School of Doctoral Studies in Biological Sciences

University of South Bohemia in České Budějovice

Faculty of Sciences

Understanding wildlife distribution in the human-dominated landscape of Nepal: implications for conservation

PhD Thesis

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České Budějovice | 2012

Annotation:

Paudel, P.K., 2012: Understanding wildlife distribution in the human-dominated landscape of Nepal: implications for conservation. PhD Thesis, in English, - 34 p. + appendices 216 p., Faculty of Science, University of South Bohemia, České Budějovice, Czech Republic

In this thesis, I have first reviewed biodiversity status and its conservation in Nepal, which indicates the need of linking the gaps between research and conservation of rare and endangered flora and fauna. Using three mountain ungulates as model species (barking deer - *Muntiacus muntjak*, Himalayan goral - *Naemorhedus goral* and Himalayan serow - *Capricornis thar*), I have investigated effects of human disturbances on wildlife distribution in the human-dominated landscapes of western Nepal, spanning from the subtropical Bardia National Park to the mountainous Shey Phoksundo National Park. I have developed habitat suitability maps for these three ungulate species and recommended a conservation priority area for their conservation. A special emphasis was placed on the study of the distribution of Himalayan serow using different factors related to habitat fragmentation, hunting and patch characteristics and connectivity of forest in midhills landscape of Nepal. Finally, wildlife hunting pattern in the region was investigated in order to explore wildlife conservation issues from the social perspective.

Financial support

Work on the thesis was funded by the grant LC06073 of the Czech Ministry of Education, by CzechGlobe – Centre for Global Climate Change Impacts Studies, Reg.No. CZ.1.05/1.1.00/02.0073 and by grant No. 206/08/H044 of the GA CR.

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Author contribution statement

Prakash Kumar Paudel, author of this Ph.D. thesis, is the first author of four papers (manuscripts) and two chapters in a book, the second author in a book chapter and has written a substantial part of these. Most of the raw data processing, as well as most of the statistical analyses were performed by him. Martin Hais helped in vegetation classification using remote sensing and geographical information system (Paper V). Vojtěch Jarošík helped to analyze "patch occupancy of serow" (Paper VII).

Pavel Kindlmann, as a supervisor, assisted and supervised research activities. All co-authors hereby consent the publication of the papers in the PhD thesis of Prakash Kumar Paudel and support it by their signatures:

Pavel Kindlmann

Martin Hais

Vojtěch Jarošík

Bishnu Prasad Bhattarai

ACKNOWLEDGEMENTS

For me carrying out a PhD research on wildlife conservation in the human-dominated Himalayan landscapes of Nepal has been a great opportunity to learn. It is true, especially, about the practical learning opportunity of the immense diversity of ecosystems from the subtropical region to alpine meadows and about people who, for centuries, have been caretakers of the natural treasures of Nepal's Himalaya. My time spent in the remote parts of mountains doing field research is a precious experience of my life.

Collection of data from highly rugged and remote mountains is a formidable task. I had the experience of many unforgettable events that made the journey an admixture of joys and anxieties. Fortunately, I was always able to maintain a strong sense of bond with the native inhabitants of the land. They were unforgettably cheerful and always stood beside me during the times of life threatening difficulties. First and foremost, I extend my heartfelt thanks to those helping people for making the research easier. I will not forget Chakra Kathayat and his team who rescued me from the precipitous cliff of a mountain. Many thanks go to Govinda Nepali, a local assistant of Jajarkot, for his brave and caring company in the dense forest even during the mid-night hours.

In addition, I would like to especially thank my supervisor Prof Pavel Kindlmann for his offer for doctoral research and his mentorship during these four years. At the Global Change Research Centre, I thank Jan Šipoš, Lenka Atexingerová, Karolína Bílá and František Zemek for being helpful to me.

I will always remember my field assistants, Purna Bahadur Biswakarma, Sahila Biswakarma and Lil Bahadur Khatri for their wonderful friendship and hard work. Thanks are also due to my friends Bishnu and Olga for their help and cooperation.

At last, but not least, I wish to thank my family and friends who contributed a lot to shape me what I am now. My parents deserve greatest gratitude for giving me hopes for the future during the times of frustration and struggle. Many thanks go to my brother Pradeep and sister Sharda for their care and encouragement that enabled me to take this journey.

I also would like to express my immense gratitude to Binod Bindu, Dipak, Umesh, Baburam, Smita, Samjhana, Pratikshya, Parbati, Yadab and Pabitra, all of whom deserve a reward for their indefatigable support. Finally, I am thankful to my wife, Sabina, for bearing this painful time of separation and making this thesis possible. Thank you.

This thesis is dedicated to my parents.

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GENERAL INTRODUCTION

The high speed of biodiversity loss, despite concerted efforts from international bodies, NGOs and states for its conservation, has been a serious challenge to ecologists worldwide (Gilbert 2009). The strategies to reverse this trend remain unsuccessful due to the lack of the scientific knowledge and appropriate conservation frameworks (Beissinger *et al.* 2009; Rands *et al.* 2010). Thus challenge for ecologists and conservationists are to provide knowledge regarding the reduction of threats to biodiversity (White *et al.* 2009).

Some of the major threats to biodiversity are habitat loss and fragmentation (Fahrig 2003), over-hunting (Bennett *et al.* 2002), climate change (Thomas *et al.* 2004; Brook 2008) and invasion by exotic species (Wilcove *et al.* 1998; Davis 2003). Furthermore, the extinction risk for wildlife increases greatly because of detrimental synergistic effects resulting from interactions of these factors (White *et al.* 2009). Therefore, scientific understanding of biodiversity pattern and causes of biodiversity loss is an indispensable part of conservation planning. Scientists are attempting to explain, why biodiversity is disproportionately high across the different parts of the Earth (Gaston 2000). Attempts to explain what influences biodiversity are made from different perspectives, including variability in geology, climate and physiography (Holdridge 1967; Connell 1978; Huston 1994; Redford and Richter 2001) and local environmental variation (e.g., rainfall, wind patterns) (Noss and Cooperrider 1994; Bailey 1996; Gaston 2000).

Furthermore, for effective conservation strategies, it is important to identify the conservation challenges and to study, to which extent these challenges pose threats to biodiversity. The greatest part of biodiversity problems concerns the relation between biodiversity and resources obtained by humanity (Perrings *et al.* 1992). The human exploitation has resulted into the destruction of 93% of the original forests, and many of the biodiversity rich areas are facing exceptional threats of destruction (Myers *et al.* 2000). Himalaya, a biodiversity hotspot (Conservation International 2006), is predicted to have 10% of the land area covered by dense forest (>40% canopy cover) by 2010, despite the growing attention and investment on conservation of this fragile area (Pandit *et al.* 2007).

Limited resources seriously affect the effectiveness of conservation efforts (Peyton 1994; Groom 2006). One of the direct consequences of resource constraints is the inability of governments to implement conservation legislation, such as anti-poaching laws (Gezelius 2002; Walsh *et al.* 2003; Rowcliffe *et al.* 2004; Gibson *et al.* 2005). Poaching is the second-most important threat to the survival of the world's mammals after habitat loss (Groom 2006). In Nepal, conservation infrastructure is primarily designed for protected areas (e.g., national parks, wildlife reserves), and non-protected areas are subjected to extreme human exploitation (Heinen and Kattel 1992; Heinen and Yonzon 1994; Heinen and Mehta 1999). The same is true for the Nepalese midhills. Although rich in ecosystems and mammalian fauna, midhills ecosystems are not adequately protected in protected areas system and wildlife populations are confined to few and isolated forest areas in the region (BPP 1995). Therefore scientific research requires addressing impending conservation challenges in the region. A review of biodiversity patterns and its conservation status in the country is a base for identification of the most important areas to be focused on.

Studies on large mammals, especially in the disturbed environment, provide important information for their conservation. The impact of human activities on the large mammals is identified as being a leading cause of species extinction (Chapin III *et al.* 2000; Ceballos 2005). Large mammals have shorter species durations than small ones (Cardillo *et al.* 2005; Liow 2008) and thus are disproportionately likely to experience higher extinction rates (Owens and Bennett 2000; Cardillo *et al.* 2005; Ceballos *et al.* 2005; Curtin and Western 2008). Thus the challenge for wildlife conservation is to integrate wildlife studies as a part of an integrated social-ecological system (White *et al.* 2009). It is critically important in a country like Nepal, where most of the conservation challenges are of anthropogenic origin and the result of an unsustainable exploitation of resources (Chaudhary 2000; Budhathoki 2004).

Therefore, it is important to understand the pattern of the wildlife distribution in the human-dominated landscape by investigating the influence of human disturbance, including wildlife hunting, habitat fragmentation and landscape pattern.

1. The status of biodiversity and its conservation in Nepal

Nepal provides an important avenue for biodiversity research along an altitudinal gradient within a relatively small geographical area. Since 1972, Nepalese Government has put a great deal of effort for conservation of the rare and endangered mammals, birds, and reptiles and established several protected areas (Heinen and Yonzon 1994). Now protected area system in Nepal, a network of eleven national parks, three wildlife reserves, one hunting reserve and six conservation areas, covers 23.1% of the country's surface (ICIMOD 2007). Most of these protected areas were established based on the biodiversity features that are already threatened (Heinen and Kattel 1992). Although the use of vulnerable biodiversity and landscapes as a basis of conservation prioritization is necessary to conserve species from immediate threats arising from human activities (Mittermeier *et al.* 1998, Myers *et al.* 2000, Brooks *et al.* 2006), it may not be enough to ensure the long-term persistence of biological and ecological integrity (Walker 1992). Since 2001, the government of Nepal is using a landscape level framework in designing conservation areas (Sharma and Chettri 2005, Chettri *et al.* 2007, Sharma *et al.* 2010).

However, one of the major gaps in the biodiversity research in Nepal is that some species (e.g., tigers, rhinoceros, elephants, snow leopards and musk deer etc.) and regions (mainly protected areas, which mostly cover lowland and highland areas) have been a focus of research and conservation (Hunter and Yonzon 1993; Heinen and Yonzon 1994; Chaudhary 2000). Consequently, the midhills, an intermediary landscape that connects the mountain region in the north with the low-land Terai in the south and harbors the highest species and ecosystem diversity (Hunter and Yonzon, 1993; BPP 1995) remain completely unprotected.

In this context, an attempt is made to explain the biodiversity patterns, conservation practices and challenges in Nepal. Although different levels of organizations (genes to ecosystem) of biological diversity can be explained, the variations of vegetation types and associated major fauna within eco-region hierarchy are provided to give an overview of biodiversity of Nepal.

2. Conservation threats posed by wildlife hunting

Protected areas are the cornerstones of wildlife conservation, because human access and use are prohibited there. Outside of the protected areas, local people have a liberty to exploit wildlife as a source of protein and cash income (Barnet 2000). In the absence of proper management, hunting will pose a serious threat to the persistence of wildlife populations, which may lead to empty forestry, as described by Redford (1992). Large mammals, in particular, are disproportionately likely to be threatened by extinction, as compared to the smaller ones due to overexploitation (Mace and Balmford 2000). This phenomenon is predicted in the midhills, where rampant wildlife hunting coupled with habitat loss and fragmentation is believed to have caused declines in wildlife populations (Green 1979; Green 1987; Wegge and Oli 1997). Large ungulates play important roles in ecological process, including dispersal of seed (Bodmer 1991; Willson 1993), influencing spatial patterns of vegetation (Augustine and McNaughton 1998) and serving as a key principle prey for leopards and other sympatric large carnivores (Karanth 1995; Karanth and Sunquist 1995). Despite having both ecological importance and danger of extinction due to overhunting in the forests of midhills, little is known about the pattern of hunting, and therefore a comprehensive research is urgently needed for devising appropriate conservation program in the region.

3. ***Wildlife distribution in a human-dominated landscape***

Habitat variables, typically those of vegetation structure or environmental attributes (e.g., topographical features of landscapes and climate) are used to explain the occurrence and abundance of species (Morrison *et al.* 1992). These attributes, however, do not necessarily guarantee the presence of fauna because human-caused disturbance on the wildlife habitat can alter natural environment (Redford and Sanderson 2000; Robinson and Bennett 2000; Terborgh and van Schaik 2002; Guangshun 2006). Anthropogenic forces affect vegetation composition and distribution through various mechanisms (Garcıa Montiel and Scatena 1994; Fuller *et al.* 1998). These mechanisms include introduction of exotic species (MacDonald *et al.* 1988), alteration of microclimatic conditions near clear-cut lands (Lovejoy *et al.* 1986) and tree logging. All these have a profound effect on the distribution of wildlife species through changing of amount or the suitability of the habitat for a species (Steidl and Powell 2006). Furthermore, numerous studies have shown that human activities cause disturbance that result in physiological stress and breeding failures (e.g., Bélanger and Bédard 1990; Grubb and King 1991; Fernandez and Azkona 1993; Arlettaz *et al.* 2007). Many wild animals respond to disturbance by avoiding disturbed areas or underutilizing them (Gill *et al.* 1996; Gill and Sutherland 2000; Frid and Dill 2002; Beale and Monaghan 2004).

Midhills ecosystems are among the least protected ecosystems, although being critically important as wildlife habitats, because no protected area has been established in the midhills (Shrestha 1984; BPP 1995). This region is extensively settled, and forest areas are affected by a wide range of human impacts. Exploitation of forests for firewood, fodder and timber, including wildlife for meat and recreation, has resulted into the alternation of natural areas, and wildlife species that depend on these areas are becoming rare, threatened, or endangered (BPP 1995; HMGN/MFSC 2002; ICIMOD 2007). Studies have shown that hunted populations exhibit significantly high response to human disturbance than non-hunted population (Stankowich 2008) and are prone to extinction (Robinson 1996; Glanz 1991). Therefore conservation of native species in the human-dominated landscape requires understanding the spatial extent of the influence of human-caused habitat disturbances on the distribution of the wildlife population.

4. Habitat suitability maps

In the recent years, use of habitat suitability modeling for rare and threatened species has become an important tool for wildlife conservation, management and planning (e.g., Pearce and Ferrier 2000; Austin 2002; Scott *et al.* 2002). There are numerous studies on habitat suitability modeling (e.g., Guisan and Zimmermann 2000; Rushton *et al.* 2004; Austin 2007), including methodologies of modeling (e.g., Manel *et al.* 1999; Miller and Franklin 2002; Elith *et al.* 2006). The fundamental part of habitat suitability modeling is that the models attempt to identify the attributes of the environment that are correlated with distribution of species and make predictions for species distribution on a large spatial scale (Peterson 2001; Guisan and Thuiller 2005; Rushton *et al.* 2004). Obtaining survey data on rare and threatened species across the large spatial area is costly and time consuming, particularly in the remote areas (e.g., Manel *et al.* 1999; Austin 2002; Engler *et al.* 2004). Habitat suitability models provide maps of a probability of occurrence of species in question in the previously un-sampled locations (Peterson 2001; Raxworthy *et al.* 2007), whose uses include designing reserves (Abbitt *et al.* 2000; Ferrier 2002), species (re)introduction (Pearce and Lindenmayer 1998; Guisan and Thuiller 2005) and rare species assessment (Engler *et al.* 2004).

A number of modeling and statistical approaches are used to develop suitability maps. It includes random forest (Breimann 2001; Prasad *et al.* 2006), generalized linear models (GLM), generalized additive models (GAM), logistic regression (e.g., Guisan and Zimmermann 2000; Pearce and Ferrier 2000; Scott *et al.* 2002), classification techniques (e.g., classification and regress tree -CART) (e.g., Breiman *et al.* 1984; De'ath and Fabricuus 2000), environmental envelopes, ordination techniques (e.g., canonical correspondence analysis) (e.g., Guisan and Zimmermann 2000) and expert opinion (e.g., Store and Kangas 2001; Yamada *et al.* 2003). However, the survey of rare animal have many absence cases, which may result into poor performance of model built by regression analysis and thus can be misleading (Austin and Meyers 1996). In response, habitat suitability models built on multiplicative approach using suitability index provide a simple approach of model construction (e.g., Larson *et al.* 2003; Liu *et al.* 2001; Dayton and Fitzgerald 2006). Model evaluation also depends on the nature of data set and species concerned. Some of the common evaluation methods include re-sampling techniques, such as cross-validation (e.g., Manel *et al*. 1999; Franklin *et al*. 2000), jack-knife (Manel *et al.* 1999; Efron and Tibshirani 1993) or bootstrapping (Efron and Tibshirani 1993; Guisan and Harrell 2000). Besides, evaluations are also performed using an independent testing dataset that is not used in the model construction (e.g., Fielding and Bell 1997). However, these methods are not robust and can suffer from pseudo-absence data. Therefore, presence only data have been used for evaluation of habitat suitability model for highly rare species across the landscape.

Information about distribution pattern of quality habitat across the landscape provides baseline information for setting conservation priority area. There is no suitability map based on habitat suitability modeling for native wildlife species in Nepal's midhills region. It offers a systematic approach to identify and protect high quality habitats that are critical for survival and existence of wildlife in Nepal's mountains.

5. Forest fragmentation, hunting and wildlife distribution

Nepal supports 3.96% of global fauna of mammals (BPP 1995). More than one out of six (17.83%) of Nepal's 185 mammal species are threatened, and a further 11.35% are quantified as near-threatened (ICIMOD 2007). Some of the species are poorly conserved in the protected areas, partly because of lack of information on the status and distribution of the species. The non-protected areas often receive very low statutory protection and thus wildlife of such areas is likely to be severely affected by the loss and fragmentation of habitats and hunting (Shively 1997; Sodhi *et al.* 2004).

Habitat loss and fragmentation negatively affect population abundance and distribution (Hanski *et al.* 1996; Gibbs 1998; Best *et al.* 2001; Guthery *et al.* 2001) and genetic diversity (Craul *et al.* 2009, Dixo *et al.* 2009) of the species. They also negatively affect distribution of large-bodied species (Gibbs and Stanton 2001), especially species at higher trophic levels and habitat specialists (Davies *et al.* 2004). Human activities in fragmented landscapes, such as wildlife hunting, exacerbate the effects of fragmentation, resulting into steady decline of many wildlife species vulnerable to local extinctions (Robinson 1996; Turner and Corlett 1996; Cullen *et al.* 2000). This is also true about the Nepalese midhills, where many species that were once widely distributed in the region, are now confined to just a few places of mountains due to habitat fragmentation and hunting (BPP 1995; Wegge and Oli 1997). However, no empirical studies have been carried out to date on the effects of habitat fragmentation and hunting on the distribution of wildlife in the large spatial scale.

Himalayan serow, a forest-dwelling mountain ungulate, is a "flagship species" in wildlife conservation and management, because it requires dense and intact forest, is susceptible to human disturbance, and is in high demand for meat. It is now believed to be scattered in remote forests in the mountains. There is no data on spatial distribution of serow in the mountains, which can be used to assess conservation needs of the entire region.

6. Patch size, connectivity and patch occupancy by wildlife species

Habitat fragmentation and loss as a result of the extension and intensification of infrastructure, cities, cropland, and pasture have resulted in the fragmented landscapes and have been implicated as being among the key drivers of the burgeoning global biodiversity crisis (Wilcox and Murphy 1985; Hilty *et al.* 2006; Chetkiewicz *et al.* 2006; Saunders *et al.* 1991). As the core forest areas supporting large vertebrates become insular due to the conversion of natural habitats, the chances of successful dispersals and colonization decrease, putting species susceptible to extinction due to stochastic, demographic, environmental, and genetic effects (Harrison 1993; Andrén 1996; Wikramanayake *et al.* 2004). Several empirical studies have shown that species occupancy is related to patch size and connectivity (e.g Hansson 1991; Merriam 1991; Dunning *et al.* 1995; Dingle 1996; Andrén 1997; Hinsley *et al.* 1998 but also see Simberloff and Cox 1987; Franken *et al.* 2004). Therefore there have been calls to develop habitat networks by restoring the spatial connectivity of fragmented habitats (Opdam 2001). Habitat networks (habitats connected by artificially made corridors) are considered to diminish the negative consequences of habitat fragmentation (Hilty and Merenlender 2004), because of their role in facilitation of the exchange of individuals between isolated subpopulations (Hilty *et al.* 2006), which reduces the negative effects of demographic stochasticity (Brown and Kordic-Brown 1977; Gilpin and Hanski 1991), and inbreeding depression (Aars and Ims 1999).

In Nepal, landscape conservation program with the aim of restoring corridors between protected areas have been recommended for conservation of tiger along the Himalayan foothills (Johnsingh *et al.* 1990; Wikramanayake *et al.* 2004). Although few quantitative data are available on the extent of corridors used by wildlife (Simberloff *et al.* 1992; Foster and Humphrey 1995; Clevenger and Waltho 2000), a connected landscape is preferable to a fragmented one (Beier and Noss 1998). Studies on patch occupancy of keystone species are necessary, especially in regions, where habitat fragmentation is high (Mwalyosi 1991; Soulé and Terborgh 1999). Such studies are important in Nepal's midhills region, as many of the wildlife populations are confined in the patchily distributed forests (HMGN/MFSC 2002**)**. We need to understand, what size of forest and what extent of connectivity is important for conservation of rare and endangered species.

Most of the forests in the midhills region consist of remnants in the mountaintops and along the mountain ridges, and still support some of the important vertebrate species (HMGN/MFSC 2002; ICIMOD 2007). Ungulates, such as Himalayan serow (*Capricornis thar*) are especially important for conservation, because (1) they occur at low population densities, (2) they are hunted extensively for meat and pharmacopeia, (2) they require dense forest with high understory and (3) they are now found only in few forest patches in their distribution range (Green 1986). Therefore, a study on patch occupancy of serow based on the patch metrics (e.g., patch size, perimeter, shape index, proximity to nearest patches) allows identifying important factors required for their conservation.

SCOPE OF THE THESIS

In this thesis, I have investigated various factors that might affect the distribution of ungulates in the human-dominated landscape of western Nepal, using three model species: barking deer (*Muntiacus muntjak*), Himalayan goral (*Naemorhedus goral*) and Himalayan serow (*Capricornis thar*). These factors included anthropogenic disturbance, forest fragmentation, hunting, and landscape connectivity. **Paper I** and **Paper II** serve as an introductory outline of biodiversity of Nepal and challenges to its conservation. The remaining papers are specific case studies on the three wildlife species used as model species.

Conservationists are far from being able to understand the enormity of biodiversity. This makes conservation increasingly a serious challenge. **Paper I** provides an overview of biodiversity pattern in Nepal, including factors (e.g., climate, physiography) that affect patterns of biodiversity. Based on the published literature, the paper explains patterns of biodiversity, especially vegetation and mammalian fauna in the eco-region hierarchy.

Paper II provides a general outline of conservation initiatives and challenges in Nepal. Thus it serves as a good “snapshot” of conservation gaps. Although Nepal is rich in biodiversity, the paper explains, why and how - despite some success - the challenges of conservation continue to increase.

Paper III gives an account of the general pattern of wildlife hunting in the region north of Bardia National Park, which covers 27 Village Development Committees of three districts (Surkhet, Dailkeh and Jajarkot). Both transect and questionnaire survey data were integrated to provide spatial and temporal pattern of hunting. The paper explores trends in wildlife hunting and techniques and investigates the relation between hunting intensity and wildlife abundance.

Paper IV investigates the influence of human disturbance on wildlife distribution in the fragmented landscapes in densely settled mountain areas. Distribution of three ungulates in relation to habitat (vegetation type, canopy cover and understory), topography (altitude, slope, topographic ruggedness) and human disturbance is assessed and human disturbance is identified as an important factor for their distribution. This paper provides fact-based insights into why wildlife populations are being increasingly rarer in the human-dominated areas of the mountains.

Paper V concentrates on preparation and validation of habitat suitability maps for barking deer, Himalayan serow and Himalayan goral. The paper provides a more pragmatic approach to habitat suitability modeling, which can be used for species reintroduction and delineation of conservation priority areas.

Paper VI gives status and distribution pattern of Himalayan serow, a Near Threatened IUCN category ungulate, along the altitudinal gradient of Nepal. This paper investigates the association between presence frequency of serow with hunting intensity, forest intactness and village density and highlights on the need of forest conservation and a ban on hunting for serow conservation.

Paper VII examines influence of variables that characterize patch size (patch area and perimeter), its shape (shape index, fractal shape complexity and perimeter area ratio, connectivity (distance to nearest patch, edge distance, number of connecting patch etc.) for the presence/absence of Himalayan serow in Nepalese mountains.

SUMMARY OF RESULTS AND DISCUSSION

The great biodiversity of Nepal is attributed to its highly variable topography and climate. The flat lowland of the Tarai region is covered with a mosaic of sal and riverine forests with large patches of tall grassland. Sal extends into the mid-hills along river gorges and valleys throughout the country. However, the vegetation on the mountain slopes in the Mahabharat and mid-hills of eastern and western Nepal is very different, because of variations in the climate. The heterogeneity in the vegetation, from subtropical to alpine, provides a mosaic of habitats for a great variety of animals, which form the basis of the interconnected Himalayan ecosystem.

Conservation in Nepal focuses mainly on the protection of flagship species, the protected areas, which are mostly located in the southern and northern part of the country. Like Tarai, the Himalayan region is rich in biodiversity that is protected by an extensive network of protected areas and a landscape conservation project. Consequently, more than 40% of the Nepal's area is currently protected under protected areas system. However, there are daunting conservation challenges, which range from habitat loss to wildlife poaching. Furthermore, Midhills and Mahabharat are under-represented in the protected area system. Historically, these regions were the first to be colonized by man, which resulted in the degradation of the forests. Thus, it is now necessary to initiate conservation programs in the Mahabharat and Midhills in order to improve the interconnectedness of the ecoregions. Bearing the various aspects of diversity of habitats and ecosystems, and anthropogenic threats into perspective, Nepal still needs an inter-ecoregion level research based conservation program. Such a program will ensure the long-term conservation of the Himalayan hotspot, of which Nepal makes up one third (**Paper I and Paper II**).

In the region of the study, the most common wildlife species are barking deer (*Muntiacus muntjak*), Common langur (*Semnopithecus entellus*), goral (*Naemorhedus goral*), wild boar (*Sus scrofa*), rhesus monkey (*Macaca mulatta)*, bear *(Ursus thibetanus)* and common leopard *(Panthera pardus).* Hunting is common in all areas, but is greater in the region, where wildlife abundances are high. Hunting is significantly positively correlated with the relative occurrence of the species. Among the all wildlife species considered, rhesus monkey is hunted less than its abundance suggests. Hunting is organized in a systematic way, where key hunters and their aides remain same for most of the time. There is a steadily increasing trend of hunting intensity from 2005 to 2007. Barking deer was the most commonly hunted animal, followed by goral, wild boar and monkey. However, goral is increasingly being hunted more in the 2006 and 2007. It is attributed to the peace resumption after a comprehensive peace accord between the Nepalese Government and the Nepalese Communist Party (Maoist). Hunters gained both weapons and places to hunt, which resulted in the increased hunting score of goral. The most common hunting techniques are chase-and-trap and wait-and-hunt. The loss of species through hunting in a fragmented landscape has profound secondary effect on the community structure of wildlife. Hence, it is necessary to implement conservation practices in these areas. (**Paper III**).

Wildlife distribution in relation to habitat (forest type, canopy cover, and understory coverage), topography (slope, altitude, topographic ruggedness) and human disturbance (village distance, number of village, forest disturbance status) showed that presence of Himalayan goral and Himalayan serow was significantly associated with habitats, whereas presence of barking deer was significantly associated with the topographic features. Thus, topographic and habitat factors accounted much of variability when treated habitat, topography and human disturbance variables separately for the presence of these three species, indicating that barking deer were characteristically present in areas consisting of flat planes, goral and serow where the terrain is steep and rugged and serow in dense forests, which are avoided by goral. However, species distribution in question depends strongly on disturbance variables in combination either habitat or topography for Himalayan serow and barking deer. All disturbance variables were significantly negatively correlated with the presence of Himalayan serow, whereas distance to nearest village was only significantly negatively associated with the presence of Himalayan goral. The positive correlation of barking deer with disturbance variables, however, does not imply that they can survive in human disturbed areas. The explanation is that barking deer prefers forests in plane areas, which are mostly subjected to extensive human disturbance. That is why the presence frequency of barking deer declined by with the number of villages and increased with distance to nearest village. The significant association between forest disturbance status and both distance to the nearest village and number of villages and no association between forest disturbance status and both topographic ruggedness and slope imply that village density and their proximity to forest are important predictors of human disturbance. It also implies that forest areas near human settlements, irrespectively of their terrain ruggedness and slope, are strongly disturbed (**Paper IV**).

Habitat suitability maps for three mountain ungulates (barking deer, Himalayan goral and Himalayan serow), developed with an aim of identifying conservation priority areas, discriminated accurately the distribution pattern of species according to the quality of habitats as evaluated by an independent data set using the Boyce index. The habitat suitability maps show that of the total area studied 57% is suitable for *M. muntjak,* 67% for *N. goral* and 41% for *C. thar*, but the amount of highly suitable habitats varied considerably among all the suitable habitats: 30% for barking deer, 4% for Himalayan goral, 40% for Himalayan serow. The records of all these three species in the habitat categories were disproportionate relative to their availability and all of them were recorded in highly suitable habitats significantly more frequently than expected by chance. Good quality habitats for Himalayan goral and Himalayan serow are patchily distributed in the south (along the boundary of the Bardia National Park) and north (along mountain ridges) of the study area. This highlights an urgent need for conservation of high quality habitats, including restoration of corridors connecting them (**Paper V**).

Paper VI indicates that serow has disappeared from many of its former geographical distribution range, especially from mid-altitudinal regions. The presence signs of serow were not seen in 4 out of 12 study sites. Frequency of presence signs of serow per 1 km of transect was significantly positively related to the forest intactness index. Frequency of hunting signs per 1 km of transect was also significantly positively related to frequency of presence signs of serow per 1 km of transect. It clearly indicates that hunters go where the best habitats of serow are. The relationship between village density and frequency of presence signs of serow per 1 km of transect revealed that there was a marginally significantly negatively association between village density and forest intactness index, indicating human encroachment and degradation is a likely cause of disappearance of serow in the region. Distribution pattern of serow clearly indicates its confinement either in national park (Bardia National Park) or in upper temperate conifer forest or forests of the sub-alpine region (>2600 m), the areas that are relatively inaccessible or far from human settlements. This clearly entails the need of habitat suitability modeling for restoration and conservation of serow habitat.

Paper VII shows that large patches are important for the presence of serow, where there is no connectivity (i.e., distance to nearest patch, number of connecting patches). However, for small and isolated patches the distance to the nearest patch and width of conducting patches is important for serow presence.

GENERAL CONCLUSIONS

In the recent years, biodiversity conservation has become a major environmental issue. Efforts are being made to address conservation challenges. However, lack of sufficient information about the status of biodiversity may impinge devising an effective and need-based conservation planning.

Paper I provides an overview of biodiversity of Nepal. It offers an insight into the site-specific examples of biodiversity components (e.g. flora, fauna, and physiography) and shows the gaps in research and conservation.

Paper II shows that conservation challenges are of multidimensional nature ranging from poverty to climate change.

Hunting is steadily increasing over time, as a combined result of lack of conservation infrastructure (e.g., legal protection, conservation awareness programs) and demand of meat for subsistence use and cash. Hunting is strongly correlated with wildlife abundance except for that wildlife which is not preferred for meat (**Paper III**).

The main result of **paper IV** is that distribution pattern of wildlife in the forests of Nepalese midhills is strongly affected by human disturbance. In the agrarian society of mountain areas, people heavily depend on the forests to meet demands of fodder for livestock, firewood for heating, timber for furniture and many others. This results in the destruction of valuable wildlife habitat.

The habitat suitability map for barking deer shows that there is a large area of suitable habitat available for this species but it is scattered throughout the study area for Himalayan goral. The map for Himalayan serow shows that its habitat is patchily distributed in the south (along the boundary of the Bardia National Park) and north (along the mountain ridges) of the study area (**Paper V**).

In the midhills landscape, once widely distributed serow is now confined in the small pockets of forest, mainly in forest areas that is far from human settlement and in the national parks. However, data implies that hunters go where best habitats of serow are. Therefore halting forest fragmentation and wildlife hunting should remain the focus of conservation efforts in this region (**Paper VI**).

The main result of the **paper VII** is that presence of serow in patch depends on sizes of patches if they are sufficiently large, and on structural connectivity (e.g., number of connecting patches) and isolation extent (distance to the nearest patch) for the smaller patches.

CONSERVATION IMPLICATIONS

Conservation implications of the research findings are their applications in addressing a real conservation problem. **Paper I** and **Paper II** provide biodiversity pattern of Nepal and show that some areas are not well protected. Thus emphasis in conservation should be placed on the representative ecosystems (e.g., midhills ecosystems) rather than on few exceptional ones (e.g., tigers in the Tarai region and snow leopards in high mountains). Furthermore, the conservation challenges of Nepal are of multidimensional nature ranging from poverty to climate change and require conservation programs integrating various human dimensions.

Paper III findings indicate that wildlife hunting is widespread all over the region, especially in the regions that hold high wildlife abundance (e.g., mountains tops, areas near Bardia National Park). Given the current rapid wildlife hunting trend, government must find ways to work with people to prevent extirpation of wildlife populations. One way could be implementation of conservation program such as community forestry with special emphasis on wildlife conservation. Besides, there is a need of a legal protection to several species currently under threat even outside of protected area.

The results of **Paper IV** indicate that human caused disturbances influence the distribution pattern of wildlife in the midhills mountain of Nepal. Thus, it is important to conserve the large areas of undisturbed forest far from human settlements for the persistence of wildlife populations, especially that of Himalayan serow. Conservation of the forest around human settlements is particularly important for the protection of wildlife, because it can help to reduce the intensity of disturbance in the core forest farther away from the villages and also provide an additional habitat for barking deer that prefers forest of plane areas.

The geographic distribution of high quality habitats demonstrates that large forest patches suitable for Himalayan goral and Himalayan serow have been, will likely remain, subjected to high fragmentation and loss. Thus conservation of high quality habitat should be the immediate focus of conservation efforts (**Paper V**).

Forest protection is critically important for Himalayan serow because it is highly sensitive to the habitat fragmentation and is hunted extensively. Serow presence, in many cases, reflects forest status because it is forest specialists and is sensitive to human caused disturbance and habitat fragmentation. The fact that serow absent in many of its historical distribution ranges because of forest fragmentation and hunting is also true for many other fauna, and further deterioration will result extinction of many wildlife populations. **Paper VI** shows that serow are confined either in subtropical or in upper temperate region and thus conservation of critical habitats is needed to facilitate the movement of serow along an altitudinal gradient of mountain in the long run.

Paper VII shows that the conservation and restoration programs in landscapes should focus on protecting large fragments (at least 5 km^2) to retain the serow in the patches. However, corridors are critically important to retain serow in smaller patches. Therefore forests growing on the mountain ridges, which connect large patches of forests in mid and northern midhills, should be preserved as corridors.

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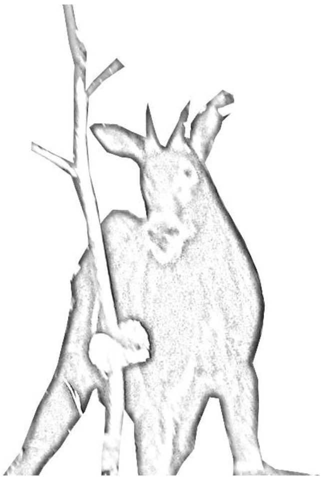
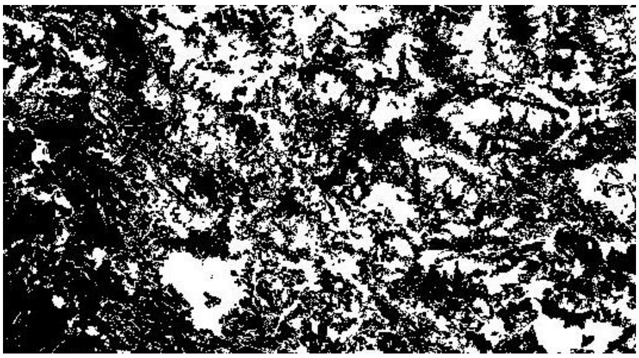
ABSTRACTS OF THE PAPERS





Paper I

PAUDEL, P.K., BHATTARAI, B.P. AND KINDLMANN, P. (2012). An overview of the biodiversity in Nepal. *In:* P. Kindlmann (ed.). *Himalayan Biodiversity in the Changing World*. Springer, Dordrecht, pp. 1 – 40

Nepal is a mountainous country in the central Himalayas, which occupies about one third of (800 km) of the entire length of the Himalayan mountain range. Nepal alone claims eight out of the top ten tallest mountains in the world, including Mount Everest (8,848 m). Apart from the mountains, deep gorges, river valleys and the flat lands it provides a unique assemblage of very different habitats and a great biodiversity within a small geographical area. The 147 181 km2 that make up Nepal is slightly less than 0.1% of the global land mass, but contains a disproportionately large diversity of plants and animals. The country's 118 ecosystems harbour over 2% of the flowering plants, 3% of the pteridophytes and 6% of the bryophytes in the world's flora. Similarly, the country harbours 3.9% of the mammals, 8.9% of the birds and 3.7% of the world's fauna of butterflies.

Keywords: Nepal, biodiversity, physiography, ecoregion, Himalaya

Paper II

BHATTARAI, B. P., PAUDEL, P. K. & KINDLMANN, P. (2012). Conservation of biodiversity: an outline of the challenges. In: Pavel Kindlmann (Ed.). *Himalayan Biodiversity in the Changing World*, Springer, Dordrecht, pp. 41–70.

The conservation of biodiversity is an important issue in developing countries like Nepal. Subsistence agriculture, including livestock rearing, is the main occupation of the majority of the people in rural areas. This puts an ever-increasing demand on the forest as the human population increases. Consequently, many forests are either badly degraded or encroached by people seeking essential resources for their survival. Thus, conservation challenges in Nepal are of anthropogenic origin and the result of an unsustainable extraction of biological resources. The challenges get more complicated as the human population grows, thus the conservation strategies need to effectively harmonize human and conservation needs.

Keywords: Conservation challenges, threats, biodiversity, Threats, Nepal, protected areas

Paper III

PAUDEL, P.K. (2012). Challenges to wildlife conservation posed by hunting in non-protected areas north of the Bardia National Park. *In*: P. Kindlmann (ed.). *Himalayan Biodiversity in the Changing World*. Springer, Dordrecht, pp. 177 - 195

The hunting of wildlife for subsistence and trade is a serious threat to conservation. It is widespread in the non-protected areas. However, there is no understanding of the nature and trends in hunting and their consequences for protected areas. The nature and scale of hunting north of the Bardia National Park were assessed to determine the spatial variations in hunting intensity. Focal group discussions with forest user groups and transect surveys were used to determine the abundance of wildlife. Detailed interviews with hunters were used to explore their hunting patterns. Apart from the information obtained from the interviews, encounters with hunting teams, hunting signs and information from herders were used to identify hunting sites. Hunting is widespread throughout the region, but the intensity of hunting is greater close to the northern edge of the national park, which is associated with the relative abundance there of wildlife. Hunting along the immediate periphery of the national park is increasing. The hunting of common and protected species suggests that it is both for subsistence and trade, which could severely deplete the wild animals in the forests and consequently affect the protected area. Hence, it is necessary to legalize community-based monitoring by forest users groups and establish effective government supervision.

Keywords Wildlife, hunting, landscape, Bardia National Park, non-protected area

Paper IV

PAUDEL, P.K. AND KINDLMANN, P. (2012). Human disturbance is a major determinant of wildlife distribution in Himalayan midhill landscapes of Nepal. *Animal Conservation*, in press

Forest landscapes in the midhills of western Nepal are not adequately conserved within a protected area network. The species and ecosystems in these human-dominated landscapes are highly endangered. Understanding the effects of human activities on wildlife is therefore important for devising an appropriate conservation strategy in this region. Here we show, using data on spatial structure of three endangered mountain ungulates, that presence of these species is determined by the level of human disturbance and habitat requirements. We show that species preferring flat areas covered by dense forest are exposed to more intensive human disturbances and even an adaptation to rugged areas does not imply less human disturbance. Abundance of all species studied declined with the number of villages in the vicinity and increased with distance to nearest village. Therefore, increasing human population may contribute to a decrease of wildlife population in the region. To prevent this, community forestry program enabling local people to protect forest near villages and land-use strategy aimed at reducing further encroachment of forest in higher altitudes should be immediately launched in the region.

Keywords: Human disturbance, midhills, wildlife conservation, mountain landscape, conservation challenges

Paper V

PAUDEL, P.K., KINDLMANN, P. AND HAIS, M. (2012). Habitat suitability maps for mountain ungulates in a human-dominated landscape of Nepal: identifying areas for conservation. Submitted to *Journal of Environmental Management*

Determining the distribution of species and of suitable habitats is a fundamental part of conservation planning. We used slope and ruggedness of the terrain, forest type and distance to nearest village to construct a habitat suitability maps for three mountain ungulates (barking deer - *Muntiacus muntjak*, Himalayan goral - *Naemorhedus goral* and Himalayan serow - *Capricornis thar)* in the midhills of western Nepal. We used locations of sightings of presence signs of these mountain ungulates collected during surveys along transects in 2008 to 2011 to derive a suitability value for each variable using Jacob's index. A multiplication approach was used to combine environmental variables and produce a habitat suitability map for each of the three species. An independent dataset was used to evaluate the maps using Boyce's index. This approach provides an overview of the probable distributions of the species in question. We predict that of the total area studied 57% is suitable for *M. muntjak,* 67% for *N. goral* and 41% for *C. thar.* Although there are suitable habitats for all three species throughout the study area, the availability of high quality habitats for these species varied considerably. Suitable habitats for *N. goral* and *C. thar* were fragmented and mostly confined to the southern and northern part of the study area. This study provides important baseline information for conservation biologists concerned with maintaining biodiversity in the midhills of Nepal.

Keyword: *Capricornis thar,* habitat model, midhills, *Muntiacus muntjak*, *Naemorhedus goral*, Nepal

Paper VI

PAUDEL, P.K. AND KINDLMANN, P. (2012). Distribution pattern of the threatened Himalayan serow (*Capricornis thar*) in western midhills of Nepal: An insight for conservation along an altitudinal gradient. Submitted to *Journal of Nature Conservation*

Almost nothing is known about the distribution and status of the Himalayan serow, an IUCN category “near threatened” ungulate, formerly widely distributed from subtropical to subalpine regions, in the Nepalese Himalaya. Heavy hunting, together with habitat loss and fragmentation are believed to have caused local extinctions in many sites within its geographical range. Distribution pattern of this dense forest dwelling threatened ungulate thus indicates conservation status of the whole unique ecosystems of this region. The objective of this study was therefore to assess distribution and status of serow in the Nepalese midhills. We conducted surveys, based on sightings and indirect presence signs, in western Nepal, between the subtropical Bardia National Park in the south and mountainous Shey Phoksundo National Park in the north, during 2008-2010. We recorded serow in the Bardia National Park. Further to the north, we recorded it only in highly rugged and inaccessible areas in the high altitudes, which suggests their possible extinction in the midhill region. The serow presence was strongly positively correlated with hunting intensity and forest intactness index. The populations of serow, scattered in the region, are small and therefore likely to be sensitive to demographic stochasticity. This all may consequently lead to future extinction of serow in the entire region. This information can be used to aid further research and decision-making processes for conservation planning along altitudinal gradient of Nepal’s Himalaya.

Keywords: *Capricornis thar,* Himalayan serow, Nepal, midhills, habitat fragmentation, altitudinal gradient

Paper VII

PAUDEL, P.K., KINDLMANN, P. AND JAROSIK, V. (2012). Patch size and connectivity predict presence of Himalayan serow in the fragmented landscape of western Nepal. *Manuscript* for *Conservation Biology*

Himalayan serow, *Capricornis thar*, is a threatened migratory dense forest specialist caprine, which inhabits mountain slopes and is a flagship conservation species for the midhills of Nepal. The relationships between signs of the presence of serow and the size, shape and connectivity of 76 forests patches (2844 km^2 ranging from 300 to 4400 m a.s.l.) were determined. Spatial distribution of serow was recorded on topographic maps, which were used to produce a map of habitats suitable for serow. Size, shape and connectivity of each patch were defined in geographical terms and the data analyzed using classification trees. Most of the patches where presence of serow were recorded in forest patches larger than 5 km^2 and with a perimeter greater than 36 km. Serow were not recorded in dense networks of small patches between which migration was not possible, when the distance to another patch is more than 1.8 km. The probability of serow presence was still 60% when the total width of corridors connecting patches was more than 28.5 m. As serow requires large areas of continuous forest there is now no area of forest left large enough for creating such large reserves. Many of the patches are forest islands on mountain tops, surrounded by human-exploited landscape. Conservation of Himalayan serow thus depends on preserving the largest forest areas and maintaining corridors between smaller patches. In terms of conservation this requires the same conditions as those necessary for conserving the unique ecosystem of this region.

Keywords: Himalayan serow, *Capricornis thar*, Midhills, Nepal, connectivity, patch