1	2	0	1	0	102	106	96.23
	Sum	103	157	139	120	134	83	94	118	120	112	103	1283	
P. Acc. (%)		87.38	82.17	69.06	75.00	70.15	80.72	97.87	72.03	81.67	100	99.03		
Overall accuracy (%)			82.2											
Kappa index = 0.80														

U. Acc. = User's Accuracy; P. Acc. = Producer's Accuracy; DS = Dry sal forest; HS = High density sal forest; LS = Low density sal forest; HM = High density mixed forest; LM = Low density mixed forest; RF = Riverine forest; SG = Short grassland; TG = Tall grassland; DG = Degraded scrub; WA = Water body; EX = Exposed surface

Table 4. Error matrix of the generalized vegetation cover classification

		Columns: Reference Test Data							
		HDF	LDF	GRS	DG	WA	EX	Sum	U. Acc (%)
Rows: Classified Data	HDF	414	45	5	14	0	0	478	86.61
	LDF	38	206	4	3	0	0	251	82.07
	GRS	6	3	184	4	0	0	197	93.4
	DG	4	19	17	98	0	0	138	71.01
	WA	0	0	0	0	112	1	113	99.12
	EX	1	0	2	1	0	102	106	96.23
	Sum	463	273	212	120	112	103	1283	
	P. Acc. (%)	89.42	75.46	86.79	81.67	100	99.03		
	Overall accuracy (%)		86.98						
	Kappa index = 0.832								

U. Acc. = User’s Accuracy; P. Acc. = Producer’s Accuracy; HDF = High density forest; LDF = Low density forest; GRS = Grassland; DG = Degraded scrub; WA = Water; EX = Exposed surface.

Table 5. Forest type coverage in seven conservation priority area

Forest type	Bandrekhal_God		Basanta North		Basanta South		Bardia-Katarn		Shamshergunj		Butwal		Bagmati	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
DS	2391.9	10.9	4014.8	15.5	2003.0	16.8	155.0	1.1	5421.3	21.0	4377.4	36.4	1017.6	7.61
HDS	2742.8	12.5	6550.0	25.3	1909.4	16.1	1234.0	8.7	2611.2	10.1	4237.0	35.2	5090.9	38.07
LDS	3842.3	17.6	4877.4	18.8	2561.5	21.5	1818.8	12.8	4728.3	18.3	517.6	4.3	1231.1	9.21
HDM	1324.6	6.1	728.1	2.8	324.6	2.7	780.7	5.5	2617.1	10.1	810.0	6.7	289.5	2.16
LDM	4573.3	20.9	5064.5	19.6	2584.9	21.7	3254.5	22.9	6848.2	26.5	426.9	3.5	473.7	3.54
RIV	0	0	2.9	0	0	0	184.2	1.3	0	0	2.9	0	736.9	5.51
SG	2198.9	10.1	1637.5	6.3	862.6	7.3	1228.1	8.6	271.9	1.1	231.0	1.9	932.8	6.98
TG	617.0	2.8	795.3	3.1	70.2	0.6	1412.3	9.9	64.3	0.3	5.9	0	64.3	0.48
DEG	3228.2	14.8	1394.8	5.4	1286.6	10.8	2704.8	19.0	2272.0	8.8	1304.2	10.8	1336.3	9.99
WAT	2.9	0	134.5	0.5	172.5	1.5	497.1	3.5	295.3	1.1	5.9	0	52.6	0.39
EXP	947.4	4.3	690.1	2.7	114.0	1.0	932.8	6.6	669.6	2.6	119.9	1.0	2146.3	16.05
Total	21869.3		25890		11889.4		14202.4		25799.3		12038.5		13371.88	

DS = Dry sal forest; HS = High density sal forest; LS = Low density sal forest; HM = High density mixed forest; LM = Low density mixed forest; RF = Riverine forest; SG = Short grassland; TG = Tall grassland; DG = Degraded scrub; WA = Water body; EX = Exposed surface

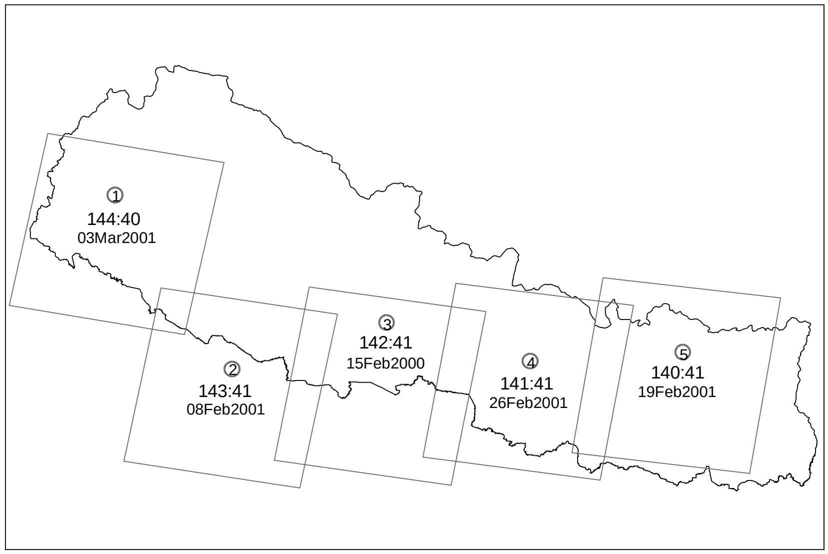


Figure 1. Arrangement and coverage of LANDSAT 7 ETM+ scenes in the Terai (Serial number for reference in circle with row and path and date of scene)

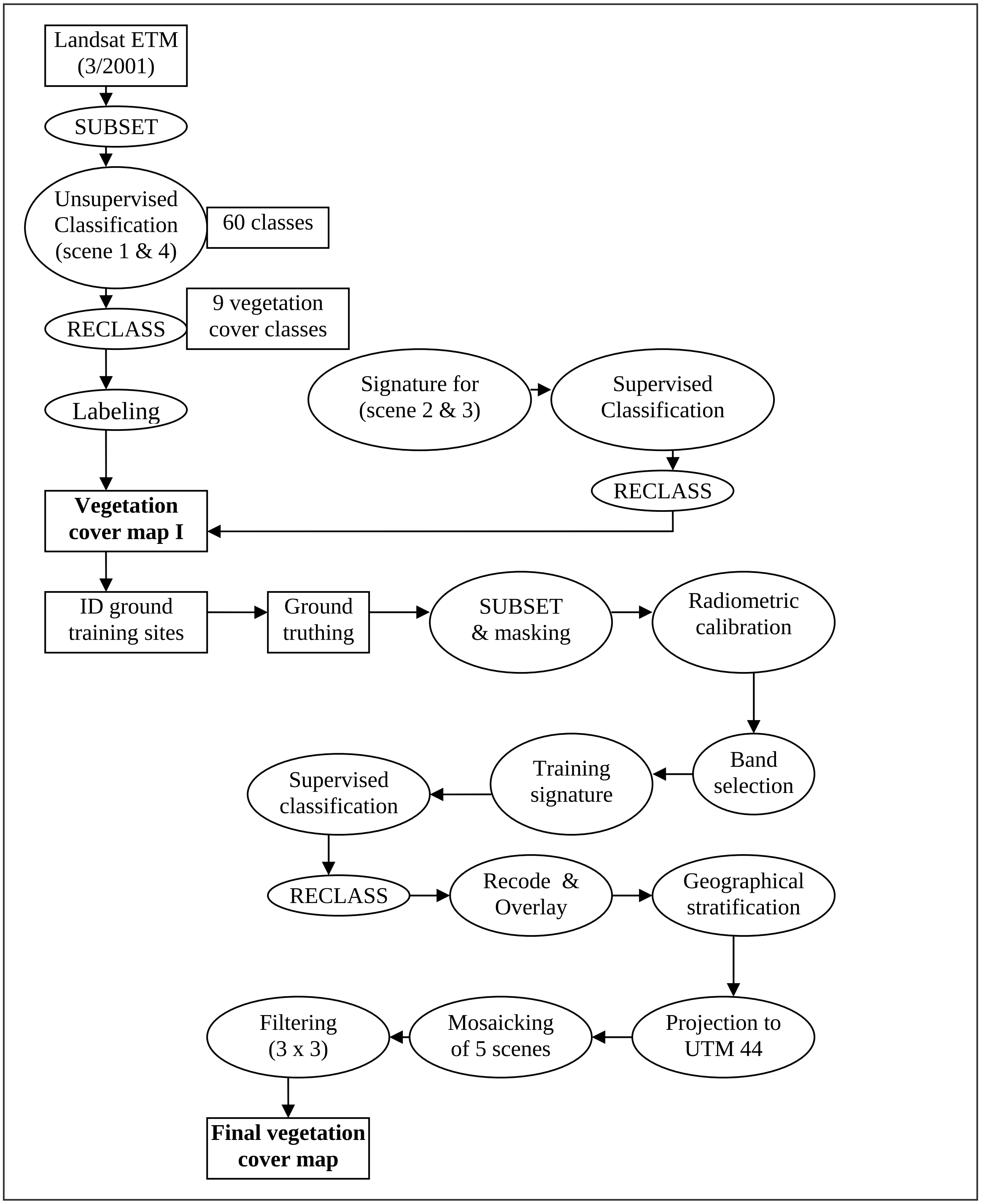


Figure 2. Flow chart of the vegetation classification process.

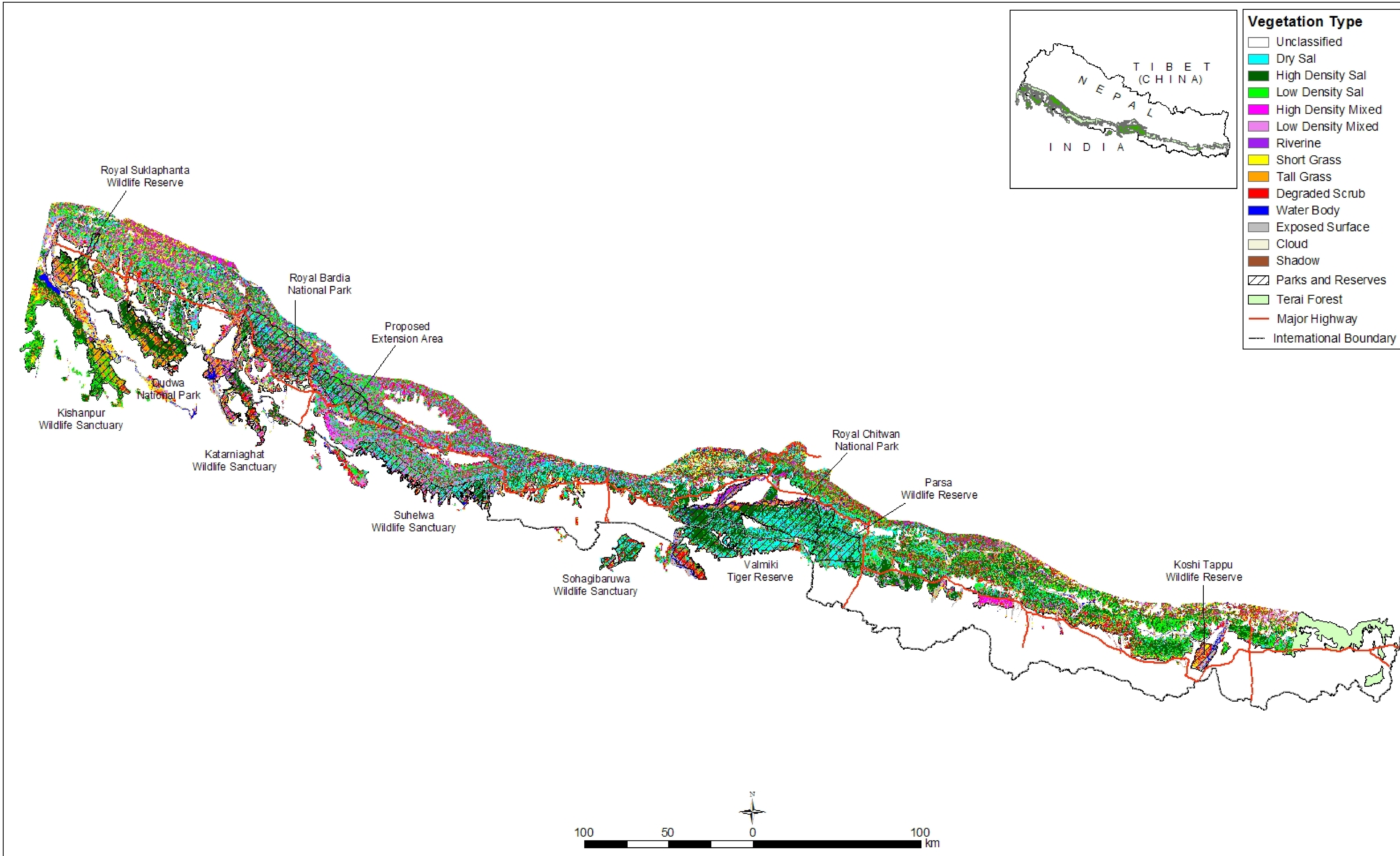


Figure 3. Detailed vegeation cover types in the Terai landscape, Nepal

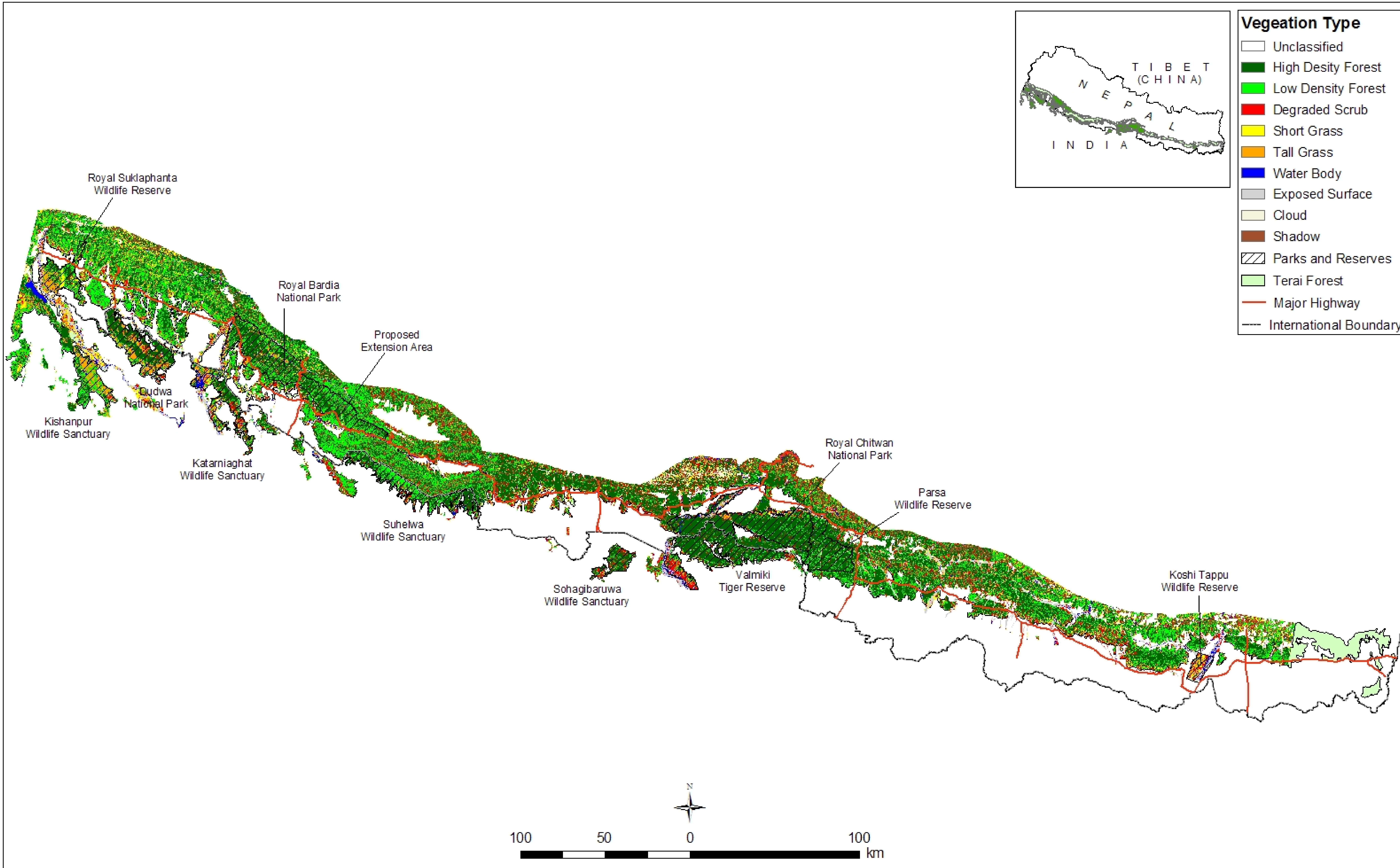


Figure 4. Generalized vegeation cover types in the Terai landscape, Nepal

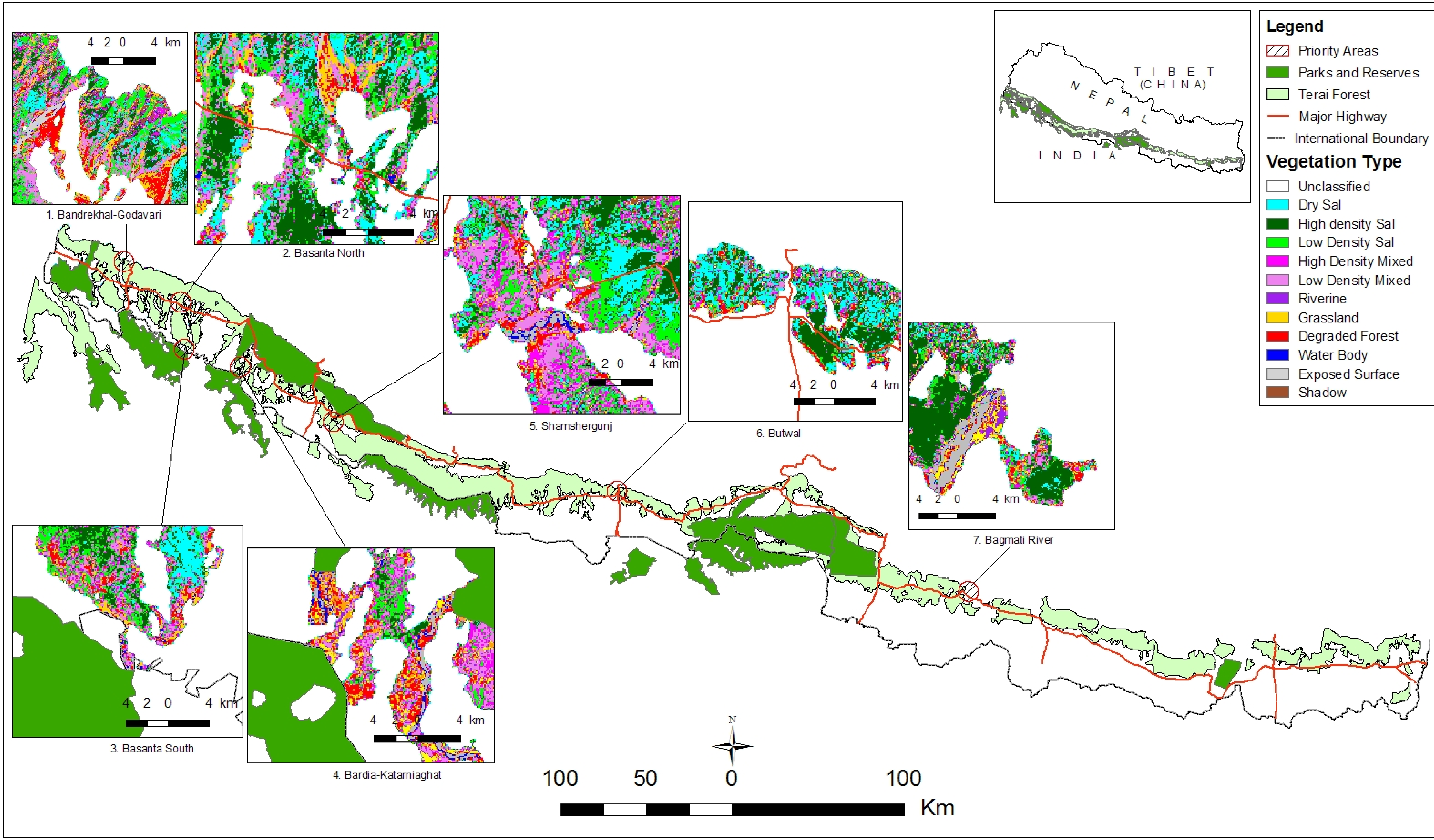


Figure 5. Priority conservation area for establishing connectivity for wildlife movement in the Terai, Nepal

Pellet Group Decay Rate in Subtropical Asia: A Comparison among Three Species of Deer

ABSTRACT

Pellet group decay rate is important in indirect estimation of ungulate abundance based on pellet group counts. However, variability in pellet group persistence in different seasons and in response to environmental correlates has previously not been fully investigated. Cohorts of deer pellet groups for every month in a 12 month period were placed in similar sets of vegetation cover types and monitored bi-weekly to determine their decay rates and the effects of environmental variables. Seasonal effect on pellet group decay was significant ($F_{3, 316} = 5.78$, $p<0.001$) with high decay rates during the monsoon rainy season ($t_{161} = -3.9$, $p<0.001$). There was no difference in decay rate among species and vegetation cover types. All pellet groups disappeared during the months of June-July. Average decay rate ranged from 2 - 28 weeks. An adjustment ratio factor was developed to be incorporated in the pellet group survey for estimating ungulate abundance in the future. The dry season (February-March) is the ideal time to count pellet groups in the lowlands of Nepal to increase accuracy of ungulate prey abundance estimates.

INTRODUCTION

Periodical population estimation of ungulates, particularly deer species, is needed to evaluate conservation programs for carnivores and their prey (Karanth & Stith 1999; Karanth & Sunquist 2000). Direct observation methods to estimate ungulate density are very labor intensive and often difficult because detection varies with habitat. Therefore, pellet group surveys are widely used to estimate ungulate abundance (Bennett et al. 1940; Rogers et al. 1958; Neff 1968; Wegge 1976; Bailey & Putnam 1981; Rowland et al. 1984; Aulak & Babinska-Werka 1990; Plumptre 1995; Harkonen & Heikkila 1999) as well as to determine their habitat use (Dinerstein 1979; Collins & Urness 1981; Loft & Kie 1988; Blake 2002). Pellet Group surveys are particularly useful in dense forest where visibility is low (Eisenberg et al. 1970; Dinerstein 1980; Wiles 1980; Ngampongsai 1987;

Barnes et al. 1997; Plumptre 2000; Walsh et al. 2001) and in landscape scale studies where large areas can be covered rapidly with a good sampling design. Reliability of the pellet group count method varies with defecation and decomposition rates especially when estimating ungulate abundance from standing crop (Wallmo et al. 1962; Neff 1968; Harestad & Bunnell 1987). Therefore, to obtain reliable estimates using this method, it is important to determine an optimal season when pellet accumulation is maximal and pellet group disappearance minimal. The purpose of this study is to determine pellet group decay rates of three tiger (*Panthera tigris*) prey species in southern lowland of Nepal, a subtropical Asian ecosystem and habitat for one of the world's largest remaining populations of tigers.

Previous research (e.g. Wallmo et al. 1962; Wiggley and Johnson 1981) on deer pellet decay rates in North America demonstrated pellets deteriorate rapidly when exposed to certain weather conditions (e.g. rain, humidity, temperature). Harestad & Bunnell (1987) also reported that persistence of ungulate pellets is highly variable in different climatic conditions and found pellets were present from a few weeks to as long as 2-4 years. In Nepal, investigators have studied tigers and their prey for 3 decades Previous studies on ungulates focused primarily on their ecology and behavior (Mishra 1982; Dhungel & O'Gara 1991) and abundance estimate were done using line transects (Seidensticker 1976) and a mixture of other methods (Dinerstein 1980). Defecation rate studies were conducted on captive or tame Chital (*Axis axis*) (Dinerstein & Holly 1982), hog deer (*Axis porcinus*) (Dhungel 1985), and sambar (*Cervus unicolor*) (Rollins et al. 1984). However, no studies have been done on decay rates of pellet groups produced by wild ungulates in Nepal. Information on these rates is critical to conservation of tigers throughout their range because pellet group analysis is the best method for estimating prey abundance and evaluating quality of habitat.

This study (i) determined decay rates of pellet groups of three tiger prey species (chital, sambar, and barking deer (*Muntiacus muntjak*) in different seasons and vegetation cover types, and (ii) used this information to recommend improvements for future tiger prey surveys in Nepal.

STUDY AREA

The study was conducted near Sauraha (27°34'N, 84°30'E) at an elevation of 185 m in the central part of Royal Chitwan National Park, Nepal (RCNP). The climate is subtropical monsoon with hot and humid summers. The monsoon in summer brings heavy rainfall causing flooding of rivers and streams. Mean annual rainfall ranges between 2000 – 2100 mm. Annual average minimum temperature is about 17.4^{o} C and the maximum is about 31^{o} C (Anon 2000). The temperature is as low as 7^{o} C in winter and may rise to 36^{o} C in late spring and summer. In winter, nights are damp and cold with heavy fog during the early hours of morning. Frosts are occasional in December and early January (Mishra 1982).

There are four distinct seasons in RCNP: monsoon (June-September), post-monsoon (October-November), cold dry winter (December-March), and pre-monsoon (April-May). Rains begin in the pre-monsoon about mid-May. The monsoon period is characterized by torrential rains causing frequent flash floods. More than 80% of the annual rainfall occurs during June-September. July has the highest amount of precipitation. Other seasons are dry with occasional light rainfall in winter.

Three main vegetation types occur in the Park: 1) Sal forest habitat is dominated by *Shorea robusta*, a dipterocarp species together with *Terminalia tomentosa*, *Terminalia belerica*, *Dilenia pentagyna*, *Litsea monopetala*, *Semicarpus anacardium*; (2) mixed/riverine forest is mainly composed of *Trewia nudiflora*, *Bombax ceiba*, *Ehretia laevis*, *Ficus sps.*, *Syzygium cumini*, *Dalbergia sissoo*, *Acacia catechu;* and (3) the grassland is composed of *Themeda sp*., *Saccharum* spp. *Imperata cylindrica, Cynodon dactylon,* and *Chrysopogon aciculatus*.

In addition to sambar, chital, and barking deer, the mosaic of habitats make the Park favorable for other ungulates such as rhinoceros (*Rhinoceros unicornis*), elephant (*Elephas maximus*), gaur bison (*Bos gaurus*), hog deer (*Axis porcinus*), and wild boar (*Sus scrofa*). Ungulate populations in the Park are important prey for large predators such as tigers and leopards (*Panthera pardus*). The chital is the most abundant deer species in the Park followed by hog deer, barking deer and sambar (Seidensticker 1976; Mishra 1982; Dhungel & O'Gara 1991) Chapter 1).

METHODS

The study was conducted between December 2000 and May 2001. Fresh pellet groups (≤ 2 days old) were randomly collected in a sealed plastic bag from the three main cover types in the Park. Within 1-2 days of collection, pellets were placed back into a similar set of cover types where they could be monitored efficiently. For each species, two replicates, consisting of 50 pellets each, were placed in grassland, Sal forest, and mixed/riverine forest at the beginning of each month (n = 72 pellet groups/species) for one year. Each group was placed on average 2 m apart and identified with a numbered stake. The cohort of pellet groups in each replication was monitored biweekly (day 1 and 15 of each month) until they decomposed beyond recognition. During every visit the detectable number of pellets was recorded. Loss of pellets by natural phenomena such as flood, fire, trampling by animals and insect activity was considered natural decomposition.

Analysis

The average persistence period of a species pellet group in a season was the number of days the pellets were detected from date of deposition in that season. Decay rates were calculated as the mean time to decay for each cohort of pellet groups deposited each month. Seasonal decay rates were computed as the mean time to decay for cohorts of pellet groups within a season. Effects of habitat, season, and species on the pellet decomposition rate were tested by one-way analysis of variance (ANOVA) using S-Plus software (S-Plus 2002). I also calculated the proportion of pellet groups that disappeared over time t, and the 95% confidence limits (Agresti 1996),

$$P = (1 - n_i / n) \pm 1.96\sqrt{p(1-p)/n}$$

where p = proportion of pellet group decomposed, n_i = number of pellets detected, and

n = number of pellets deposited at the beginning of the experiment.

RESULTS

Decay rates were determined for 12 pellet groups (24 total with replicates) of sambar, chital and barking deer over one year. Pellets within a group did not decay at equal rates. Season had a significant effect on decay rate ($F_{3, 316} = 5.78$, $p<0.001$). The difference was significant between winter and monsoon seasons ($t_{161} = -3.9$, $p<0.001$), a slight difference between pre-monsoon and monsoon ($t_{110} = -2.06$, $p<0.04$) and monsoon and post monsoon ($t_{163} = 3.57$, $p<0.001$). Average decay rate ranged from 2 weeks to as long as 28 weeks (Fig. 1 & 2). In general, it was slower in post monsoon (22 weeks) and winter (18 weeks) and comparatively faster in pre-monsoon (9 weeks) and monsoon (9 weeks) seasons. If we examine the decay rate month by month, it was highest in June and July which are also the months of highest rainfall, temperature and humidity (Table 1, 2, and 3). Pellet groups from all species disappeared within 12 weeks in all three cover types during April to July.

No pellets disappeared in any cover types from October until mid-March. Temporal patterns of pellet decay rates for all three species was similar ($F_{2, 317} = 0.28$, $p = 0.76$; Fig. 1). Smaller and larger sized pellets decayed at the same rate. The decay rate appeared slightly faster in grassland and mixed habitat than in the Sal forest (Fig. 1 and 2). However, decay rate was not significantly affected by vegetation cover type ($F2_{, 317} = 0.49$, $p = 0.61$; Fig. 1). Similarly, interactions between season and species ($F_{6, 306} = 0.21$, $p = 0.97$, species and habitat ($F4_{, 308} = 0.08$, $p = 0.99$, season and habitat ($F_{6, 306} = 0.42$, $p = 0.87$), and three-way interaction among species, season, and habitat ($F_{28, 284} = 0.22$, $p = 0.99$) did not significantly affect the pellet decay rate.

We observed that pellets of all deer species were decomposed by coprophagous beetles and spread out by jungle fowl (*Gallus gallus*). In general, coprophagous beetles and jungle fowl were more active in grassland and mixed forest as compared to sal forest.

Standardization of Pellet Group Counts

I developed an adjustment ratio factor for pellet counts to include the number of days that pellets were collected and pellet deterioration rate. Each month during the survey period was divided into two week intervals corresponding to the biweekly monitoring frequency of the experimental plots. Number of days that pellet groups were collected at the beginning of the prey survey (1 February) was estimated to be 123 days. A ratio factor (RF) for the subsequent survey periods was calculated as,

$$RF = td/123$$

where, td = total number of days of pellet group persistence from October. Number of pellet groups in any time period was multiplied by the ratio factor to obtain a comparable number of pellet groups. The ratio factor for pellet groups varied for each half month of the survey period based on the accumulation period and persistence of the pellets. The second half of March had the highest accumulation of pellet groups (Table 4).

DISCUSSION

Seasonal Effects

I found season affects decay rate of pellets. Seasonal climatic conditions contributed to observed high variability in pellet decay rate. Pellet group cohorts from the dryer post-monsoon season took longer to decay than those from the other three seasons. Precipitation, temperature, and humidity were important factors influencing decay of pellet groups due to increased fungal, bacterial and insect activities as reported by Dinerstein and Holly (1982). Although decay rate may vary between years, depending on rain fall frequency and/or quantity, but in general, timing of the beginning and end of the monsoon varies less than the amount of rainfall during the monsoon. By October it was dry enough and insect activity had declined to the extent that pellets lasted 22 weeks, on average. In contrast, pellets deposited in September lasted only 6 weeks. Additional research is needed to determine if climate effects on pellet decay rate varies among the different regions (e.g. east and west Nepal).

Persistence of pellet groups in a subtropical climate like the lowlands of Nepal is rarely longer than 6 months whereas some studies in North America have found deer pellet groups remain intact as long as 2 years (Harestad & Bunnell 1987). In Nepal, no pellet groups persisted after the monsoon season; they all disappeared during the months of June-July. Furthermore, during the monsoon season, torrential rains (Wallmo et al. 1962), inundation and flash floods caused movement and loss of pellet groups from their original site of deposition. Wallmo et al. (1962) also found heavy rain affected deer pellet persistence in the mountain region of western Texas, USA.

Cover Type Effects

Decay rates in the three cover types were similar but were slightly faster in grassland habitat and mixed forest as compared to the Sal forest. The differences, however, were not statistically significant. This is possibly because of Nepal has characteristic wet (monsoon) and dry seasons that affect all habitats quite uniformly..

In grasslands and mixed forest, decay rates of pellets may be influenced by greater moisture in the soils. Most of the grasslands and mixed forests areas are located in the flood plain and therefore are inundated for a considerable period of time following heavy rains. Under moist forest cover in Nepal, decomposition rates were typically higher than in the dryer upland Sal forest. Higher humidity on the forest floor in mixed forests appears to facilitate decomposition activities of microbes and insects. This is in contrast to the slower decay rates in upland Sal. Moreover, soil in the mixed forest remains moist and humidity is comparatively higher due to several layers of vertical vegetation strata and density. Sal forest has an extensive canopy but very little understory.

Higher decay rates in the grasslands are also influenced by human activities in this vegetation type. Grasses such as *Imperata cylidrica* are in high demand for roofing material in the local communities and are harvested in the winter. Grasslands are usually burnt after the harvest in the dry season to encourage a fresh lush green grass for wildlife animals and domestic livestock. Ground fires that burn the dead litter on the forest floor are common across the Terai during the dry period in the pre-monsoon season. Rapidly progressing ground fires leave pellets intact and recognizable, however, they do have a deteriorating effect (loosens or partially burns) on pellets. These effects in combination with trampling by ungulates and livestock result in their rapid disappearance. Wiles (1980) found a similar result in a study of large ungulates in Thailand.

Species Effects

I found no difference among species in pellet decay rates. In part, this result may be explained because all three species co-occur in the three habitat types and therefore are exposed to the same environmental conditions. However, the three deer species produce pellets that are significantly different in size (smallest by barking deer, largest by sambar) and they also have different diets. For example, barking deer and chital are grazers and sambar graze and browse. Given these differences, it is puzzling why no species effects were found among pellet decay rates.

Implications for Improving Pellet Group Survey Techniques

Pellet group surveys are used by wildlife biologists to estimate ungulate presence/absence in addition to population size, density and trends. In Nepal, this method has been used for three decades to evaluate habitat quality, in terms of prey abundance, for tigers. Results from this study, indicate that pellet group surveys will produce the most accurate information in Nepal's lowlands if conducted during February-April. These surveys should not be conducted in the rainy season or in the post-monsoon. Additionally, because decomposition is extremely slow during the dry season, it is necessary to use a correction factor to avoid over estimating ungulate population size and density as the dry season progresses. Finally, an important discovery during this study is that pellets deposited in February typically are still present in April or May. When surveys are conducted over large areas and during an extended period, the standing crop of pellets will steadily increase as the season progresses. Without formally addressing this issue, ungulate estimates will be lower at the beginning of the survey than at the end. I recommend, in addition to the correction factor, length of the survey period should be shortened to reduce variance in the standing crop of pellets. Although these implications are specific for Nepal, they are likely relevant to other similar habitats in south Asia.

LITERATURE CITED

Agresti, A. 1996. An introduction to categorical data analysis. John Wiley & Sons, Inc, New York.

Anon. 2000. Royal Chitwan National Park and Buffer Zone Management Plan (2001-2005). Ministry of Forests and Soil Conservation, Deartment of National Parks and Wildlife Conservation, kathmandu, Nepal.

Aulak, W., and J. Babinska-Werka. 1990. Estimation of roe deer density based on the abundance and rate of disappearance of their faeces from the forest. Acta Theriologica **35**:111-120.

Bailey, R. E., and R. J. Putnam. 1981. Estimation of fallow deer (Dama dama) populations from faecal accumulation. Journal of Applied Ecology **18**:697-702.

Barnes, R. F. W., K. Beardsley, F. Michelmore, K. L. Barnes, M. P. T. Alers, and A. Blom. 1997. Estimating forest elephant numbers with dung counts and a geographic information system. Journal of Wildlife Management **61**:1384-1393.

Bennett, L. J., P. F. English, and R. McCain. 1940. A study of deer populations by use of pellet-group counts. Journal of Wildlife Management **4**:398-403.

Blake, S. 2002. Forest buffalo prefer clearings to closed-canopy forest in the primary forest of northern Congo. Oryx **36**:81-86.

Collins, W. B., and P. J. Urness. 1981. Habitat preferences of mule deer as rated by pellet-group distribution. Journal of Wildlife Management **45**:969-972.

Dhungel, S. K. 1985. Defecation rate of hog deer in captivity. Journal of Wildlife Management **49**:925-926.

Dhungel, S. K., and B. W. O'Gara 1991. Ecology of the hog deer in Royal Chitwan National Park, Nepal. Wildlife Monograph No. 119. Wildlife Society, Bethesda, MD.

Dinerstein, E. 1979. An ecological survey of the Royal Karnali Bardia Wildlife Reserve Nepal. Part II. habitat and animal interactions. Biological Conservation **16**:265-300.

Dinerstein, E. 1980. An ecological survey of the Royal Karnali-Bardia Wildlfie Reserve, Nepal. Part III: Ungulate populations. Biological Conservation **18**:5-38.

Dinerstein, E., and T. D. Holly. 1982. Daily defecation rate of captive axis deer. Journal of Wildlife Management **46**:833-835.

Eisenberg, J. F., C. Santiapillai, and M. Lockhart. 1970. The study of wildlife populations by indirect methods. Ceylon Journal of Science **8**:53-62.

Harestad, A. S., and F. L. Bunnell. 1987. Persistence of black-tailed deer fecal pellets in coastal habitats. Journal of Wildlife Management **51**:33-37.

Harkonen, S., and R. Heikkila. 1999. Use of pellet group counts in determining density and habitat use of moose Alces alces in Finland. Wildlife Biology **5**:233-239.

Karanth, K. U., and B. M. Stith. 1999. Prey depletion as a critical determinant of tiger population viability. Pages 100-113 in J. Seidensticker, S. Christie, and P. Jackson, editors. Riding the tiger: tiger conservation in human-dominated landscapes. Cambridge University Press, Cambridge, United Kingdom.

Karanth, K. U., and M. E. Sunquist. 2000. Behavioural correlates of predation by tiger (Panthera tigris), leopard (Panthera pardus) and dhole (Cuon alpinus) in Nagarahole, India. Journal of Zoology **250**:255-265.

Loft, E. R., and J. G. Kie. 1988. Comparison of pellet-group and radio triangulation methods for assessing deer habitat use. Journal of Wildlife Management **52**:524-527.

Mishra, H. R. 1982. The ecology and behaviour of chital (Axis axis) in the Royal Chitwan National Park, Nepal. Ph. D. thesis. University of Edinburgh.

Neff, D. J. 1968. The pellet-group count technique for big game trend, census, and distribution: a reveiw. Journal of Wildlife Management **32**:597-614.

Ngampongsai, C. 1987. Habitat use by the sambar (*Cervus unicolor*) in Thailand: A case study for Khao-Yai National Park. Page 577 in C. M. Wemmer, editor. Biology and Management of the Cervidae. Smithsonian Institutions.

Plumptre, A. J. 2000. Monitoring mammal populations with line transect techniques in African forests. Journal of Applied Ecology **37**:356.

Plumptre, A. J. H. S. 1995. Estimating the biomass of large mammalian herbivores in a tropical montane forest: a method of faecal counting that avoids assuming a 'steady state' system. Journal of Applied Ecology 32(1): 111-120, 1995.

Rogers, G., O. Julander, and W. L. Robinette. 1958. Pellet-group counts for deer census and range-use index. Journal of Wildlife Management **22**:193-199.

Rollins, D., C. B. Fred, and M. Roxanne. 1984. Fecal pH and defecation rates of eight ruminants fed known diets. Journal of Wildlife Management **48**:807-813.

Rowland, M. M., G. C. White, and E. M. Karlen. 1984. Use of pellet-group plots to measure trends in deer and elk populations. Wildlife Society Bulletin **12**:147-155.

Seidensticker, J. 1976. Ungulate populations in Chitwan Valley, Nepal. Biological Conservation **10**:183-210.

Wallmo, O. C., A. W. Jackson, T. L. Hailey, and R. L. Carlisle. 1962. Influence of rain on the count of deer pellet groups. Journal of Wildlife Management **26**:50-55.

Walsh, P. D., L. J. T. White, C. Mbina, D. Idiata, Y. Mihindou, F. Maisels, and M. Thibault. 2001. Estimates of forest elephant abundance: projecting the relationship between precision and effort. Journal of Applied Ecology **38**:217-228.

Wegge, P. 1976. Terai Shikar Reserves: survey reports and management proposals. FAO Project Nepal Field Document No. 4, Kathmandu, Nepal.

Wigley, T. B., and M. K. Johnson. 1981. Disappearance rates for deer pellets in the Southeast. Journal of Wildlife Management **45**:251-253.

Wiles, G. J. 1980. Faeces deterioration rates of four wild ungulates in Thailand. Natural History Bulletin of Siam Society **28**.

Table 1. Proportion of pellets (x and 95% CI) of barking deer that decomposed 1 month and 3 months after deposition in Royal Chitwan National Park 2000-2001.

	Habitat type					
Period	Grassland		Mixed forest		Sal forest	
Months (Weeks)	x	95% CI	x	95% CI	x	95% CI
1 month (4 wks)						
Dec	0.06	0.05	0.12	0.06	0.00	
Jan	0.08	0.05	0.20	0.08	0.00	
Feb	0.04	0.04	0.10	0.06	0.01	0.02
Mar	0.02	0.03	0.11	0.06	0.01	0.02
Apr	0.34	0.09	0.34	0.09	0.65	0.09
May	0.14	0.07	1.00		0.56	0.10
June	1.00		1.00		0.95	0.04
Jul	1.00		0.84	0.07	0.92	0.05
Aug	0.91	0.06	0.39	0.10	0.65	0.09
Sep	0.85	0.07	0.83	0.07	0.69	0.09
Oct	0.29	0.09	0.42	0.10	0.31	0.09
Nov	0.09	0.06	0.17	0.07	0.21	0.08
3 months (12 wks)						
Dec	0.16	0.07	0.25	0.08	0.05	0.04
Jan	1.00		0.32	0.09	0.14	0.07
Feb	1.00		0.87	0.07	0.42	0.10
Mar	0.47	0.10	1.00		0.82	0.08
Apr	1.00		1.00		1.00	
May	1.00		1.00		1.00	
June	1.00		1.00		1.00	
Jul	1.00		1.00		1.00	
Aug	1.00		0.97	0.03	1.00	
Sep	1.00		1.00		0.98	0.03
Oct	0.55	0.10	0.52	0.10	0.56	0.10
Nov	0.30	0.09	0.27	0.09	0.39	0.10

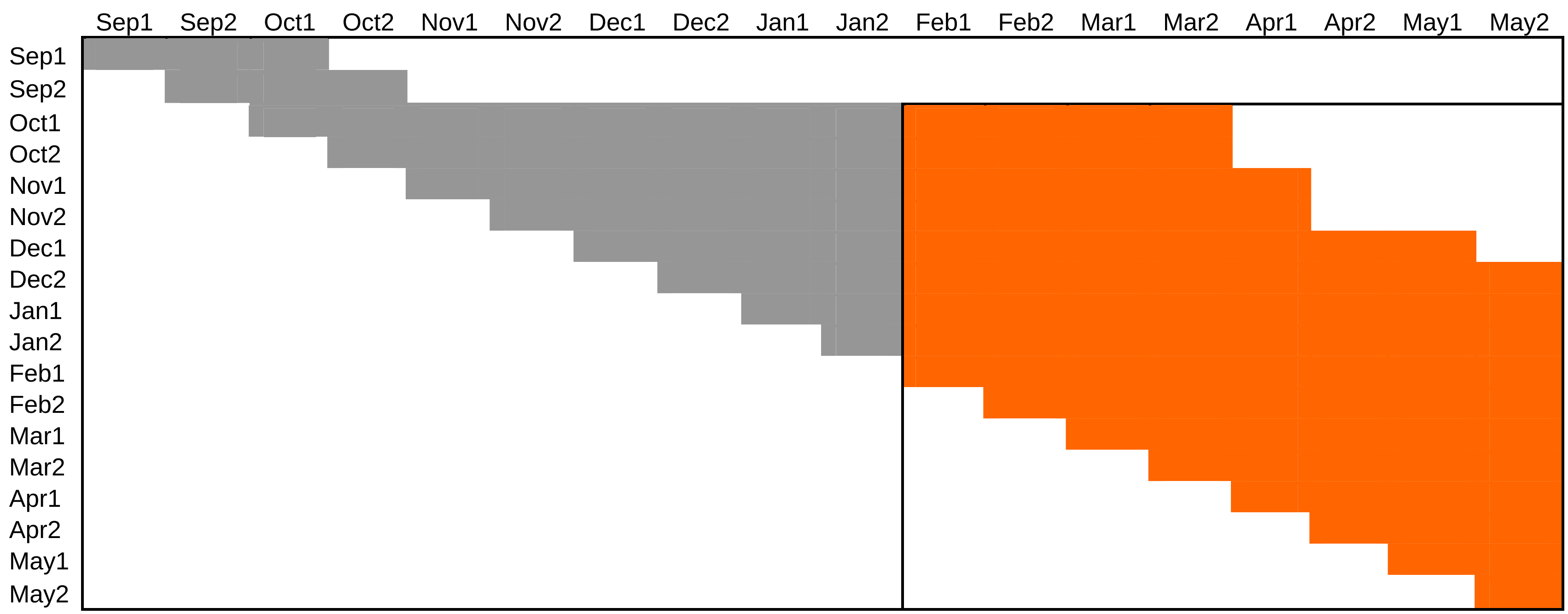
Table 2. Proportion of pellets (x and 95% CI) of sambar deer that decomposed 1 month and 3 months after deposition in Royal Chitwan National Park 2000-2001.

Period	Habitat type					
	Grassland		Mixed forest		Sal forest	
Months (Weeks)	x	95% CI	x	95% CI	x	95% CI
1 month (4 wks)						
Dec	0.25	0.08	0.18	0.08	0.07	0.05
Jan	0.08	0.05	0.15	0.07	0.11	0.06
Feb	0.22	0.08	0.00		0.10	0.06
Mar	0.05	0.04	0.09	0.06	0.06	0.05
Apr	0.11	0.06	0.71	0.09	0.56	0.10
May	0.26	0.09	0.77	0.08	0.29	0.09
June	1.00		1.00		0.46	0.10
Jul	0.94	0.05	1.00		0.67	0.09
Aug	0.66	0.09	0.60	0.10	0.56	0.10
Sep	0.96	0.04	0.58	0.10	0.58	0.10
Oct	0.50	0.10	0.19	0.08	0.50	0.10
Nov	0.27	0.09	0.13	0.07	0.60	0.10
3 months (12 wks)						
Dec	0.55	0.10	0.28	0.09	0.40	0.10
Jan	1.00		0.40	0.10	0.47	0.10
Feb	1.00		0.53	0.10	0.32	0.09
Mar	0.54	0.10	0.95	0.04	0.71	0.09
Apr	1.00		1.00		1.00	
May	1.00		1.00		1.00	
June	1.00		1.00		1.00	
Jul	1.00		1.00		1.00	
Aug	1.00		1.00		0.98	0.03
Sep	1.00		0.95	0.04	0.97	0.03
Oct	0.78	0.08	0.27	0.09	0.83	0.07
Nov	0.57	0.10	0.61	0.10	0.81	0.08

Table 3. Proportion of pellets (x and 95% CI) of axis deer that decomposed 1 month and 3 months after deposition in Royal Chitwan National Park 2000-2001.

	Habitat type					
Period	Grassland		Mixed forest		Sal forest	
Months (Weeks)	x	95% CI	x	95% CI	x	95% CI
1 month (4 wks)						
Dec	0.00		0.05	0.04	0.01	0.02
Jan	0.05	0.04	0.05	0.04	0.00	
Feb	0.11	0.06	0.07	0.05	0.19	0.08
Mar	0.00		0.21	0.08	0.49	0.10
Apr	0.89	0.06	0.87	0.07	0.78	0.08
May	0.61	0.10	0.98	0.03	0.63	0.09
June	1.00		1.00		0.70	0.09
Jul	0.89	0.06	0.90	0.06	0.83	0.07
Aug	0.73	0.09	0.32	0.09	0.67	0.09
Sep	0.99	0.02	0.70	0.09	0.56	0.10
Oct	0.66	0.09	0.25	0.08	0.38	0.10
Nov	0.17	0.07	0.17	0.07	0.20	0.08
3 months (12 wks)						
Dec	0.30	0.09	0.26	0.09	0.17	0.07
Jan	1.00		0.19	0.08	0.28	0.09
Feb	1.00		0.68	0.09	0.76	0.08
Mar	0.90	0.06	1.00		0.99	0.02
Apr	1.00		1.00		1.00	
May	1.00		1.00		1.00	
June	1.00		1.00		1.00	
Jul	1.00		1.00		1.00	
Aug	1.00		0.92	0.05	1.00	
Sep	1.00		0.98	0.03	1.00	
Oct	0.84	0.07	0.48	0.10	0.66	0.09
Nov	0.31	0.09	0.32	0.09	0.53	0.10

Table 4. Adjustment ratio factor for pellet survey period



	Feb1	Feb2	Mar1	Mar2	Apr1	Apr2	May1	May2
Days pellets persisted =	123	138	151	166	151	136	151	135
Correction factor =	1.00	1.12	1.23	1.35	1.23	1.11	1.23	1.10

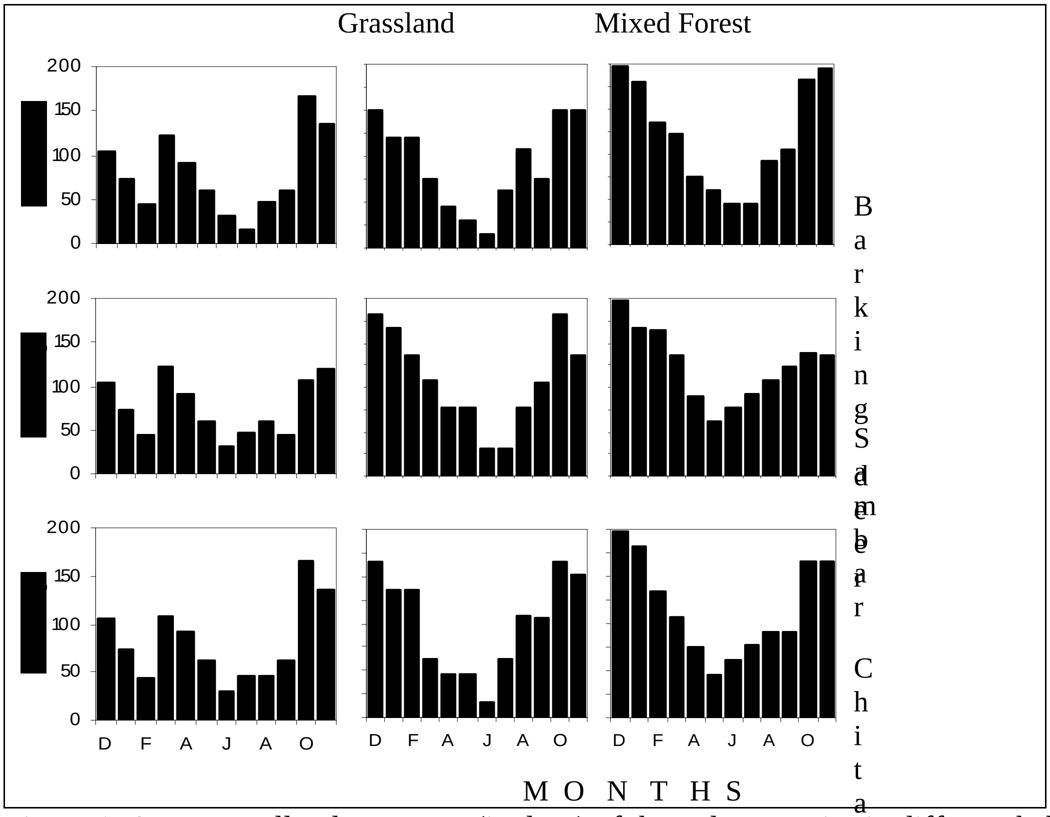


Figure 1. Average pellet decay rates (in days) of three deer species in different habitats for various months in which the pellets were deposited.

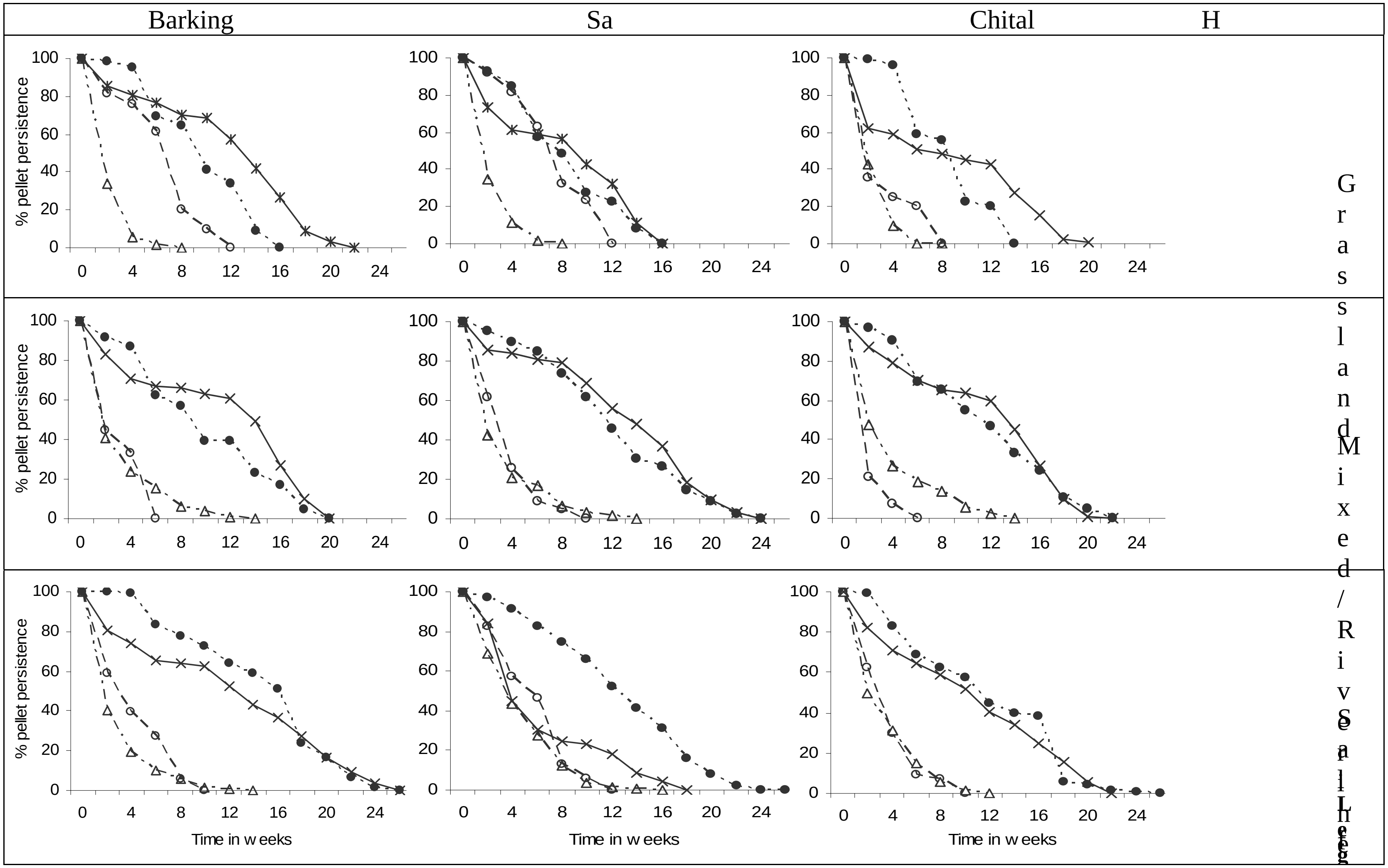


Figure 2. Seasonal decomposition rate of pellets of three ungulate species expressed as the proportion of experimental pellets decayed over time in 3 habitat types in Royal Chitwan National Park, Nepal, 2000-2001