COUPLED HUMAN AND NATURAL SYSTEMS APPROACH TO TIGER
CONSERVATION IN CHITWAN, NEPAL AND BEYOND

By

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ABSTRACT

COUPLED HUMAN AND NATURAL SYSTEMS APPROACH TO TIGER CONSERVATION IN CHITWAN, NEPAL AND BEYOND

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Protecting wildlife and their habitats is important for human well-being. However, protecting wildlife and their habitats while simultaneously meeting the resource needs of a growing human population is a major sustainability challenge. Addressing this challenge necessitates a holistic understanding of how people, wildlife, and ecosystems are inter-connected. Inherently integrative in nature, a coupled human and natural systems (CHANS) approach brings together theories and analytical techniques from diverse disciplines, including those from ecological and social sciences, to understand the interrelationships between humans and nature. I used a CHANS approach in my dissertation research to study the interactions between a subsistence-based agricultural community and the globally endangered tiger (*Panthera tigris*) in and around Nepal's Chitwan National Park, a global biodiversity hotspot. I chose tigers in Chitwan because the challenges facing tiger conservation there (e.g., habitat degradation, human-tiger conflict) epitomize the challenges facing wildlife conservation in many regions around the world. Thus insights and lessons learned from this research can be useful for many other regions around the world (e.g., Pantanal in South America). My research had three interrelated objectives: 1) evaluate and map human attitudes toward tigers, 2) evaluate how land management practices and policies impact tiger habitat, and 3) assess how tigers respond to human activities in space and time. To achieve these objectives, I collaborated with U.S. and Nepali institutions performing long-term sociological and environmental studies in the region

and used remotely-sensed data, individual surveys, ecological field data, and agent-based modeling and simulation.

Research findings revealed new and valuable insights about how local people value tigers, how human activities and policies impact tiger habitat across space and through time, and how tigers use the landscape with respect to humans. For instance, using a novel psychological framework, I found that dissatisfaction with government management of tiger-related risks (i.e., attacks on livestock and people) and the sense of vulnerability to those risks strongly influenced local capacity to live with tigers (Chapter 2). I also found that one's position in society (i.e., educational level, ethnicity, and gender) shaped attitudes toward tigers more so that direct experiences with tigers (e.g., attacks on livestock) (Chapter 3). Furthermore, land-management practices recently implemented (late 1990's and early 2000's) in the multiple-use forest outside the National Park, including community-based resource management and the prohibition of livestock grazing, has restored previously degraded tiger habitat (Chapter 4). Using data from motion-sensing field cameras, I found relatively high tiger densities despite ubiquitous human presence (i.e., people on foot and vehicles), due in part to tigers offsetting their temporal activity patterns to be much less active during the day when human activity peaked (Chapter 5). Also, results from an agent-based model indicated that tigers may spend considerably less time feeding on prey in the presence of people than in the absence of people (Chapter 6). In addition to filling several knowledge gaps that promote the long-term coexistence between people and tigers, my dissertation highlights new substantive research directions that will advance science and on-the-ground conservation efforts. Integrative and interdisciplinary CHANS research, characterized by this dissertation, is an effective approach to addressing some of the most pressing wildlife conservation challenges in a world increasingly crowded by people.

ACKNOWLEDGEMENTS

Virtually all challenges are surmountable with a strong and supportive network of friends and family. I'm lucky to have such a network. My parents fostered my desire to work in the

field of wildlife conservation and to pursue a PhD every step of the way. They have never wavered in their unconditional support and they continue to be a reliable and constant source of inspiration and confidence for me. My fiancée, Jenna Jones, has been a rock-hard pillar of support throughout my doctoral work. She endured my long, incommunicado stints in the field. She championed me even when my self-confidence floundered. She kept me balanced during my PhD, enabling me to thoroughly enjoy and cherish my time at Michigan State University. To say meeting her just before I started my PhD was auspicious is an understatement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

The recent and ongoing declines of wildlife species around the world are caused primarily by impacts associated with the rapid growth of human populations. Overhunting, spread of invasive species, and the rapid expansion and intensification of human land-uses, among other impacts, have triggered an extinction crisis jeopardizing global biodiversity (Cardillo et al. 2004). Many of those wildlife species facing extinction provide vital ecosystem functions, such as pollination, nutrient regulation, and biological control. By virtue of their ecosystem functions, wildlife species affect the goods and services that people rely on, such as the availability of food and medicines, the provision of raw materials (e.g., timber and fuelwood) and agricultural products (e.g., fodder), and the control of pests and diseases (De Groot et al. 2002). In addition, wildlife are of economic, aesthetic, cultural, religious, existential, and educational significance to people around the world (Manfredo et al. 2009, Carter et al. 2012a). As such, protecting wildlife and their habitats is not only important for human well-being (Estes et al. 2011) but many argue that it is also a moral responsibility (Ehrlich and Wilson 1991). . However, protecting wildlife habitat while simultaneously meeting the resource needs of a growing human population is a major sustainability challenge, especially because the world is projected to add 1.4 billion more people over the next two decades (United Nations 2010a) and 10 to 20% of the world's remaining natural grasslands and forests are expected to be converted to human land uses (e.g., agriculture, urban) by 2050 (MEA 2005).

Given these future possibilities, reconciling the needs of wildlife and people necessitates a holistic understanding of how people, wildlife, and ecosystems are inter-connected. However, most studies are constrained to a single discipline, such as ecology or sociology, due to historical precedent as well as a lack of expertise in or respect for other fields of study by disciplinary investigator(s) (Liu et al. 2007b). For example, studies on the dietary requirements of wildlife species are not usually put into the broader research context of how wildlife food availability and

quality changes as a result of changes in human natural resource consumption patterns (Ramesh et al. 2012). When human-wildlife-ecosystem interactions are explicitly studied, they are typically done so from either a natural or social science perspective, with an emphasis on unidirectional relationships. For instance, ecological studies have examined how human activities, such as hunting and land-use, affect ecosystems and the wildlife they support (Trombulak and Frissell 2001, Peres and Lake 2003). Alternatively, demographic studies have investigated how environmental changes affect childbearing and migration behaviors (Biddlecom et al. 2005, Massey et al. 2010a). Although valuable, such research that holds factors from other disciplines as "exogenous" or as background and does not link processes together insufficiently accounts for the inherent complexity of systems in which humans and wildlife are integral parts of (An 2012). Overlooking these interactions hinders researchers, managers, and policy makers from adequately understanding and managing these systems.

Inherently integrative in nature, a coupled human and natural systems (CHANS) approach brings together theories and analytical techniques from diverse disciplines, including those from ecological and social sciences, to understand the interrelationships between humans and nature (Liu et al. 2007a, Liu et al. 2007b). The CHANS approach is thus well suited for understanding wildlife dynamics in human-dominated landscapes. First, by transcending a single discipline, the approach can account for the patterns and processes that link people with wildlife and their habitats (Liu et al. 2007b). Second, rather than focusing on unidirectional relationships, the approach can identify key reciprocal interactions between people and wildlife. Third, the approach can help us understand within- and cross-scale interactions (e.g., spatial, temporal, and organizational) between people and wildlife (Liu et al. 2007b). By integrating all of these aspects, the CHANS approach can disentangle relationships between people and wildlife. Doing so will enable the identification of underlying causes of ecosystem degradation

and wildlife loss, and potentially broaden the array of policies and interventions that mitigate or reverse those trends in human-dominated landscapes.

For the abovementioned reasons, I believe a CHANS approach can substantially advance conservation efforts for the globally endangered tiger (*Panthera tigris*). Approximately 3,500 tigers currently remain in the wild (Wikramanayake et al. 2011) and are scattered throughout South Asia and a small portion of Russia. These remaining tigers are confined to <7% of their historic range at well below potential carrying capacity due primarily to poaching, prey depletion (due to human hunting), and habitat loss (Seidensticker et al. 1999, Dinerstein et al. 2007, Wikramanayake et al. 2011). Three tiger sub-species (Bali, Caspian, and Javan) have already gone extinct in the second half of the 20th century (Seidensticker et al. 1999) with a 4th subspecies (South China Tiger) considered unviable in the wild (Tilson et al. 2004). Although human impacts have dramatically reduced global tiger numbers and habitat throughout the 20th century, people worldwide value tigers for aesthetic (e.g., physical beauty), cultural (e.g., symbol in Chinese zodiac), religious (e.g., vehicle of a revered Hindu deity), economic (e.g., eco-tourism benefits), and existential reasons (Seidensticker et al. 1999, Norris 2005, Dua et al. 2010). Additionally, tigers are recognized as being important regulators of many ecosystems throughout their range (Seidensticker et al. 1999). As such, protected areas have been established to conserve ecosystems harboring the last vestiges of tigers.

One such protected area is Nepal's Chitwan National Park, which is located mostly within Chitwan district at the base of the Himalayas: a global biodiversity hotspot (Myers et al. 2000). Chitwan National Park (1,000 km^2, established in 1973) was declared a World Heritage Site in 1984 and supports one of the largest populations of tigers in South Asia (~125 adult tigers). However, extraction of natural resources (e.g., fuelwood for cooking and heating, grass for fodder, thatch and timber for construction) by the human population (most of whom are

4

subsistence farmers) living next to the park (ca. 580,000 people as of 2011) exerts negative

effects on Chitwan's ecosystems (Stræde and Treue 2006). Moreover, the annual rate of new

home construction over the last three decades (~5.5%) in Chiwan has almost doubled population

growth (~3%), which suggests that per capita natural resource use has increased (Liu et al. 2003).

In addition, tiger attacks on people are a growing concern: 65 local residents were killed 1998 –

2006 compared to 6 during the 1989 – 1997 period (Gurung et al. 2008).

Although there have been various studies in Chitwan addressing tiger behavior (Smith et

al. 1998), prey abundance (Shrestha 2004), forest change (Panta et al. 2008) and rural sociology

(Chettry et al. 2005), none of these projects have integrated both human and natural dimensions

and thus insufficiently address the challenging conservation issues at hand. By collaborating

with U.S. and Nepali institutions performing long-term sociological and environmental studies in

the region, I have had the unique opportunity of conducting CHANS research on tigers and their

conservation in Chitwan since 2007.

My dissertation, entitled "Coupled human and natural system approach to tiger

conservation in Chitwan National Park, Nepal, and beyond", is an effort to integrate data,

methods, and theories from disparate disciplines to understand how the interactions between

tigers and people in and around the park impact tiger conservation efforts and human livelihoods.

To guide my research, I developed a conceptual model of human-tiger interactions in Chitwan,

which consists of five main components: local residents, natural land covers, tigers, policy/policy

makers, and global processes (Fig. 1.1). The characteristics of each of these components are

interrelated and influence the characteristics of the other components. For example, the spatial

distribution of households influences the distribution of tigers (e.g., spatial/temporal avoidance).

In addition, various activities of local residents (e.g., fuelwood collection, timber harvesting)

affects land-cover characteristics (e.g., composition, structure). Changes in land-cover

characteristics reciprocally affect local residents, for example, income from the sale of natural resources is related to land-cover composition. Changes in land-cover characteristics, such as the spatial location of forest patches, also impact the quality of tiger habitat (e.g., fragmentation). Tigers, in turn, can affect land cover (e.g., by reducing numbers of herbivores) or impact local residents (e.g., tiger attacks on people engender negative attitudes). Interactions within and among each of these components prompt policy makers (e.g., government agencies, community organizations) to develop and implement new policies (e.g., devolving resource management to local communities), that in turn modify component dynamics (e.g., local resident socioeconomic conditions, tiger population size). Global processes (e.g., external markets, tourism, migration) also influence system dynamics. For example, tourism influences socioeconomic conditions of local residents (e.g., infrastructure employment associated with the tourist industry, income from selling local products to tourists), which in turn has cascading effects on the land cover (e.g., modifying local demand for natural resources) and tigers (e.g., influencing rates of habitat degradation).

Evaluating every possible interaction illustrated in the conceptual model was beyond the scope of my dissertation. However, the conceptual model combined with an extensive review of the scientific literature and a visit to Chitwan in 2008 led me to identify four major research gaps relevant to long-term tiger conservation in Chitwan. The research questions demonstrate the interdisciplinary nature of the challenges facing tigers in this region. The four major questions are:

1. What determines local people's capacity to cohabit with tigers?
2. What determines the spatial distribution of attitudes towards tigers?
3. How has tiger habitat changed across different land management regimes?
4. How do tigers behaviorally respond to human presence?

Through my intensive fieldwork from 2008 to 2011 with colleagues from Michigan State University, University of Michigan, and Nepal, I collected multi-temporal datasets (e.g., daily, decadal) spanning disparate disciplines (e.g., social psychology, ecology) and acquired at various spatial scales (e.g., wildlife occurrence data, individual survey data, and remotely sensed images). These datasets include over 350,000 pictures of tigers, their prey, and people inside and outside the park; high spatial resolution remotely sensed satellite images of Chitwan in 1989, 1999, and 2009; survey data from 499 individuals whose households were georeferenced using a global positioning system (GPS) unit; 1996 digital topographic data (e.g., administrative boundaries, rivers, roads) from Nepal Survey Department; and census data from 1971 to 2011. These data were instrumental in helping me address the four major research questions.

Chapter 2 of my dissertation addresses question 1 by first developing a novel conceptual model of the psychological factors affecting the capacity for local people to cohabit with large carnivores, like tigers, and then empirically testing the validity of the conceptual model using survey data collected in 2010. This chapter was published in Oryx (Carter et al. 2012a), and conforms to the style of that journal. Shawn Riley and Jianguo Liu co-authored the paper. Shawn Riley, Jianguo Liu, and I designed the research; I performed research; I analyzed the data; and Shawn Riley, Jianguo Liu, and I wrote the paper.

Chapter 3 addresses question 2 by evaluating how attitudes toward tigers relates to one's position in society and interactions with tigers, and by modeling and mapping spatial clusters of attitudes toward tigers. The chapter was published in AMBIO, a Journal of the Human Environment (Carter et al. 2013), and conforms to the style of that journal. This paper was coauthored by Shawn Riley, Ashton Shortridge, Binoj Shrestha, and Jianguo Liu. Shawn Riley, Jianguo Liu, and I designed the research; Binoj Shrestha and I performed research; I analyzed the data; and Shawn Riley, Ashton Shortridge, Binoj Shrestha, Jianguo Liu, and I wrote the paper.

Chapter 4 addresses question 3 by focusing on the habitat dynamics of tigers and how land management policies and practices affect those dynamics. This chapter is in press in the journal Ecosphere, and its style conforms to this journal. Bhim Gurung, Andrés Viña, Henry Campa III, Jhamak Karki, and Jianguo Liu co-authored the manuscript. Jianguo Liu and I designed the research; I performed research; Andrés Viña and I analyzed the data; and Bhim Gurung, Andrés Viña, Henry Campa III, Jhamak Karki, Jianguo Liu, and I wrote the paper.

Chapter 5 addresses question 4 by evaluating the spatial and temporal activity patterns of tigers with respect to different human activities (e.g., resource collection by local residents, tourists walking along trails) occurring inside tiger habitats. This chapter was published in the Proceedings of the National Academy of Sciences (Carter et al. 2012b), and the writing style is primarily in accordance with that journal. The paper was co-authored with Binoj Shrestha, Jhamak Karki, Narendra Man Babu Pradhan, and Jianguo Liu. Jianguo Liu and I designed the research; Binoj K. Shrestha and I performed research; I analyzed the data; and Binoj K. Shrestha, Jhamak B. Karki, Narendra Man Babu Pradhan, Jianguo Liu, and I wrote the paper.

Chapter 6 also addresses question 4 by using an agent-based modeling approach to better understand how human presence indirectly impacts tiger fitness (e.g., how avoiding humans decreases time spent eating prey). The ABM presented in Chapter 6 is preliminary, but lays the groundwork for building a significantly more complex model of human-tiger interactions. The ABM I developed in this chapter was built on an existing ABM developed by Ahearn et al. (2001) and Imron et al. (2011). I wrote the chapter and performed all analyses.

Each of these chapters revolves around one central theme: identifying conditions that enable both people and tigers to coexist into the long-term future. Integrative and interdisciplinary CHANS research, characterized by this dissertation, is an effective approach to identifying those conditions.

Figure 1.1: Conceptual model of human-tiger system in Chitwan, Nepal. I used this model to guide my dissertation research.
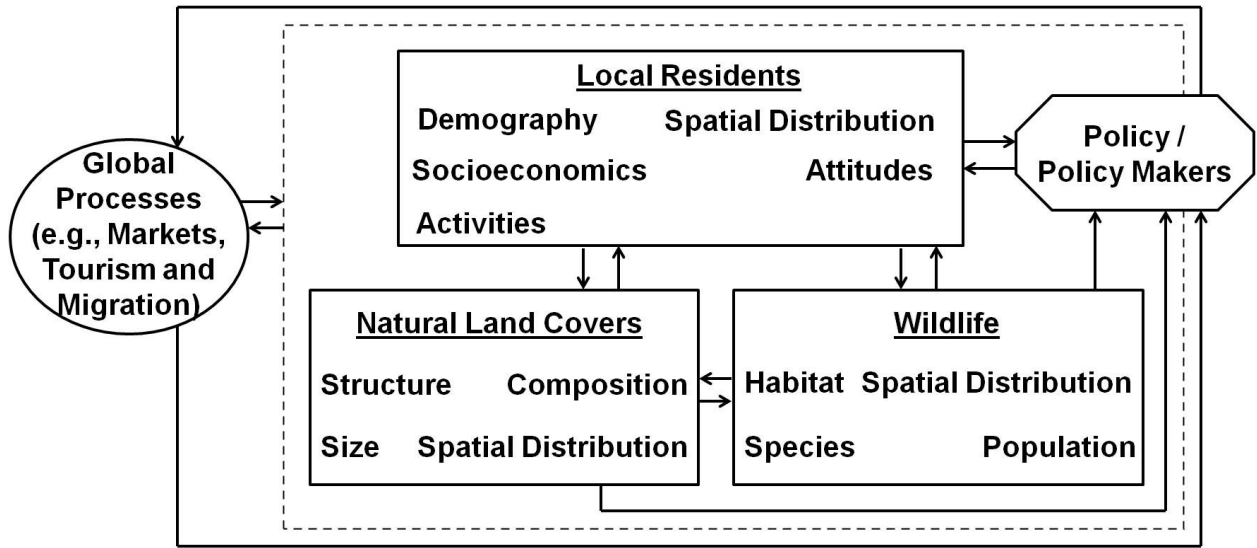
CHAPTER 2

UTILITY OF A PSYCHOLOGICAL FRAMEWORK FOR CARNIVORE CONSERVATION

In collaboration with

Shawn J Riley and Jianguo Liu

Abstract

Conserving threatened carnivore species increasingly depends on the capacity of local people to cohabit with those species. To examine such capacity, we developed a novel psychological framework for conservation in regions of the world where there are human-carnivore conflicts, and used endangered tigers *Panthera tigris* to explore the utility of this framework. Specifically, we tested 3 hypotheses in Chitwan National Park (CNP), Nepal where the increasing rate of human-tiger conflicts potentially jeopardizes long-term coexistence. We administered a survey to 499 individuals living <2 km from CNP and nearby buffer zone to record preferred future tiger population size and factors that may influence preferences including past interactions with tigers (e.g., livestock predation) as well as beliefs and perceptions about tigers. Over 17% of respondents reported that a tiger had attacked their livestock or threatened them directly. Results from a structural equation model indicated that respondents who preferred fewer tigers in the future were less likely to associate tigers with beneficial attributes, more likely to associate tigers with undesirable attributes, and more likely to believe that government officials poorly manage tiger-related risks and that people are vulnerable to risks from tigers. Our framework can help address current and future conservation challenges because it 1) integrates an expansive and generalized set of psychological concepts, 2) enables the identification of conservation interventions that foster coexistence between people and impactful carnivores, and 3) is suitable for broad application.

Introduction

Competition between humans and carnivores over limited resources, such as space and food, often leads to human-carnivore conflicts. These conflicts occur worldwide, and are increasing in regions where human land-uses, driven by population growth, are expanding and intensifying (Treves and Karanth 2003, Inskip and Zimmermann 2009). Human-carnivore conflicts are defined here as direct threats to economic (e.g., livestock depredation), health and safety (e.g., transmission of disease, attacks on people), and psychological (e.g., fear of attack) well-being of local people (Woodroffe et al. 2005). A common reaction to real or perceived conflicts is a reduction in carnivore populations (Woodroffe and Ginsberg 1998). Responses range from individual people killing specific animals to governments sanctioning large-scale carnivore eradications. For instance, in the 19th and 20th centuries, eradication programs nearly extirpated wolves *Canis lupus* and cougar *Puma concolor* from the contiguous United States to relieve negative effects of those species on livestock (Woodroffe 2000). Similarly, for decades beginning in the 1950's, tigers were subjected to uncontrolled killing in China after the government declared tigers a pest (Seidensticker et al. 1999). More recently, several conflict-prone carnivore species, including African wild dog *Lycaon pictus*, Spotted hyena *Crocuta crocuta*, and Grizzly bear *Ursus arctos horribilis* have experienced substantial population reductions due to human persecution (Woodroffe 2001).

The long-term viability of threatened carnivores (i.e., species with increased risk of regional extirpation or global extinction) is significantly jeopardized when local people take action to eliminate 'problem' animals (e.g., by poisoning them). Human-caused mortality impacts carnivore population dynamics, for example, by creating population sinks, and decreases the probability of population persistence (Woodroffe and Ginsberg 1998). The extent and degree

12

of these impacts on carnivore populations are substantial as much of the remaining range of threatened carnivores is in human-dominated land (Dickman et al. 2011).

Therefore, sustaining threatened carnivore species depends on the capacity of local people to tolerate carnivore-related risks and desire increasing or expanding carnivore populations, or at the very least, policy favorable to their conservation (Riley and Decker 2000b). Previous studies have shown that the capacity of local people to cohabit with impactful wildlife species is strongly influenced by subjective psychological factors including beliefs and perceptions (Decker and Purdy 1988, Riley and Decker 2000b, Zinn et al. 2000, Bruskotter et al. 2009). Several studies have assessed these factors independently with respect to threatened carnivores in various regions (Saberwal et al. 1994, Marker et al. 2003, Romañach et al. 2007), but none of these studies integrated psychological concepts into a comprehensive framework.

We developed a novel psychological framework for conservation in regions of the world where there are human-carnivore conflicts, and used endangered tigers *Panthera tigris* to explore the utility of this framework. We evaluated the effects of past interactions with tigers as well as beliefs and perceptions towards tigers on preferred future tiger population size among local people living near Chitwan National Park, Nepal, where the increasing frequency of human-tiger conflicts negatively impacts tigers and people (Gurung et al. 2008).

Our research represents the first quantitative evaluation of the relationships between past interactions with carnivores, psychological concepts, and preferred future carnivore population size. Our psychological framework integrates a comprehensive and generalized set of concepts allowing researchers to systematically test hypotheses and develop theories regarding the ways people relate to carnivores under a wide range of conditions. The framework also enables the identification of interventions with the greatest effect on preferences for carnivores, and thereby helps understand constraints and opportunities in Nepal and some other parts of the world.

Psychological Framework

We posited that an individual's personal experience or interactions with carnivores affect his or her beliefs and perceptions associated with these species, which, in turn, affect his or her preferences for population sizes (Fig. 2.1).

Past Interactions with Carnivores

Personal interactions with an *in-situ* carnivore may occur in places where humans and carnivores live in close proximity. We defined these interactions as direct, which included livestock predation and encounters between local people and carnivores in the wild (e.g., carnivore scat or pugmark seen by local person, carnivore seen or heard by local person in nearby forest, person attacked) (Saberwal et al. 1994, Wang et al. 2006). In addition to direct interactions, social amplification of risk theory posits that interpersonal connections and media outlets serve to 'amplify' risk 'signals' (i.e., intensify information about risk) regarding a particular event or interaction (Kasperson et al. 1988). We defined these interactions as indirect, which included hearing or reading news about human-carnivore encounters from the media or personal contacts including friends, family, and neighbors (Gore and Knuth 2009). Several studies demonstrate that direct and indirect interactions with carnivores affect cognitions (e.g., beliefs) and emotions (e.g., worry) towards the carnivore species (Saberwal et al. 1994, Wang et al. 2006, Gore and Knuth 2009).

Beliefs about Carnivores and Carnivore-related Risks

Beliefs are broadly defined as "associations or linkages that people establish between the attitude object and various attributes" (Eagly and Chaiken 1993). Beliefs mediate the relationships between broad, abstract values (e.g., honesty) and behavior (Fulton et al. 1996). We posited that beliefs about carnivores were based on beneficial and undesirable attributes

typically associated with the species. Benefits associated with carnivores included cultural, religious, economic (e.g., tourism), ecological, and existential attributes (Kellert 1985); whereas, nuisance behavior and resource competition were undesirable attributes (Sharma 1990, Kissui 2008). Based on risk literature, we posited that beliefs about carnivore-related risks were associated with the perceived 1) duration that the individual has been exposed to the risk, 2) rate of change in exposure to the risks, 3) ability of the individual to adapt to and avoid the risks, 4) ability of authorities to understand and address the risks, and 5) balance of benefits compared to the risks (Slovic 1987, Sjöberg 1998, Riley and Decker 2000b, Gore et al. 2006).

Perceptions of Carnivore-related Risks

Riley and Decker (2000a) suggested that risk perceptions are a product of an underlying belief system rather than a cause of these beliefs. We postulated that people have affective and cognitive risk perceptions towards encounters with carnivores that threaten human livelihood (e.g., carnivore attacks livestock) and safety (e.g., carnivore attacks someone in the village). Whereas affective risk measures the dread or worry an individual feels towards a specific negative human-carnivore encounter occurring (Sjöberg 1998, Gore and Knuth 2009), cognitive risk estimates the perceived likelihood of the encounter occurring (Riley and Decker 2000a). Importantly, perceptions and beliefs are subject to manipulation through information and education (Zinn et al. 2000).

Preferences for Future Carnivore Population Size

According to theories of human cognition (Ajzen 1991, Fulton et al. 1996) and empirical studies (Fulton et al. 1996, Riley and Decker 2000a, Bruskotter et al. 2009, Gore and Knuth 2009), beliefs about wildlife, wildlife-related risks, and perceptions of those risks strongly influence an individual's 'acceptance capacity' for wildlife. Wildlife Acceptance Capacity (WAC), first introduced by Decker and Purdy (1988), was initially defined as the "maximum

wildlife population level in an area acceptable to people", and acknowledged that people have a limited capacity to cohabit with wildlife (Carpenter et al. 2000). We used preference for future carnivore population size to measure an individual's acceptance capacity for carnivores. Since human behaviors limit carnivore distribution and population sizes (Woodroffe and Ginsberg 1998), the ability to support a carnivore population within any habitat may be as much a function of WAC as biological carrying capacity (Riley and Decker 2000a).

Unlike previous research on WAC, our study focused on conservation of threatened carnivores rather than management of abundant wildlife species (Zinn et al. 2000, Whittaker et al. 2006, Lischka et al. 2008). We broadly define an abundant wildlife species as an animal that can suffer a systematic reduction in population size and remain ecologically viable (e.g., deer in the Eastern United States). Measures to control (i.e., systematically reduce) populations of abundant wildlife species, for example, through a cull or contraception, normally are incompatible and undesirable in the context of threatened wildlife conservation (Treves et al. 2006).

Hypotheses

Based on our psychological framework, we formulated 3 main hypotheses concerning the relationships between endangered tigers and local people living near Chitwan National Park (CNP), Nepal:

1) The effect of past interactions with tigers on preference for future tiger population size is mediated by beliefs and perceptions about tigers.

2) Perceptions of tiger-related risks are strongly influenced by beliefs about tigers and tiger-related risks.

16

3) Preferred future tiger population size is strongly influenced by beliefs about tigers, tiger-related risk, and perceptions of those risks.

Materials and Methods

Study Area

Our study site was western Chitwan district directly north of CNP approximately between 27º30'00" N and 27º43'00" N latitude and 84º9'00" E and 84º29'00" E longitude (Fig. 2.2). Chitwan district is located in a river valley basin along the flood plains of the Rapti, Reu and Narayani rivers with an altitudinal range of 150 m – 815 m. Conditions in Chitwan district are subtropical with a summer monsoon from mid-June to late-September, and a cool dry winter (Laurie 1982). Chitwan district has a complex mixture of ethnicities (Axinn and Ghimire 2007). Many people in Chitwan depend on their crops and livestock for their livelihood, and rely on nearby forests for thatch, reeds, fodder, fuelwood, timber, and other products to support their agricultural lifestyles (Sharma 1990).

Chitwan National Park, established in 1973, is a globally important protected area for conservation of tigers (Walston et al. 2010). Approximately 30-50% of Park revenue is invested into the surrounding buffer zone established in 1996 to support community development programs, including alternative income opportunities and community forestry (Government of Nepal 1993). At the time of this research, the study area comprised a mosaic of land-uses including National Park, National Forest, community forests, agriculture, and urban development. As of 2001, the human population in our study area was approximately 200,000, and the total number of households was approximately 41,300.

Survey Design

In June 2008, we conducted a focus group of local people (n=10) around Chitwan to discuss their beliefs and perceptions about tigers. We used insights from this focus group to understand vernacular and modify previously tested survey items, particularly Riley (1998) and Peyton et al. (2001). Local Nepali experienced in social survey research design worked with us to ensure internal validity of our survey measures. We designed a structured survey to record interactions with tigers, beliefs about tigers, beliefs about tiger-related risks, perceptions of tiger-related risks, and preferred future tiger population size, as well as respondent age, ethnicity, gender, education level, and occupation. In December 2009, we pre-tested the survey (n=17) in a site adjacent to our study area to improve survey effectiveness. Preferred number of tigers living nearby in the next 10 years was based on a 5-point bi-polar scale (i.e., much less, less, same, more, and much more). We chose 10 years because it is a round number and a conceivable time-frame in which tiger population size can change significantly. All belief questions were binary (i.e., no, yes) or on a 3-point bi-polar scale (i.e., less, same, more). All risk perception questions were on a 3-level nominal scale (i.e., none, somewhat, very). "Don't know" options were provided on all questions.

Sample Selection

Wards (smallest administrative unit) that had at least 50% of their area within 1 km of the CNP/buffer zone border, where the majority of tiger human conflicts occur (DNPWC unpublished human-wildlife conflict data), were selected. Ward boundary data were extracted from 1996 digital topographic data obtained from Nepal Survey Department (www.dos.gov.np) because these are the most recent data and little change in ward boundaries had occurred since 1996. We randomly selected 500 residences from within the wards based on residence locations in 1996 (N=5,400). The number of residences has increased since 1996 (the most recent data on

18

spatial locations of residences). In February 2010, the name and age of all persons living in each of the 500 residences (inclusion criterion was that they must have been residing in the house during the week prior to the time when the survey would be administered) were recorded and compiled in a list. From this list, a single individual (age 15 – 59) was randomly selected for survey from each of the 500 randomly selected residences, resulting in a total of 500 possible respondents. From March – April 2010, trained Nepali interviewers contacted each possible respondent to administer the survey face-to-face.

Data Analyses

We used structural equation modeling (SEM) to assess interrelationships among interactions with tigers, beliefs about tigers and tiger-related risks, perceptions of tiger-related risks, and preferred future tiger population size as hypothesized in our psychological framework. Unweighted data were used to develop the models. SEM is ideal for evaluating our multi-level framework because it simultaneously measures associations among several independent and dependent variables, whereas multiple regressions and analysis of variance techniques only measure one relationship at a time (Reisinger and Mavondo 2007).

Confirmatory factor analysis, an inherent procedure in SEM, was conducted to assess the degree to which 20 survey items (i.e., observed variables) loaded on 4 *a-priori* defined latent (unobserved) variables: 1) beliefs about tigers; 2) beliefs about tiger-related risks; 3) perceptions of affective risk; and 4) perceptions of cognitive risk. We constrained each item to load on only one latent factor. The factor analysis could not support missing data (i.e., survey items with 'don't know' responses). As such, we omitted 11 cases (2.2%) with missing data from our survey sample using listwise deletion, which is acceptable if the number of cases omitted is <5% of the total sample (Schafer 1999).

Structural equation models measure the direct and indirect effects of variables on one another according to a path diagram. We developed a path diagram that linked a variable we created to describe interactions with tigers to the belief and perception latent variables, and linked these latent variables to preferences for future tiger population size. The variable we created to describe interactions with tigers ranged from 1 (very low) to 5 (very high). Category 1 (very low) included respondents who indicated no direct or indirect interactions with tigers, category 2 (low) included respondents who had read or heard about tiger-human conflicts as well as those who had seen evidence of tigers nearby (e.g., pugmark, scat), category 3 (moderate) included respondents who had seen a tiger in the wild, knew somebody who had livestock attacked by a tiger, and had a friend, neighbor, or relative that had been threatened or attacked by a tiger, category 4 (high) included respondents whose livestock were killed by tigers, and category 5 (very high) included respondents that had been threatened directly by a tiger. If a respondent reported multiple interactions with tigers (e.g., read about tiger-human conflict and livestock killed by tiger), we used the category (1-5) corresponding to the greater degree of interaction with a tiger (e.g., category 4 corresponding with livestock depredation).

We used maximum likelihood estimation to calculate model parameters. Parameter significance was estimated from bias-corrected bootstrap 95% confidence intervals based on 2,000 bootstrap samples (Preacher and Hayes 2008). Standardized root mean square residual (SRMR) and comparative fit index (CFI) were used to assess goodness-of-fit of our model to the data (Hu and Bentler 1999). Structural equation modeling was performed using software Amos version 18. We used software PASW version 18 to compute Cronbach's alpha reliability coefficients for each set of items composing the belief and perception variables in the final model.

Results

Characteristics of Respondents

The survey was completed by 499 of 500 individuals contacted while the remaining one individual opted to not participate in the study. Average age of respondents was 33.7 (15-59) years and nearly 37% were male. Respondents were predominantly female since many men leave Chitwan to work in urban centers in Nepal or elsewhere (Bohra and Massey 2009). Respondents ranged in ethnic background including higher caste Hindu, hill Tibeto-Burmese, lower caste Hindu, Newar, Terai Tibeto-Burmese, and other Indian castes. Respondents were crop farmers (51%), livestock producers/keepers (0.5%), mixed farmers (i.e., crop and livestock farmers, 18%), business owners (3%), business employees (8%), daily wage laborers (2%), students (15%), and various other occupations (2.5%). They had a range of education levels ranging from none (31%) to post graduate degrees (1%).

Past Interactions with Tigers

Interactions between respondents and tigers varied, but a rather large majority of respondents experienced low to moderate levels of interaction with tigers (72%). Approximately 11% reported no direct and indirect interactions with tigers, whereas 17% of respondents reported that a tiger had attacked their livestock (high) or threatened them directly (very high). Nearly 82% of respondents interacted with tigers on multiple occasions.

Beliefs and Perceptions about Tigers

A majority of respondents (59% - 91%) associated tigers with cultural, religious, economic (i.e., tourism), ecological, and existential benefits. However, nearly 40% of respondents believed tigers were a nuisance, and that there was not enough room for both tigers and people in the nearby forests. A majority of respondents believed that negative encounters

with tigers have occurred for a long time (73%) but agreed that the risks from tigers were avoidable (71%) and something that local people could adapt to over time (65%). Nearly two-thirds of respondents agreed that risks from tigers were understood by government officials (63%), but only 45% believed officials were satisfactorily addressing the risks. Proportions were approximately the same for those who believed the number of problems (i.e., conflicts) with tigers had decreased (36%), stayed the same (31%), or increased (33%) over the previous 10 years. Nevertheless, the proportion of respondents who thought that the risks of living near tigers outweighed the benefits (39%) was much larger than the proportion of those who thought the benefits outweighed the risks (12%).

In general, respondents perceived greater cognitive risk (i.e., likelihood) than affective risk (i.e., worry) of attacks by tigers on pets and livestock. Some respondents reported high levels of cognitive risk despite low levels of affective risk perception. Yet, in nearly all cases high levels of affective risk were accompanied by high levels of cognitive risk perceptions. This relationship was strongest in situations where human safety was at risk. Whereas the proportions of respondents who perceived cognitive and affective risk of tiger attacks on someone in their village and tiger attacks on them or someone in their family were comparatively equal (Fig. 2.3a-d).

Preferred Future Tiger Population Size

The distribution of respondents' preferences for future tiger population size was nearly uniform. An equal proportion of respondents (40%) preferred fewer tigers and more tigers in nearby forests over the next 10 years compared to 2010.

Structural Equation Model

The initial model ($\chi^2 = 1102.83$, df = 261) fit the empirical data poorly as the SRMR index was >0.8 and the CFI was <0.9. Thus, we re-specified the model *post-hoc* based on

modification indices and standardized factor loadings (Reisinger and Mavondo 2007).

Modification indices >100 indicated that beliefs about tigers were better explained using one

latent variable measuring beneficial attributes and one latent variable measuring undesirable

attributes. Beliefs about tiger-related risks were also better explained using two latent variables:

government poorly manages tiger-related risks and people are vulnerable to these risks (Table

2.1). Belief about the balance of benefits compared to the risks of having tigers nearby loaded

adequately (standardized factor loading >0.5) as a beneficial attribute (Table 2.1) rather than a

belief about tiger-related risks. Beliefs about the religious importance of tigers, the duration that

the individual has been exposed to risks from tigers, and the rate of change in exposure to risks

from tigers were removed from the model as they did not load adequately on any of the latent

variables. The reliability of each set of items composing the belief and perception variables was

acceptable (i.e., >0.65, Vaske 2008) in the re-specific model (Table 2.1). Results from the re-

specified model ($\chi^2 = 622.13$, df = 188) adequately fit the data as SRMR = 0.07 and CFI = 0.91.

Determinants of Preferred Future Tiger Population Size

There was a significant direct effect in 10 of 20 paths between model variables (Fig. 2.4).

Past interactions with tigers had a significantly positive relationship with affective risk

perception, but was not related to any other variable. Additionally, the indirect effect (i.e.,

mediated effect) of interactions with tigers on preferences for future tiger population size was

insignificant (Table 2.2), leading us to reject hypothesis 1. Beliefs about tigers and tiger-related

risks strongly influenced affective and cognitive risk perceptions (Fig. 2.4), which supports

hypothesis 2. However, risk perceptions did not have a significant direct effect on preferences

for future tiger population size, leading us to reject hypothesis 3 that both beliefs and perceptions

would strongly influence preferences. Beliefs about benefits of having tigers nearby had the

greatest effect on preferences (Fig. 2.4). Respondents who preferred fewer tigers in the future

23

were less likely to associate tigers with beneficial attributes, and more likely to associate tigers with undesirable attributes. These respondents were also less likely to believe that risks from tigers are avoidable, and that people can adapt to risks from tigers over time. Additionally, they were less likely to believe that risks from tigers in Chitwan are understood and satisfactorily addressed by government officials.

Discussion

Our model results affirm the idea that human cognitions and emotions towards carnivores are complex and inter-related (Fulton et al. 1996). The hierarchical relationships among variables would have been missed if a multiple linear regression was used to evaluate the data, as has been done in some other studies on local attitudes towards wildlife (Kaczensky et al. 2004, Lischka et al. 2008). We found that preferences for future tiger population size was primarily driven by beliefs about tigers and tiger-related risks, not unlike Bruskotter (2009) who found that similar cognitive factors were related to the acceptability of specific management actions towards wolves.

Beliefs about Tigers

Beliefs about tigers in Chitwan reflect changes in social-economic conditions. For instance, tourism has grown to become a powerful industry in Chitwan with 836 entry permits to the Park sold in 1974 increasing to over 113,788 in 2009 (Curry et al. 2001, Government of Nepal 2009). This may explain why 50% more respondents agreed that tigers should stay in nearby forests because they attract tourists than the number who agreed that tigers should stay because they keep the forests healthy. However, tigers regulate ungulate populations (Terborgh et al. 1999) which, if unchecked, may eat crops in nearby agricultural fields more frequently and to a greater extent. Crop raiding by protected fauna has already been identified as a major source

24

of resentment among local people towards the Park (UNEP/WCMC 2008). Education programs

that target specific beliefs may positively condition (Zinn et al. 2008) local people to view larger

tiger populations in terms of their beneficial contributions to people (e.g., eco-tourism revenue),

society (e.g., cultural significance), and the environment (e.g., ecological value) than merely as

threats to livelihood and safety.

Assessing the effect of beliefs about carnivores on preferred future carnivore population

size is important, as conservation actions that fail to account for differences in local beliefs with

respect to region and species may not effectively increase the capacity of local people to support

those carnivores. For instance, Kissui (2008) found that cultural sentiments of local people

towards African lions *Panthera leo*, leopards *Panthera pardus*, and spotted hyenas influenced

the vulnerability of those species to retaliatory killing. Therefore, carnivore persecution,

influenced by subjective beliefs, may continue despite reductions in livestock predation.

Beliefs about Tiger-related Risks

Local people living near and among carnivores incur the greatest costs from those species

(Wang and Macdonald 2006, Gurung et al. 2008). Yet, management responsibility of threatened

carnivores typically rests with government/conservation agencies rather than local communities

(Treves et al. 2006). Our results from Chitwan underscore a need for government/conservation

agencies to supplement mitigation of human-tiger conflicts through direct intervention (e.g.,

translocating or killing a conflict-prone tiger) by building local trust and satisfaction in agency

programs (Slovic 1993). This is particularly important in developing rural areas where local

people often have limited options with which to respond to human-wildlife conflicts (Ogada et

al. 2003).

Respondent belief that people are vulnerable to tiger-related risks reflects a perceived

inability to control one's environment (Ajzen 2002). This sense of vulnerability combined with

perceived inefficacy of government/conservation agencies may compel local people to resolve human-carnivore conflicts by illegal means (Treves et al. 2002). Employing a number of conservation tools, including proactive education and awareness programs, effective compensation programs (Dickman et al. 2011), and carnivore-response teams with a contingent of local people (see Gurung et al. 2008), may increase satisfaction in government/conservation agencies and reduce the sense of vulnerability among local people to carnivore-related risks. In addition, incorporating local communities as partners in conservation planning and implementation may increase preferences for future carnivore population size (Treves et al. 2006).

Interactions with Tigers and Risk Perceptions

Previous WAC studies have alluded to the strong effect that past experiences with carnivores, particularly negative interactions (e.g., livestock attack), has on preferences for carnivore population size (Riley and Decker 2000b, Bruskotter et al. 2009). However, these studies focused on perceived impacts rather than an explicit measure of past experience with carnivores because actual human-carnivore interactions at the study sites (i.e., Montana and Utah, USA) were so infrequent. By explicitly measuring past experiences, we found that the proportion of people in Chitwan who had direct interactions with tigers (i.e., high impact) was surprisingly high, likely similar to many other places where human-carnivore conflicts are severe.

People in Chitwan have lived in close proximity to tigers for hundreds of years (McLean 1999), and frequently enter the forests to collect natural resources for subsistence or for sale in nearby markets (Stræde and Treue 2006). Thus, tiger-human interactions in Chitwan are generally more consistent and direct than those between carnivores and human populations in developed countries (Manfredo et al. 2009). After such long and persistent exposure to threats

posed by tigers, people in Chitwan may have internalized the risks into their day-to-day lives (Slovic 1987), which may explain why past interactions with tigers and risk perceptions did not influence preferences for future tiger population size. Whereas, in Montana, USA, where one fatality from cougar attack in the 20th century has been documented, perceptions of cougar-related risks were significantly related to preferences for future cougar population size (Riley and Decker 2000a). Similar research conducted in other areas facing similar human-carnivore conservation issues would be useful in refining model variables and testing the external validity of our model.

Conclusions

Human-carnivore conflicts are predicted to increase in developing regions of the world (Baillie et al. 2004), which will likely lead to increased rates of retaliatory killings and additional burdens on limited conservation resources that already suffer from monetary and personnel shortages (Treves et al. 2006). Our novel psychological framework can help address current and future conservation challenges because it 1) integrates an expansive and generalized set of concepts, 2) enables the identification of conservation interventions that foster coexistence between people and conflict-prone carnivores, and 3) is applicable to many other species in other parts of the world. For instance, in places with human-lion conflicts, using our framework would inform policies that address the beliefs and perceptions germane to local preferences for future lion population size, such as implementing education programs in Tanzania, where human-lion conflict is severe (Chardonnet et al. 2010), to reduce the risk belief that attacks on people are unavoidable. Moreover, focusing conservation efforts on people who prefer smaller future populations of threatened carnivores may be an effective means of distributing limited resources, reducing human-carnivore conflicts, and engaging local communities in conservation.

APPENDIX

Figure 2.1: Psychological framework illustrating relationships between interactions with carnivores, psychological concepts, and preferred future carnivore population size. The dashed lines illustrate potential management actions influencing preferences for carnivores. Management actions include those that affect the physical environment in which carnivores and humans interact and those which affect the human dimensions.
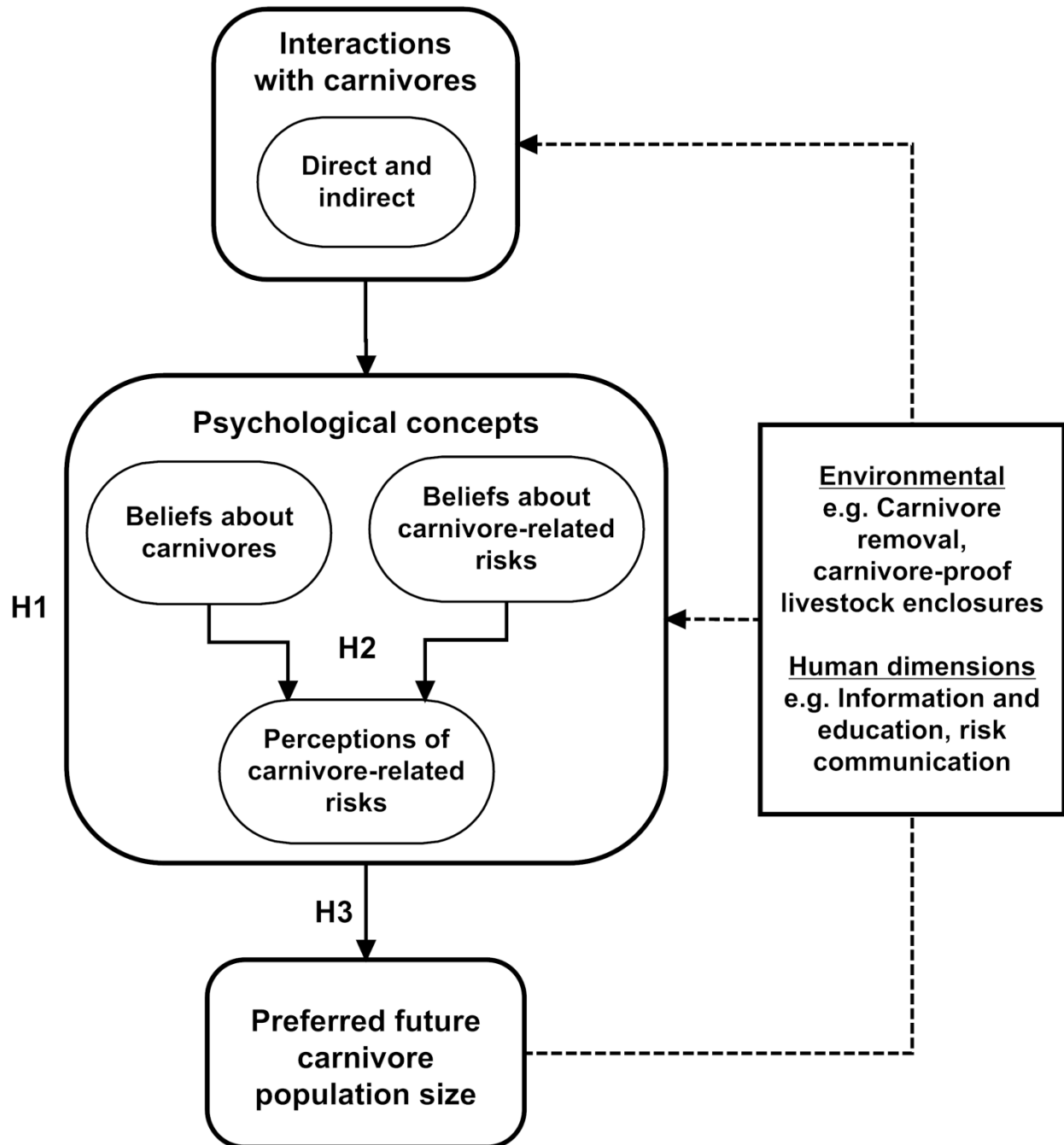
Figure 2.2: Location of study site in Chitwan, Nepal to evaluate psychological relationships between local people and tigers.
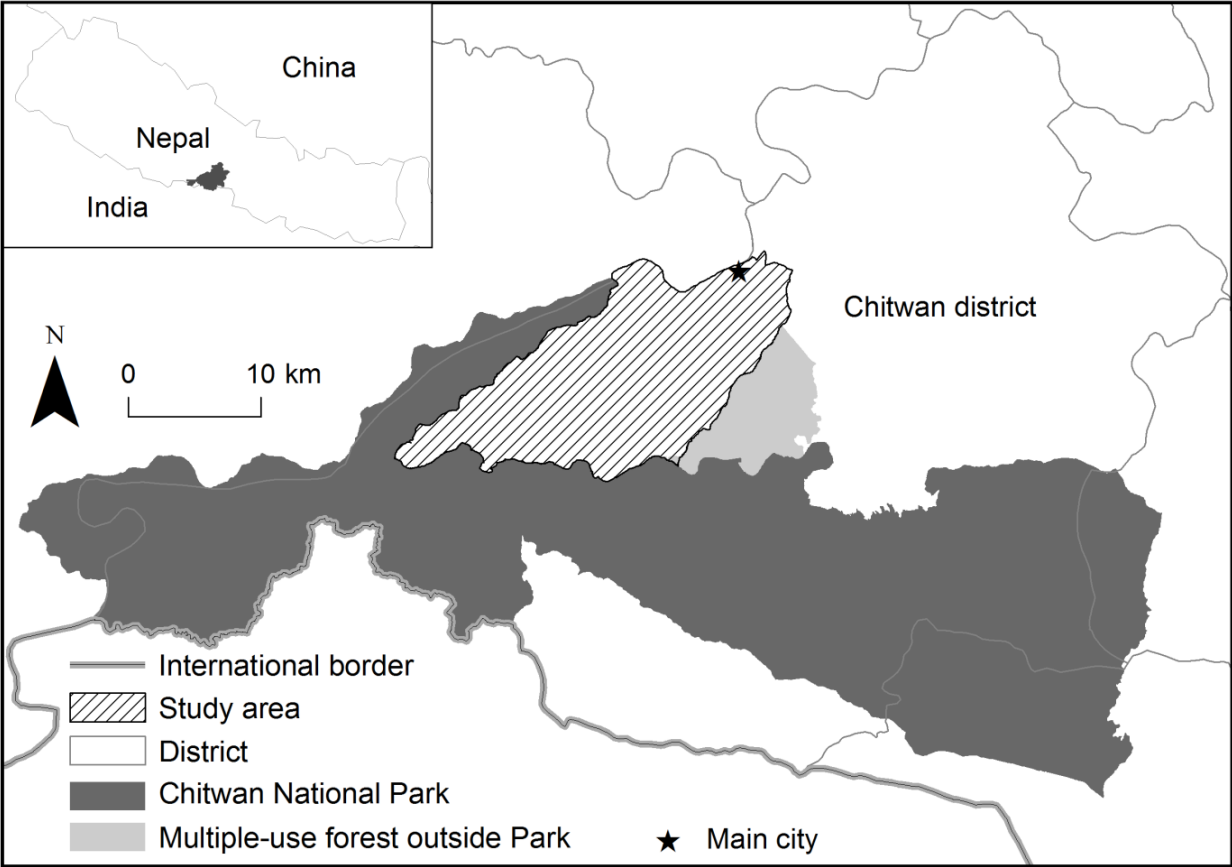
Figure 2.3: The percentage of respondents who expressed varying degrees of affective (not worried: 1, somewhat worried: 2, very worried: 3) and cognitive risk (not likely: 1, somewhat likely: 2, very likely: 3) towards tiger attacks on (a) their pets, (b) their livestock, (c) someone in their village, and (d) themselves or someone in their family. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation.
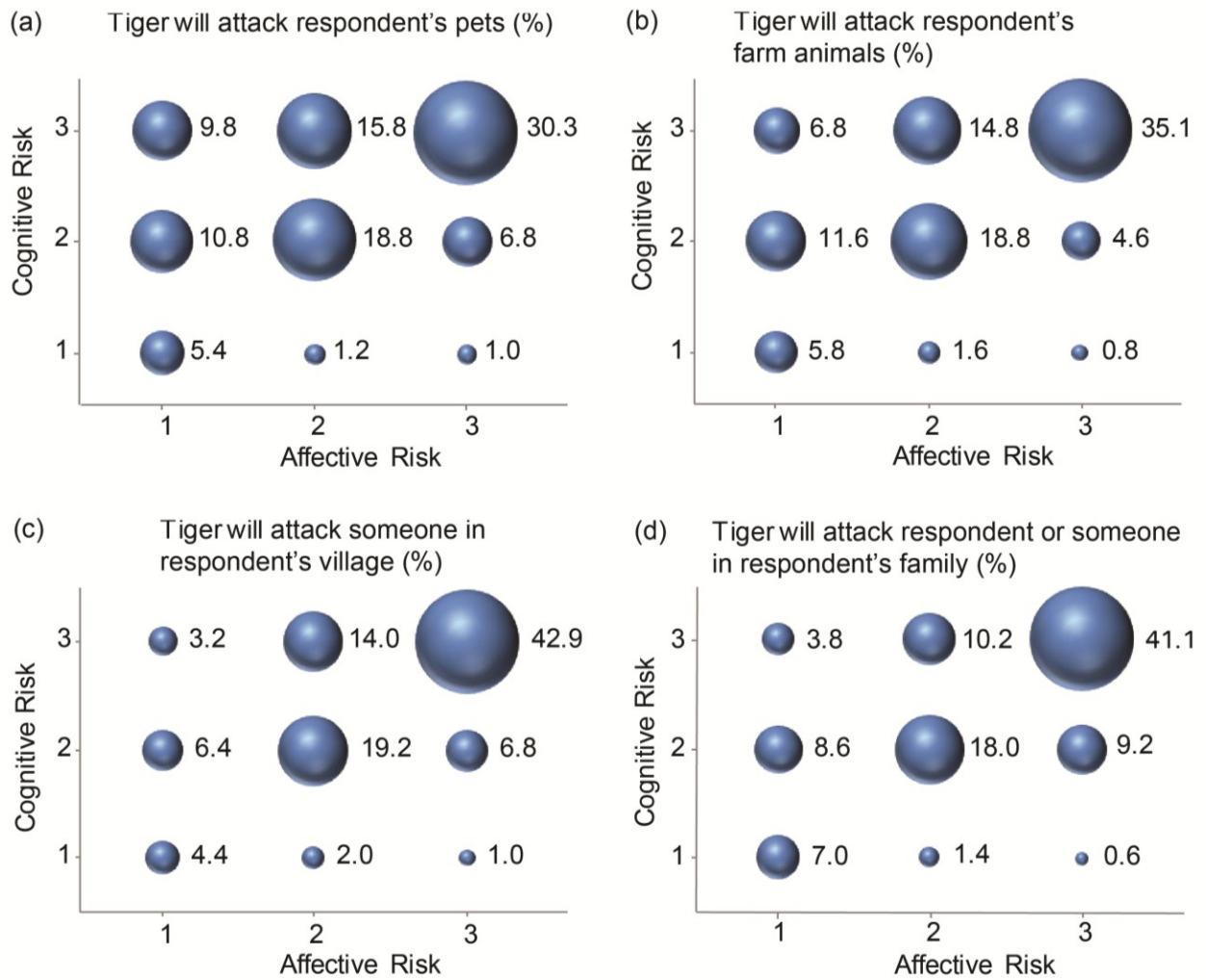
Figure 2.4: Path diagram used in final structural equation model. See text and Table 1 for definitions of variables. Solid black lines between variables indicate significant direct effects (*P*<0.05) with standardized regression coefficients shown to the left of line. Dashed gray lines indicate no significant direct effect. Correlation between beneficial attributes associated with tigers and undesirable attributes associated with tigers is −0.527 (P < 0.05). Correlation between government poorly manages tiger-related risks and people are vulnerable to tiger-related risks is −0.054 (P < 0.05). Correlation between affective risk of tiger attack and cognitive risk of tiger attack is 0.576 (P < 0.05).
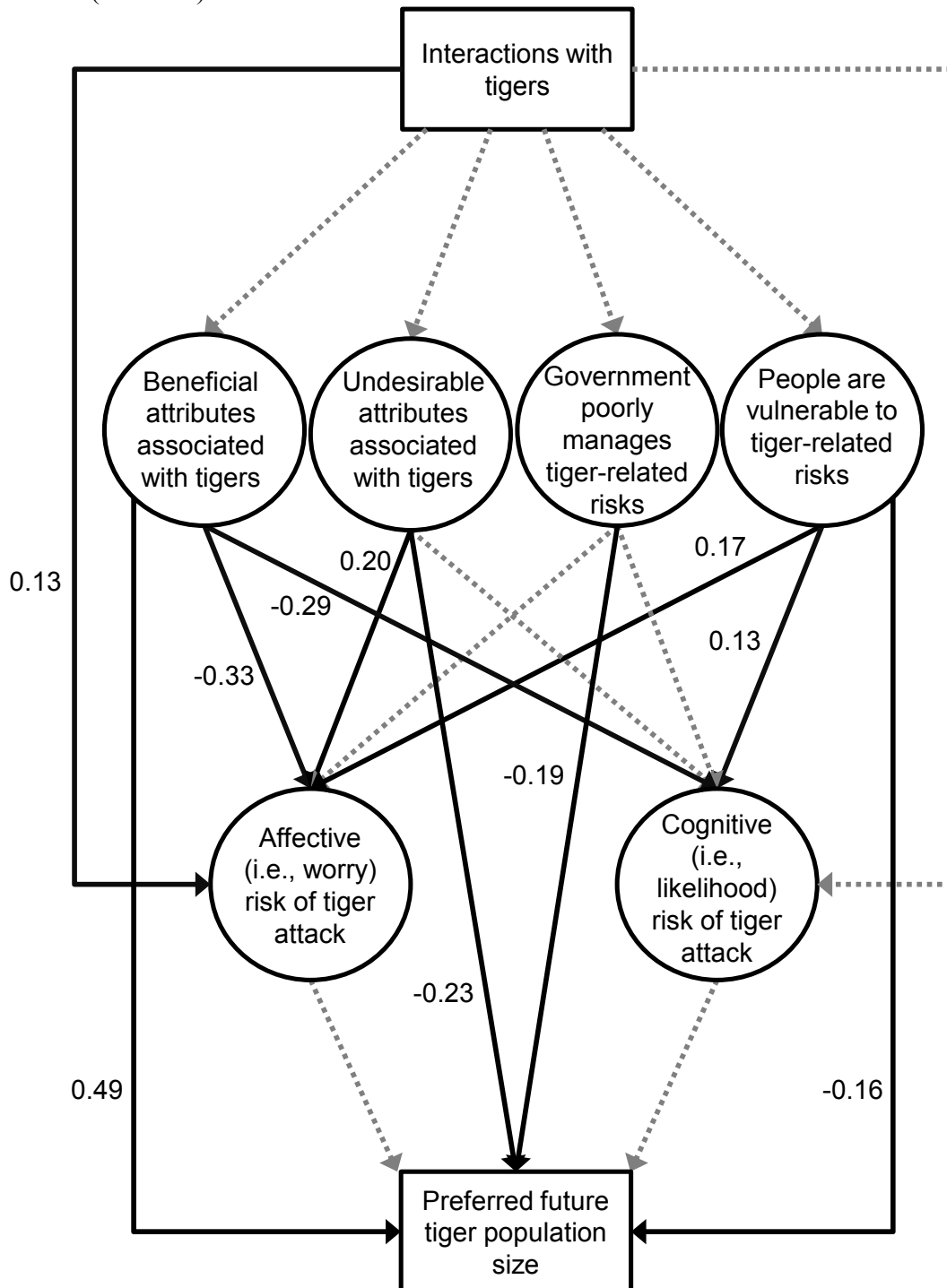
Table 2.1: Reliability and confirmatory factor analysis of latent variables used in final structural equation model.

Latent variable/survey item	Factor loading[1]	Cronbach's Alpha
Beneficial attributes associated with tigers		0.76
Do you agree that your village will benefit from more tourism if tigers are in the nearby forests?	0.51	
Do you agree that tigers should stay in the nearby forests because they keep the forests healthy?	0.73	
Do you agree that tigers are an important part of your culture and should continue roaming the nearby forests?	0.62	
Do you agree that tigers were in Chitwan before humans and have the right to live in the nearby forests alongside humans?	0.54	
Does it please you just knowing that tigers exist in the nearby forests?	0.72	
Do you think that the benefits of living near tigers are greater than, equal to, or less than the risks?[2]	0.59	
Undesirable attributes associated with tigers		0.74
Do you agree that tigers are a nuisance and should be kept out of the nearby forests at all costs?	0.84	
Do you agree that there is not enough room for both tigers and humans to live in Chitwan so tigers should leave the nearby forests?	0.7	
Government poorly manages tiger-related risks		0.66
Are the risks from tigers in Chitwan understood by the government or government officials?[2]	0.76	
Are the risks from tigers in Chitwan being satisfactorily addressed by the government or government officials?[2]	0.64	
People are vulnerable to tiger-related risks		0.73
Are the risks from tigers something people living in Chitwan can adapt to over time?[2]	0.84	
Are risks from tigers avoidable?[2]	0.68	
Perceived affective risk of tiger attack		0.89
How worried are you about tigers from the nearby forests will attack your pets?	0.64	
How worried are you about tigers from the nearby forests will attack your farm animals?	0.8	
How worried are you about tigers from the nearby forests will attack someone in your village?	0.9	
How worried are you about tigers from the nearby forests will attack you or someone in your family?	0.91	
Perceived cognitive risk of tiger attack		0.89
How likely is it that tigers from the nearby forests will attack your pets?	0.71	

Table 2.1 (cont'd)

Latent variable/survey item	Factor loading[1]	Cronbach's Alpha
How likely is it that tigers from the nearby forests will attack your farm animals?	0.84	
How likely is it that tigers from the nearby forests will attack someone in your village?	0.88	
How likely is it that tigers from the nearby forests will attack you or someone in your family?	0.85	

Notes: [1]Factor loadings were standardized and were all significant at $P<0.05$
[2]Items were reverse coded

Table 2.2: Indirect and total effects of independent variables on preferred future tiger population size (i.e., dependent variable) determined from structural equation model.

Dependent/independent variables	Indirect effects[a]	Total effects[a]	R^2
Preferred future tiger population size			0.51
Past interactions with tigers	0.02	--	
Beneficial attributes associated with tigers	0.02	0.51[b]	
Undesirable attributes associated with tigers	-0.01	-0.24[b]	
Government poorly manages tiger-related risks	0.01	-0.19[b]	
People are vulnerable to tiger-related risks	-0.01	-0.17[b]	
Perceived affective risk of tiger attack	--	-0.01	
Perceived cognitive risk of tiger attack	--	-0.08	

Notes: [a]Standardized regression coefficients
[b]Significant at *P*<0.05

CHAPTER 3

SPATIAL ASSESSMENT OF ATTITUDES TOWARD TIGERS IN NEPAL

In collaboration with

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Abstract

In many regions around the world, wildlife impacts on people (e.g., crop raiding, attacks on people) engender negative attitudes toward wildlife. Negative attitudes predict behaviors that undermine wildlife management and conservation efforts (e.g., by exacerbating retaliatory killing of wildlife). Our study 1) evaluated attitudes of local people toward the globally endangered tiger (*Panthera tigris*) in Nepal's Chitwan National Park; and 2) modeled and mapped spatial clusters of attitudes toward tigers. Factors characterizing a person's position in society (i.e., socioeconomic and cultural factors) influenced attitudes toward tigers more than past experiences with tigers (e.g., livestock attacks). A spatial cluster of negative attitudes toward tigers was associated with concentrations of people with less formal education, people from marginalized ethnic groups, and tiger attacks on people. Our study provides insights and descriptions of techniques to mitigate or improve attitudes toward wildlife in Chitwan and many regions around the world with similar conservation challenges.

Introduction

Where people and wildlife live in close proximity, wildlife can negatively affect human livelihoods (e.g., depredate livestock, raid crops), health (e.g., transmit disease), and safety (e.g., attack people) (Ogada et al. 2003, Woodroffe et al. 2005, Chardonnet et al. 2010). These impacts, in turn, often encourage people to kill wildlife (Woodroffe et al. 2005, Kissui 2008), degrade wildlife habitat, or not comply with regulations designed to protect wildlife (Nyhus et al. 2005). Such activities contribute to declines of many wildlife populations, especially those of large herbivores and carnivores, and hinder the success of species conservation programs in many regions around the world (Woodroffe 2001, Romañach et al. 2007, Milliken et al. 2009).

Attitudes are a strong predictor of a person or group's intentions to behave in a particular manner (e.g., comply with wildlife protection regulations) (Fulton et al. 1996). As such, assessing attitudes toward wildlife provides insights on the degree to which people are willing to cohabit with wildlife. Attitudes toward wildlife are seldom uniform across space because factors affecting attitudes, such as interactions with wildlife, are spatially heterogeneous (Sitati et al. 2003, Naughton-Treves and Treves 2005). Consequently, human-caused mortality of wildlife occurs in spatial clusters, which creates wildlife population sinks that negatively affect wildlife population persistence (Woodroffe and Ginsberg 1998, Liu et al. 2011). Information on the spatial distribution of attitudes can thus inform managers and conservation agencies on where best to focus their interventions, thereby mitigating human-wildlife conflict and advancing conservation efforts. Such information will be increasingly important as the world is expected to add approximately 1.4 billion more people over the next two decades (United Nations 2010b), which will likely result in people and wildlife having closer and more frequent interactions.

Numerous studies have examined attitudes toward wildlife (Kellert and Berry 1987, Saberwal et al. 1994, Naughton-Treves et al. 2003, Wang et al. 2006, Morzillo et al. 2010), however, few have examined the spatial distribution of attitudes toward wildlife (Bowman et al. 2004, Karlsson and Sjöström 2007, Morzillo et al. 2007). None of these studies assessed attitudes towards an imperiled wildlife species for which such information may be especially helpful in developing effective conservation interventions. To help fill this information gap, we evaluated determinants and spatial properties of attitudes toward tigers (*Panthera tigris*), a globally endangered species, near Chitwan National Park, Nepal.

We focused on tigers because conflicts between tigers and people are some of the most severe in the world (Inskip and Zimmermann 2009). Chitwan was an ideal study site because interactions between people and tigers that give rise to human-tiger conflicts there are representative of human-wildlife dynamics occurring throughout many other regions of the world (e.g., South America, Asia, Africa). As it is the case for many developing regions, most people in Chitwan depend on crops and livestock for their livelihood, and rely on nearby forests (including National Park forest) for thatch, reeds, fodder, fuelwood, timber and other products to support their agricultural lifestyles (Sharma 1990). Tigers from inside the park, however, occasionally prey on livestock. Tiger attacks on people inside (e.g., when people are collecting forest resources) and outside the park are a growing concern: 65 local residents were killed 1998 – 2006 compared to 6 during the 1989 – 1997 period (Gurung et al. 2008). Ensuring that people do not kill tigers in retaliation to these threats is imperative for tiger conservation because the park is one of only 28 reserves in the world that can support >25 breeding female tigers (Wikramanayake et al. 2011). Evaluating the spatial attributes of attitudes toward tigers in Chitwan will help foster human-tiger coexistence there and provide useful insights for other regions that face similar conservation challenges.

We had three main objectives in this study: 1) evaluate the effects of several factors on attitudes toward tigers in a human settled area directly adjacent to Chitwan National Park; 2) use geostatistical techniques to identify and map spatial clusters of negative and positive attitudes toward tigers; and 3) investigate possible causes of any patterns.

Conceptual Background: Attitudes toward Wildlife

As a key step in understanding how people relate to wildlife, previous studies have assessed how socioeconomic and demographic variables affect attitudes toward wildlife (Kellert and Berry 1987, Gadd 2005, Naughton-Treves and Treves 2005, Romañach et al. 2007, Morzillo et al. 2010). For example, In an area adjacent to Tanzania's Selous Game Reserve, women – having less influence in public life and political activity than men – expressed more negative attitudes toward wildlife conservation than men (Gillingham and Lee 1999). In an area around Nepal's Kosi Tappu Wildlife Reserve, people from higher Hindu castes, with more political and economic influence in Nepal than lower castes, had more positive attitudes toward wildlife conservation activities of the reserve than lower castes (Heinen 1993). Furthermore, in central Kenya, commercial ranchers had more positive attitudes toward large carnivores than subsistence-oriented livestock farmers, because carnivores have a proportionally smaller impact on the wealth of commercial ranchers than subsistence livestock farmers (Romañach et al. 2007).

Previous research on an array of species in an array of geographical locations also indicate that negative interactions with wildlife influence people's attitudes toward wildlife (Riley and Decker 2000b, Naughton-Treves and Treves 2005, Wang et al. 2006, Romañach et al. 2007, Zimmermann et al. 2010). In the Pantanal of Brazil, for example, respondents whose cattle had been attacked by jaguars (*Panthera onca*) were more likely to view jaguars as a threat (Zimmermann et al. 2005). In addition to direct negative interactions, indirect negative

interactions such as hearing or reading about wildlife attacks on livestock or people may also engender negative attitudes (Karlsson and Sjöström 2007, Zimmermann et al. 2010). For example, Karlsson and Sjöström (2007) attributed negative attitudes toward wolves (*Canis lupus*) in Sweden to exposure to negative information about wolves from friends, peers, and media.

Increased exposure to wildlife-related risks (e.g., long-term residency, collecting forest resources) has been linked to negative attitudes (Newmark et al. 1993, Naughton-Treves and Treves 2005, Arjunan et al. 2006). For example, villagers who had lived near Kalakad-Mundanthurai Tiger Reserve for a longer period of time were less likely to report positive attitudes toward tiger conservation (Arjunan et al. 2006). Nepal and Weber (1995a) learned that villagers who frequently entered Chitwan National Park to collect forest resources tended to have hostile attitudes toward wildlife.

A few studies indicate that attitudes toward wildlife vary with location. For example, Bowman et al. (2001) found that respondents in Mississippi were more likely to support efforts to increase the black bear (*Ursus americanus*) population than respondents in Arkansas, where negative experiences with bears were more common. Karlsson and Sjöström (2007) indicated that having wolves in Sweden was more important to urban respondents than for rural respondents. Morzillo et al. (2007) found that positive attitudes toward restoration of black bears were spatially clustered in the most urbanized part of an area around Big Thicket National Preserve, Texas.

Based on past research, we hypothesize that 1) attitudes toward tigers will be associated with a) one's position in society as measured by several socioeconomic and demographic variables, b) direct and indirect negative interactions with tigers in the past, and c) exposure to tiger-related risks; and 2) attitudes toward tigers will form non-random spatial clusters.

Materials and Methods

Study Site

Situated in south central Nepal, our study site (Fig. 3.1) was the human settled area in western Chitwan district to the north of Chitwan National Park. Chitwan district is located in a river valley basin along the flood plains of the Rapti and Narayani Rivers at altitudes of 150–815 m. The area is subtropical, with a summer monsoon from mid June to late September, and a cool dry winter (Laurie 1982). In the late 1970's and early 80's a series of all-weather roads were built that linked Chitwan's city, Narayanghat (Fig. 3.1), to the rest of the country. Since then, Narayanghat has become a transportation hub in Nepal with new businesses, wage labor opportunities, commercial enterprises, and government services proliferating in and around the city (Axinn and Ghimire 2007). Chitwan National Park ($\sim$1,000 km^2), established in 1973, is a globally important protected area for conservation of tigers (Walston et al. 2010). Approximately 30 – 50% of park annual revenue was invested into the surrounding buffer zone, established in 1996, to support community development (e.g., infrastructure improvement) and forest protection programs (e.g., community forestry) (Government of Nepal 1993). At the time of our research the study site comprised a mosaic of land uses, including National Park, National Forest, community forests, agriculture and urban development. In 2011 the human population in our study site was $\sim$275,000, and the total number of households was $\sim$68,000 (Nepal Central Bureau of Statistics 2012).

Attitude Survey

We designed a structured survey to record attitudes toward tigers and potential determinants of these attitudes. Local Nepali experienced in social survey research design worked with us to ensure internal validity of our survey measures. In December 2009 we pre-

tested the survey (n=17) in a site adjacent to our study area, to improve survey effectiveness. Attitudes toward tigers were recorded using three survey items: "Do you enjoy having tigers in your area?", "Would you be happy if no tigers existed in the nearby forests?", "How many tigers would you prefer living in the nearby forests in the next 10 years compared to now?" The first two attitude questions were binary (i.e., yes, no), and future tiger preferences was based on a 5-point bi-polar scale (i.e., much less, less, same, more, and much more). We chose to record preferences for tigers 10 years in the future because it is a round number and a conceivable time-frame in which tiger population size can change considerably.

Demographic information included age, gender, and ethnicity. Ethnicity was grouped into four categories for analytical purposes: higher caste Hindus, lower caste Hindus, Hill Tibeto-Burmese, and Terai Tibeto-Burmese (see Barber et al. 1997 for breakdown of ethnic groups in Chitwan). Socioeconomic information included respondent education level, occupation, and household livestock holding. Education level was determined by the number of years respondent received formal education. Occupation was grouped into 6 categories: crop farmer, mixed farmer (i.e., livestock producer and crop farmer), business owner (e.g., owns shop selling food, clothing, etc.), salaried employment (e.g., receives regular salary from government or non-government organization or private company), daily wage laborer (e.g., receives daily wages from work on farm or construction sites), and student. Respondent livestock information included number of cattle/buffalo and sheep/goats because these livestock are most important in terms of household economics (Gurung et al. 2009).

Exposure to tiger-related risks included the number of years that a respondent had lived in Chitwan and the amount of time spent in the nearby forests (i.e., tiger habitat) collecting forest products. Amount of time respondents spent in the forests was determined with the question "since last year till now, out of 365 days, approximately how many work days do you think you

have spent in the nearby forest collecting fodder or firewood?" Negative direct experiences were recorded using two survey items: "Do you have a family member that has been threatened or attacked by a tiger?" and "Has a tiger ever killed your livestock?" Additionally, respondents indicated if they had been personally threatened by a tiger in the survey item "other types of experiences with tigers?" Negative indirect experiences with tigers were recorded using two survey items: "Do you know a friend or neighbor who has been threatened or attacked by a tiger?" and "Have you read or heard about farm animals being attacked nearby by a tiger?" The option "don't know" was provided on all questions.

Wards (the smallest administrative unit in the district) that had at least 50% of their area within 1 km of Chitwan National Park or the buffer zone forest adjacent to the park, where the majority of human–tiger conflicts occur (Department of National Parks and Wildlife Conservation, unpubl. data), were selected. Ward boundary data were extracted from 1996 digital topographic data obtained from the Nepal Survey Department (Nepal Survey Department 1996); these are the most recent data and little change in ward boundaries has occurred since. We randomly selected 500 residences within the wards based on residence locations in 1996 (n=5,400). The number of residences has increased since 1996 (the most recent data on spatial locations of residences). In February 2010, the name and age of all persons living in each of the 500 residences (inclusion criterion was that they must have been residing in the house during the week prior to the time when the survey would be administered) were recorded and compiled in a list. From this list, a single individual (age 15 – 59) was randomly selected for survey from each of the 500 randomly selected residences, resulting in a total of 500 possible respondents. From March – April 2010, trained Nepali interviewers contacted each possible respondent to administer the survey face-to-face. A verbal consent script was read to the subjects, because many adult subjects were not literate. Interviews and collection of respondent's exact household

location with a hand-held Global Positioning System (GPS) unit proceeded only after the

subjects gave their verbal consent. In case of non-consent, no further information was recorded.

The study, including the verbal consent process and script, was reviewed and approved by the

Institutional Review Board (IRB# 08-274) of the Michigan State University

(http://www.humanresearch.msu.edu/).

Evaluating Determinants of Attitudes

For future preference of tiger population size, responses "less" and "much less" were

recoded as 0, and responses "same", "more", and "much more" were recoded as 1. Responses to

"do you enjoy having tigers in your area?" were recoded such that "no" = 0 and "yes" = 1.

Responses to "would you be happy if no tigers existed in the nearby forests" were reverse coded

such that "yes" = 0 and "no" = 1. Applying standard social sciences methodology, we created a

single scale of all three attitude survey items to measure the general attitude toward tigers, using

principal component analysis and Cronbach's alpha reliability test (Cronbach 1951, Ericsson

and Heberlein 2003, Sirkin 2005).

Relationships between the general attitude towards tigers (i.e., single scale) and potential

explanatory variables (respondent age, gender, ethnicity, formal education, occupation, number

of cattle/buffalo, number of sheep/goat, days in forest per year, years living in Chitwan, past

tiger threats/attacks on respondent family member and respondent livestock, hearing or reading

about tiger attacks on neighbor/friend and nearby livestock) were analyzed using Spearman's rho

correlation coefficient, t-tests, and analysis of variance (ANOVA). For the ANOVA tests, we

also used Tamhane's T2 post hoc test (does not assume equal variances) to investigate pair-wise

differences between levels of the explanatory variables. A generalized linear model was used to

identify which combination of potential explanatory variables best predicted general attitude

towards tigers (McCullagh and Nelder 1989). Multicollinearity between explanatory variables

was tested using variance inflation factors (O'brien 2007). We used Pearson chi-square to

compute the scale parameter, maximum likelihood to estimate model coefficients, and the Wald

statistic to estimate the significance and relative effect of each explanatory variable on attitudes.

We computed χ^2 goodness-of-fit statistic to determine if the model was significantly better at

predicting negative attitudes than a null model. All model analyses were performed using SPSS

v. 20 (Chicago, IL, USA). To explicate relationships among explanatory variables, subsequent

bivariate analyses (i.e., ANOVA, χ^2) were performed.

Evaluating Spatial Distribution of Attitudes toward Tigers

Our analyses of the spatial distribution of attitudes toward tigers were based on the spatial

locations of the respondent's households. First, we mapped the factors affecting attitudes at the

ward-level to visualize general spatial patterns. Next we mapped individual respondent attitude

scores. We used the global Moran's index *I*, a measure of spatial autocorrelation, to determine

the nature of the spatial distribution of attitudes (Moran 1950) across the study site. A positive

index indicates that respondents nearer to each other have similar attitudes. A negative index

indicates that attitudes are dispersed in space, while an index value near '0' indicates a random

distribution. The Moran's *I* statistic requires a weight matrix which defines how neighboring

respondents are related to each other. We assumed that neighboring respondents within a

threshold distance influenced each other. We did not have a-priori information on what the

threshold distance was, therefore, we calculated the global Moran's *I* at various threshold

distances ranging from 1 km to 7 km (1 km intervals). We constrained threshold distances to 7

km because that is the minimum distance between respondents on opposites sides of the study

site. As we do not have information from respondents in the interior of the study site, assessing

spatial processes at distances that span the length of the study site may generate inaccurate

results. Moran's *I* values at each of the threshold distances were standardized to z-scores, so that

the significance level of the index could be tested based on a normal distribution (Morzillo and

Schwartz 2011, Aguilar and Farnworth 2012). The distance threshold where the global Moran's

I z-score was at its highest significant positive value (i.e., > 1.96) indicated where the spatial

process of interest (i.e., attitudes toward tigers) was most pronounced (Morzillo and Schwartz

2011, Aguilar and Farnworth 2012).

Although the global Moran's *I* is useful for determining whether the data is

autocorrelated across the whole study site, it does not indicate if or where spatial clusters occur

within the study site or which type of cluster (i.e., negative or positive attitudes) respondents

belong to. Thus, we calculated the Getis-Ord local G_i^* statistic for each respondent to determine

if respondents belong to local-scale clusters (Getis and Ord 1992). The statistic is given as:

$$G_i^* = \frac{\sum_{j=1}^{n} W_{i,j} X_j - \overline{X} \sum_{j=1}^{n} W_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

where X_j is the attitude score for respondent at location *j*, $\overline{X}$ is the mean attitude score for all

respondents, *n* is equal to the total number of respondents, S is the standard variation of the

attitude scores among all respondents, and $W_{i,j}$ is the spatial weight between locations *i* and *j*. A

distance threshold reflecting maximum spatial autocorrelation, as determined by the global

Moran's *I* procedure, was used for the Getis-Ord local G_i^* spatial weights (Aguilar and

Farnworth 2012). A significantly positive G_i^* (> 1.96) indicates that a respondent belongs to

cluster of respondents with positive attitudes, whereas a significantly negative G_i^* (< -1.96)

indicates that a respondent belongs to cluster of respondents with negative attitudes. Clusters of respondents with negative and positive attitudes were mapped. Global Moran's I and local G_i^* analyses were performed in ArcGIS 10.

Results

Attitudes toward Tigers

The survey was completed by 499 of 500 individuals contacted while the remaining one individual opted to not participate in the study. Nearly 30% of the respondents did not enjoy having tigers nearby, and > 35% would be happier if no tigers existed in the nearby forests. The distribution of respondents' preferences for future tiger population size was nearly uniform: 40% preferred fewer tigers and 40% preferred more tigers in nearby forests over the next 10 years compared to 2010.

The measurement of the three attitude items showed high consistency (Cronbach's alpha = 0.8). The principal component analysis produced a single factor solution that accounted for 72% of the variation in the three attitude items. Thus, we kept the first factor to index the overall attitude toward tigers (eigenvalue = 2.15, eigenvalues of factors 2 and 3 < 0.48). The communality estimates of the attitude items ranged from 0.67 to 0.74, and the item loading of the retained factor was uniform (enjoyment toward nearby tigers = 0.86, happiness if all tigers gone = 0.86, preference for future tiger population size = 0.82). The extracted factor ranged from -1.62 (i.e., more negative attitudes) to 0.87 (i.e., more positive attitudes) with a mean score = 0.

Demographic and Socioeconomic Characteristics

Average age of respondents was 33.7 (15-59) years and nearly 37% were male (Table 3.1). Respondents were predominantly female since many men leave Chitwan to work in urban

centers in Nepal or elsewhere (Bohra and Massey 2009). Respondents ranged in ethnic background with the majority being higher caste Hindu (57%).

Respondents also had a range of education levels: 36% of respondents had less than four years of formal education, whereas 11% had at least 12 years of formal education (Table 3.1). Nearly 90% of respondents owned livestock. On average, respondents owned more sheep/goats than cattle/buffalo. The occupation for less than 30% of respondents was "off the farm."

Exposure to Tiger-related Risks and Past Negative Experiences with Tigers

On average, respondents had been living in Chitwan for over 20 years (Table 3.1). Approximately 60% of respondents spent at least one work day per year entering nearby forests to collect natural resources. Nearly 25% of all respondents spent more than 20 work days per year collecting resources from the forest.

While 10% of respondents indicated that a tiger had attacked their livestock in the past, over 25% of the respondents stated that a tiger had threatened/attacked someone in their family in the past (Table 3.1). Just under 5% indicated both that a tiger had threatened/attacked a family member and their livestock. While over half of the respondents indicated that a tiger had threatened/attacked a neighbor or friend in the past, nearly 60% had heard or read about tigers attacking livestock in the nearby areas (Table 3.1). Nearly 40% stated both that a tiger had threatened/attacked a friend or neighbor and had heard/read about tiger attacks on livestock in the nearby areas.

Factors Affecting Attitudes toward Tigers

Based on bivariate analyses, respondents were less likely to have positive attitudes toward tigers if they had < 8 years of formal education ($F_{3,494} = 48.95$, $P < 0.01$, Tamhane's, $P < 0.01$), were lower caste Hindu or Terai Tibeto-Burmese ($F_{3,492} = 21.88$, $P < 0.01$, Tamhane's,

$P < 0.01$), were female ($t_{442} = 7.24$, $P < 0.01$), were farmers (crop or mixed) or daily wage laborers ($F_{5,483} = 10.26$, $P < 0.01$, Tamhane's, $P < 0.01$), owned fewer cattle/buffalo ($r_s = 0.15$, $P < 0.01$), and were older ($r_s = -0.12$, $P < 0.01$). These results support hypothesis 1a. Also, those who had reported that a tiger had threatened/attacked someone in their family at some point in the past ($t_{225} = 3.38$, $P < 0.01$) and had spent more days/year collecting forest products ($r_s = -0.26$, $P < 0.01$) were less likely to have positive attitudes toward tigers, which supports hypothesis 1b and 1c.

The single scale of attitudes toward tigers, derived from the principal component analysis, was used as our response variable in the generalized linear model. Significant collinearity was not detected between any of the explanatory variables. The model fit the data better than a null model ($\chi^2 = 217$, df = 22, $P < 0.01$). Education level had the largest effect on attitudes, followed by ethnicity, gender, and threats/attacks on family members (Table 3.2). Results from the multivariate model indicated that respondents were more likely to have negative attitudes toward tigers if they had less formal education, were lower caste Hindu or Terai Tibeto-Burmese, female, or a tiger had threatened/attacked someone in their family at some point in the past.

Subsequent bivariate analyses among explanatory variables indicated that higher caste Hindus were more likely than other ethnic groups to have > 8 years of formal education ($\chi^2 = 82.26$, df = 9, $P < 0.01$) and to have salaried employment or be a student ($\chi^2 = 26.08$, df = 15, $P < 0.05$). While time spent in the forest and number of cattle/buffalo did not differ with respect to gender, higher caste Hindus and respondents with > 8 years of formal education generally spent less time in the forests collecting forest products and had more cattle/buffalo than other groups (Table 3.3, 3.4). Respondents with < 3 years of formal education tended to be older (Table 3.3)

and be a farmer ($\chi^2 = 150.62$, df $= 15$, $P < 0.01$). Reports that tigers had threatened/attacked a family member in the past did not significantly differ among ethnic group, education level, or gender (Table 3.5).

Spatial Distribution of Attitudes

All of the factors influencing attitudes in the generalized linear model, except for gender, display discernible spatial patterns. Respondents with an education level < 8 years, from lower caste Hindu and Terai Tibeto-Burmese ethnic groups, and who reported that a tiger had threatened/attacks a family member in the past appear to be concentrated along the western portion of the study site (Fig 3.2).

The global Moran's I z-score peaked ($I = 0.14$, z-score $= 31.79$, $P < 0.001$) when using 7 km as the threshold distance for the spatial weights, and demonstrated that attitudes toward tigers was spatially correlated across the study site. Local G_i^* values indicate that two statistically significant spatial clusters of attitudes exist, which supports hypothesis 2. Whereas negative attitudes toward tigers were clustered in the western portion of the study site, positive attitudes toward tigers were clustered in the eastern portion (Fig. 3.3).

Discussion

Despite being a region where human-wildlife conflicts are severe, factors in Chitwan characterizing one's position in society shaped attitudes toward tigers more so than negative experiences with tigers. In particular, people from marginalized groups in the region including lower caste Hindus and Terai Tibeto-Burmese, less educated, and women expressed more negative attitudes toward tigers.

Higher caste Hindus and hill Tibeto-Burmese enjoy the most socioeconomic and political power in the region (Massey et al. 2010b). By being in positions of influence, higher caste

Hindus and hill Tibeto-Burmese are perhaps more likely to obtain off-farm employment associated with the tourist industry (e.g., porter, cook, guide), and thus enjoy most of the economic benefits from wildlife tourism (Mehta and Kellert 1998). Money from tourist activities is one of the major values local people associate with having tigers in Chitwan (Carter et al. 2012a) and likely explain, in part, why these ethnic groups expressed more positive attitudes toward tigers. As education level varied by ethnicity, additional surveys are needed to separate the effects of ethnic or caste position. Nevertheless, it is possible that education broadens people's perspective on tigers and, perhaps, encourages greater awareness of the benefits of tigers (e.g., ecological importance) (Carter et al. 2012a). Williams et al. (2002) indicated that positive attitudes toward wolves in regions around the world was related to education likely because increased education often brings a greater awareness of wildlife and the environment. Similar relationships between greater education level and positive attitudes expressed toward large carnivores are a prevalent phenomenon (Riley and Decker 2000a).

In contrast to higher caste Hindu and hill Tibeto-Burmese ethnic groups, lower caste Hindus and Terai Tibeto-Burmese (a group indigenous to Chitwan) have fewer opportunities, receive less formal education, and typically own less land (Massey et al. 2010b). By being more dependent on forest resources, lower caste Hindus and Terai Tibeto-Burmese may have elevated dread and risk beliefs toward tigers that inhabit those forests (Carter et al. 2012a). On the other hand, people from these marginalized ethnic groups may have more negative attitudes toward tigers because they resent the policies associated with tiger conservation, which restrict their access to forest products that they rely on for their livelihoods (Biddlecom et al. 2005). The lack of decision-making authority and control over one's environment may be key factors influencing attitudes toward tigers (Zinn et al. 2000, Carter et al. 2012a). For example, Bjerke et al. (2000) found that sheep farmers in Norway who believed that land use was being increasingly

controlled by central political authorities (i.e., external locus of control) were more likely to have negative attitudes toward large carnivores.

As with marginalized ethnic groups, women in Chitwan lack decision-making authority in most community contexts (Agrawal and Ostrom 2001). Furthermore, in most households in Chitwan, women's and men's roles and duties are segregated, with women being primarily responsible for taking care of children, preparing food, and carrying out specific agricultural tasks (Yabiku 2005). In south-east Tanzania, women were excluded from many aspects of public life and political activity, and as a result, tended to construct their views of wildlife based largely on their direct experience of wildlife-related costs and benefits in the spheres of domestic life and farmwork (Gillingham and Lee 1999). Similarly, in Chitwan, a lack of control over how they interact with tigers (e.g., having no choice but to enter forests to collect essential natural resources) and constrained perspectives on the benefits of living near tigers (e.g., tangible negative consequences versus less obvious benefits) may engender negative attitudes among women toward tigers. More research is needed in this region to evaluate the causal linkages between socio-cultural-economic factors, fear of tigers, loci of control, and attitudes toward tigers.

People with less formal education and from marginalized ethnic groups tended to live in western portion of the study site, where negative attitudes toward tigers were clustered. This spatial distribution suggests that these marginalized groups lack access to and are unable to fully utilize (due to lower social class) the schools, universities, markets, and off-farm employment opportunities concentrated in the city, Narayanghat, located in the northeast. The spatial cluster of negative attitudes in the west is also likely influenced by the increased frequency of tiger attacks on people that have occurred there over the last 15 years (Gurung et al. 2008). The reason for the greater prevalence of attacks in the west is uncertain. It is probably not due to

differences in human/tiger density ratios between the west and east, as human densities are comparatively lower in the west while tiger densities are roughly equal in both (Carter et al. 2012b, Nepal Central Bureau of Statistics 2012). An explanation for the greater prevalence of attacks in the west proposed by locals is that tigers acquire a 'taste' for human flesh after feeding on the remains of partially cremated bodies that wash up on the Narayani River bank after being sent afloat during traditional Hindu funerals. More recent tiger-human interactions likely have a comparatively greater role in shaping attitudes toward tigers (Eagly and Chaiken 1993). A program exists to monetarily compensate households where someone has been attacked, but as the psychological and economic impacts on family members can be tremendous, monetary compensation does not appear to completely offset the effects of these attacks on negative attitudes.

The spatial concentration of positive attitudes in the east reflects, in part, the spatial distribution of those people with greater political and economic influence who tend to live closer to the city in the northeast. The cluster of positive attitudes in the east is also likely related to management actions. Management intensity is greater in and near the buffer zone forest in the east as it is considered a crucial wildlife corridor to forested areas outside the park, as the forest in the west does not have the same function. For instance, beginning in 2001, a subsidized fence was constructed along the entirety of the boundary separating the human settled area and the buffer zone forest in the east to mitigate human-wildlife conflict (UNDP 2007). In Sweden, subsidies for fencing to reduce wolf predation on sheep increased positive attitudes toward wolf presence (Karlsson and Sjöström 2011). Similarly, the fence in Chitwan likely has increased satisfaction in government policies and reduced risk from tigers. The World Wildlife Fund (WWF-Nepal), National Trust for Nature Conservation and other local non-government organizations have launched several conservation programs in the buffer zone forest area

including wildlife education workshops, alternative income and eco-tourism projects, and community-based anti-poaching units (UNDP 2007). These efforts have perhaps enabled people living in the eastern portion of the study site to view tigers more in terms of their benefits rather than their costs. Our results are not unlike those from Heinen et al. (1993), which found that people on the east side of Nepal's Kosi Tappu Wildlife Reserve had more positive attitudes toward the reserve than people on the west because people on the east had more access to management and a greater voice in managerial activities. However, more research is required to evaluate the causal linkage between the spatial locations of management actions and the spatial distribution of attitudes toward tigers.

Our findings suggest that processes influencing attitudes toward tigers in Chitwan are occurring at spatial scales around 7 km. This may be the scale at which information flow (e.g., dissemination of news regarding tiger attack) through social networks in Chitwan is most pronounced. Muter et al. (2013) revealed that social networks and the strength of dyadic ties between individuals influenced contagion effects of perceptions and risk attitudes toward a fish-eating predator, Double-crested Cormorants (*Phalacrocorax auritus*). Presumably, dyadic ties are strong in a rural community like Chitwan. Furthermore, previous research in Chitwan indicates that markets, schools, health services, and employers tend to be within a few kilometers of households (Dirgha and Axinn 2006), which suggests that 7 km is a conceivable distance in which interactions between local people are frequent. In addition, landscape features (e.g., topography) and infrastructure (e.g., paved roads) may facilitate or hinder information flow among people. Although Chitwan is flat, information flow may be constrained because most roads are unpaved and rugged and often flood during the monsoon season. Assessing how social networks in Chitwan influence spatial patterns in attitudes and how spatial patterns in attitudes

vary with respect to different landscapes and social contexts are important avenues of future research.

Attitudes toward tigers may change as one's position in society shifts. Like many regions around the world, the socioeconomic and political contexts in Chitwan are rapidly transforming (The World Bank 2011b), and the capacity for people to cohabit with tigers may shift as well. Moreover, attitudes toward tigers will likely shift in space as the landscape is modified through time. For instance, reforestation efforts outside Chitwan National Park may attract more tigers, potentially intensifying human-tiger interactions, and changing local attitudes accordingly. On the other hand, urban development may reduce negative direct experiences with tigers, but also may disassociate people from the benefits of having nearby tigers. However, we cannot make strong inferences on the effect of such changes on attitudes as our study is a 'snapshot' of local attitudes toward tigers. A longitudinal analysis of attitudes toward tigers in Chitwan, based on this study, would help demonstrate these dynamics. In addition, similar research conducted in other areas facing similar human-wildlife conservation issues would provide additional insights on how to facilitate coexistence under varying conditions.

Conclusion

Our study has several implications for conservation policy and wildlife management. First, concentrating mitigation and conservation efforts at the specific locations where wildlife-related impacts occur will likely reduce negative attitudes toward wildlife within larger areas encompassing those locations. Second, complementing conventional mitigation measures, such as translocating or lethally removing 'problem' animals, with a range of conservation actions will also likely reduce negative attitudes toward wildlife. Such actions depend on the context and include, among others, education and awareness programs, fencing, payments for ecosystem

56

services, and conflict-response teams with a contingent of local people (Gurung et al. 2008, Dickman et al. 2011, Karlsson and Sjöström 2011). Third, our findings suggest that conservation policymakers and practitioners can anticipate attitudes toward wildlife in different contexts based on the linkages between attitudes and socio-cultural-economic variables, such as those evaluated in our study. Explicating these linkages will help direct resource and institutional support decisions of wildlife management authorities and conservation agencies. Fourth, spatially-explicit maps of attitude clusters enable limited resources such as money and personnel to be efficiently and effectively allocated to those areas dominated by negative attitudes. Conservation actions informed by attitude research and focused in space may help increase local compliance with conservation policies and possibly decrease human-caused mortality of imperiled wildlife.

APPENDIX

Figure 3.1: Location of the study site in Chitwan. The shaded area on the inset indicates the location of Chitwan district in Nepal.
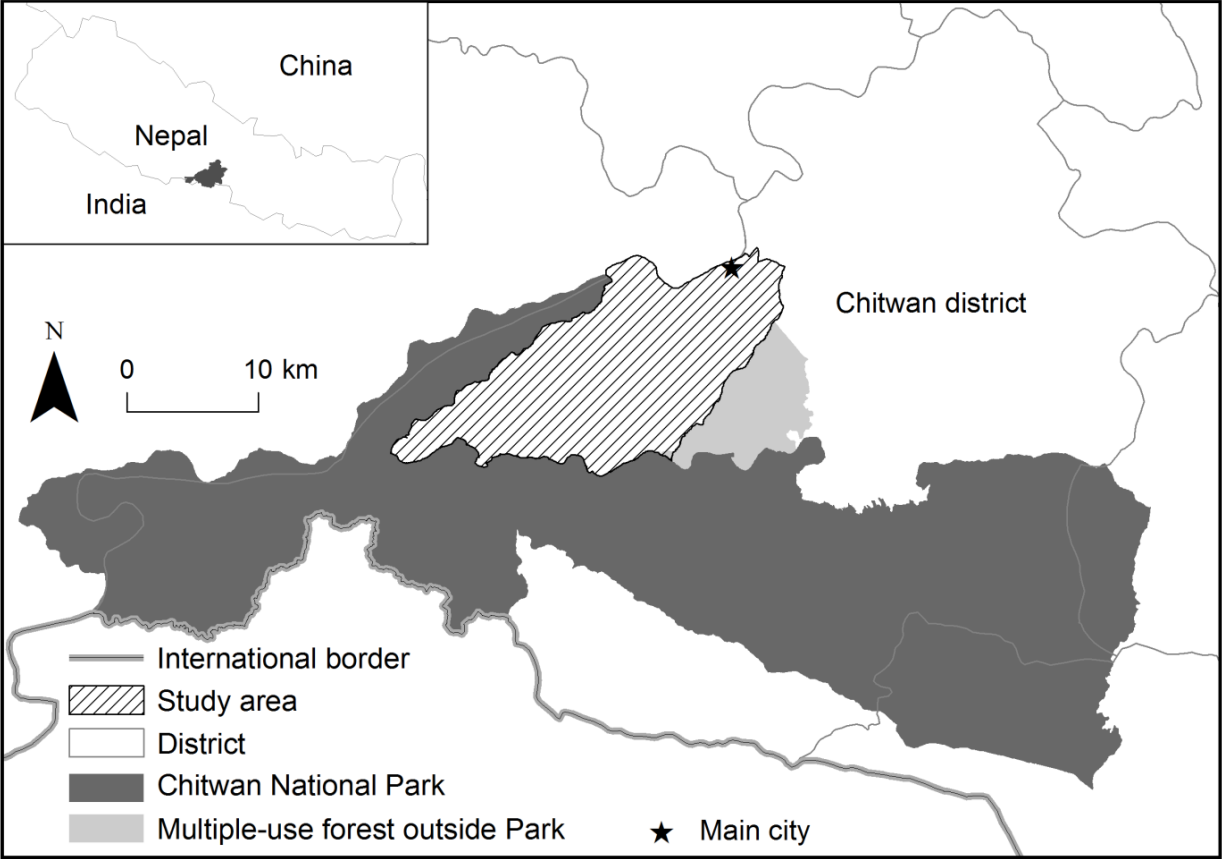
Figure 3.2: Maps showing percentage of respondents per ward that (a) had < 8 years of education, (b) were from lower caste Hindu and Terai Tibeto-Burmese ethnic groups, (c) were female, and (d) reported that a tiger had threatened/attacked a family member in the past. Percentage categories were defined by equal intervals.
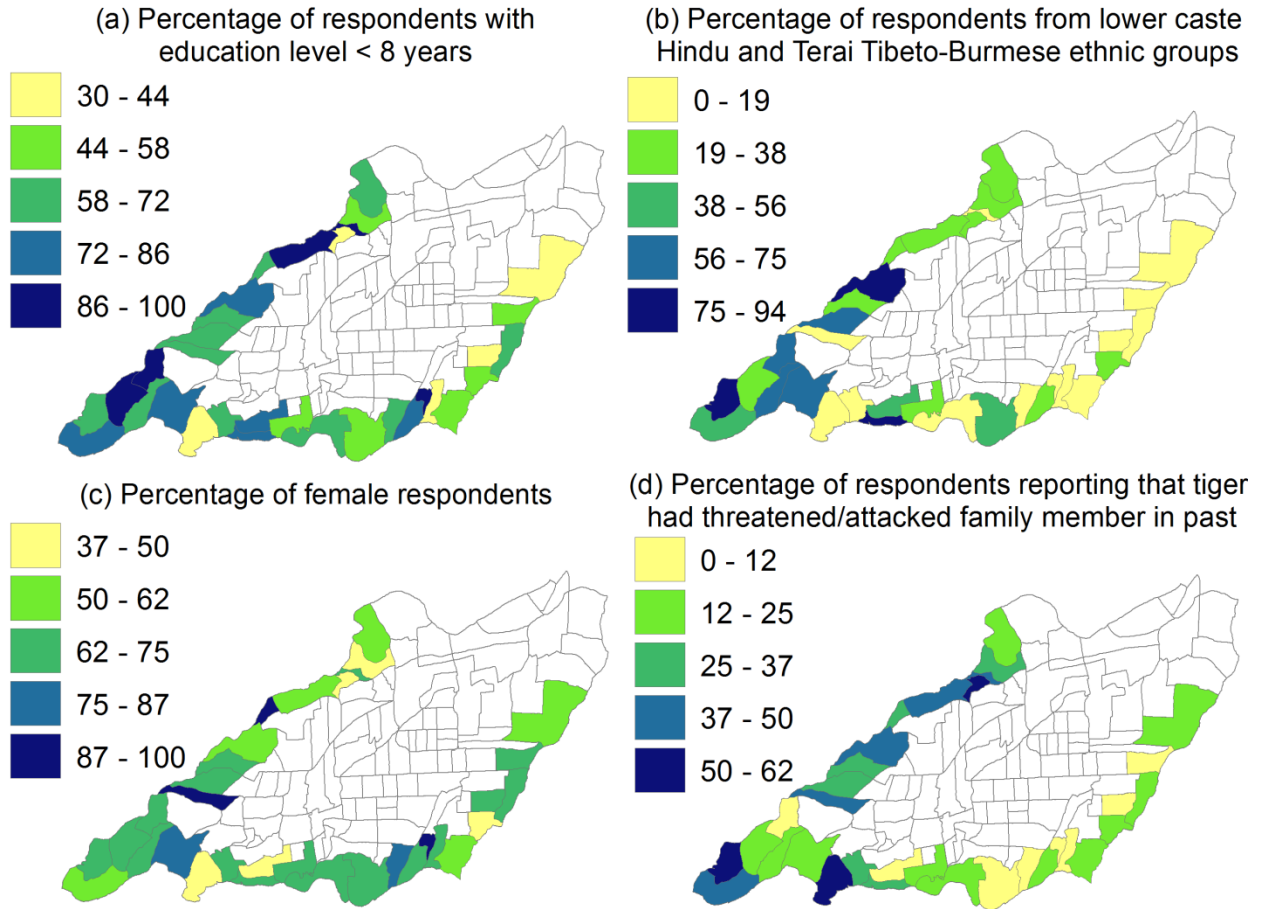
Figure 3.3: Maps of (a) respondent attitude scores and (b) spatial clusters of negative and positive attitudes toward tigers in Chitwan, Nepal.
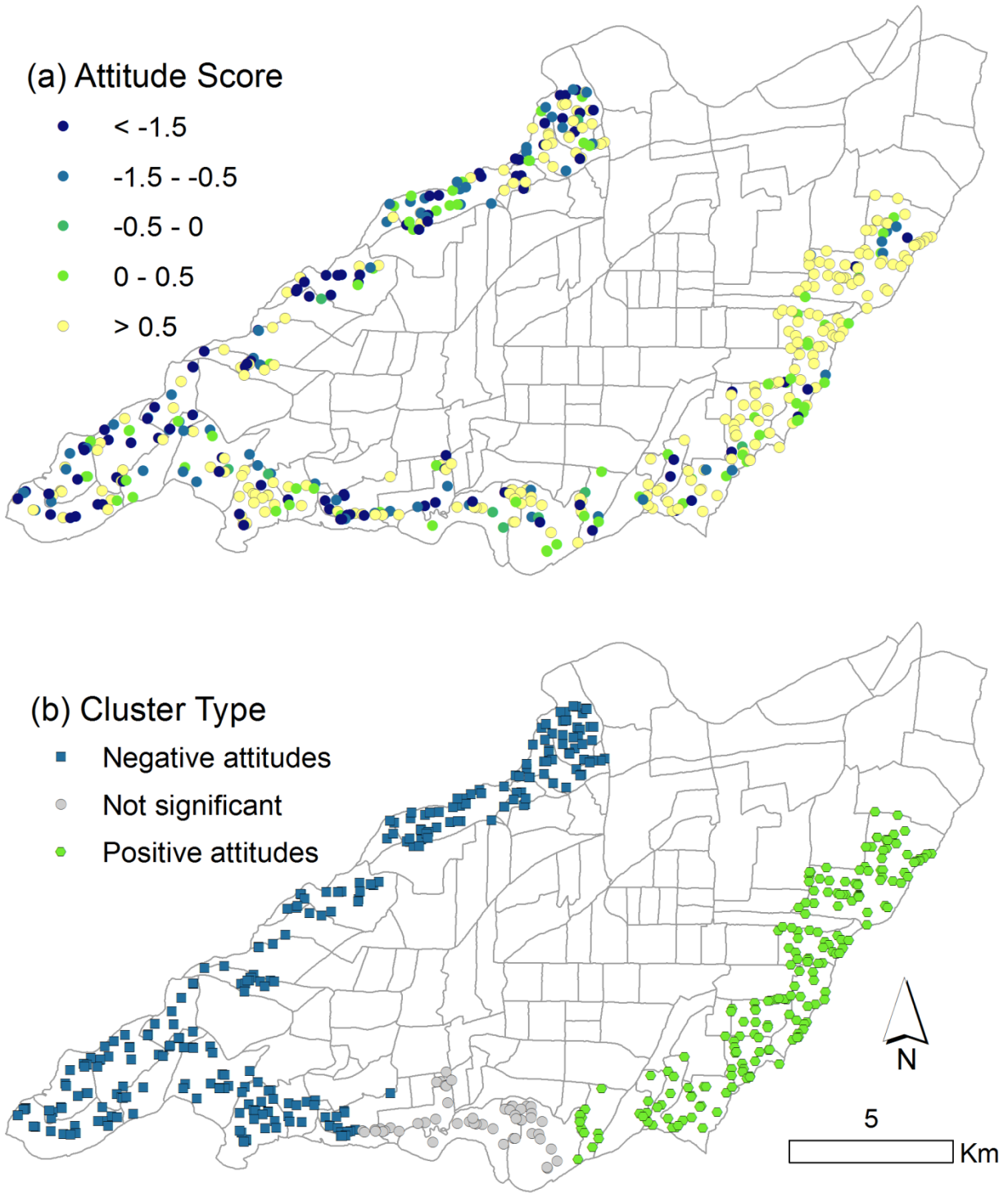
Table 3.1: Descriptive results for survey items related to factors that potentially influence attitudes toward tigers in Chitwan, Nepal.

Factor / Survey response	Descriptive results
Age	Range = 15 – 59, Mean = 33.69, SD = 12.95
Gender	
Male	36.67%, n = 183
Female	63.33%, n = 316
Ethnicity[a]	
Higher caste Hindu	57.38%, n = 280
Hill Tibeto-Burmese	13.32%, n = 65
Lower caste Hindu	13.11%, n = 64
Terai Tibeto-Burmese	16.19%, n = 79
Years of formal education	
0 – 3	35.67%, n = 178
4 – 7	23.25%, n = 116
8 – 11	30.06%, n = 150
>12	11.02%, n = 55
Occupation[b]	
Crop farmer	52.45%, n = 257
Mixed (livestock and crop) farmer[c]	18.78%, n = 92
Business owner	2.65%, n = 13
Salaried employment	8.57%, n = 42
Daily wage laborer	2.04%, n = 10
Student	15.51%, n = 76
Household livestock holding	
Cattle/Buffalo	Range = 0 – 10, Mean = 2.4, SD = 1.77
Sheep/Goat	Range = 0 – 21, Mean = 3.12, SD = 2.79
Days in forest per year	Range = 0 – 365, Mean = 32.46, SD = 73.25
Years living in Chitwan	Range = 1 – 59, Mean = 23.33, SD = 13.97
Tiger threatened/attacked family member	
No	72.95%, n = 364
Yes	27.05%, n = 135
Tiger attacked livestock	
No	86.97%, n = 434
Yes	13.03%, n = 65
Tiger threatened/attacked neighbor or friend	
No	47.29%, n = 236
Yes	52.71%, n = 263

Table 3.1 (cont'd)

Factor / Survey response	Descriptive results
Heard/read about nearby tiger attack on livestock	
No	40.48%, n = 202
Yes	59.52%, n = 297

Notes: [a]Category "other Indian castes" was omitted from analysis because number of respondents was very small (n = 2)
[b]Category "other occupations" was omitted from analysis because it lacks definition and the number of
respondents was small (n = 9)
[c]Category "livestock producer" (n = 2) was combined with "mixed farmer"

Table 3.2: Linear model of attitudes toward tigers in Chitwan, Nepal. Variables listed in descending order of effect on attitudes.

Variable	β	SE	Wald
Education			
0 -3 years[a]	0	--	--
4 – 7 years	0.21	0.11	3.4
8 – 11 years	0.73*	0.12	35.4
> 12 years	0.85*	0.17	25.7
Ethnicity			
Higher caste Hindu[a]	0	--	--
Hill Tibeto-Burmese	0.12	0.12	0.91
Lower caste Hindu	-0.36*	0.13	7.82
Terai Tibeto-Burmese	-0.48*	0.12	17.37
Gender			
Male[a]	0	--	--
Female	-0.39**	0.09	18.8
Family member threatened/attacked			
No[a]	0	--	--
Yes	-0.28*	0.09	10.61
Occupation			
Crop farmer[a]	0	--	--
Mixed farmer	-0.06	0.1	0.34
Business owner	-0.06	0.23	0.07
Salaried employment	0.17	0.15	1.29
Daily wage laborer	0.29	0.27	1.2
Student	0.21	0.13	2.54
Respondent livestock attacked			
No[a]	0	--	--
Yes	0.21	0.12	3.33
Heard or read about nearby livestock being attacked			
No[a]	0	--	--
Yes	0.12	0.08	1.89
Number of cattle/buffalo[b]	0.03	0.02	1.34
Heard of read about other people threatened/attacked			
No[a]	0	--	--
Yes	-0.1	-0.09	1.25
Neighbor or friend threatened/attacked			
No[a]	0	--	--
Yes	-0.08	0.08	0.83
Number of sheep/goat[b]	-0.01	0.01	0.13
Days in forest per year[b]	0.01	0.01	0.83
Years living in Chitwan[b]	0.01	0.01	0.65

Table 3.2 (cont'd)

Variable	β	SE	Wald
Age[b]	0.01	0.01	0.02

Notes: *$P<0.05$

[a]Set to zero.

[b]Continuous variable was standardized to have mean of zero and standard deviation of one

Table 3.3: Mean time spent in forest, number of cattle/buffalo, and age for different education levels in Chitwan, Nepal.

	0-3 years	4-7 years	8-11 years	>12 years
Time spent in forest (days/year)	52.42^{A,B}	34.84^{C}	18.25^{A,D}	1.56^{B,C,D}
Number of cattle/buffalo	2.05^{A}	1.7^{B,C}	2.31^{B}	2.91^{A,C}
Age	42.83^{A,B,C}	30.02^{A}	27.71^{B}	33.69^{C}

Notes: Like letters indicate a significant difference between groups (Tamhane's, $P < 0.05$)

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Table 3.4: Mean time spent in forest, number of cattle/buffalo, and age for different ethnic groups in Chitwan, Nepal.

	Higher caste Hindu	Hill Tibeto-Burmese	Lower caste Hindu	Terai Tibeto-Burmese
Time spent in forest (days/year)	22.42^{A,B}	55.91^A	58.81^B	29.35
Number of cattle/buffalo	2.57^{A,B}	1.55^A	0.98^{B,C}	2.03^C
Age	34.54	35.62	30.41	31.89

Notes: Like letters indicate a significant difference between groups (Tamhane's, $P < 0.05$)

Table 3.5: Proportion (%) of respondents from different socioeconomic and demographic groups indicating whether or not a tiger had threatened/attacked a family member in the past.

		Family member threatened/attacked by tiger	
		No	**Yes**
Education	0-3 years	70.79	29.21
	4-7 years	71.55	28.45
	8-11 years	75.33	24.67
	> 12 years	76.36	23.64
Ethnicity	Higher caste Hindu	75.43	24.57
	Hill Tibeto-Burmese	73.85	26.15
	Lower caste Hindu	73.44	26.56
	Terai Tibeto-Burmese	63.29	36.71
Gender	Male	71.58	28.42
	Female	73.73	26.27

CHAPTER 4

ASSESSING SPATIOTEMPORAL CHANGES IN TIGER HABITAT

ACROSS DIFFERENT LAND MANAGEMENT REGIMES

In collaboration with

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Abstract

Human-induced habitat loss and degradation are increasing the extinction probability of many wildlife species worldwide, thus protecting habitat is crucial. The habitat of thousands of imperiled wildlife species occurs in a variety of land management regimes (e.g., protected areas, multiple-use areas), each exerting differing effects. We used the globally endangered tiger (*Panthera tigris*) to examine the relationships between habitat change and land management in Nepal's Chitwan district, a global biodiversity hotspot. We evaluated the effects of environmental and human factors on tiger habitat based on data acquired by motion-detecting cameras and space-borne imaging sensors. Spatiotemporal habitat dynamics in Chitwan National Park and a multiple-use area outside the park were then evaluated in three time periods (1989, 1999, and 2009). Our results indicate that tigers preferred areas with more grasslands and higher landscape connectivity. The area of highly suitable habitat decreased inside the park over the entire 20 year interval, while outside the park habitat suitability increased, especially from 1999 to 2009. The loss of highly suitable habitat inside the park may be associated with an increasing trend of unauthorized resource extraction by a rapidly growing human population, coupled with natural processes such as flooding and forest succession. In contrast, community-based management of natural resources and the prohibition of livestock grazing since the late 1990's likely improved tiger habitat suitability outside the park. Results of this study are useful for evaluating habitat change and guiding conservation actions across the tiger range, which spans 13 countries. Moreover, quantitatively assessing habitat change across different land management regimes in human-dominated areas provides insights for conserving habitat of many other imperiled wildlife species around the world.

Introduction

Human demand for natural resources has transformed much of the earth's land surface (Sanderson et al. 2002), and between 10 and 20% of the world's remaining natural grasslands and forests are expected to be converted to agriculture, cities, and infrastructure by 2050 (MEA 2005). This conversion of natural ecosystems to areas used intensively by humans is considered the main cause of the current global decline in biodiversity and, by removing vast amounts of wildlife habitat, has put many wildlife species and communities at a greater risk of extinction (Liu et al. 2001, Sanderson et al. 2002, Viña et al. 2007).

Over 170,000 protected areas currently covering 12.7% of the world's land area have been set aside "to achieve the long term conservation of nature" and are considered a core part of the habitat conservation programs for many wildlife species (Bertzky et al. 2012). However, human activities within and adjacent to protected areas (e.g., development, collection of natural resources, livestock grazing, and poaching) are pervasive and threaten the conservation effectiveness of such areas (DeFries et al. 2005, Linkie et al. 2006, Western et al. 2009, Liu and Raven 2010). Furthermore, the current global protected area network covers small or no portions of the ranges of many imperiled wildlife species (Margules and Pressey 2000, Rodrigues et al. 2004). For example, 89% (3,467) of all imperiled wildlife species analyzed by Rodriguez et al. (2004) had either none or only part of their ranges covered by protected areas. Consequently, the habitat of many imperiled species is located on human-dominated multiple-use areas, which typically allow for more extractive activities than in protected areas (García-Fernández et al. 2008). Thus, strategies that mitigate human impacts on wildlife habitat across different land management regimes, such as protected areas and multiple-use areas outside them, are important for realizing conservation goals (Margules and Pressey 2000).

71

In this study, we examined the relationships between different land management regimes and habitat of the tiger (*Panthera tigris*), a globally endangered and widely valued species (Carter et al. 2012a). We chose tigers because their large space requirements necessitates landscape-scale approaches to habitat protection that encompass strictly protected and multiple-use areas, where nearly 80% of the tiger's remaining range occurs (Linkie et al. 2008, Forrest et al. 2011, Wikramanayake et al. 2011). We conducted our study in tiger habitat on two adjacent yet distinctly different land management regimes in Chitwan district, Nepal: the Chitwan National Park and the multiple-use area outside the park. As a human-dominated tiger habitat region, Chitwan, Nepal, is an excellent site to examine the historic and current constraints on, and opportunities for, tiger habitat conservation across different land management regimes. Our two objectives were to: (1) evaluate changes in tiger habitat suitability from 1989 to 2009 on a section of Chitwan National Park and a nearby multiple-use area outside the park; and (2) assess the potential influence of resource management policies and practices inside and outside the park on observed changes in tiger habitat suitability.

Land Management Regimes in Chitwan, Nepal

Chitwan National Park (~ 100,000 ha) was established in 1973 to protect the biodiversity of the Himalayan lowlands, a globally important region for tigers (Sanderson et al. 2006). Since 1975, a contingent of the Nepal Army has been stationed inside the park and with the task of patrolling the park to deter illegal activities such as wildlife hunting, logging, and collection of other natural resources (Martin 1992). These exclusion policies of the park created resentment among local people who felt that access to natural resources they relied on, such as fodder for livestock, thatch and timber for household construction, and fuelwood for cooking and heating, was denied without their consent (Nepal and Weber 1995a). To reduce park-people conflicts, a 'grass-cutting' program was initiated in 1976 to allow local residents to enter the park for several

days (ranging from 20 days in the past to 3 days in 2010) annually to legally collect thatch grass, reeds, rope bark, and rope grass (Stræde and Helles 2000). However, this concession only marginally offsets local demand for natural resources; thus, local residents also illegally collect various natural resources throughout much of the year (Nepal and Weber 1995b, Stræde and Treue 2006). Although illegal utilization of natural resources in the park does not automatically lead to wildlife habitat loss, the resource demands of the human population adjacent to the park, which has tripled from 1971 to 2011 (Nepal Central Bureau of Statistics 2012), may be degrading wildlife habitat inside the park, particularly tiger habitat.

To mitigate human pressure on Chitwan's ecosystems and other natural resources, a buffer zone (75,000 ha) surrounding the park was established in 1996 with the dual purpose of restoring ecosystem integrity while also improving human livelihoods. For instance, livestock grazing was prohibited from the multiple-use areas outside the park as ecosystem degradation due to overgrazing had become a major concern (Sharma 1990, Gurung et al. 2008). To offset this imposition, 30-50% of the park's annual revenue must be invested into the surrounding buffer zone to support community development programs, including alternative income opportunities and infrastructure improvement (Government of Nepal 1993). In addition, forested areas in the buffer zone adjacent to human settlements, which previously were part of the State-controlled national forest system, could be handed over to local user-group committees as community forests. User-group committees have had a considerable degree of management responsibility and control over resource use, for example, by dictating the amount and times of year that local people can collect or purchase fuelwood, timber, and fodder from the community forests (Nagendra et al. 2005). Previous research indicates that community-based resource management and restrictions on livestock grazing may be reversing deforestation and fragmentation outside the park (Gurung et al. 2008, Nagendra et al. 2008).

Materials and Methods

Study Site

Situated in south central Nepal, our study site (Fig. 4.1) was located in a river valley basin along the flood plains of the Rapti, Reu and Narayani rivers with an elevational range of 150 m to 815 m. Climate in Chitwan was subtropical with a summer monsoon from mid-June to late-September, and a cool dry winter. Mean annual rainfall was 240 cm, 90% of which falls during the monsoon from June to September. Temperatures were highest (maximum 38°C) during the monsoon and drop to a minimum of 6°C in the post-monsoon period (October to January, Laurie 1982). The park and multiple-use area outside the park has retained the unique natural vegetation communities distinctive of the Himalayan lowlands, including *Sal* (*Shorea robusta*) forest, *khair* (*Acacia catechu*) and *sissoo* (*Dalbergia sissoo*) riverine forests, and grasslands dominated by species of the genera *Saccharum*, *Themeda*, and *Imperata* (Chaudhary 1998). As of 2011, human population in the areas adjacent to our study site (26,100 ha) was approximately 275,000 distributed in approximately 68,000 households (Nepal Central Bureau of Statistics 2012).

Tiger Detection Data

From January to April (i.e., the dry season before monsoon) in 2010, we assessed tiger occurrence using 19 pairs of digital Reconyx RM45 passive infrared motion detecting cameras (Reconyx Inc., WI, USA). Motion detecting cameras have been used to effectively measure wildlife activity in numerous sites (O'Connell et al. 2010). We established four adjoining sample blocks that covered naturally vegetated areas inside and outside the park and were roughly oriented parallel to the human settled area. Each block was then subdivided into a grid with nineteen 100 ha cells. To maximize the probability of detecting tigers across the spatial extent of

our study site, a camera pair (hereafter a 'camera trap') was located at or close to the center of each grid cell along the nearest road, path, or animal trail. Thus, we set the camera traps at a total of 76 locations, 46 of which were inside the park and 30 outside. The grid size and sample block design were chosen to maximize the likelihood that all tigers in the area were detected, given female tiger home-range sizes in this region of approximately 1,500 ha (Sunquist 1981). Two cameras facing each other were used in each camera trap to simultaneously photograph both sides of an animal, thus increasing the probability of identifying individual tigers. We used a handheld Garmin eTrex (Garmin International Inc., KS, USA) global positioning system (GPS) receiver to record the location of each camera trap. The cameras were mounted on trees at approximately 1 – 1.5 m from the ground, angled downward and set to operate 24 h/day with no more than the minimum mechanical delay between sequential pictures.

We sampled the first block in the westernmost portion of the study site for 20 days and then moved eastward to sample the next blocks in succession, each for 20 days. We defined the camera trap as our sampling unit and one day (i.e., noon to noon the following day) as our sampling occasion. Therefore, cameras were set for a total of 1,510 trap-days, with 920 trap-days inside the park and 590 outside (one camera trap was damaged for 10 trap-days). We created a trap-by-occasion matrix, with rows i representing the camera trap sampling units and columns t representing the one-day sampling occasions. We identified individual tigers from the pictures using their unique stripe patterns (Karanth and Nichols 2002), and recorded the number of individual tigers for occasion t at trap i in the matrix.

Tiger Habitat Data

Environmental factors

As longitudinal data on prey density across our study site did not exist, we chose to use land-cover composition and spatial configuration as factors in our models because previous

studies show that those factors influence tiger dispersal, acquisition of prey, and tiger prey density (Seidensticker and McDougal 1993, Smith 1993, Shrestha 2004). In addition, these factors can be measured across space and through time using remotely sensed images, thus enabling assessment of habitat change.

As such, we obtained a cloud-free, multi-spectral Landsat TM image (Path 142, row 41 WRS-2; resolution: 28.5 m x 28.5 m) for October 2009 to be consistent with the time period in which we collected the tiger detection data (i.e., 2010). The image was obtained from the United States Geological Survey (USGS; http://glovis.usgs.gov) and was received geometrically corrected (i.e., level-1G product). Image processing was performed using ERDAS IMAGINE 9.3 (Leica Geosystems). We used an improved dark object subtraction method to radiometrically and atmospherically correct the image (Chavez 1996). An unsupervised classification algorithm using the ISODATA technique (Jensen 1996) was then applied to the image to produce 100 spectral classes. We used high-resolution Google Earth images (http://www.earth.google.com) and our knowledge of the area to merge the 100 spectral classes into six land-cover classes potentially related to tiger habitat: open water, grassland, *Sal* dominated forest, low density *Sal*, riverine forest, and barren (e.g., floodplain) (Shrestha 2004). Although the image was acquired in a different month (i.e., October) than when the tiger detection data was collected (i.e., January to April), the six land-cover classes derived from the image are quite distinct from one another and robust to seasonality. To eliminate outlier pixels (i.e., misclassified pixels caused by impulse noise), we applied a 3 x 3 majority filter to the land-cover map (Gurney and Townshend 1983). We assessed the accuracy of the land-cover classification map using 300 randomly selected pixels (i.e., 50 pixels per land-cover class), whose land-cover class was determined in contemporary high spatial resolution images, accessed in Google Earth (Biradar et al. 2009).

To determine habitat selection by tigers at fine spatial scales (i.e., smaller than the average tiger home-range size), we used a circular area with a radius of 400 m (i.e., ca. 50 ha) around each camera trap location. We chose this scale for two reasons. First, radio-telemetry data of tigers in Chitwan collected over many years indicate that they actively search for prey within a radius of approximately 400 m (Ahearn et al. 2001). Second, 50 ha is roughly the same size as home ranges for several tiger prey species (e.g., barking deer [*Muntiacus muntjak*], hog deer [*Axis porcinus*], and spotted deer [*Axis axis*]) in Nepal (Moe and Wegge 1994, Odden and Wegge 2007). In each 50 ha circular area surrounding each camera trap we summarized the land-cover composition (i.e., areas of each class) in the 2009 map. In addition, we used FRAGSTATS 3.3 (McGarigal et al. 2002) to calculate eight class and landscape-level metrics (Table 4.1) from the 2009 land-cover map to characterize the spatial configuration of the different land-cover classes (Riitters et al. 1995). These metrics were calculated using a neighborhood of eight pixels surrounding the focal pixel.

Human factors

Proximity to human settlements or human-made landscape features (e.g., roads) may also influence habitat selection by tigers (Kerley et al. 2002, Johnson et al. 2006). Park and buffer zone boundary data were obtained from the world database on protected areas (www.protectedplanet.net). We calculated the distance from each camera trap to the border of the human settled area as delineated by the boundary of the park/buffer zone. Road vector data were obtained from a 1996 survey performed by the Nepal Survey Department (www.dos.gov.np). This road vector coverage was updated to include roads constructed after 1996 by digitizing roads visible in high resolution imagery accessed through Google Earth. All roads within the study site were minor unpaved roads, except for two unpaved roads (one inside and one outside the park) that were used comparatively more often by local people to travel

across the forest. Using the updated road vector layer, we calculated the distance from each camera trap to the nearest road. We also calculated the road density within the 50 ha circular area surrounding each camera trap location. Lastly, we created a dummy variable that indicated whether the camera trap was inside or outside the park (Table 4.1).

Modeling Tiger Habitat Selection

We used N-mixture models (Royle 2004) to estimate the relative effect of environmental (derived from the 2009 image) and human factors (Table 4.1) on the spatial variability of tiger abundance from the 2010 camera trap data. Using model results we predicted location-specific tiger "abundance." The abundance index indicated whether a location is more or less likely to be visited by tigers (Linkie et al. 2010). Thus, the abundance index was used as a surrogate of tiger habitat suitability based on the assumption that habitat conditions in a location are directly related to the number of times it is visited by the target species (Boyce and McDonald 1999).

We let n_{it} denote the number of individual tigers detected at trap i (=1, 2, …, R) and occasion t (=1, 2, …, T). We assumed that the tiger population being sampled was demographically closed so that the number of detected individuals may be viewed as independent and identically distributed binomial random variables:

$$n_{it} \sim \text{Binomial } (N_i, p)$$

where N_i is tiger abundance at trap i and p is the detection probability. The N_i were regarded as random effects with a Poisson distribution with mean λ. We chose a Poisson variant of the N-mixture model because it has been shown to generate more ecologically realistic parameter estimates than the negative binomial and zero inflated negative binomial variants (Joseph et al. 2009). Mean trap abundance, λ_i, was allowed to vary in response to all environmental and human factor covariates by adopting a log-linear model:

$$\log(\lambda_i) = \beta_0 + \Sigma_{k=1}^{K} x_{ik} \beta_k \tag{4.1}$$

where x_{ik}; $k = 1, 2, \ldots, K$ are the K measurable covariates and β is a K-dimensional vector of covariate parameters for trap i. Detection probability, p, can vary with time in addition to trap-specific covariates (i.e., environmental and human factors) (MacKenzie et al. 2002). To create a time-specific covariate, we calculated the Julian date (Hein et al. 2009) for each day that the traps were operational. Detection probability was allowed to vary in response to time and trap-specific covariates using a logistic regression model:

$$\text{logit}(p_i) = \alpha_0 + \Sigma_{k=1}^{K} x_{ik} \alpha_k \tag{4.2}$$

where p_i is the probability that a tiger will be detected at trap i and α is a K-dimensional vector of covariate parameters. The integrated likelihood from all R traps was established as:

$$L(p, \lambda \mid \{n_{it}\}) = \Pi_{i=1}^{R} \left\{ \Sigma_{N_i=\max_t n_{it}}^{\infty} \left(\Pi_{t=1}^{T} \text{Bin}(n_{it}; N_i, p) \right) f(N_i; \lambda) \right\} \tag{4.3}$$

Conventional maximum likelihood was used to estimate parameters from this integrated likelihood.

Models were ranked according to their second-order Akaike's information criterion (AIC_c), with higher-ranked models having lower AIC_c values (Burnham and Anderson 1998). Because several models with different combinations of covariates performed comparatively well (i.e., $\Delta\text{AIC}_c < 4$), we averaged model results (i.e., covariate coefficients, detection probability, and the abundance index) from the top-ranked models using multimodel inference (Anderson 2007). Model-averaged coefficient estimates were considered significant if their unconditional 95% CIs did not include zero.

We used parametric bootstrapping to evaluate the goodness-of-fit of the top-ranked models. We simulated 100 data sets from each of the top-ranked models and fit the models to the data using the Freeman-Tukey fit statistic. We then compared the value of the Freeman-

Tukey fit statistic of the observed data set to the fit statistics of the simulated data sets. A model was considered to adequately fit the observed data if the observed fit statistic value did not exceed the 0.05 percentile of the distribution of the fit statistics calculated from the simulated data sets (Sillett et al. 2012). Model specification, parameter estimation, averaging, and goodness-of-fit were performed using the 'unmarked' and 'AICcmodavg' packages in the R software (Fiske and Chandler 2011).

Mapping Tiger Habitat Suitability

We processed Landsat TM and ETM+ images from November 1989 and December 1999 using the same procedures we used to process the 2009 image. Accuracy of the land-cover maps obtained for 1989 and 1999 was not evaluated due to unavailability of reference data covering these time periods. Nevertheless, accuracy of these maps was expected to be similar to that of the 2009 land-cover map, since map production followed exactly the same procedures.

The three time periods comprised intervals of time roughly prior to (i.e., 1989 – 1999), and after (i.e., 1999 – 2009) the implementation of buffer zone policies in the multiple-use area outside the park. Restrictions on livestock grazing outside the park did not take effect until community forest user groups were organized. This happened about a couple of years after the buffer zone was established in 1996 (N.M.B. Pradhan, personal communication).

For 1989, 1999, and 2009 we combined covariate GIS layers and the model-averaged parameter estimates to assign a tiger "abundance" value to pixels on a grid with a spatial resolution equal to that of the Landsat imagery (i.e., 28.5 m x 28.5 m). First, covariate GIS layers for each time period were produced using ArcGIS 10 and FRAGSTATS, wherein a circular window with a 400 m radius was passed over each pixel in the grid and metrics at the class or landscape level were calculated at the focal pixel. Then, using the covariate GIS layers

and parameter estimates as input, we took the exponent of the right-hand side of equation (4.1) to estimate per-pixel tiger abundances (i.e., per-pixel estimates of λ) for all three time periods.

To avoid over-extrapolation, the maps of tiger habitat suitability obtained were restricted to the areas accessible to tigers detected by the cameras. Habitat suitability outside the park was mapped in the naturally vegetated area south of the 'East-West' highway, which delineates the northern boundary of the buffer zone (Fig. 4.1). Within park habitat suitability was mapped in an area delineated by the Churia hills to the west, the park border to the north, and one-half the mean maximum distance traveled (MMDM/2) by the tigers in the southern and eastern boundaries of the park. MMDM/2 was determined as the distance between the two farthest capture locations for all individual tigers, and is often used to delineate the effective sample area for population density estimates (Karanth and Nichols 1998). Maps of habitat change from 1989 to 1999 and 1999 to 2009 were created by calculating the per-pixel difference in tiger habitat suitability between the respective time periods. Changes in the area of different habitat suitability categories were assessed for each land management regime across time. Mean change and 95% confidence intervals in habitat suitability were calculated at 100 m intervals away from the human settled area up to 3,000 m. We chose 3,000 m because local people do not usually travel much farther than that to collect natural resources.

Results

Tiger Detections

We obtained a total of 131 adult tiger detections, with 92 and 39 detections inside and outside the park, respectively. We identified 17 individual adult tigers across all camera traps. Twelve adults were detected inside the park and 6 were detected outside the park, with one tiger being photographed in both areas. Across our study site, 75% (57/76) of all camera traps were

triggered by tigers. A larger percentage of cameras outside the park (83%) were triggered by tigers than inside the park (70%). The number of tiger detections at each camera trap ranged from 0 – 9 inside the park ($\bar{x}$ = 2), and 0 – 4 outside the park ($\bar{x}$ = 1.3). MMDM/2 was 2,371 m.

Changes in Land Cover

Overall accuracy of the 2009 land-cover map was 85.3% suggesting that the classification procedure adequately represented the land-cover classes in the study area (Congalton 1991). Land-cover classifications for all three time periods revealed that from 1989 to 2009 grassland area decreased (-323 ha) inside the park and increased (192 ha) outside the park (Table 4.2). In contrast, barren land-cover, which mostly consisted of sandy floodplain, increased (451 ha) inside the park and decreased (-106 ha) outside the park. *Sal* forest decreased both inside (-910 ha) and outside the park (-411 ha) while riverine forest increased both inside (786 ha) and outside (327 ha) the park over the 20 year period (Table 4.2).

Predictors of Detection Probability and Tiger Habitat

We ran approximately 200 models with different combinations of variables. Model AIC_c values ranged from 892.35 to 873.05. The bootstrap *P* values for the top-ranked models (Table 4.3) based on the Freeman-Tukey fit statistic were 0.45, 0.46, 0.51, and 0.47, suggesting the models fit the data adequately. Model-averaging indicated that tiger abundance was positively associated with correlation length (β = 0.32, 95% CI: 0.06 – 0.57) and grassland area (β = 0.23, 95% CI: 0.04 – 0.42), suggesting that tigers selected areas consisting of more connected land-cover patches and with more grassland. Detection probability was negatively associated with riverine forest area (β = -0.37, 95% CI: -0.69 – -0.06) and Julian date (β = -0.44, 95% CI: -0.75 – -0.12), suggesting that tigers were less likely to be detected in areas with more riverine forest and

later in the sampling period. With the covariates set to zero (i.e., mean), detection probability

was 0.02 (SE = 0.008) across all traps in the study site.

Tiger Habitat Suitability and its Changes

Tiger habitat suitability, as measured using a per-pixel abundance index, ranged from

1.64 to 11.07 ($\bar{x}$ = 4.38), 1.53 to 11.08 ($\bar{x}$ = 4.38), and 0.63 to 11.73 ($\bar{x}$ = 4.36) for 1989, 1999,

and 2009, respectively. The habitat suitability index (HSI) in all three time periods was the most

heterogeneous along the Rapti River and in areas adjacent to human settlements, whereas

relatively homogenous and moderate habitat suitability tended to occur deeper inside the study

site (Fig. 2). The mean tiger HSI was higher inside the park (1989: 4.54, 1999: 4.54, 2009: 4.46)

than outside the park (1989: 4.09, 1999: 4.1, 2009: 4.23) in all three time periods, although the

difference in mean HSI inside and outside the park diminished through time (i.e., 10.98%,

10.55%, and 5.35% in 1989, 1999, and 2009, respectively).

The relatively small changes in mean HSI values through time conceal rather large

changes in different HSI categories. Across the entire study site, approximately 110 ha overall

became more suitable habitat (i.e., HSI categories 5-6, 6-7) from 1989 to 1999 (Table 4.4, Fig.

4.3a). However, from 1999 to 2009, approximately 350 ha of habitat in the three highest HSI

categories (12 to 17% of each category) downgraded to lower HSI categories (i.e., 3-4 and 4-5).

Inside the park, approximately 100 ha became more suitable habitat (i.e., HSI categories 5-6, 6-

7) from 1989 to 1999, although the lowest HSI category increasing by 275 ha (17%, Table 4.4,

Fig 4.3b). Moreover, from 1999 to 2009, approximately 410 ha of habitat in the three highest

HSI categories (17 to 24% of each category) downgraded to lower categories (i.e., 3-4, 4-5),

resulting in a net decline in HSI inside the park over that time. In contrast, outside the park, over

400 ha in the lowest HSI category upgraded to more suitable habitat over the 20-year interval

(Table 4.4, Fig. 4.3c). The highest HSI category increased by 52 ha (50%) from 1999 to 2009, contributing to a net increase in the HSI outside the park over that time.

Per-pixel change in tiger habitat suitability from 1989 to 1999 and 1999 to 2009 ranged from -7.56 to 7.37 and -7.59 to 8.34, respectively. Negative values are associated with habitat becoming 'less suitable' over time, while positive values are associated with habitat becoming 'more suitable' over time (Fig. 4.4). Habitat suitability inside the park changed the most along the Rapti River and in the large grassland/riverine complexes to the west and east. Habitat suitability outside the park changed the most along the border with the human settled area (Fig. 4.4).

From 1989 to 1999, the mean change in the tiger HSI across the entire study site was negative at distances of 100 to 1,800 m away from the human settled area, with the nadir (-0.7 in HSI) occurring at about 600 m from the human settled area (Fig 4.5a). From 1999 to 2009, the mean change in the HSI was positive (ranging from 0.1 to 0.4) at distances of 100 to 1,700 m, with the changes significantly different from those that occurred from 1989 to 1999 within the same distance interval. Beyond 1,700 m the mean change was negative, reaching a nadir (-0.41) at approximately 2,500 m. In general, a similar pattern to the entire study site was evident inside the park over the 20-year period, although the magnitudes of negative changes were greater (Fig. 4.5b). Mean change in the habitat suitability outside the park from 1989 to 1999 was initially negative at 100 m and then became positive from 200m to a distance of 1,000 m. The positive changes that occurred from 200 m to 1,000 m outside the park were significantly different from the negative changes that occurred within the same distance interval inside the park during the same time period (Fig. 4.5b, 4.5c). Beyond 1,000 m, mean changes outside the park from 1989 to 1999 were negative. From 1999 to 2009, mean change outside the park peaked around 300 m

(0.62) and remained positive until approximately 1,800 m, with most of the changes within 1,800 m significantly more positive than those that occurred from 1989 to 1999 (Fig. 4.5c).

Discussion

Factors Affecting Tiger Habitat and Detection

Alluvial grasslands support high densities of tiger prey and contain important sources of water (Eisenberg and Seidensticker 1976, Sunquist 1981). Thus, tigers may select areas with more grassland to look for prey and obtain water. Unlike land-cover types with relatively low understory density, grasslands may also provide adequate cover for tigers' hunting activities (Sunarto et al. 2012). Correlation length can be considered a measure of connectivity since it represents the average distance a tiger can move within a land-cover patch before encountering a patch boundary. Contiguous land-cover patches may facilitate movement and dispersal across the landscape (Short Bull et al. 2011). Tiger preference for contiguous land-cover patches at a fine spatial scale as shown in this study supports Sunarto et al. (2012), which found that, at a coarse spatial scale, tigers in Sumatra prefer large contiguous forest tracts.

Since the understory of riverine forest is typically more dense than *Sal* forest (Sunquist 1981, Lehmkuhl 1994), understory vegetation may be more likely to obstruct the field of view of cameras in riverine forest than in *Sal* forest, which could lower detection probability. In addition, as animal/walking trails in riverine forests are perhaps smaller and less defined than other forest types, tigers may traverse riverine forests along multiple, unpredictable routes and consequently be detected less often by the cameras. There are a couple possible reasons why detection probability decreased over time. By monitoring breeding tigers from 1973 and 1989, Smith and McDougal (1991) showed that the distribution of births across all 12 months of the year was not significantly different from a uniform distribution, although a peak in births did

occur between May and July. Just prior to this peak, females may be more wary and less active, which could lower detection probability relative to earlier in the year. Another possible explanation is that tigers are generally less active and mobile in March and April when temperatures increase (Seidensticker 1976). By formally accounting for variation in detection probability as a function of riverine forest and time, the N-mixture model we used provides reliable estimates of tiger habitat suitability across the whole entire study site (Royle 2004).

Habitat Change across Different Land Management Regimes

Protected areas in many temperate and tropical regions have experienced declines in natural land covers and wildlife habitat as a result of human impacts (Liu et al. 2001, DeFries et al. 2005). While the overall estimated suitability of tiger habitat in Chitwan National Park was high over the 20-year study period (Table 4.4), persistent and increasing human pressures may have degraded habitat suitability inside the park through time. We found that habitat inside the park became less suitable for tigers from 1989 to 1999 in the areas closest to human settlements. Likewise, Nagendra et al. (2008) indicated that forest degradation from 1989 to 2000 was much more extensive along the park periphery than in the multiple-use areas outside the park. The authors attribute this comparatively higher forest degradation inside the park to high natural resource demands by local people. We found that habitat suitability inside the park increased somewhat in the areas closest to human settlements from 1999 to 2009, however, habitat suitability decreased in areas deeper inside the park. Although it is possible that this shift resulted from natural forest dynamics, these changes may indicate that human resource collection activities occurred deeper inside the park during that time frame. A similar pattern was shown inside China's Wolong Nature Reserve, where local people traveled farther from their homes to collect fuelwood after the fuelwood supply was depleted in the areas nearest to them (He et al. 2009).

Stræde and Treue (2006) indicated that households living near Chitwan National Park on average collect 11.4%, 5.3%, and 15.1% of their annual timber, fuelwood, and fodder needs, respectively, from inside the park. The majority of timber and fuelwood collected from inside the park was *Sal* (Stræde et al. 2002), which is considered the most valuable and exploited tree species in the region (Nagendra 2003). Removal of forest understory and woody biomass from the park may have reduced hiding cover for tigers (Sunarto et al. 2012) and induced land cover fragmentation (Gasparri and Grau 2009). In addition, Stræde and Helles (2000) noted that demand for park resources, especially grasses, by local people has been steadily increasing. The decline in grassland area inside the park, and consequential loss of highly suitable tiger habitat, may be partially attributed to substantial anthropogenic pressure (Peet et al. 1999, Stræde and Helles 2000).

Other disturbances such as flooding and fire also likely affected tiger habitat suitability. Habitat suitability heterogeneity along the northern boundary of the park is likely due, in part, to the large-scale movement of the Rapti River, which constantly erodes, deposits alluvium, and changes course across the floodplain (Peet et al. 1999). When the river changes course some areas become inundated while other areas are deposited with alluvium and rapidly colonized by *S. spontaneum* grasses (Peet et al. 1999). In addition, fire, either naturally or human caused, delays the succession from grasslands to riverine forest. However, fire cannot prevent succession entirely because of variations in fire intensity and occurrence (Lehmkuhl 1994). Thus, decreasing grasslands and *Sal* forest and the corresponding increase in riverine areas observed inside the park over the 20 year period may be due to a combination of human and natural disturbances. Despite the degradation of highly suitable areas inside the park, especially from 1999 to 2009, the tiger population inside the park appears to be stable (Carter et al. 2012b). This is perhaps because the change in habitat suitability to date is not large or extensive enough

to induce a change in the tiger population. Alternatively, a time-lag may exist between changes in habitat suitability and the tiger population.

As the area outside the park was considered heavily degraded prior to the establishment of the buffer zone (Sharma 1990), resource collectors likely had to travel relatively far into the multiple-use area to find adequate supplies of high-quality resources. The extraction of natural resources from deeper inside the multiple-use area may have induced the slight average decrease in estimated tiger habitat suitability from 1989 to 1999 around 1.5 km from human settlements. The prohibition of livestock grazing and institutionalization of community-based resource management outside the park shortly after the buffer zone was established in 1996 substantially altered resource consumption patterns. For example, the removal of domestic livestock likely enabled the area outside the park to support a greater density of wild prey animals (Gurung et al. 2008) and provide better hiding cover for tigers. The control of overharvesting of shared natural resources in community forests in the buffer zone may also have improved tiger habitat outside the park. . This is supported by improvements in estimated habitat suitability occurring mostly in areas adjacent to human settlements that are designated as community forests. In addition, as resource extraction policies and practices influence the spatial distribution of human activities, these, in turn, affect the spatial configuration of the land cover. As such, before the buffer zone was established, uncontrolled open-access resource extraction likely fragmented the land cover. In contrast, the coordinated management of forest tracts by user-group committees after the buffer zone was established may have helped reverse this fragmentation (Nagendra et al. 2008), and thus improved tiger habitat suitability.

The improvement of estimated tiger habitat suitability outside the park is independently supported by an increasing frequency of tiger sightings over the last decade (DNPWC 2007). While searching for tiger tracks and kills from 1999 to 2003, Gurung et al. (2006) did not find

any evidence of breeding females (i.e., adult female tracks with cub tracks) in the multiple-use area outside the park. From our 2010 camera trap data, we identified a female tiger living completely outside the park and accompanied by three of her cubs, suggesting that the habitat outside the park has improved over the last decade. Currently, tiger densities inside and outside the park in our study site are approximately equal (Carter et al. 2012b). Attacks on people outside the park have also increased since the late 1990's (Gurung et al. 2008), and efforts to mitigate human-tiger conflicts are vital to fostering coexistence in Chitwan. The main purpose of community forests is to sustainably provide natural resources to local communities; however, their formation does not automatically lead to the protection and/or improvement of tiger habitat. Moreover, the demands, practices, and compositions of the community forest user groups are constantly changing, and consequently, tiger habitat may degrade in the future in areas where it is currently improving. Therefore, coupled with efforts to mitigate human-tiger conflicts, we suggest that tiger habitat suitability be monitored regularly inside and outside the park to ensure that the land continues to support tigers.

The management policies and practices inside and outside the park and their impacts on tiger habitat are not mutually exclusive. Not only do these two management regimes adjoin each other in space, but the effects of one may have direct or indirect effects on the other. For instance, while local people legally extract natural resources from the buffer zone outside the park, it appears that the products obtained do not fully substitute those collected inside the park (Stræde and Treue 2006). Therefore, given projected human population growth and current per-capita resource demands in Chitwan (Stræde and Treue 2006, Nepal Central Bureau of Statistics 2012), protecting tiger habitat will become increasingly difficult over time. As such, policies that reduce human reliance on natural resources (e.g., by encouraging the use of non-wood fuel sources and improved livestock breeds) and actively manage tiger habitat are urgently needed

(Hjortsø, et al. 2006, Thornton 2010). Furthermore, experimenting with participatory-based management of ecosystems in and around the park, wherein local people are partners in designing, implementing, and enforcing resource management actions, may also foster sustainable conservation of tiger habitat over the long-term (Agrawal and Ostrom 2001). Such institutional arrangements, for instance, may enable the creation and maintenance of grasslands and early successional ecosystems in Chitwan through coordinated management treatments, including tree thinning and grassland cutting and burning (Brown 2003, Smit 2004).

Methodological Considerations

In this study, we assumed that the tiger population remained closed to demographic change for 89 days, which may be appropriate in this context as tigers are long-lived and Chitwan has relatively long seasons (O'Brien and Kinnaird 2011). We also assumed that the determinants of tiger habitat suitability remained unchanged from 1989 to 2009, which may be appropriate as tiger-habitat relationships characterize fundamental interactions between tigers and their environment (Morrison et al. 2006). However, tigers may have adjusted their space use over the 20 year period as a result of changes in the composition of prey, the density of tigers, or human disturbances. For example, although tigers may be habituated to the forest road network currently in the study site, the construction of those forest roads in the past may have strongly disturbed tiger space use and consequently decreased habitat suitability of the areas surrounding the roads for an extended period of time.

Our results on habitat suitability also refer to the dry season only (i.e., January to April). Tigers may select areas differently at different times of the year. For example, the use of grasslands by tigers may decrease in the wet season because the grasslands are periodically inundated, which forces prey animals to move to drier ground in upland forests (Sunquist 1981). Our findings are likely valid across seasons, however, because the factors influencing habitat

suitability identified in this study are similar to those from several other studies that spanned different seasons (Seidensticker 1976, Sunquist 1981, Smith et al. 1998). Nevertheless, collecting longitudinal (i.e., annual) tiger occurrence data across different seasons in conjunction with data on environmental and human factors would eliminate confounding issues of temporal variation in tiger habitat selection. Integrating such information with detailed data on individual-level tiger behaviors (e.g., from GPS collars) would explicitly link individual and population-level processes, and potentially allow for the design of "adaptive" models of habitat suitability that better capture temporal dynamics in habitat selection (Persson and De Roos 2003)

Although abundance is generally correlated with habitat suitability (Boyce and McDonald 1999), in some cases it is possible to find low or no relation between the frequency of animal occurrences and habitat selection. For instance, occurrences in suitable habitat may be low due to hunting or disease or to lack of colonization due to dispersal barriers. Conversely, animal occurrences in low quality habitat may be high, because less competitive juveniles are relegated to those areas (Van Horne 1983), or animals use those areas as travel corridors. However, circumstances such as these seem to be uncommon in our study site as tiger poaching in Chitwan has been relatively low since the end of the civil war in Nepal in 2006. Furthermore, tigers seem to have colonized the entire study site long before the study was performed, and with the exception of the Rapti River, no obvious barriers to tiger movement (e.g., expanses of cultivated or urban developed land) are conspicuous.

Explicitly linking habitat conditions to tiger survival and reproduction would potentially enable evaluating changes in tiger population size in areas under different management regimes. However, with the data collected in this study we were unable to quantitatively relate changes in tiger habitat suitability to tiger population dynamics and persistence. As a result, it is still unclear how the changes observed affect tiger population viability in the area.

91

Conclusions

Our first study objective (i.e., evaluate changes in tiger habitat suitability from 1989 to 2009) was addressed through the integration of data obtained from camera traps and remotely-sensed imagery. Our results indicated that the estimated habitat suitability was higher inside the park than outside; however, over the 20-year study period a gradual decline in habitat suitability was observed inside the park while a gradual improvement was observed outside the park. Our second study objective (i.e., assess the potential influence of resource management policies and practices on observed changes in tiger habitat suitability) was addressed using a thorough literature review combined with personal knowledge of the study site. This analysis suggested that the top-down, exclusion policies of the National Park have not adequately stopped the natural resource collection activities of a growing human population from detrimentally impacting tiger habitat inside the park. In contrast, habitat improvement outside the park occurred after policies that involved local people in the management of local natural resources (e.g., preventing livestock grazing) were implemented.

Degradation of highly suitable habitat inside the park is concerning and warrants assiduous monitoring efforts to ascertain whether or not this trend is continuing, and if it is, actions to reverse the trend should be pursued (e.g., actively managing grasslands, creating and maintaining communal grasslands outside park, encouraging the use of non-wood fuels). Expanding the involvement of local people in the management of local natural resources may indeed help improve tiger habitat suitability in important multiple-use areas that link tiger source populations in protected areas (Wikramanayake et al. 2004). However, the costs to local people (e.g., tiger attacks on people and livestock) must be carefully addressed for the conservation of tigers and their habitat in such areas to be sustainable.

In addition to Chitwan, our study methods and analyses can be applied to protected areas distributed throughout the tiger's range to determine if habitat suitability of tigers has decreased, remained stable, or increased therein. Furthermore, by extending the evaluation of habitat change beyond protected areas to multiple-use areas, both of which are integral components of landscape-scale conservation initiatives, researchers can also assess how effective are a plethora of management practices and policies (e.g., integrated conservation and development projects, community-based natural resource management, etc.) at maintaining or expanding tiger habitat throughout their range. Effective tiger habitat conservation strategies will also promote the conservation of thousands of other imperiled animal and plant species that use the same ecosystems as tigers, such as the Indian elephant (*Elephas maximus indicus*), the Indian rhino (*Rhinoceros unicornis*), the sloth bear (*Ursus ursinus*), the dhole (*Cuon alpinus*), and the gaur (*Bos gaurus*) (Joshi et al. 1995, Karanth and Sunquist 1995, Wikramanayake et al. 1998, Nyhus and Tilson 2004).

As camera traps are increasingly being used to study wildlife species in many regions of the world and multi-temporal and multi-spectral imagery exist for most of the earth's land surface, we encourage similar evaluations of the status of the habitat of many other imperiled wildlife species be performed around the world. Such studies can identify the major factors influencing habitat suitability and provide high resolution maps of habitat suitability over time. These results would be especially useful for monitoring changes in habitat availability and suitability of wide-ranging and elusive species such as the giant panda (*Ailuropoda melanoleuca*), the jaguar (*Panthera onca*), the snow leopard (*Uncia uncia*), or the cougar (*Panthera concolor*). Information on how (e.g., dynamics in key habitat determinants) and where (e.g., specific locations and regions) habitat is changing will help guide conservation

actions in human-dominated regions, which prevail throughout the ranges of many if not all of

these imperiled species.

APPENDIX

Figure 4.1: Study site in Chitwan district, Nepal, where camera trap data on tigers were collected in 2010.
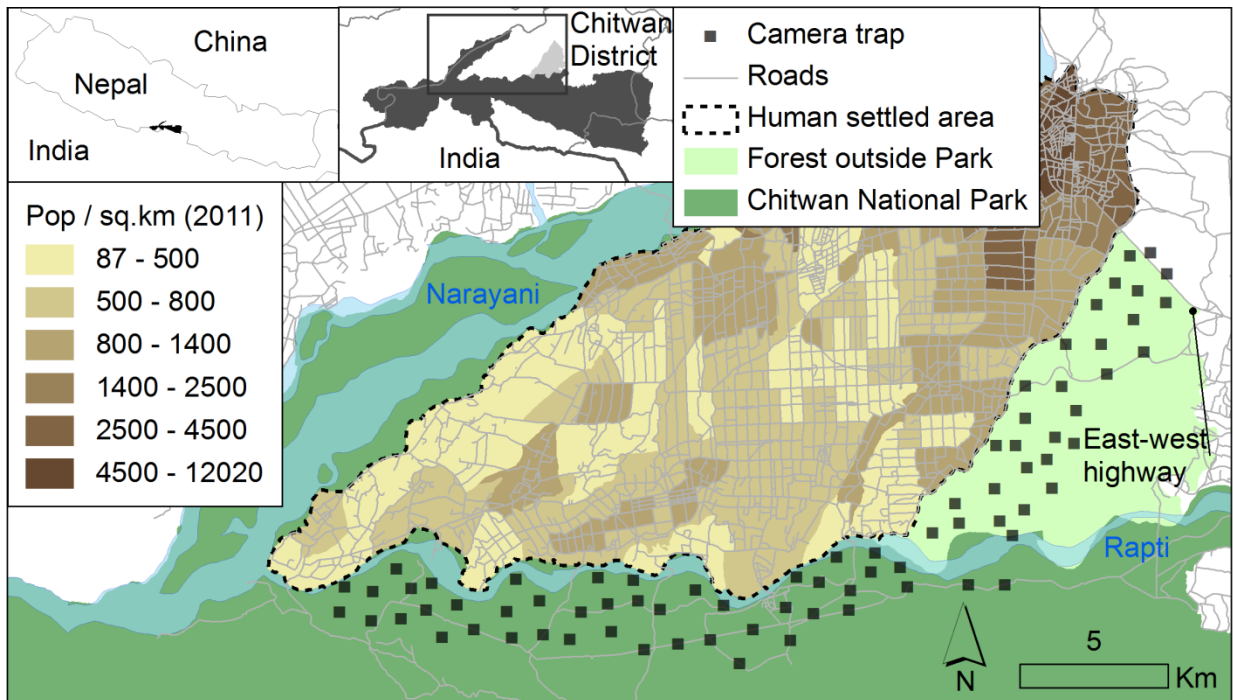
Figure 4.2: Map of estimated tiger habitat quality inside and outside Chitwan National Park in three time periods: a) 1989, b) 1999, and c) 2009.

a) 1989 estimated habitat suitability

b) 1999 estimated habitat suitability

c) 2009 estimated habitat suitability

Habitat Suitability Index

<3 3-4 4-5 5-6 6-7 >7

Multiple-use area outside park

5

N

Km
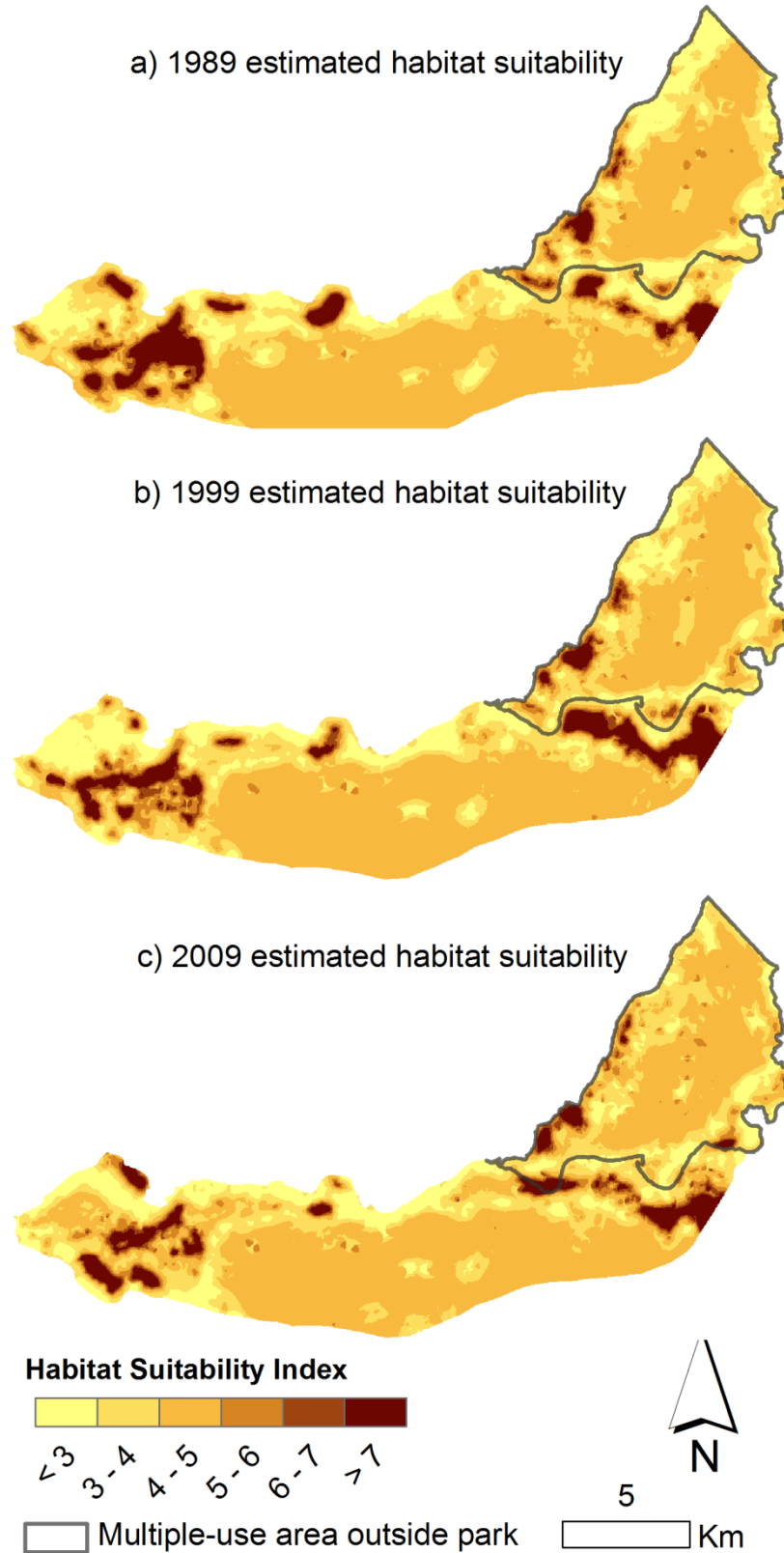
Figure 4.3: Change in area (ha) of different tiger habitat suitability index categories from 1989 to 1999 and 1999 to 2009 for a) entire study site, b) inside the park, and c) outside the park.
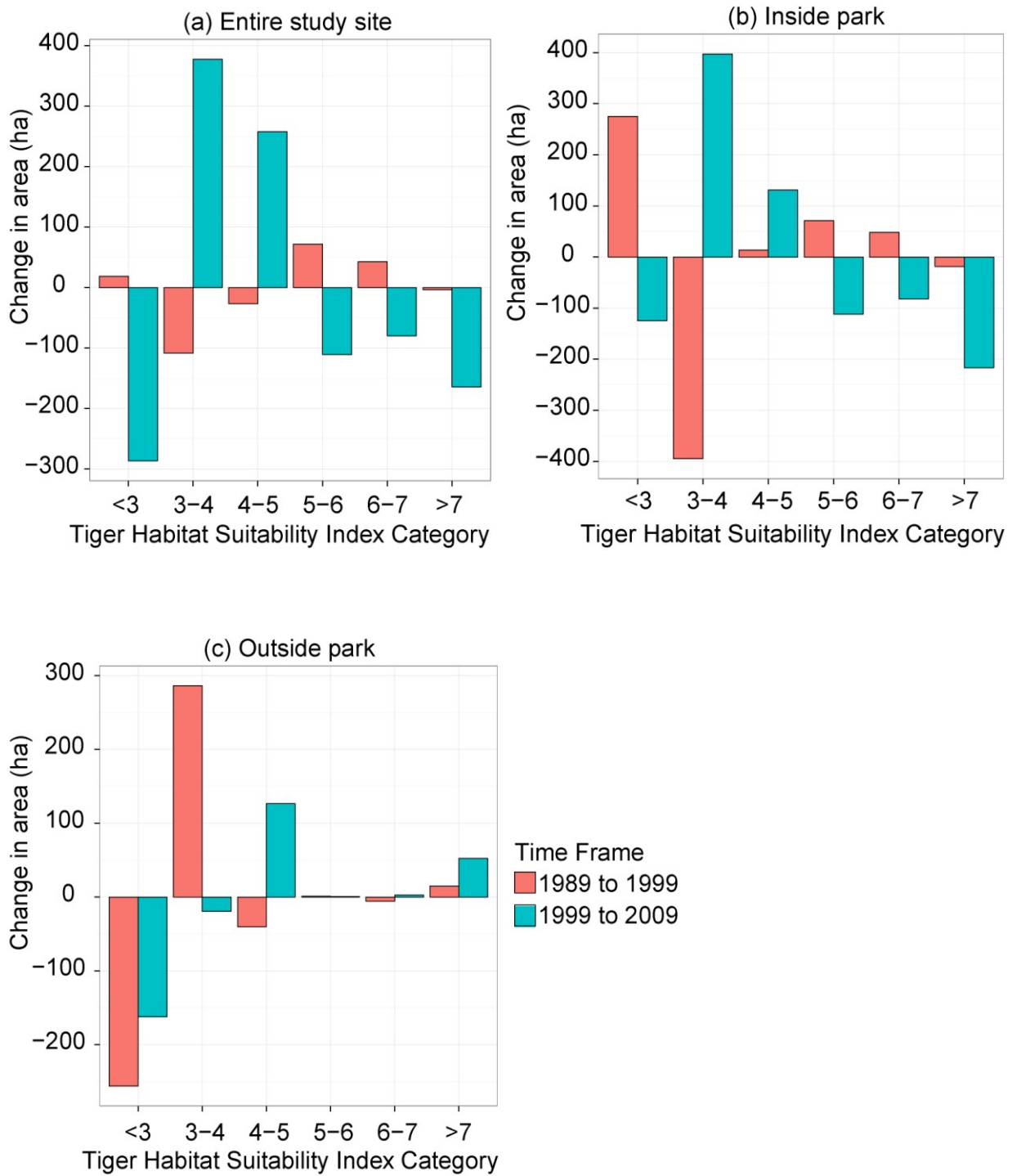
Figure 4.4: Map of change in estimated tiger habitat inside and outside Chitwan National Park from a) 1989 to 1999 and b) 1999 to 2009.

a) change in estimated habitat suitability from 1989 to 1999

b) change in estimated habitat suitability from 1999 to 2009

Habitat Suitability Change

<-3   -3--1   -1-1   1-3   >3

Multiple-use area outside park

5

Km

N
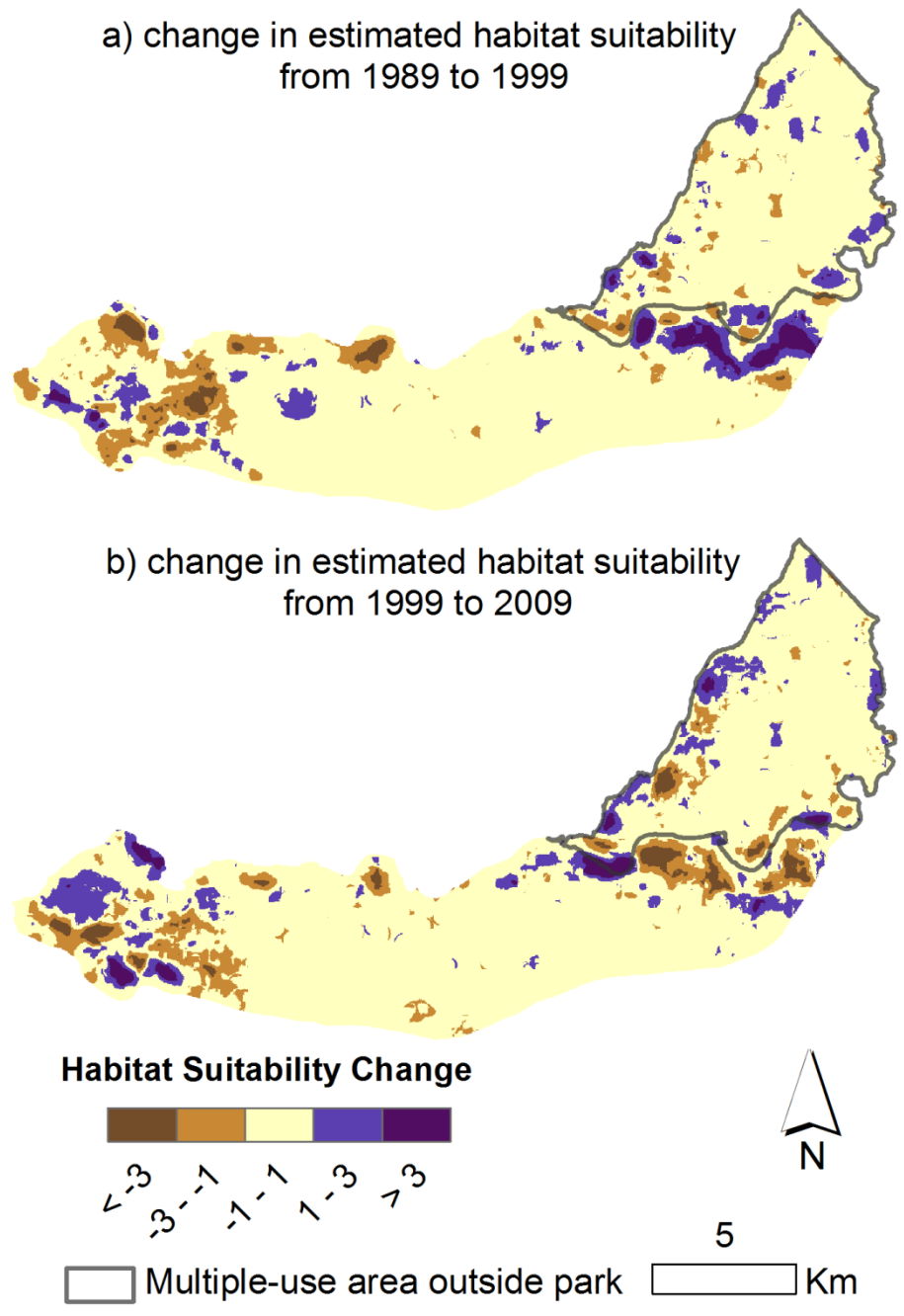
Figure 4.5: Mean change (95% CI) in estimated tiger habitat suitability index (HSI) from 1989 to 1999 and 1999 to 2009 by distance from human settled area for a) entire study site, b) inside the park, and c) outside the park.
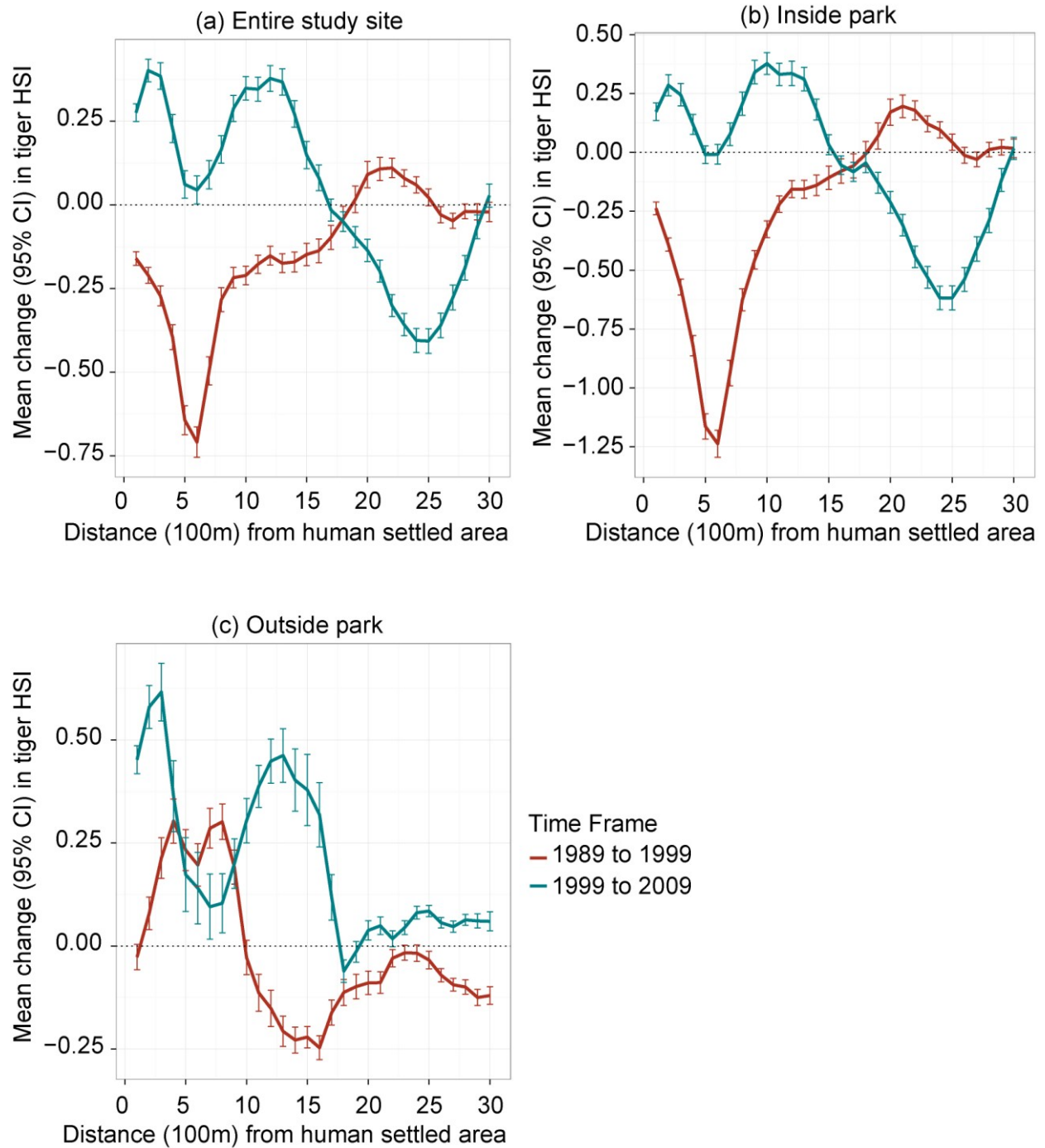
Table 4.1: Environmental and human factors potentially influencing tiger habitat selection in Chitwan, Nepal.

Covariate category / name	Description[a]
Environmental factors	
Area	Total land-cover class area (ha)[b]
Class mean patch size[c]	Area-weighted mean size of patches from each land-cover class
Number of patches[d]	Total number of land-cover patches
Landscape mean patch size[d]	Area-weighted mean size of all land-cover patches
Largest patch index[d]	Approaches 0 when largest patch is increasingly small, and approaches 100 when entire area consists of a single patch
Correlation length[d]	Equal to 0 when all patches consist of a single pixel, and increases as patch extent increases
Patch shape[d]	Equal to 1 when all patches are square and increases with increasing patch shape irregularity
Patch contagion[d]	Approaches 0 when patches are disaggregated and interspersed, and approaches 100 when patches are aggregated
Shannon's diversity index[d]	Equal to 0 when there is only one patch in the landscape and increases as number of patch types increases
Human factors	
Road density	Sum (m) of road length
Distance to settlement	Distance (m) from camera trap location to nearest human settlement
Distance to forest road	Distance (m) from camera trap location to nearest forest road
Location	1 if inside park; 0 if outside the park

Notes: [a]All covariates are continuous and, except distance to settlement and road, were calculated within a circular area (radius of 400 m) around each camera trap location.
[b]Land-cover classes included open water, grassland, *Sal* dominated forest, low density *Sal*, riverine forest, and barren.
[c]Class metric
[d]Landscape metric

Table 4.2: Land-cover areas (ha) for each time period.

Land cover	1989	1999	2009
Entire study site			
Water	800	691	797
Grassland	4852	4952	4722
Sal forest[a]	11602	11089	10281
Riverine forest	1308	1561	2421
Barren	355	625	698
Inside park			
Water	640	593	637
Grassland	3447	3461	3124
Sal forest[a]	7333	7129	6423
Riverine forest	1209	1169	1995
Barren	184	462	635
Outside park			
Water	160	99	160
Grassland	1396	1482	1588
Sal forest[a]	4269	3961	3858
Riverine forest	99	393	426
Barren	170	162	64

Notes: [a]Comprises *Sal* dominated and low-density *Sal* forest.

Table 4.3: Summary of tiger habitat models.

Model	K	AIC$_c$	ΔAIC$_c$	w_i	LL
λ(correlation length + grassland area)p(riverine area + Julian date)	6	873.05	--	0.48	-429.92
λ(correlation length + grassland area)p(riverine area + Julian date + road density)	7	874.29	1.24	0.26	-429.32
λ(correlation length + grassland area)p(riverine area + Julian date + location)	7	875.16	2.1	0.17	-429.76
λ(correlation length + grassland area)p(riverine area + location)	6	876.49	3.44	0.09	-431.64

Notes: Covariate coefficient estimates were averaged from these four top-ranked models. λ is the index of abundance, p is the detection probability, ΔAIC$_c$ is the difference in AIC$_c$ values between each model and the model with the lowest AIC$_c$ value, w_i is the AIC$_c$ model weight, and LL is the logarithm of the likelihood. K = Number of model parameters including intercepts and covariates, location = location of the camera trap (i.e., inside or outside Chitwan National Park).

Table 4.4: Areas (ha) of different tiger habitat suitability index (HSI) categories for each time period.

HSI Category	1989	1999	2009
Entire study site			
<3	2798	2817	2530
3-4	4189	4081	4459
4-5	9616	9590	9847
5-6	825	897	786
6-7	489	532	453
>7	1001	998	834
Inside park			
<3	1622	1897	1773
3-4	2737	2343	2740
4-5	6560	6573	6705
5-6	601	672	560
6-7	382	430	348
>7	911	893	676
Outside park			
<3	1176	920	758
3-4	1452	1738	1719
4-5	3057	3016	3143
5-6	224	225	225
6-7	107	102	104
>7	90	105	157

CHAPTER 5

COEXISTENCE BETWEEN WILDLIFE AND HUMANS AT FINE

SPATIAL SCALES

In collaboration with

Binoj K. Shrestha, Jhamak B. Karki, Narendra Man Babu Pradhan, and Jianguo Liu

Abstract

Many wildlife species face imminent extinction due to human impacts. As such, a prevailing belief is that some wildlife species, particularly large carnivores and ungulates, cannot coexist with people at fine spatial scales (i.e., cannot regularly utilize the exact same point locations). This belief provides rationale for various conservation programs, such as resettling human communities outside protected areas. However, quantitative information on the capacity and mechanisms for wildlife to coexist with humans at fine spatial scales is scarce. Such information is vital as the world becomes increasingly crowded. Here we provide empirical information about the capacity and mechanisms for tigers (a globally endangered species) to coexist with humans at fine spatial scales inside and outside Nepal's Chitwan National Park, a "flagship" protected area for imperiled wildlife. Information obtained from field cameras in 2010 and 2011 indicated that human presence (i.e., people on foot, vehicles) was ubiquitous and abundant throughout the study site; yet, tiger density was also high. Surprisingly, even at a fine spatial scale (i.e., camera locations), tigers spatially overlapped with people on foot and vehicles in both years. However, in both years, tigers offset their temporal activity patterns to be much less active during the day when human activity peaked. In addition to temporal displacement, tiger-human coexistence was likely enhanced by abundant tiger prey and low levels of tiger poaching. Incorporating fine scale spatial and temporal activity patterns into conservation plans can help address a major global challenge – meet human needs while sustaining wildlife.

Introduction

The extent and degree to which threatened wildlife can coexist with humans over a sustained period of time is a central issue in conservation science and policy (Woodroffe et al. 2005, Dickman et al. 2011). Numerous conservation models (e.g., state-managed reserves, community-managed areas, privately owned sanctuaries) have been proposed and implemented to facilitate coexistence at different spatial scales (Western et al. 1994, Berkes 2007, Dudley 2009, Western et al. 2009). For example, protected areas are designed to facilitate coexistence at a regional scale (Fig. 5.1A) by conserving wildlife amid a surrounding mosaic of human land-uses and activities (Dudley 2009, Western et al. 2009). Alternatively, community-based conservation approaches, which emphasize sustainable natural resource extraction for local consumption while conserving biodiversity, envision human and wildlife activities being comparatively more interspersed in space and aim to facilitate coexistence at smaller, intermediate scales (Fig. 5.1B) (Western et al. 1994, Berkes 2007). Regardless of the conservation model, however, a rapidly growing world human population and a long history of competition between people and wildlife for limited resources (e.g., food, Woodroffe et al. 2005) has led to a general belief among conservation practitioners and policy makers that some wildlife species, such as large carnivores and ungulates, cannot coexist with humans at fine spatial scales (i.e., regularly utilize the exact same locations as shown in Fig. 5.1C, see Brashares et al. 2001, Parks and Harcourt 2002, Cardillo et al. 2004, Karanth et al. 2010). This belief motivates conservation policies including resettlement of human communities (Agrawal and Redford 2009) away from threatened wildlife populations and the expulsion of certain types of non-consumptive human activities (e.g., researchers) from protected areas (Bagla 2012). Yet, empirical and quantitative information on the capacity and mechanisms for wildlife to coexist with humans at

fine spatial scales is lacking. Such information is urgently required as human pressures on protected areas (e.g., livestock grazing, natural resource collection, hunting), although illicit, have increased enormously (Wittemyer et al. 2008, Western et al. 2009). In addition, the world is projected to add approximately 1.4 billion more people over the next two decades forcing human and wildlife populations to share the same space (United Nations 2010b).

To help fill this critical information gap, we investigated the spatio-temporal patterns of tigers (*Panthera tigris*) and human activities inside and outside Chitwan National Park in Nepal (27º30'N to 27º43'N, 84º9'E to 84º29'E, Fig. 5.2). We focused on the globally endangered tiger because the conventional belief is that they cannot persist in areas with high human densities (e.g., >10 people / km^2) (Cardillo et al. 2004, Karanth et al. 2010). We chose Chitwan for four main reasons. First, Chitwan National Park, established in 1973, covers approximately 1,000 km^2 and is one of 28 reserves in the world that can support >25 breeding female tigers (DNPWC 2007, Wikramanayake et al. 2011). Second, human activities inside and outside the Park are diverse (and are likely to affect tiger behavior differently (George and Crooks 2006)): local residents collect forest products (e.g., fodder for livestock, fuel wood) to support their resource-dependent livelihoods (Stræde and Treue 2006), a growing number of tourists from around the world visit the area each year (Bookbinder et al. 1998), Nepal Army personnel patrol the Park to deter illegal activities (e.g., wildlife hunting, logging), and motorized vehicles frequently transport people throughout the area. Third, the Park and multiple-use forests outside the Park are crucial parts of a landscape-level initiative to connect tiger reserves in India and Nepal through habitat corridors (MFSC 2004). And fourth, the Park is a flagship reserve and has received exceptional financial and technical support from the Nepal government and many international organizations, such as the World Wildlife Fund (WWF) (DNPWC 2007). To a large degree, the fate of tigers along the base of the Himalayas, a globally important region for

tigers, depends on the success or failure of conservation efforts in Chitwan (Sanderson et al. 2006, Walston et al. 2010).

In this study, we tested three specific hypotheses: 1) tiger density is higher inside the National Park than in the multiple-use forest outside the Park; 2) tigers avoid locations visited by people and/or vehicles; and 3) tigers are more active at night to avoid human disturbance. To test these hypotheses empirically, we used data from motion-detecting field cameras set inside and outside the Park in 2010 and 2011.

Materials and methods

From January to May (i.e., dry season before monsoon) in 2010 and 2011 we used state-of-the-art camera 'trap' technology (O'Connell et al. 2010) to collect field data on tigers, their main prey species (spotted deer [*Axis axis*], barking deer [*Muntiacus muntjak*], wild boar [*Sus scrofa*], sambar [*Rusa unicolor*], hog deer [*Axis porcinus*], and gaur [*Bos gaurus*]) (Seidensticker and McDougal 1993), and human presence (local residents, tourists, army personnel, and vehicles). In both years we sampled the exact same locations inside and outside the Chitwan National Park (both regions dominated by Sal [*Shorea robusta*] forest) in four successive blocks, each sampled for approximately 20 days at approximately 20 locations. In 2011 we also sampled one additional location in each block, thus, we placed traps in a total of 76 locations in 2010 and 79 locations in 2011 (one was stolen in 2011, Table 5.1). Traps were placed approximately 1 km apart across the study site, and their spatial coordinates were recorded using a Global Positioning System (GPS) receiver. Cameras were set to operate 24 hours/day with no more than mechanical minimum delay between sequential photographs. For each picture we recorded entity (i.e., tiger, prey species, human presence type), location (based on trap ID), date, and time. We summed the number of detections for each entity for each camera trap. Detections were defined as 1)

consecutive pictures of different individuals or vehicles, 2) consecutive pictures of individuals or vehicles >0.5 hours apart, and 3) nonconsecutive pictures of individuals or vehicles (Johnson et al. 2006). If the number of detections varied between cameras in a pair, we used the larger number. We calculated detection frequency (# of detections per 100 trap-days) of each species and human presence type at each camera trap (Johnson et al. 2006).

The Mann-Whitney U statistic was used to test for significant differences in detection frequencies of each entity inside and outside the Park within and between years. Data on individually identified adult tigers (not possible for prey animals and people) enabled us to also estimate tiger density. Tiger density was estimated using a spatially explicit capture-recapture model, which accounts for imperfect detection (Royle et al. 2009). The model integrates individual animal capture histories and the spatial locations of camera traps using a statistical point process model. This approach avoids having to use an ad-hoc effective sample area (e.g., minimum convex polygon), which often inflates density estimates (Obbard et al. 2010), and instead calculates density as the number of animal 'activity centers' that fall within some region encompassing the trap array. We ran three capture-recapture models for each year using data from different groups of camera traps: 1) inside the Park, 2) outside the Park, and 3) entire study site. The models were specified with a Bernoulli encounter process, in which an individual tiger may be captured in each trap only once during each sampling occasion (i.e., 1 day interval from 12:00 to 12:00). The Bernoulli encounter process was related to spatial animal movements using a half-normal detection function, similar to that commonly used in distance sampling (Royle and Gardner 2011). We added 'all zero' encounter histories (5 x number of identified tigers) to augment each model dataset. After a 'burn-in' of 1,000 iterations, parameter posterior distributions computed from a single chain of 49,000 Markov chain Monte Carlo iterations were

used to determine parameter mean, standard deviation, and 95% confidence intervals (Royle et al. 2009).

We used occupancy models to estimate the relative effect of prey and human covariates on the spatial variability in tiger presence (MacKenzie et al. 2002) across the entire study site over the 2-year period. Occupancy models are ideal for camera trap data because they formally account for imperfect detection and allow the probability of an animal occupying and being detected at a location to vary in response to covariates. We evaluated the effects of prey, human presence types (i.e., total number of detections of people on foot, local residents, tourists, army personnel, and vehicles at each camera trap), location (i.e., a binary variable indicating whether the data was from inside or outside the Park), distance to settlement (i.e., straight-line distance from camera trap to nearest human settlement abutting forests inside and outside Park) and forest road (i.e., roads in the forests inside and outside Park), and year (i.e., a binary variable indicating whether the data was from 2010 or 2011) on tiger occupancy and detection. We combined tiger detection and covariate data from 2010 and 2011 using data from camera traps that were placed in the exact same locations in both years (i.e., 75 locations in 2010 and 2011 for a total of 150). We ran models where the prey covariate was included as a single variable summing the total number of detections for all six primary prey species at each camera trap (Karanth et al. 2011). We did this rather than include the total number of detections from each of the six prey species as covariates because two prey species (i.e., gaur and hog deer) were not detected outside the Park. As spotted deer comprised 75% of all prey detections (Fig. 5.3, 5.4), we also ran each model just using the total number of spotted deer detections at each camera trap as the prey covariate. This produced similar results to those using the combined prey covariate, therefore, we only report models using the combined prey covariate. Models were ranked according to their second-order Akaike's information criterion (AIC_c), with higher ranked models having

111

lower AIC_c values. As several models with different combinations of covariates performed

comparatively well (i.e., $\Delta AIC_c < 4$), we averaged model results (i.e., covariate coefficients,

detection probability, and occupancy) from the top-ranked models using standard methods (i.e.,

multi-model inference, Burnham and Anderson 2004). Model-averaged coefficient estimates

were considered significant if their unconditional 95% confidence intervals did not include zero.

We used kernel density estimation to estimate the probability density function of the activity

patterns (i.e., density of activity) of tigers and types of human presence. Then we used

procedures described in Linkie and Ridout (2011) to measure the extent of overlap between

them.

Results

We recorded relatively high tiger densities, abundant prey, and ubiquitous human

presence inside and outside the Park in 2010 and 2011 (Tables 5.2, 5.3). Specifically, tiger

density across the study site was 4.44 / 100 km^2 (95% CI: 3.19 – 5.67) in 2010 and 6.35 / 100

km^2 (95% CI: 4.08 – 7.09) in 2011 (Table 5.2). Contrary to expectation, tiger density did not

significantly differ between inside and outside the Park in either year, leading us to reject

hypothesis 1. However, tiger density significantly increased inside the Park from 2010 (3.51 /

100 km^2, 95% CI: 2.5 – 4.8) to 2011 (8.7 / 100 km^2, 95% CI: 5.57 – 12.1) (Table 5.2). In both

years, mean prey detection frequency inside the Park, which is considered to have some of the

highest ungulate densities in South Asia (Eisenberg and Seidensticker 1976), did not

significantly differ from outside the Park (Table 5.3). High numbers of tigers and prey animals

were recorded during the two-year period despite humans triggering 85% of the cameras and

accounting for 75% of all detections. Local residents, typically collecting forest resources,

accounted for 96% of all human foot traffic outside the Park (Fig. 5.3, 5.4), and were

112

approximately three times as prevalent outside the Park as inside in both years (Table 5.3).

However, the detection frequency of total people on foot, local residents, and army personnel

inside the Park significantly increased from 2010 to 2011 (Table 5.3).

Surprisingly, even at a fine spatial scale (i.e., camera trap locations), abundances of total

prey, people on foot, and vehicles had no significant effects on the probability of tiger occupancy

across both years (Table 5.4), leading us to reject hypothesis 2. Tigers occupied approximately

80% of the camera trap locations during the two-year period ($\psi = 0.82$, SE = 0.04), with no

significant difference between the two years. However, human-related covariates did influence

the probability of detecting tigers (Table 5.4). The probability of detecting tigers in 2010 and

2011 was higher at locations further from human settlement ($\beta = 0.35$, 95% CI: 0.15 – 0.54) and

inside the Park ($\beta = 0.96$, 95% CI: 0.51 – 1.41) (Fig. 5.5). Being inside the Park had the

strongest effect on tiger detection probability. The positive relationships between tiger detection

probability and being inside the Park and distance to settlement did not change significantly

between 2010 and 2011. In 2011, however, tigers were more likely to be detected at locations

closer to forest roads ($\beta = -0.55$, 95% CI: -0.99 – -0.12) and less likely to be detected at locations

with higher abundances of local residents ($\beta = -0.41$, 95% CI: -0.81 – -0.01) than in 2010 (Table

5.4, Fig. 5.5). With all covariates set to their mean, the model-averaged detection probability

was higher in 2010 ($p = 0.1$, SE = 0.01) than in 2011 ($p = 0.7$, SE = 0.01).

In both years, tigers offset their temporal activities, especially outside the Park, by being

less active during the day when human activity peaked (for 2010 see Fig. 5.6; for 2011 see Fig.

5.7), which supports hypothesis 3. Over the two-year period, on average, only 20% of all tiger

detections in the Park occurred during the day between 6:00 and 18:00 (i.e., average times of

sunrise and sunset during study), whereas only 5% of tiger activity outside the Park occurred

during the day. Tiger temporal activity across both years overlapped the most with army personnel and the least with local residents.

Discussion

In contrast to the general belief, we found that tigers and people frequently co-occurred at fine scales both inside and outside the Park in both years. The estimates of tiger density across our study site in Chitwan were higher than numerous sites in Central and North India (Jhala et al. 2011), and several times higher than sites in Laos, Indonesia, Malaysia, and Bhutan (O'Brien et al. 2003, Kawanishi and Sunquist 2004, Johnson et al. 2006, Wang and Macdonald 2006). In addition, tiger occupancy was 12% - 30% greater than sites in Indonesia and India (Karanth et al. 2011, Wibisono et al. 2012). Human foot traffic across the study site was also orders of magnitude greater than those reported for other areas of the tigers' range (using similar methodology) (Kawanishi and Sunquist 2004, Johnson et al. 2006). Over the last decade, tigers have maintained high densities in Chitwan (DNPWC 2007, The World Bank 2011a), although human density in settled areas surrounding the Park has increased 20% (212 to 255 people / km^2) (Nepal Central Bureau of Statistics 2012), approximately twice the average human density (127 people / km^2) among 12 of the 13 tiger range countries (except Bangladesh) in 2010 (United Nations 2010b).

Tiger density has remained high in Chitwan despite an increasing human population size likely because tigers are adjusting their activity in space and time according to the type and magnitude of human presence in the forest. Although more wary near human settlement (i.e., lower detection probability), tigers spatially overlapped with people on foot and vehicles at a fine spatial scale in both years perhaps by using the night to avoid human disturbance associated with local resource collection. The time spent, noise made, and physical impact on the forest during

resource collection likely disturbs animal behavior more than non-consumptive human activities (e.g., wildlife viewing by tourists). For instance, the collection of woody biomass, which is a frequent activity in Chitwan's forests (Stræde and Helles 2000, Stræde and Treue 2006), requires repeated and relatively loud chopping in a given area for an extended period of time. Tigers across the study site in Chitwan were consequently one-sixth less active during the day than at sites in Malaysia and Indonesia where human activity was considerably less (Kawanishi and Sunquist 2004, Linkie and Ridout 2011). In particular, the much greater prevalence of local resource collection outside the Park than inside the Park may have caused tigers there to become almost completely inactive during the day (Fig. 5.6, 5.7).

The 55% increase in the presence of local residents across the study site from 2010 to 2011 may have caused tigers to alter their space use by being more wary in areas with higher local resident foot traffic. In 2011, increased detection of tigers near forest roads, which are energetically efficient means of traversing the landscape (Karanth 1995), may indicate that tigers were also avoiding the smaller trails typically used by local residents when on foot. Moreover, the increase in tiger density inside the Park in 2011 was concurrent with greater numbers of local residents entering the forests across the study site, which suggests that the Park is an important refuge from high levels of disturbance for tigers; whereas the forest outside the Park, despite supporting several tigers, does not appear to serve that function to the same extent. Increasing presence of local residents across the study site may reflect their greater reliance on Chitwan's forests for fuel wood. Possible explanations for increasing demand for fuel wood include an 1) unexpected increase in the price of kerosene and liquefied petroleum gas, and 2) curbed illegal use of electrical services (e.g., unauthorized connections between households and main electrical lines) due to stricter enforcement. The two years of data we collected are insufficient, however, to conclusively test the abovementioned arguments. Collecting information over a longer time

frame than two years will enable stronger inferences about spatio-temporal interactions between humans and tigers, and the capacity for long-term coexistence in human-dominated regions.

Co-occurring high densities of tigers and people inside and outside the Park at fine scales may have been enhanced by two other factors. First, tiger prey numbers have increased in forests directly outside the Park after the implementation of conservation–oriented policies in 1996, such as removal of livestock and participatory forest management (Gurung et al. 2008, Nagendra et al. 2008). For instance, forest biomass outside the Park increased after livestock were prohibited from grazing there, enabling these forests to support a higher density of wild ungulates (i.e., tiger prey) (Gurung et al. 2008). Moreover, local communities are reforesting many areas outside the Park (Nagendra et al. 2008), thus improving wild ungulate habitat conditions. With high numbers of prey inside and outside the Park, other factors, such as tiger social structure (e.g., female philopatry) and territorial behavior may influence tiger space use more so than fine scale spatial heterogeneity of prey abundance (Smith et al. 1987, Smith 1993). Second, human exploitation of tigers, such as poaching, has been relatively controlled since the end of the civil war in Nepal in 2006 (DNPWC 2007). Exploitation is a key determinant of tiger abundance since it can increase mortality rates and lead tigers to avoid areas with people (Frank and Woodroffe 2001).

Our findings affirm the notion that effective management policies, such as those that improve habitat conditions and lower exploitation, are more important to tiger conservation than human density *per se* (Linnell et al. 2001). Unique socioeconomic and institutional factors in Chitwan, such as Park management intensity, tourism infrastructure, initiatives to include local communities in eco-development, massive efforts to reduce and control poaching, and social tolerance towards tigers (Bookbinder et al. 1998, Dinerstein 1999, Carter et al. 2012a), likely increased the capacity for tigers and people to coexist at fine spatial scales. As such, the spatial

116

and temporal interactions between people and tigers observed in Chitwan may differ in other human-dominated regions that have different socioeconomic and institutional characteristics. Similar research conducted in other human-dominated regions would be extremely useful in expanding and clarifying our understanding of how tigers behaviorally respond to humans at fine spatio-temporal scales. For instance, it would be important to address questions such as, what energetic costs to tigers are associated with temporal displacement (e.g., decreased hunting success at night), are there disturbance thresholds (see thresholds in Liu et al. 2007a) beyond which tigers dramatically alter their spatial and temporal behavior, and what effects do behavioral changes in space and time have on tiger population persistence.

Here we have shown that tigers can adapt and thrive in a human-dominated landscape by displacing their spatial and temporal activity from humans. Our study demonstrates the need and feasibility to incorporate temporal activity patterns into conservation planning, which typically focuses on spatial relationships (e.g., see zoning in Hull et al. 2011). For example, reducing the abundance of livestock left unattended at night when carnivores are typically active to reduce livestock predation (Valeix et al. 2012). Vehicular activity may also be restricted during certain times (e.g., dusk and dawn) in order to facilitate nocturnal dispersal across and use of human-dominated landscapes.

Whether illicit or authorized, human activities within natural ecosystems around the world, such as hunting bushmeat, herding livestock, and collecting forest products, is pervasive and, in many cases, increasing (Liu et al. 2001, DeFries et al. 2005, Georgiadis et al. 2007, Wittemyer et al. 2008). The reaction of threatened wildlife to these activities will vary according to context-specific conditions, including region, type and frequency of human activities, behavioral ecology of the wildlife species, and management policies. Similarly, conservation actions intended to modify the ways people and wildlife interact in space and time must fully

117

consider the context-specific social and political implications (e.g., altering access to land for different groups of people, Ramnath 2008) in addition to ecological effects. Regardless of context, however, conservation plans informed by fine scale spatial and temporal insights can help address a major global challenge -- meet human needs while sustaining wildlife in an increasingly crowded world.

APPENDIX

Figure 5.1: Schematic diagram of human-wildlife coexistence at different scales. Protected areas aim to facilitate coexistence between wildlife and humans at regional scales (A) by spatially segregating them into distinct zones. Community managed areas in which people can extract natural resources on a limited basis, such as pro-wildlife cattle ranches and community forests, encourage coexistence at comparatively smaller, intermediate scales (B). Most conservation models, however, are based on the belief that some wildlife species, like large carnivores, cannot coexist with humans at fine spatial scales (C) because of a fundamental conflict over limited resources (e.g., food). We empirically test this prevailing belief using data from camera traps to quantify the capacity and mechanisms of tigers, a notoriously elusive carnivore, to coexist with humans at a fine spatial scale (i.e., exact same point locations) in Chitwan, Nepal.
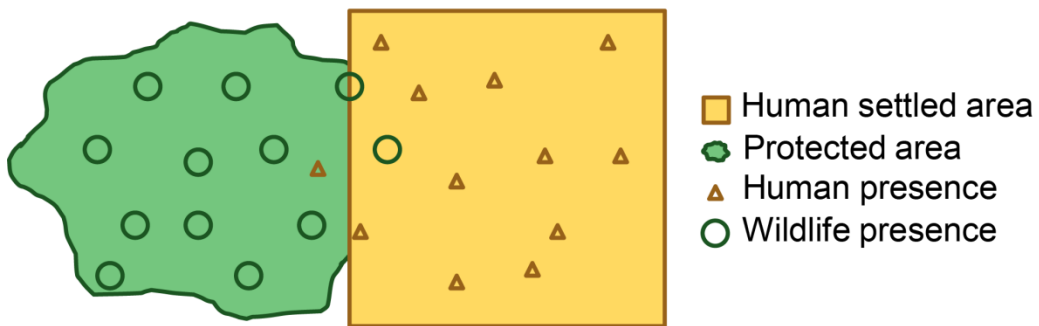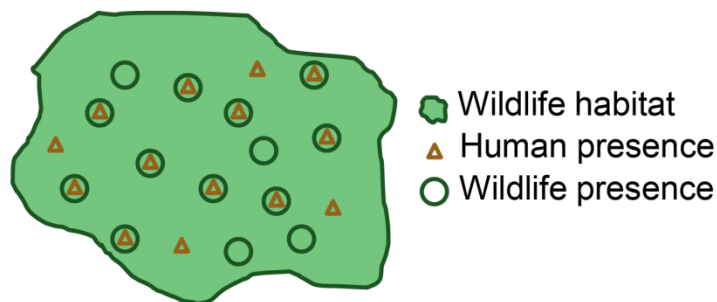
Figure 5.2: Study site in Chitwan, Nepal. Camera traps were placed inside Chitwan National Park and a multiple-use forest corridor outside the Park in 2010 and 2011. Land use in the human settled area is predominately agriculture and not suitable as tiger habitat, thus camera traps were not placed there. Total Park staff is about 279 including executive officers, veterinarians, game scouts, elephant handlers, administrative assistants, and others. As of 2008, there were about 800 Nepal army personnel posted in and around the Park, most of whom patrol the Park daily.
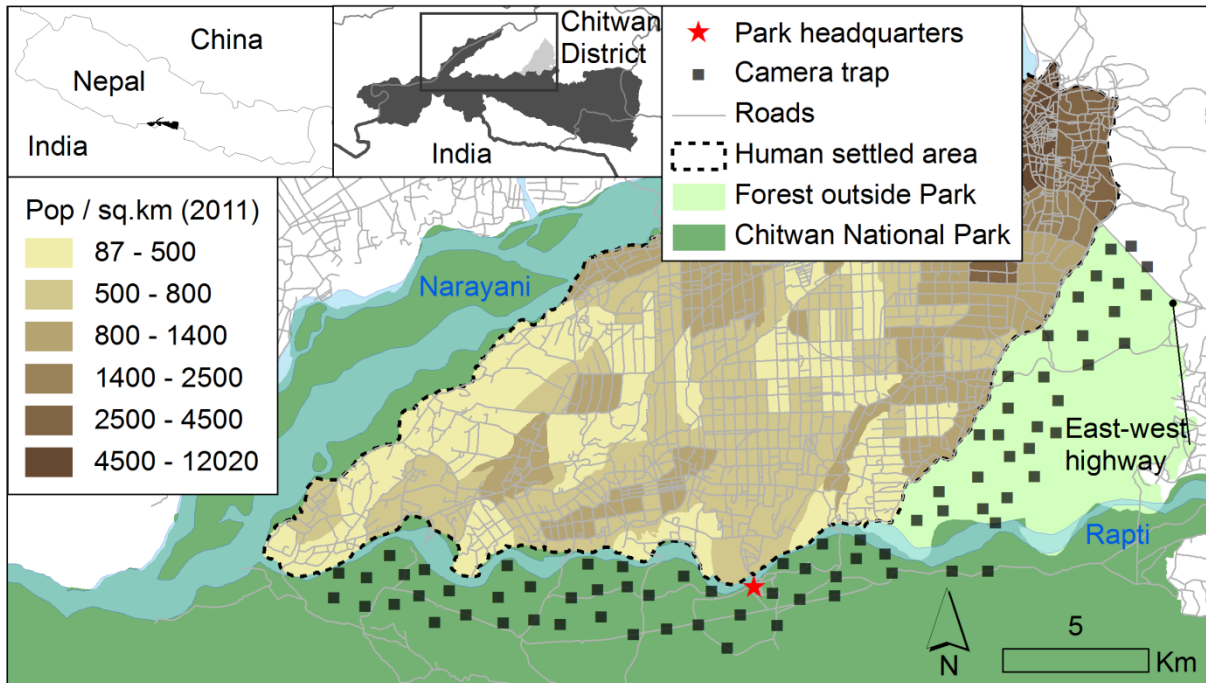
Figure 5.3: Tiger prey species and human presence types in 2010. Percentages of six main tiger prey species A, inside and B, outside Chitwan National Park, Nepal in 2010. Percentages of human presence types C, inside and D, outside the Park in 2010. Number of detections indicated in parentheses.
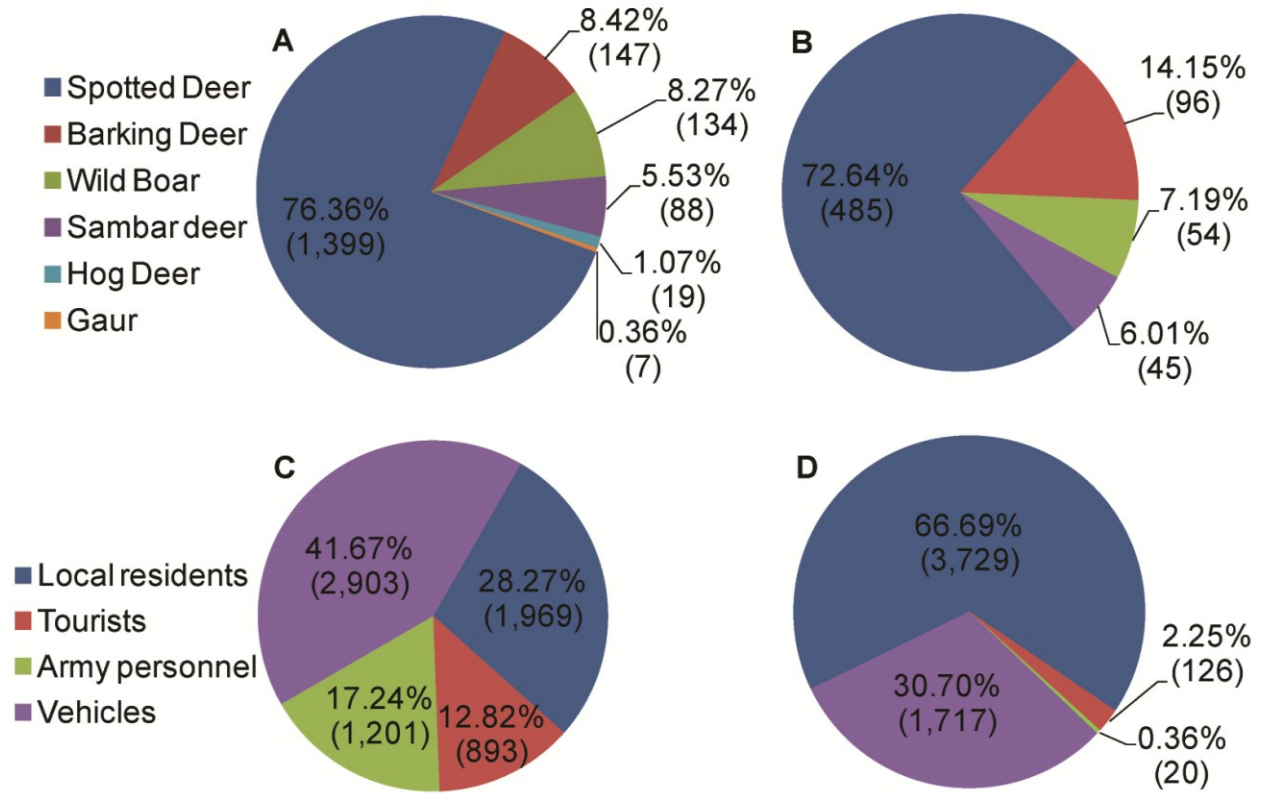
Figure 5.4: Tiger prey species and human presence types in 2011. Percentages of six main tiger prey species A, inside and B, outside Chitwan National Park, Nepal in 2011. Percentages of human presence types C, inside and D, outside the Park in 2011. Number of detections indicated in parentheses.
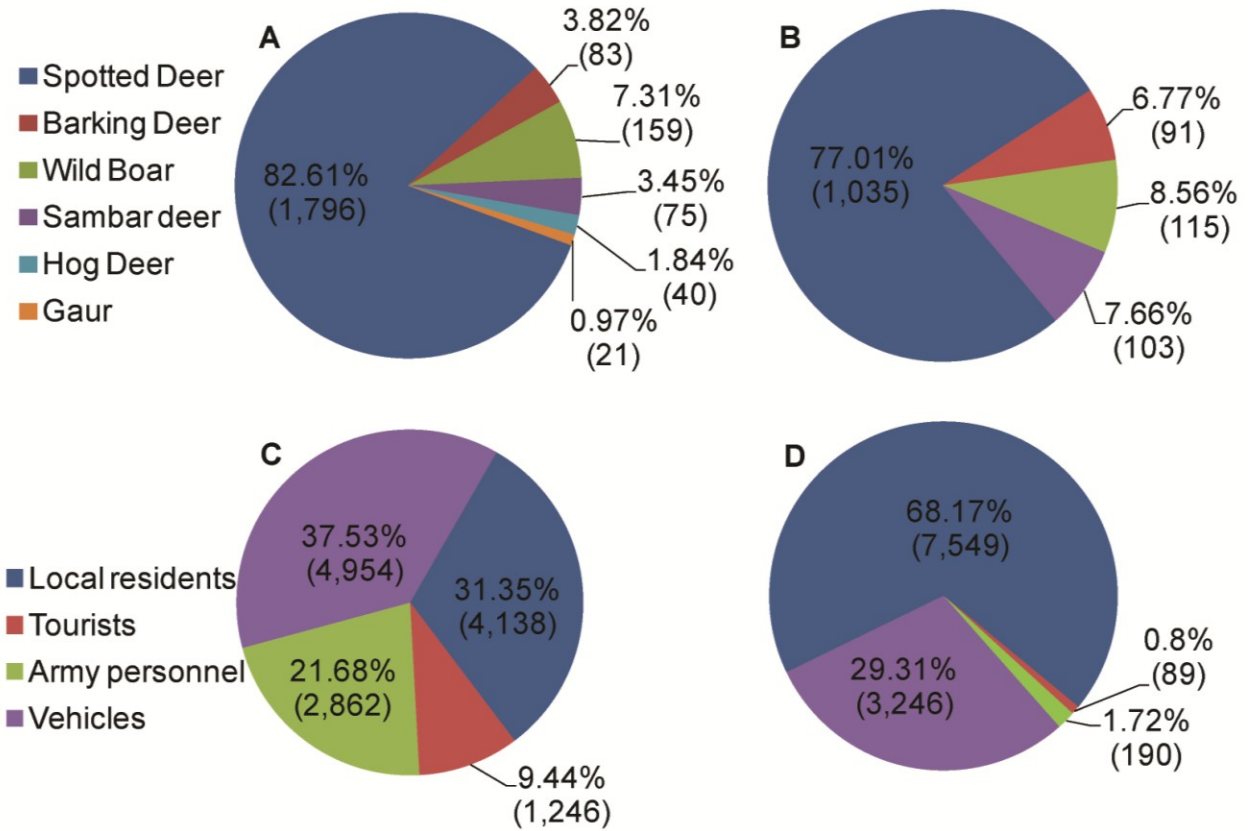
Figure 5.5: Tiger detection probability with respect to human-related covariates. Predictions of tiger detection probability, based on model-averaged covariate coefficient estimates, with respect to A, location (i.e., inside or outside Park), B, distance to human settlement (m), C, distance to forest road, D, and local resident abundances (detections per 100 trap-days). Boxes in A represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, black lines within boxes represent medians, and circles outside the whiskers represent outlier values. B, C, and D display detection probabilities by year (2010 values indicated by black circles and 2011 values indicated by grey triangles), and include linear regression lines (2010 linear regression line in black and 2011 linear regression line in grey) with R^2 values shown inside panels.
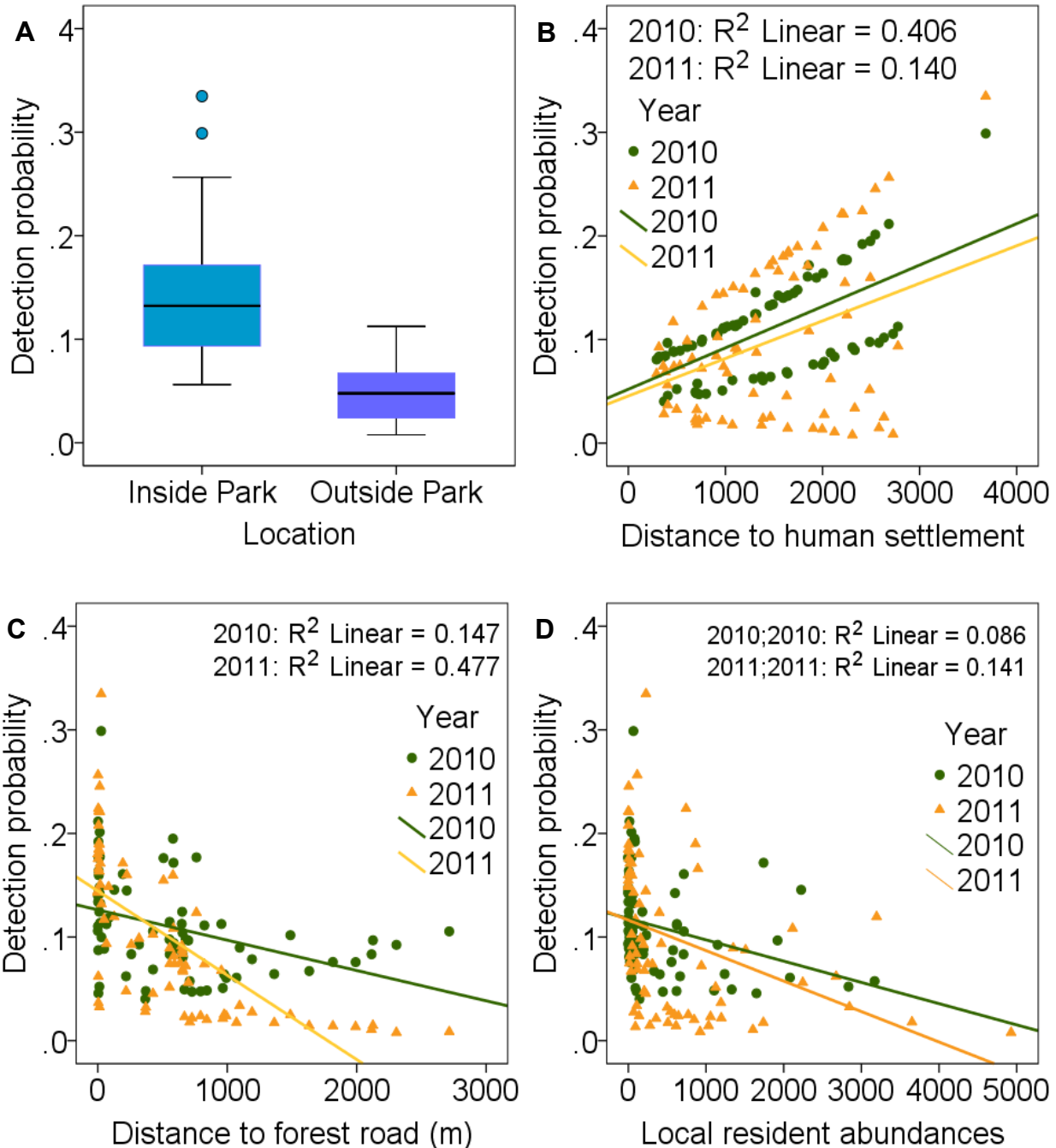
Figure 5.6: Temporal overlap of tiger and human activity patterns in 2010. Activity patterns of tiger (dashed lines) and human presence types (solid lines) inside (A – E) and outside (F – J) Chitwan National Park, Nepal in 2010. A,F, total people on foot; B,G, local residents; C,H, tourists; D,I, army personnel; and E,J, vehicles. The estimate of temporal overlap, $\hat{\Delta}$ [from 0 (no overlap) to 1 (complete overlap)], is indicated by the orange area, and is shown in each panel. Overlap was defined as the area under the curve formed by taking the minimum of the two activity patterns at each point in time. Approximate 95% bootstrap confidence intervals of overlap estimates are indicated in parentheses. Average time of sunrise was 6:00 and average time of sunset was 18:00 during the study.

Figure 5.6 (cont'd)

D Army personnel
$\hat{\Delta}$ = 0.31 (0.23−0.38)

I Army personnel
$\hat{\Delta}$= 0.12 (0.04−0.20)

E Vehicles
$\hat{\Delta}$= 0.18 (0.11−0.23)

J Vehicles
$\hat{\Delta}$= 0.08 (0.02−0.16)

Density of Activity

Time of day
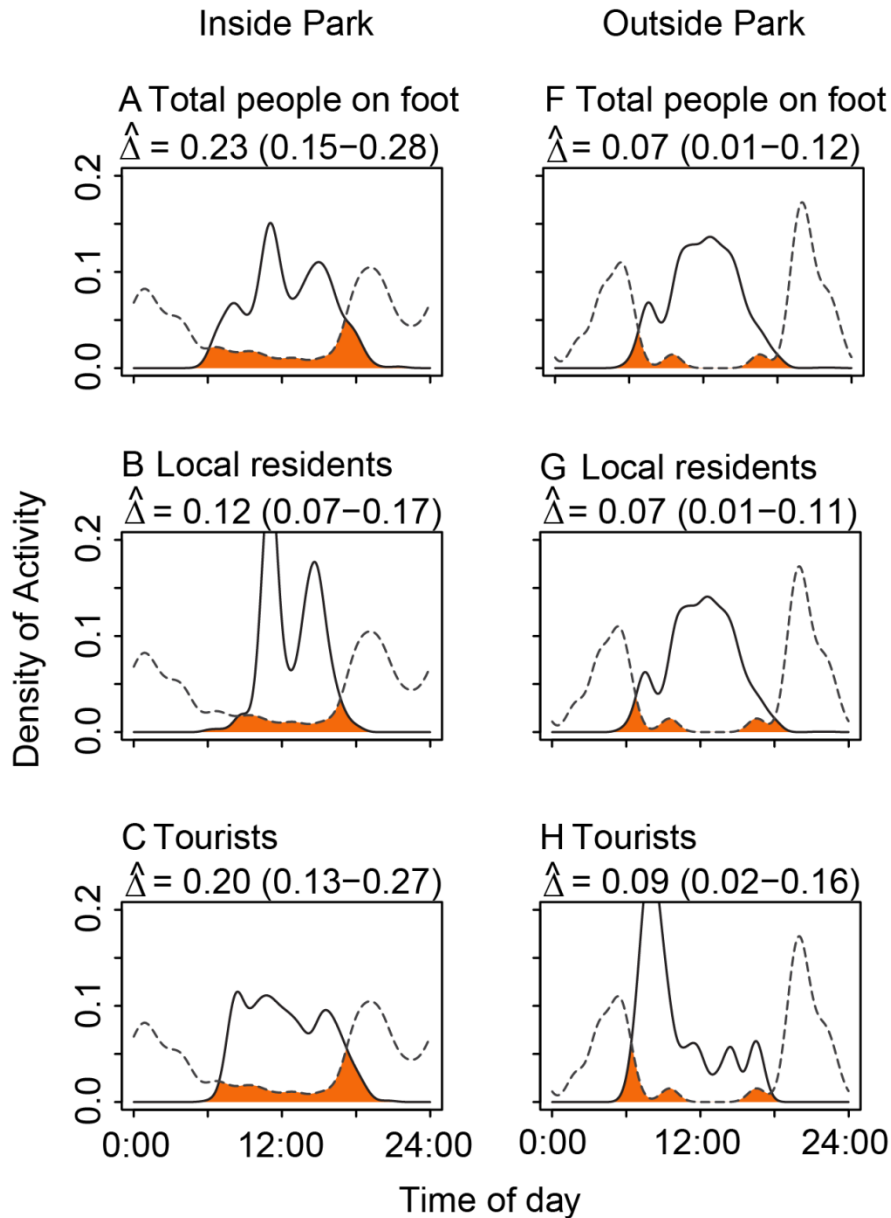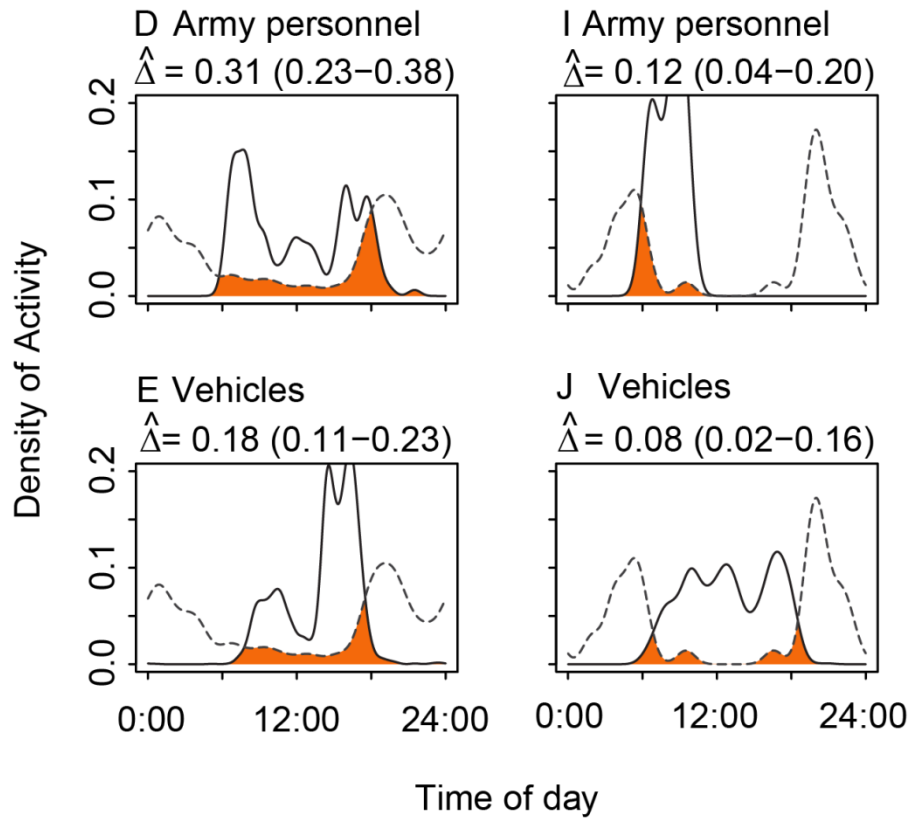
Figure 5.7: Temporal overlap of tiger and human activity patterns in 2011. Activity patterns of tiger (dashed lines) and human presence types (solid lines) inside (A – E) and outside (F – J) Chitwan National Park, Nepal in 2011. A,F, total people on foot; B,G, local residents; C,H, tourists; D,I, army personnel; and E,J, vehicles. The estimate of temporal overlap, $\hat{\Delta}$ [from 0 (no overlap) to 1 (complete overlap)], is indicated by the orange area, and is shown in each panel. Overlap was defined as the area under the curve formed by taking the minimum of the two activity patterns at each point in time. Approximate 95% bootstrap confidence intervals of overlap estimates are indicated in parentheses. Average time of sunrise was 6:00 and average time of sunset was 18:00 during the study.

Figure 5.7 (cont'd)

128
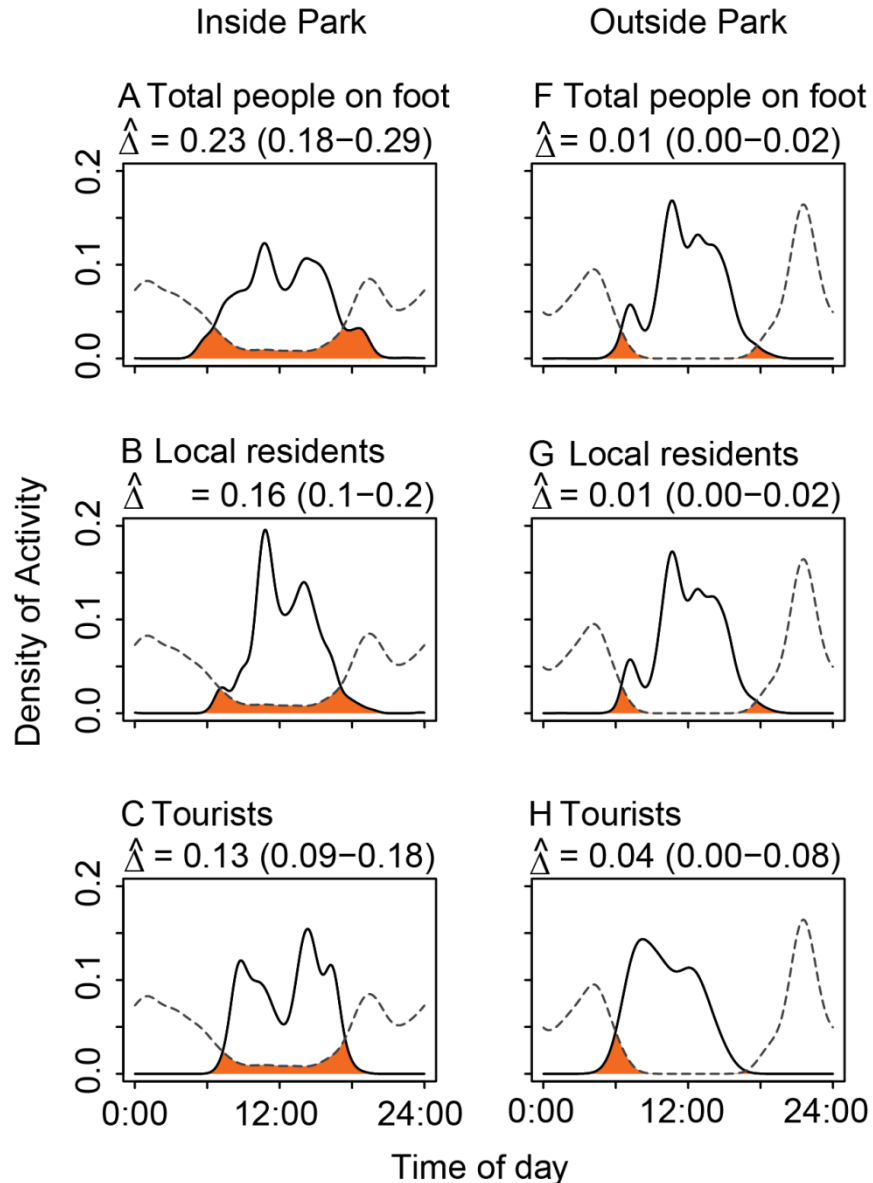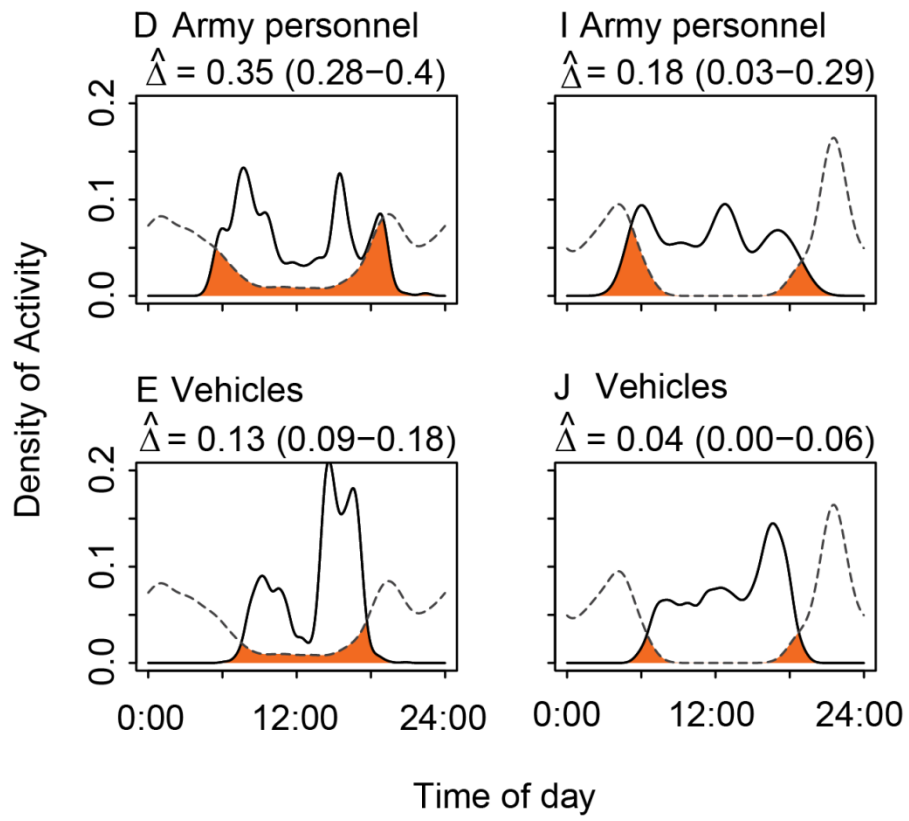
Table 5.1: Summary of 2010 and 2011 camera trap sampling efforts and tiger data.

	2010		2011	
	Inside Park	**Outside Park**	**Inside Park**	**Outside Park**
No. of days camera traps were operational	68	44	72	51
Total trap-days	920	590	1,091	735
No. of trap locations	46	30	48	31
No. of tiger detections	92	39	150	16
No. of individual tigers detected	12[a]	6	18[b]	4
No. of trap-days/tiger detection	10	15	7	46

Notes: [a]A total of 17 adult tigers were identified in 2010 but one identified tiger was photographed both inside and outside the Park.
[b]A total of 21 adult tigers were identified in 2011 but one identified tiger was photographed both inside and outside the Park.

Table 5.2: Tiger population size and density (animals per 100 km^2) calculated from spatially-explicit capture-recapture models.

Parameter	2010			2011		
	Mean	SD	95% CI	Mean	SD	95% CI
Inside park						
Pop. size	18.29	3.5	13 - 25	45.27	8.88	28 – 62
Density	3.51	0.67	2.5 - 4.8	8.7	1.71	5.57 - 12.10
Outside park						
Pop. size	16.84	5.45	7 - 27	13.46	4.90	4 – 22
Density	5.89	1.91	2.45 - 9.44	4.82	1.71	2.1 - 8.04
Entire study site						
Pop. size	25.02	3.75	18 - 32	35.79	5.52	25 - 46
Density	4.44	0.66	3.19 - 5.67	6.35	0.98	4.61 - 8.33

Notes: Estimates of tiger density inside and outside the Park are not independent from one another as the model sampling regions overlap, and because one tiger was present in both regions.

Table 5.3: Detection frequencies (mean ± SE) of tigers, human presence types, and tiger prey species.

Category	2010		2011	
	Inside Park	**Outside Park**	**Inside Park**	**Outside Park**
Tiger	10 ± 1.8	$6.7 \pm 1^{*}$	**13.9 ± 2.5**	**$2.3 \pm 0.6^{*}$**
Total people on foot	$456.8 \pm 89.2^{\dagger}$	716.7 ± 152.3	$745.4 \pm 136.9^{\dagger}$	1041.3 ± 207.2
Local residents	**$218.9 \pm 73.9^{\ddagger}$**	**688.5 ± 151**	**$381.6 \pm 99^{\ddagger}$**	**1003.8 ± 202.6**
Tourists	**101.3 ± 27.2**	**24.3 ± 11.1**	**109.3 ± 36.3**	**13.8 ± 7.1**
Army personnel	**$136.6 \pm 45.2^{\S}$**	**3.8 ± 2.1**	**$254.5 \pm 70.9^{\S}$**	**23.7 ± 14**
Vehicles	339.7 ± 88.2	286.8 ± 193.9	**455.4 ± 124.7**	**378 ± 252.67**
Total prey animals	214.2 ± 37.8	142.5 ± 26.3	199.6 ± 28	187.3 ± 30
Spotted deer	163.6 ± 36.7	103.5 ± 25.4	164.6 ± 27.7	145.2 ± 27
Barking deer	**18 ± 5.4**	**20.2 ± 4.4**	**7.4 ± 1.3**	**12.4 ± 1.9**
Wild boar	17.7 ± 3.1	10.2 ± 2.2	14.9 ± 3.1	15.7 ± 3.4
Sambar	11.8 ± 4.1	8.7 ± 2.4	**6.8 ± 2.2**	**13.9 ± 2.5**
Hog deer	2.3 ± 0.9	--	3.7 ± 1.2	--
Gaur	0.8 ± 0.5	--	2.1 ± 1.7	--

Notes: Values in bold indicate within-year samples were significantly different from one another (Mann-Whitney U test, $P < 0.05$).

$^{*, \dagger, \ddagger, \S}$indicate that between-year samples were significantly different from one another (Mann-Whitney U test, $P < 0.05$).

Hog deer and Gaur were not detected outside the Park in both years.

Unlike detection frequency, estimates of tiger density are based on identified individuals and take into account imperfect detection. Consequently, in our study, tiger detection frequencies and density estimates inside and outside the Park differed relative to each other in 2010.

Table 5.4: Summary of top ranked tiger occupancy models.

Model	K	AIC_c	ΔAIC_c	w_i	LL
$\psi(\cdot)\,p$(road + year + road*year + settlement + location + location*year)	8	1720.31	--	0.46	-851.6
$\psi(\cdot)\,p$(road + year + road*year + settlement + location)	7	1721.59	1.28	0.24	-853.4
$\psi(\cdot)\,p$(road + year + road*year + settlement + location + local + local*year)	9	1722.28	1.97	0.17	-851.5
$\psi(\cdot)\,p$(road + year + road*year + settlement + location + settlement*location + local + local*year)	10	1722.81	2.5	0.13	-850.6

Notes: ψ is occupancy, p is detection probability, '·' indicates that the parameter was held constant (i.e., intercept-only), 'road' is distance to nearest forest road, 'year' is the year data was collected (i.e., 2010 or 2011), 'settlement' is distance to nearest human settlement, 'location' is location of camera trap (i.e., inside or outside Chitwan National Park), 'local' is abundance of local residents, K is number of model parameters (includes intercepts and covariates), AIC_c is second-order Akaike's information criterion, ΔAIC_c is the difference in AIC_c values between each model and the model with the lowest AIC_c value, w_i is the AIC_c model weight, and LL is the logarithm of the likelihood. Interaction terms are shown as well (e.g., 'road*year'). Covariate coefficient estimates were averaged from these four top ranked models. The AIC_c of the intercept-only model (i.e., $\psi(\cdot)\,p(\cdot)$) was 1797.4.

CHAPTER 6

SIMULATING TIGER RESPONSE TO HUMAN PRESENCE USING AN AGENT-BASED APPROACH

In collaboration with

Muhammad Ali Imron

Abstract

Avoiding human disturbance (e.g., running away from nearby human) can negatively affect an animal's fitness-related behaviors, such as feeding, mating, and parental care. Agent-based modeling (ABM) is an excellent tool to test theories regarding human-wildlife interactions; however, few studies have employed ABMs to assess indirect human impact on endangered wildlife. To help fill this information gap, I developed and implemented a prototype ABM to explore the indirect impact of human presence on the globally endangered tiger (*Panthera tigris*) in Nepal's Chitwan National Park, a global biodiversity hotspot. Agents in the model included a single tiger, Sambar deer (*Rusa unicolor*), and humans (i.e., local people entering the forest to collect natural resources). The model simulated several tiger behaviors including maintaining its home-range, hunting, feeding on Sambar deer, and avoiding people in the forest. Avoidance of humans was defined by two parameters: alert distance (i.e., AD, distance at which tiger becomes aware of nearby human and stops moving) and flight initiation distance (i.e., FID, distance at which tiger flees from nearby human). I also quantified the impact of avoidance behaviors (i.e., varying AD and FID) on tiger movement per hour and number of days feeding on Sambar deer per month. Tiger and prey behaviors when people were absent in the ABM were validated against field observations. Tiger movement during the daytime decreased with greater AD, because people were active during the day. For all ADs, the tiger moved more per hour and spent less time feeding on Sambar deer when FID increased. Thus the model results suggest that tiger-human interactions mediated by two parameters, AD and FID, potentially impact tiger fitness. The prototype model lays the groundwork for a more complex model of tiger-human interactions and also informs future data collection efforts. Using ABMs to generate information

on how wildlife adapt to human activities can inform management/conservation policies that lessen the impact of human activities on wildlife.

Introduction

People directly affect wildlife populations, for example, through hunting (Brashares et al. 2004). People also influence wildlife indirectly. For example, many wildlife species deliberately avoid human presence and activities (Miller et al. 2001, Karlsson et al. 2007, Reimers and Colman 2009). Avoiding people not only affects species distributions but also may negatively affect fitness-related behaviors, such as feeding, mating, and parental care (Giese 1996, Reimers and Colman 2009). Modifying fitness-related behaviors due to disturbance avoidance can negatively impact wildlife population persistence (Gill 2007).

Previous literature on avoidance behaviors has mostly focused on birds and ungulates (Miller et al. 2001, Blumstein et al. 2003, Stankowich 2008, Reimers and Colman 2009). For example, Stankowich (2008) found that humans on foot were more evocative of a flight response among different ungulate species than vehicles or noises. Few studies have examined avoidance behaviors of mammalian carnivores to humans (Sunde et al. 1998, Karlsson et al. 2007). In part, this is because the process of collecting data on mammalian carnivores, which are often elusive, is expensive, difficult, and may lead to biased results. For example, Global Positioning System (GPS) collars used to monitor fine-scale activity patterns of wildlife is comparatively more expensive than other techniques, such as bait stations or camera traps. Capturing and collaring rare wildlife species, such as the giant panda (*Ailuropoda melanoleuca*) is sometimes prohibited due to government mandate (Hull et al. 2011). Also, an animal may expend more energy when moving with the added weight of a collar (Wilson and McMahon 2006), which would influence assessments of individual fitness.

In the absence of experimental data using GPS collars, agent-based modeling (ABM) is an excellent tool to explore indirect human impacts on wildlife. An ABM creates virtual objects

with autonomous behavior (i.e. agents), to represent real-world actors (e.g., people, wildlife) and their interactions with each other and their environment (Rounsevell et al. 2012). By comparing model results to patterns in empirical data, an ABM approach allows testing of different theories regarding wildlife-human interactions (Grimm et al. 2005). Very few studies have employed ABMs to assess indirect human impact on wildlife (Blumstein et al. 2005, Grosman et al. 2011), and none of these studies examined mammalian carnivores. To help fill this information gap, I developed and implemented an ABM to explore the indirect impact of human presence (i.e., local people walking in the forest) on the globally endangered tiger (*Panthera tigris*). Using ABMs to generate information on how wildlife adapt to human activities can inform management/conservation policies (e.g., developing buffer zones around important wildlife populations) that lessen the impact of human activities on wildlife. Such information would be especially pertinent to conservation efforts of globally endangered species, such as the tiger, for which changes in animal fitness can substantially affect species extinction probabilities.

The ABM in this study focuses on two parameters, flight initiation distance and alert distance, which are often evaluated in studies on avoidance behaviors. Flight initiation distance (FID) is the distance at which an animal flees a disturbance or predator (Stankowich 2008). However, an animal usually detects and responds (e.g., increased heart rate) to a disturbance or predator before it decides to flee. As such, alert distance (AD) refers to the distance at which an animal becomes aware of a nearby disturbance or predator. The decision to flee in animals occurs when the costs of staying (e.g., risk of injury or death) exceed the benefits of not fleeing (e.g., access to food and mates). Both distance metrics are accurate indices of fear in animals (Miller et al. 2006) and are related to many factors including environmental conditions (e.g., amount of vegetative cover, season), an animal's sensory capabilities (e.g., dependence on

olfactory or visual cues), life-history period (e.g., pregnant female), and social dynamics (e.g., solitary or group living animals) (Stankowich 2008).

The primary objective of this study is to recreate the empirically observed temporal activity pattern of tigers in Nepal's Chitwan National Park (see Carter et al. 2012b) by varying AD and FID in an ABM of tiger-human interactions. Unlike disturbance-free areas, Carter et al. (2012b) showed that tigers inside the park had become less active during the day when human activity (e.g., local residents entering the park to collect natural resources) peaked. The camera trap data in Carter et al. (2012b) show general spatial and temporal activity patterns of tigers, but these data do not indicate how tigers actually perceive and avoid contact with people. The ABM in this study helps fill that gap. The second objective of this study is to quantify the impact of avoidance behaviors on tiger movement and feeding behaviors. The prototype model presented in this chapter lays the groundwork for a more complex model of tiger-human interactions that incorporates landscape dynamics and agent learning, and also informs future data collection efforts.

Methods

The Model

The ABM described in this research draws from an existing model of tiger movement and population dynamics (Ahearn et al. 2001). The existing model was successfully implemented in Chitwan (Ahearn et al. 2001) and Sumatra's Tesso-Nilo National Park (Imron et al. 2011). The existing model provides a good starting point for the development of our model because it parameterized and validated complex interactions between tigers and wild prey animals based on datasets acquired during previous field observation in Chitwan and India (McDougal 1977, Sunquist 1981, Smith et al. 1987, Karanth and Sunquist 1992, Smith 1993, Chundawat et al.

1999). However, the model does not include several key dynamics, including human agents entering the forest and tigers responding to the presence of human agents.

To guide the design of the ABM, I developed a conceptual model illustrating the focal interactions between humans, tigers, and tiger prey in Chitwan (Fig. 6.1). The conceptual model includes 4 components: local people, forests, tigers, and wild tiger prey. The ABM simultaneously models local residents walking through the park, movement and grazing behaviors of prey animals, and movement, hunting, and avoidance behaviors of an individual tiger. The following description of the model follows the ODD (overview, design concepts, and details) protocol for describing individual- and agent-based models (Grimm et al. 2006). The ODD protocol is an effective, widely-used, and standardized method for describing individual- and agent-based models.

Purpose of the Model

The purpose of this prototype model is to simulate how a tiger spatiotemporally responds to human presence in the tiger's habitat.

State Variables and Scales

The model has three types of agents: humans, tigers, and Sambar deer (*Rusa unicolor*). State variables for the individual tiger included sex and age class, and hunger and starvation level (Table 6.1). State variables for Sambar deer included age and hunger level (Table 6.1). As I was interested in modeling tiger response to human presence, the inclusion of state variables for the human agents was not necessary. The time-step for the model was one hour. The simulated area was a rectangle of 28 km^2 (4 km x 7 km). This simulated area completely contains the area of a female tiger's home-range (20 km^2).

Process Overview and Scheduling

Aging

139

Tigers and Sambar deer increase in age with each hourly time step. Different behavioral patterns (e.g., hunting) are determined by animal age-class and internal state conditions (e.g., hunger). This prototype model includes one adult female tiger (Fig. 6.2) and many Sambar deer of different age-classes.

Movement

The model simulates both random and directed movement for the agents. The tiger generally stays within its home-range. When maintaining its home-range, the tiger moves forward in a random direction and distance. The direction is randomly chosen from within 90 degrees in either direction of the trajectory the tiger was moving in previously. Ninety degrees in each direction ensures that the tiger is generally moving forward at each time step rather than moving backward. When hunting, the tiger targets a Sambar deer and deliberately moves in the direction of the deer. When feeding, the tiger moves randomly around the kill site. However, the tiger will stay still (i.e., stop maintaining home-range and hunting but will continue feeding) when humans are detected within the tiger's AD, and the tiger will halt feeding and move in the opposite direction of the nearest human detected within the tiger's FID. All of the tiger's movements, except distance moved away from people, were parameterized based on field observations of tigers (Table 6.2). No empirical data exists for how far a tiger moves away from people when disturbed. I set the distance moved away from people within the tiger's FID to 300 m, which corresponds to the median distance moved away from people by the lynx (*Lynx lynx*) reported in Sunde et al. (1998). To my knowledge, Sunde et al. (1998) is the only study measuring felid avoidance of humans using field observations. Future versions of the ABM will use a range of distances that tigers move away from people to test how sensitive the model is to variation in that parameter.

Fine-scale field observations of Sambar deer movement also does not exist. Thus Sambar deer movement was parameterized based on Fryxell et al. (2008), which indicated that elk (*Cervus elaphus*) moved 0.23 – 7 km per day corresponding to both encamped and exploratory modes. I used this range of values in the simulation, such that Sambar deer movement per hour was randomly selected from 0 m to 300 m (i.e., equivalent to a total of 7.2 km per day).

The ABM simulates the presence of people walking in the forest and therefore does not test how different human activities (e.g., cutting grass, patrolling the park, hunting, etc.) affect tiger avoidance behaviors. Humans walk in the forest with directed movement. Based on camera trap observations in Carter et al. (2012b), humans moved south and walk in the forest during the morning hours (0600 to 1200) and move north out of the forest in the afternoon hours (1200 to 1800).

Hunger and starvation

The range of values used to parameterize hunger and starvation levels are identical to those used in both Ahearn et al. (2001) and Imron et al. (2011). Changes in hunger and starvation levels for the tiger and Sambar deer are designed to reflect rates of change in those conditions determined from the field (McDougal 1977, Sunquist 1981, Smith et al. 1987, Karanth and Sunquist 1992, Smith 1993, Chundawat et al. 1999). The hunger level ranges from 0 – 100 for the tiger. The hunger level for the tiger increases by an increment of 0.625 for each time step (i.e., hour) the tiger has not fed. In other words, the hunger level increases by 15 over one day. When the hunger level exceeds 60, the tiger will begin to actively hunt. When the hunger level exceeds 90, the starvation process will initiate. The starvation level increases by an increment of 0.042 up to 30 (i.e., one month), after which the tiger dies. After the tiger has caught a Sambar deer, the starvation level is reset to 0 and the hunger level decreases by 1.042 per time step over the entire feeding period. Sambar deer and tigers have different food

requirements and acquire food differently; therefore, their hunger/starvation processes are different from one another. The hunger level for Sambar deer ranges from 0 – 200, with the higher value being the starvation limit. The hunger level for Sambar increases by an increment of 0.83 for each time step, which is equivalent to an increase of 20 per day. The model is designed to accommodate different forage qualities for different land-cover types. However, for our current purposes, we used a single forested land cover type, such that the energy acquired from each forest patch (i.e., grid cell) by Sambar deer is homogenous across the simulated landscape. As a result, when foraging, the hunger-level for Sambar deer decreases by 1.3 each time-step.

Hunting

When the hunger level exceeds 60, the tiger will actively search for a Sambar deer within a specific hunting radius. Once a Sambar deer has been sensed (i.e., seen or smelled) by the tiger, the tiger orients itself toward the deer and chases it. Based on empirical data from Chitwan (Sunquist 1981), the hunting success rate for the tiger was assumed to be 25%.

Feeding

A tiger kills prey approximately every seven days and remains close to their hunted prey. Without interruption (e.g., from humans), a tiger in Chitwan will consume a Sambar deer for 2-3 consecutive days (Sunquist 1981). However, tigers reduce meat consumption and the amount of time spent feeding when disturbed by human presence (Kenney et al. 1995). In the simulation, the tiger will continue feeding even when humans have been detected within the tiger's alert distance, but the tiger will leave a kill and not return to it when humans are detected within their flight initiation distance.

Reproduction

Reproduction is not modeled for the tiger because there is only one individual and the model is run for only one month, during which time the probability of reproducing is low. Sambar deer reproduce annually with 1 litter each year between the ages of 2-6 years. The birth rates for Sambar deer were density dependent, such that Sambar deer will continue to reproduce until the population reaches the carrying capacity (Table 6.2).

Mortality

The tiger dies when its starvation level exceeds 30. A Sambar deer dies when it reaches 17 years old (Nugent et al. 2001), starves (i.e., hunger level >200), or is killed by the tiger.

Design Concepts

Interaction

Tigers interact with Sambar deer directly by preying on them. Tigers also interact with humans by avoiding them.

Sensing

The tiger senses the presence of humans when humans are within the tiger's alert distance. The tiger moves away from the closest human within the tiger's flight initiation distance.

Stochasticity

Animal behavior is complex and not perfectly described by a single parameter value. Thus, to account for random variation in behaviors, stochastic processes were incorporated into the tiger's movement and feeding behaviors (i.e., 2-3 days feeding when uninterrupted). Likewise, Sambar deer and human movements also incorporated stochasticity.

Details

Initialization

The model was initialized with a single female tiger. Her home-range size was set to 20 km^2, which is the average home-range size for female tigers in Chitwan (Smith et al. 1987). The tiger occurs in a "forested" landscape of 21 km^2 (3 km x 7 km), which completely contains the home-range of the tiger. North of the forested landscape is the human settled area of 7 km^2 (1 km x 7 km). Sambar deer density was set to 8 individuals/km^2, which approximates the high ungulate density in Chitwan (Ahearn et al. 2001). Carter et al. (2012b) indicated that in 2010 people visited each camera trap inside the National Park approximately 5 times per day. Camera traps were set approximately 1 km apart from each other. Thus a simulated forest area of 21 km2 would contain approximately 20 camera traps. I initialized the model with 100 human agents assuming 5 people visit 20 camera traps per day.

Input

The rectangular simulation landscape was represented by 400 x 700 grid cells (including forested area [21 km^2] and human-settled area [7 km^2] adjacent to forest), with a cell resolution of 10m.

Implementation

The model was implemented in NETLOGO 5 (Wilensky 1999). The model was carried out for a simulation time of 2 months to assess tiger movement per hour of the day. The simulation was iterated 30 times, with a simulation time of 1 month, to assess total time feeding on prey in a month and average distance moved in an hour.

Scenarios and Analysis

The model was carried out with varying ADs and FIDs. I assessed how varying these two factors influenced tiger movement per hour and time feeding on prey per month. Based on experiments where a couple people walked directly towards radio-collared Lynx (*Lynx lynx*) in Norway, Sunde et al (1998) reported a median FID of 50 m for the Lynx. Using a similar experimental approach, Karlsson et al. (2007) reported a median FID of 106 m for wolves (*Canis lupus*) in Sweden. Thus I varied FID from 50 m to 100 m at 10 m intervals in the model.

In Boulder, Colorado, mule deer (*Odocoileus hemionus***)** became alert to pedestrians off-trail at a mean distance of 66 m (Miller et al. 2001), and caribou (*Rangifer tarandus*) in Newfoundland became alert to snowmobiles at a mean distance of 288 m (Mahoney et al. 2011). Although they do not provide any specific values, Curry et al. (2001) suggest that tigers likely have a greater alert distance than ungulates. Thus I varied AD from 100 m to 500 m at 100 m intervals for the tiger in the model. I used analysis of variance (ANOVA) to test for significant differences in the means of the two outputs (i.e., tiger movement per hour, time feeding on prey per month) for different ADs and FIDs. I also compare these outputs to those from simulations with no human presence.

Results

The median movement during the day (0600-1800) decreased with greater AD (Fig. 6.3 - 6.8). For example, with FID held constant at 50 m, the proportion of median movement occurring during the day decreased 38% from 0.47 (100 m AD) to 0.29 (500 m AD) (Fig. 6.3, 6.9). A comparatively large decrease in the median daytime movement occurred at an AD of 400 m for FIDs of 50 m, 60 m, 70 m, and 80 m (Fig. 6.9). In addition, beyond an AD of 400 m,

the variation in movement per hour noticeably decreased during the day, especially for FIDs of 50 m, 60 m, 70 m, and 80 m (Fig. 6.3 – 6.8).

For all ADs, the tiger moved more per hour when FID increased (AD = 100 m: $F_{5,174}$ = 15.76, $P < 0.01$; AD = 200 m: $F_{5,174}$ = 17.57, $P < 0.01$; AD = 300 m: $F_{5,174}$ = 24.72, $P < 0.01$; AD = 400 m: $F_{5,174}$ = 28.03, $P < 0.01$; AD = 500 m: $F_{5,174}$ = 25.53, $P < 0.01$) (Fig. 6.10). For example, with the AD held constant at 100 m, median movement per hour increased 13.2% from 56.1 m at the shortest FID to 63.5 m at the longest FID (Fig. 6.11). In contrast, for all FIDs, the tiger moved less per hour when AD increased (FID = 50 m: $F_{4,145}$ = 40.08, $P < 0.01$; FID = 60 m: $F_{4,145}$ = 25.02, $P < 0.01$; FID = 70 m: $F_{4,145}$ = 38.65, $P < 0.01$; FID = 80 m: $F_{4,145}$ = 19.96, $P < 0.01$; FID = 90 m: $F_{4,145}$ = 25.04, $P < 0.01$; FID = 100 m: $F_{4,145}$ = 18.8, $P < 0.01$) (Fig. 6.10). For example, with FID held constant at 50 m, median movement per hour decreased 15.3% from 56.1 m at the shortest AD to 47.5 m at the longest AD (Fig. 6.11). In comparison, median movement per hour was 52.7 m when no humans were present. In terms of percentage change in medians, the impact of AD and FID on movement per hour appeared to be equivalent. Variation in the average movement per hour across simulation iterations for different AD and FID values were approximately equal, suggesting that movement was monotonically related to these parameters and not overly sensitive to incremental changes in their values (Fig. 6.10).

Except when FID was 60 m, the median number of days the tiger fed on Sambar deer per month varied little across different AD (FID = 50 m: $F_{4,145}$ = 0.66, $P = 0.62$; FID = 60 m: $F_{4,145}$ = 3.76, $P < 0.01$; FID = 70 m: $F_{4,145}$ = 0.77, $P = 0.55$; FID = 80 m: $F_{4,145}$ = 1.26, $P = 0.29$; FID = 90 m: $F_{4,145}$ = 1.05, $P = 0.38$; FID = 100 m: $F_{4,145}$ = 1.55, $P = 0.19$)(Fig. 6.12). However, for all ADs, the median number of days feeding decreased with greater FID (AD = 100 m: $F_{5,174}$ = 12.23, $P < 0.01$; AD = 200 m: $F_{5,174}$ = 20.39, $P < 0.01$; AD = 300 m: $F_{5,174}$ = 14.6, $P < 0.01$;

AD = 400 m: $F_{5,174} = 22$, $P < 0.01$; AD = 500 m: $F_{5,174} = 16.35$, $P < 0.01$). For example, with the AD held constant at 100 m, the median number of days feeding per month decreased by 30% from 10.3 days at the shortest FID to 7.2 days at the longest FID (Fig. 6.13). In addition, variation in the number of days feeding across the simulation iterations appeared to increase with greater FID (Fig. 6.12). In comparison, the median number of days feeding per month was 11.87 when no humans were present.

Discussion

This prototype agent-based model is the first to simulate interactions between human and tiger agents. The model results suggest that human-tiger interactions mediated by two parameters, AD and FID, potentially impact tiger fitness. The tiger in the model stopped moving when people were within the AD, which field observations of other wildlife species (e.g., elk, ptarmigans) affirms is a common response to human disturbance (Gabrielsen and Smith 1995, Frid and Dill 2002, Preisler et al. 2006). For example, Preisler et al. (2006) indicates that elk often remain completely still while all-terrain vehicles pass close by, even within 50 – 100 m of them.

In Carter et al. (2012b), 20% of tiger activity inside Chitwan National Park occurred during the day. Most simulations did not reflect the pattern observed in the field in Carter et al. (2012b). However, the proportion of movement per hour during the day in the model with a FID of 50 m or 60 m and AD of 400 m or 500 m corresponded most closely to the pattern observed in the field. A FID of 50 m or 60 m has been noted in other carnivore species. For example, Ashenafi et al. (2005) indicated that Ethiopian wolves (*Canis simensis*) frequently ignored the presence of local natural resource collectors at a distance as close as 50 m. The tiger spent more time fleeing from people during the day as FID increased in the model. As a result, when FID

exceeded 90 m, tiger movement per hour during the day was roughly equivalent to the movement per hour during the night. When fleeing, however, tigers are not feeding, mating, and their stress hormones are likely elevated (Creel et al. 2013), all of which impact individual fitness. Although Ethiopian wolves mostly ignored human presence, Ashenafi et al. (2005) also indicated that the wolves spent more time running when people were nearby than when people were absent.

An AD of 400 m or 500 m for tigers in Chitwan seems reasonable, although comparisons are difficult because to my knowledge no other studies have assessed the AD of carnivores to human disturbance. Pronghorn antelope (*Antilocapra americana)* in Utah became alert to people hiking on trails at an average distance of 350 m (Taylor and Knight 2003). The AD of tigers in Chitwan may be greater than this, because as Blumstein et al. (2005) suggests, cryptic species (e.g., tiger) have greater AD than more conspicuous species. Moreover, since tigers have relatively large home-ranges and daily movements compared to other mammals, the capacity for tigers to perceive and react to objects at a distance of 400 m or 500 m is plausible.

With little to no human disturbance, tigers consume between 1,825 – 2,190 kg of meat/year (Sunquist et al. 1999). Given the level of human presence in our model, our results suggest that with a 50 m FID tigers would consume about 14% less meat/year (1,588 – 1,905 kg) and with a 100 m FID would consume about 39% less meat/year (1,113 – 1,336 kg). Reducing meat consumption by such a substantial amount would negatively affect a suite of tiger behaviors. For example, tigers would be forced to spend more time searching for food rather than on other activities, like maintaining home-ranges and searching for mates. Reduced meat consumption would also increase adult mortality, especially as tigers have greater maintenance energy requirements than other large felids, like lions (*Panthera leo*) and clouded leopards (*Neofelis nebulosa*) (Allen et al. 1995). In addition, females with offspring must acquire approximately 50% more meat to feed their young (Sunquist et al. 1999). A reduction of meat

148

consumption by 14% to 39% would certainly increase cub mortality, which decreases population persistence. However, these results should be interpreted with caution, because the feeding process with respect to human disturbance may be more complex than that of the model. In the model, tigers flee from people within the FID and leave the kill permanently, and if they were still hungry, begin hunting again immediately. It is possible that tigers leave a kill temporarily while fleeing and return shortly thereafter to feed again. In this case, the magnitude of reduction in meat consumption due to human disturbance would be less than our model indicates.

AD and FID likely differ with respect to the type of human disturbance. For example, among many ungulate species, individuals from populations exposed to hunting tend to have longer AD and FID than individuals from populations not hunted (Stankowich 2008, Reimers and Colman 2009). In other words, animals learn to avoid the stressful experiences of being hunted, and consequently stay farther away from people. As such, we might expect that the FID of tigers in Chitwan, where poaching has been relatively well controlled for some years, is shorter than in regions where poaching is common. There is also evidence that greater exposure to humans influences FID of animals (Blumstein et al. 2003). For example, caribou and elk have comparatively shorter FIDs in areas where people are more active than where they are less active (Cassirer et al. 1992, Reimers and Colman 2009). This suggests a habituation process.

The preliminary results from the ABM illustrate the importance of avoidance behavior in food acquisition and energy expenditure, both of which impact animal fitness. As such, field research is needed to empirically validate tiger AD and FID with respect to human presence. Doing so in different contexts would explicate how (or if) tigers adjust AD and FID to different degrees and types of human presence. Such information would allow for better predictions of tiger individual- and population-level response to human activities, which are highly relevant to tigers as approximately 80% of their current range is in human-dominated areas outside

protected areas (Forrest et al. 2011). In addition, such information has implications for understanding and managing human-tiger conflict, considered some of the most severe human-wildlife conflict in the world (Inskip and Zimmermann 2009). For example, if acquiring enough meat from wild prey becomes too difficult in the presence of people (i.e., long FID) then the propensity for tigers to attack domestic livestock or humans may increase.

Conclusion

Agent-based modeling is a highly flexible tool enabling researchers to learn more about human-wildlife interactions that are difficult to observe in the wild and how such interactions impact wildlife. The prototype ABM described in this chapter demonstrated that human presence in the forest can have a detrimental impact on tiger fitness. The model underscores the importance of acquiring additional information to better calibrate how tigers avoid humans. For example, empirical observations on how tigers of different age classes avoid people, how females with offspring avoid people, how far tigers move to avoid human presence, and how AD and FID varies with respect to different human activities would significantly improve the ABM. The ABM lays the groundwork for a more complex model of human-tiger interactions that can be used to assess how different policy scenarios affect tigers, tiger habitat, and human livelihoods.

APPENDIX

Figure 6.1: Basic conceptual model of human-tiger-prey interactions inside Chitwan National Park. This conceptual model was used as a guide in developing an agent-based model.
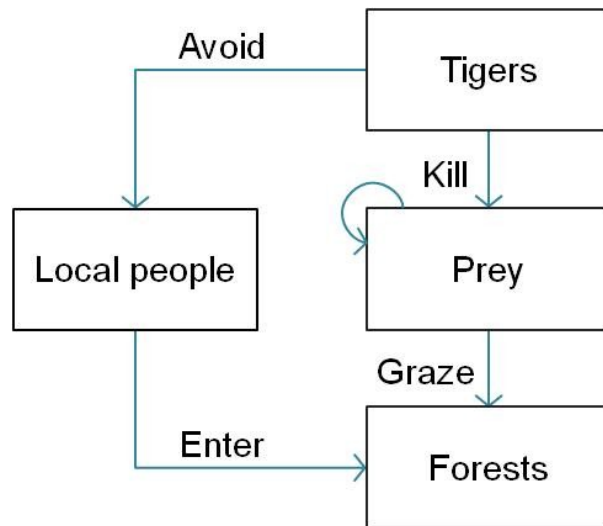
Figure 6.2: Conceptual diagram of main tiger behaviors in the agent-based model.
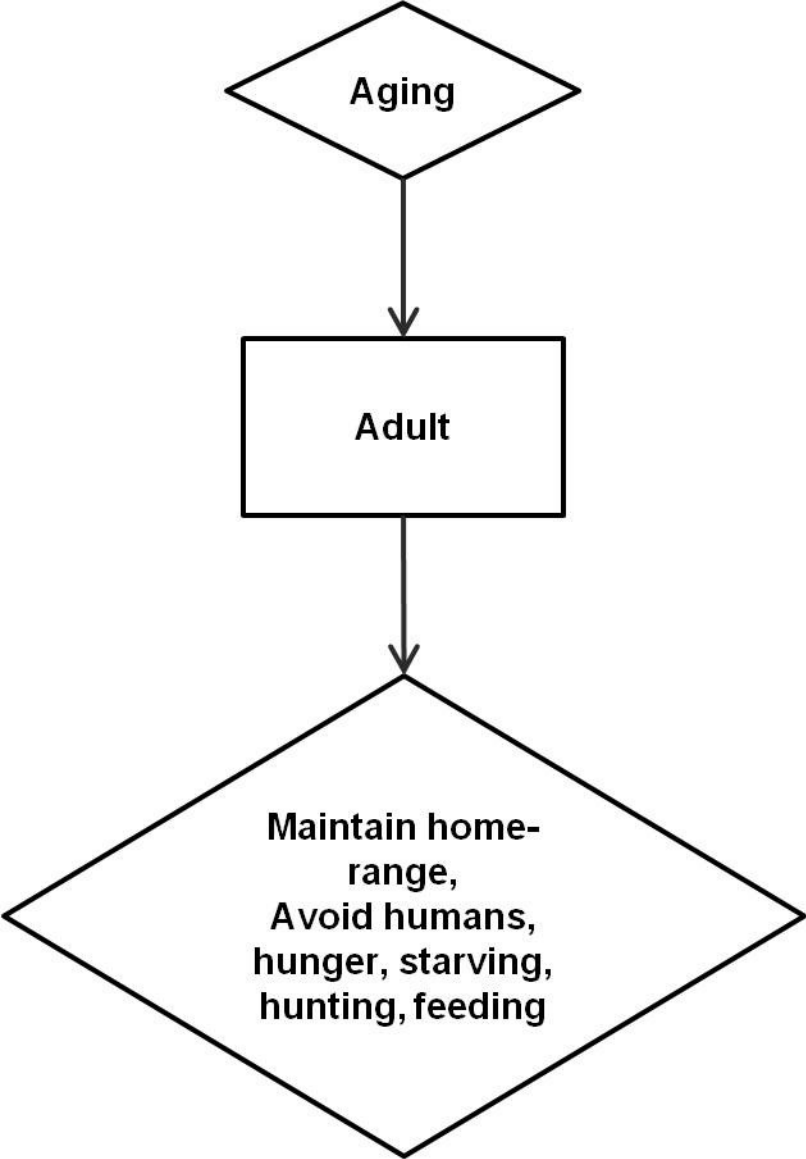
Figure 6.3: Tiger movement distances per hour of the day for a 2-month simulation with a flight initiation distance (FID) of 50 meters and alert distances (AD) of (A) 100 m, (B) 200 m, (C) 300 m, (D) 400 m, (E) 500 m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, and black lines within boxes represent medians. Outliers were common for each hour, because movement distances range from a few meters per hour when feeding to several hundred when maintaining home-range. Thus outliers were removed to aid visualization of pattern.
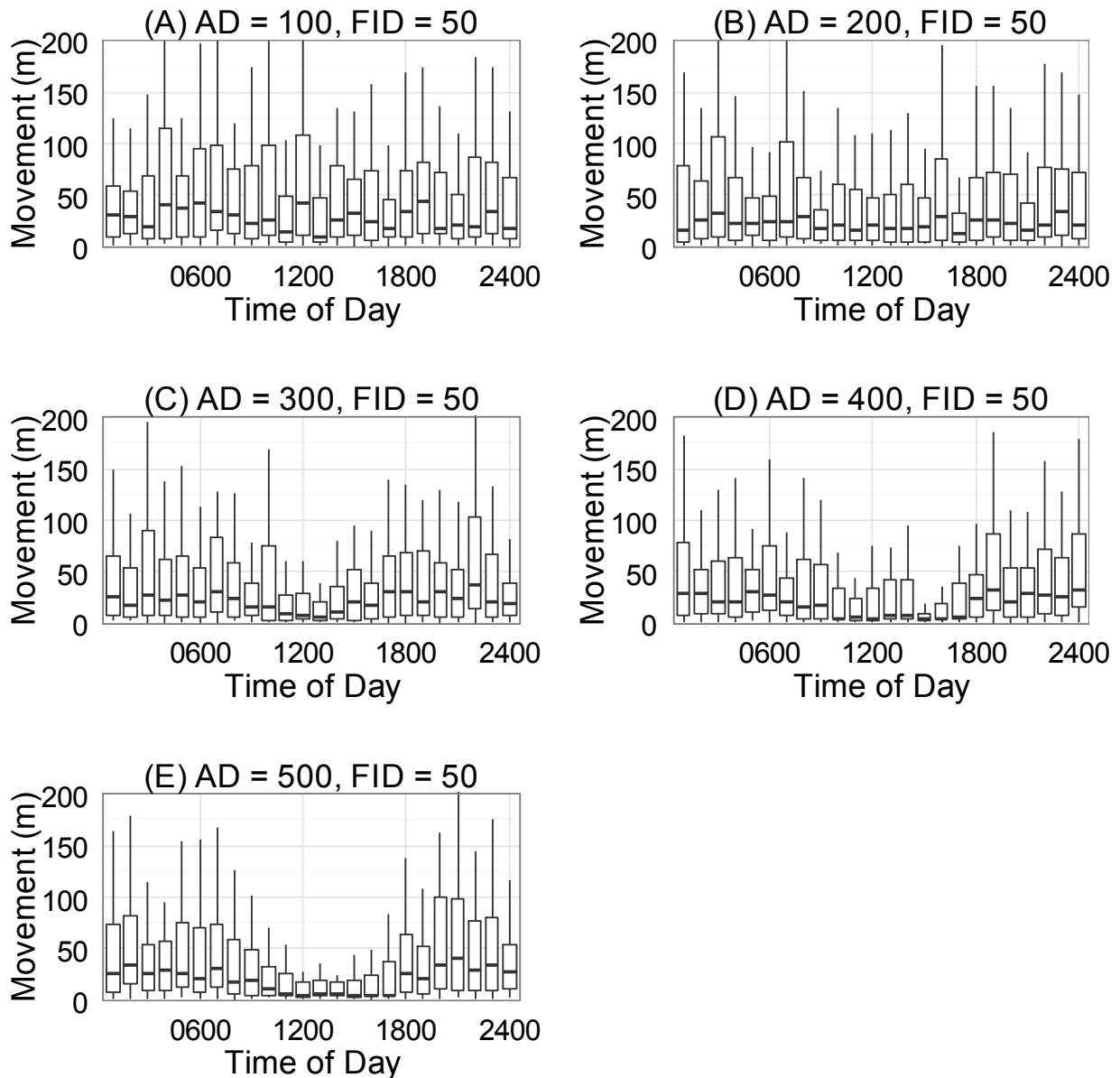
Figure 6.4: Tiger movement distances per hour of the day for a 2-month simulation with a flight initiation distance (FID) of 60 meters and alert distances (AD) of (A) 100 m, (B) 200 m, (C) 300 m, (D) 400 m, (E) 500 m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, and black lines within boxes represent medians. Outliers were common for each hour, because movement distances range from a few meters per hour when feeding to several hundred when maintaining home-range. Thus outliers were removed to aid visualization of pattern.
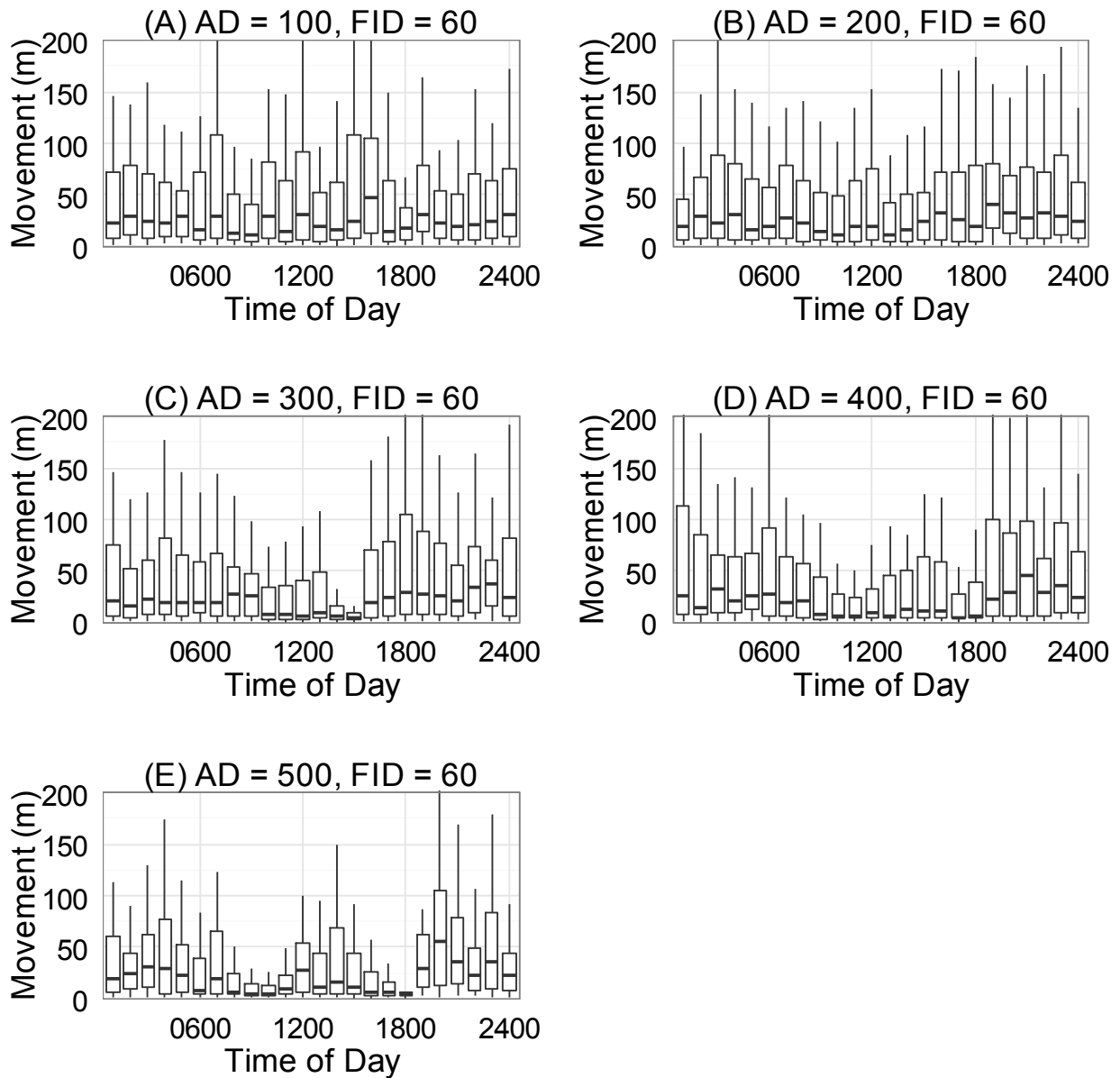
Figure 6.5: Tiger movement distances per hour of the day for a 2-month simulation with a flight initiation distance (FID) of 70 meters and alert distances (AD) of (A) 100 m, (B) 200 m, (C) 300 m, (D) 400 m, (E) 500 m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, and black lines within boxes represent medians. Outliers were common for each hour, because movement distances range from a few meters per hour when feeding to several hundred when maintaining home-range. Thus outliers were removed to aid visualization of pattern.
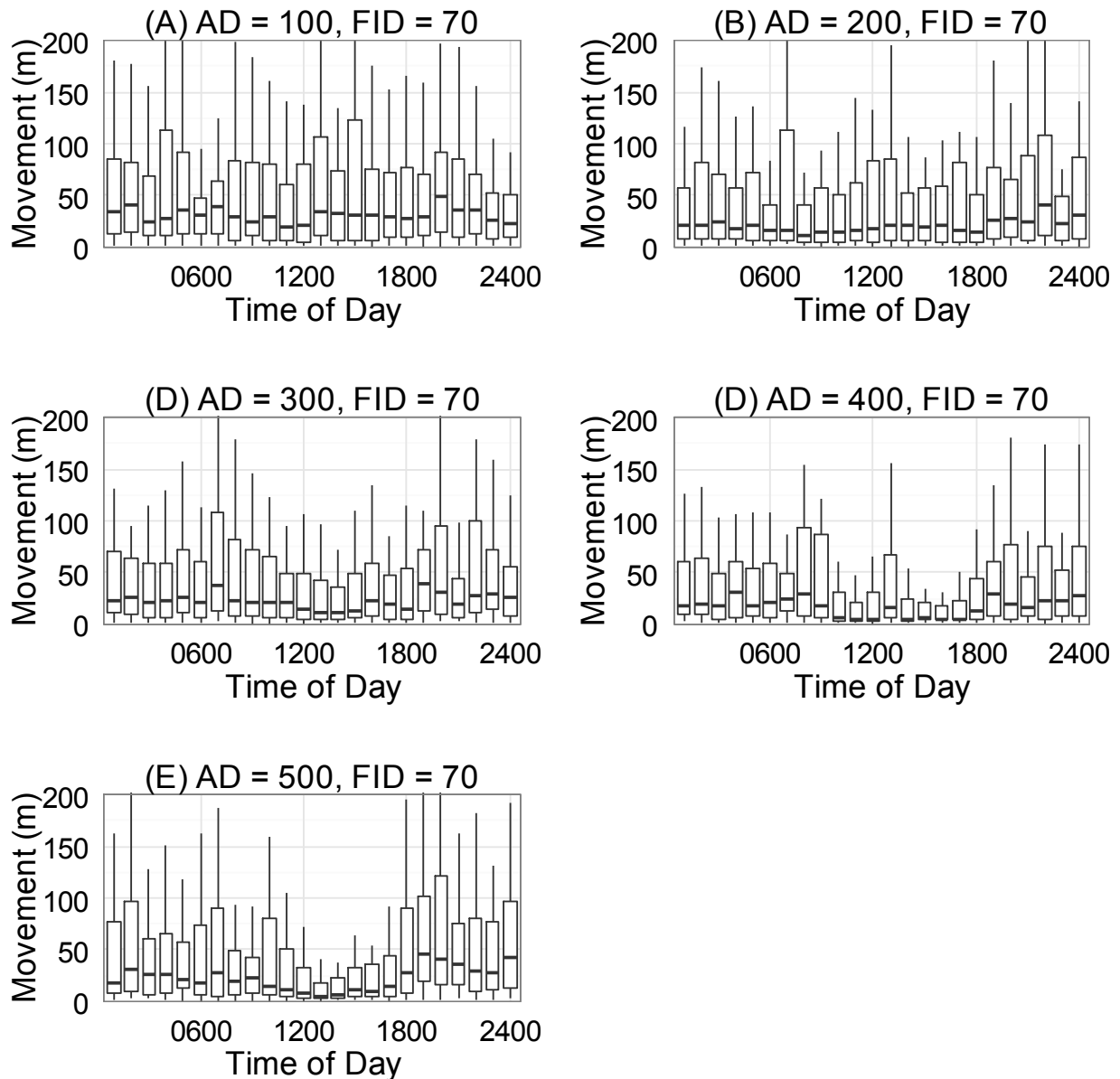
Figure 6.6: Tiger movement distances per hour of the day for a 2-month simulation with a flight initiation distance (FID) of 80 meters and alert distances (AD) of (A) 100 m, (B) 200 m, (C) 300 m, (D) 400 m, (E) 500 m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, and black lines within boxes represent medians. Outliers were common for each hour, because movement distances range from a few meters per hour when feeding to several hundred when maintaining home-range. Thus outliers were removed to aid visualization of pattern.
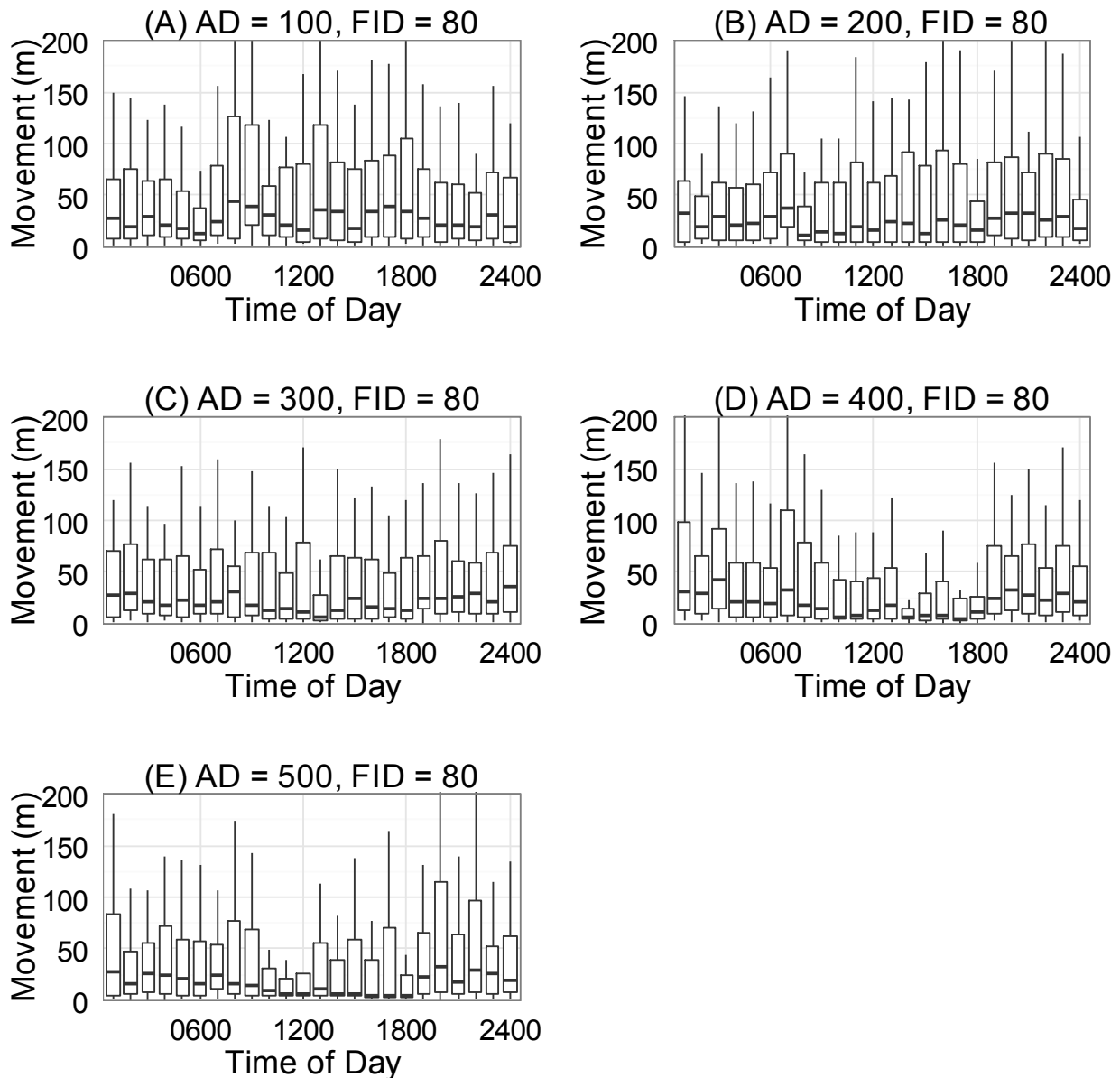
Figure 6.7: Tiger movement distances per hour of the day for a 2-month simulation with a flight initiation distance (FID) of 90 meters and alert distances (AD) of (A) 100 m, (B) 200 m, (C) 300 m, (D) 400 m, (E) 500 m Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, and black lines within boxes represent medians. Outliers were common for each hour, because movement distances range from a few meters per hour when feeding to several hundred when maintaining home-range. Thus outliers were removed to aid visualization of pattern.
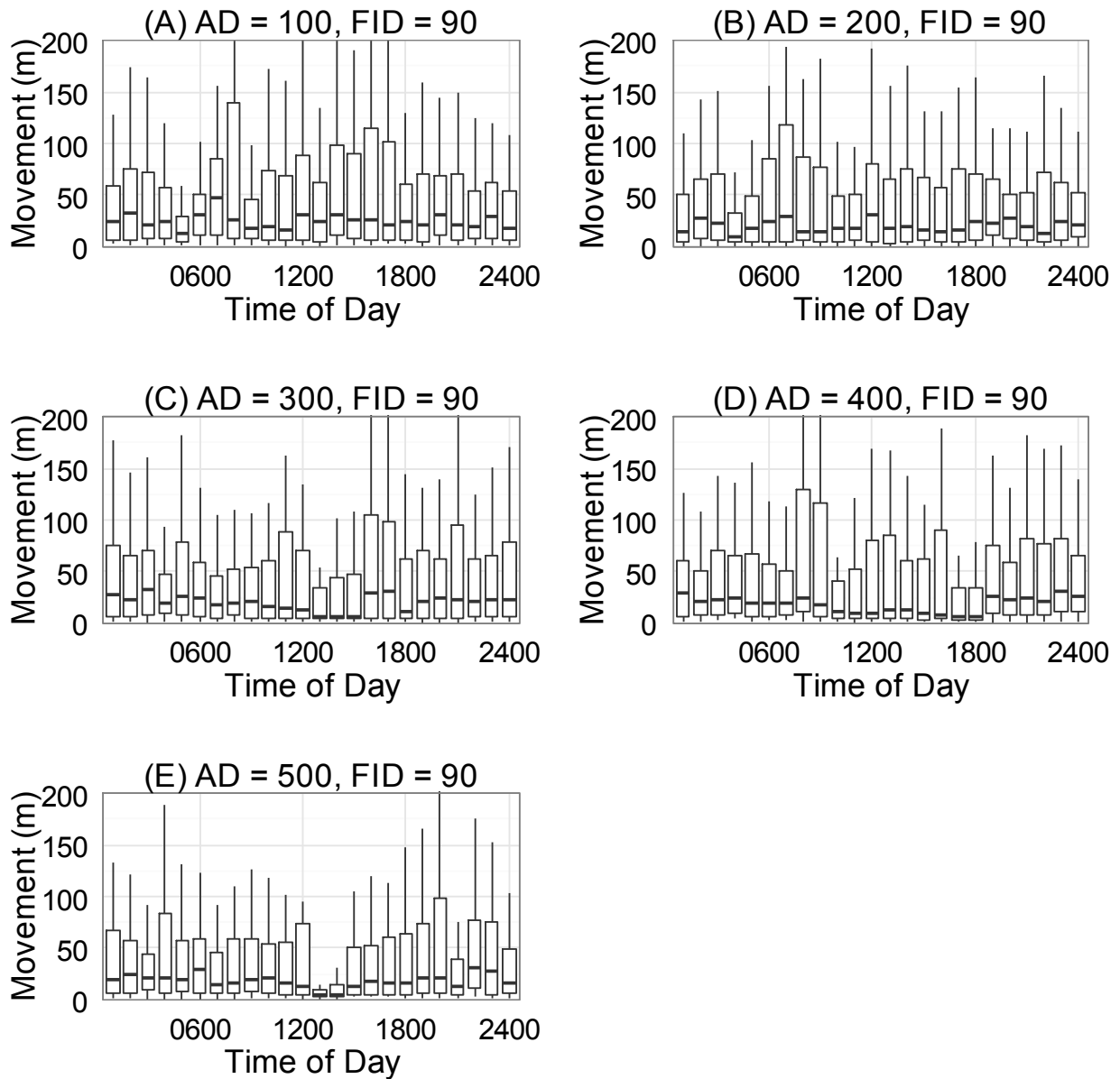
Figure 6.8: Tiger movement distances per hour of the day for a 2-month simulation with a flight initiation distance (FID) of 100 meters and alert distances (AD) of (A) 100 m, (B) 200 m, (C) 300 m, (D) 400 m, (E) 500 m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, and black lines within boxes represent medians. Outliers were common for each hour, because movement distances range from a few meters per hour when feeding to several hundred when maintaining home-range. Thus outliers were removed to aid visualization of pattern.
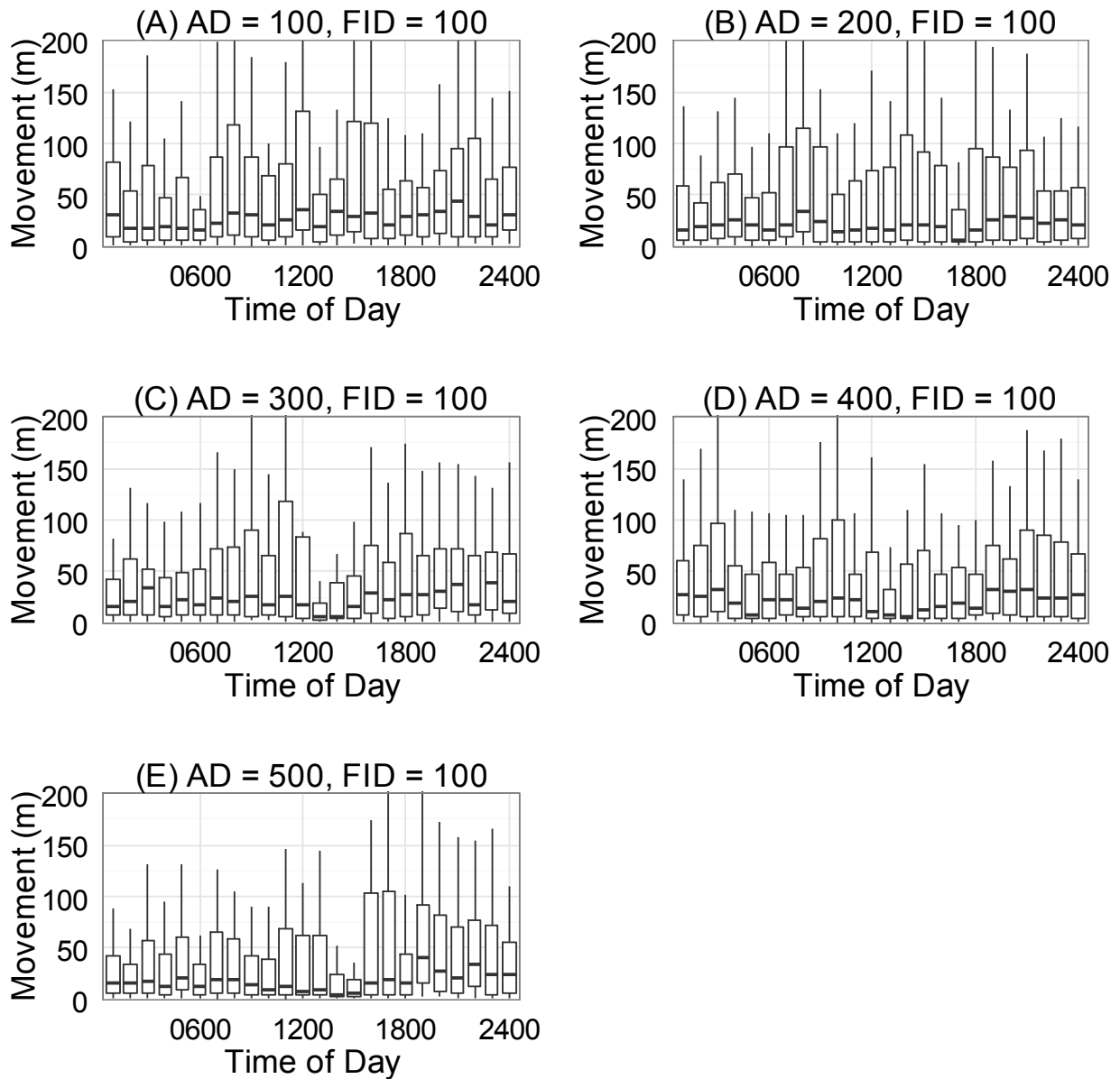
Figure 6.9: Proportion of median movement values per hour that occurred during the day for different alert distances and flight initiation distances (FID).
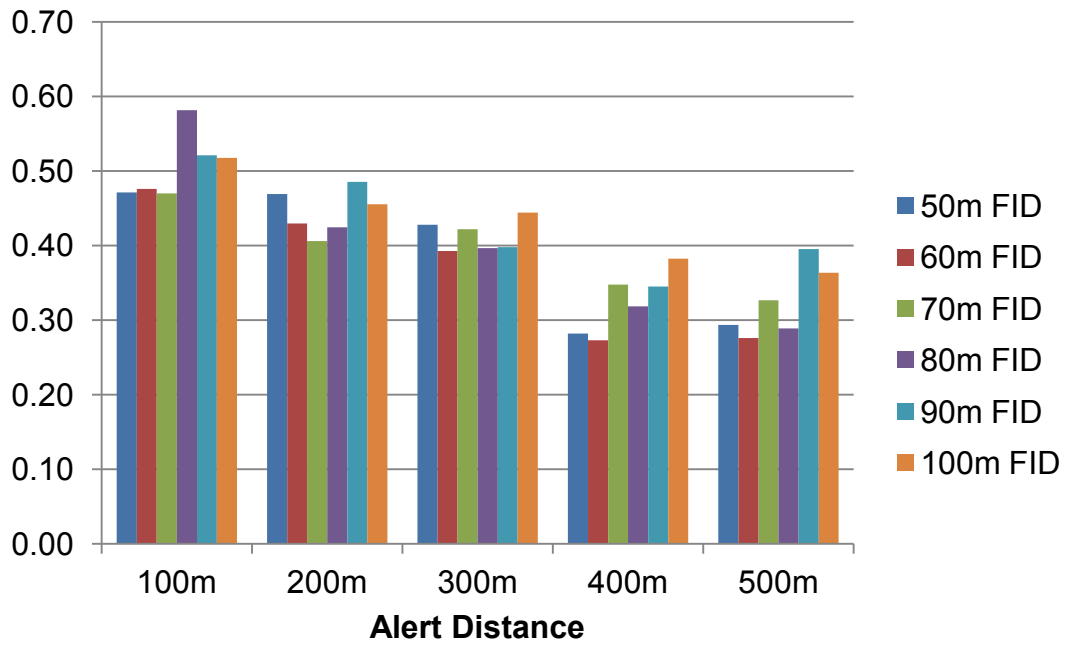
Figure 6.10: Average hourly movements (m) of the tiger across simulation iterations (n=30) for different alert distances and flight initiation distances of (A) 50 m, (B) 60 m, (C) 70 m, (D) 80 m, (E) 90 m, and (F) 100m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, black lines within boxes represent medians, and black circles outside the whiskers represent outlier values.
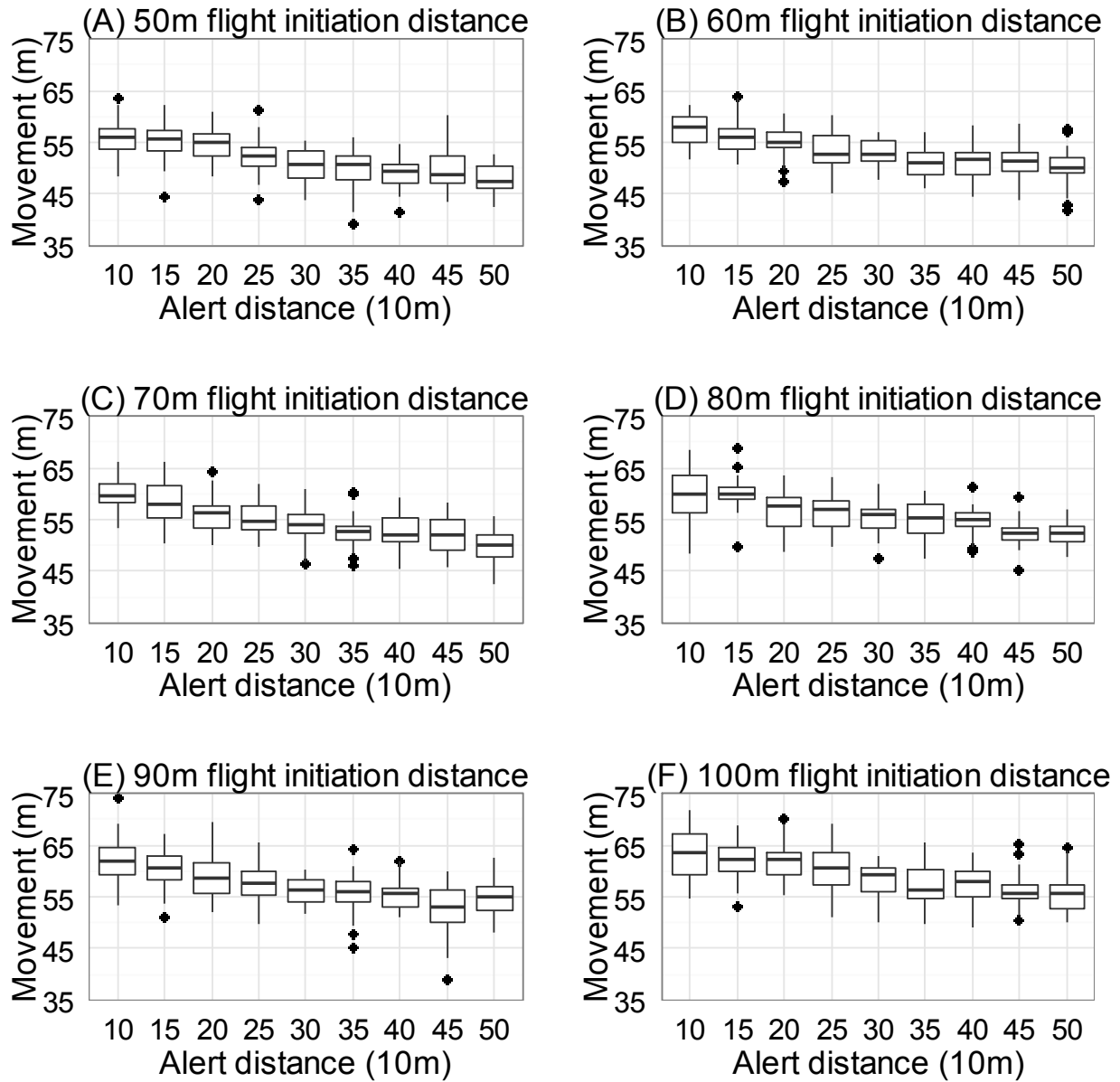
Figure 6.11: Medians of the average tiger movement per hour from simulation iterations (n=30) at different flight initiation distances and alert distances (AD).
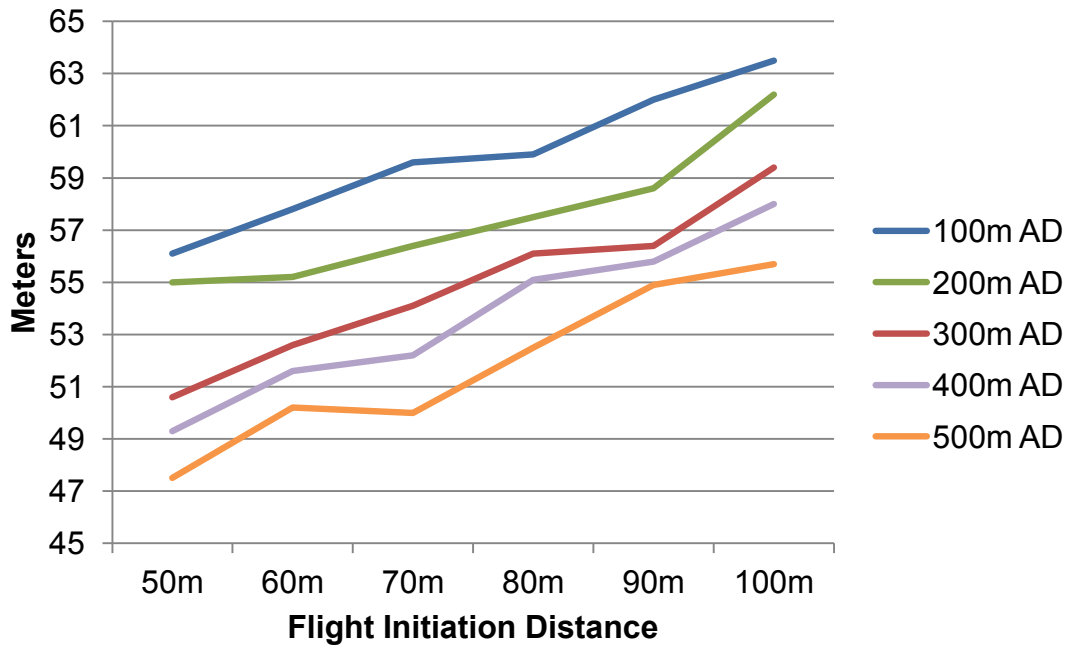
Figure 6.12: Total days tiger was feeding on prey in a month across simulation iterations (n=30) for 100 m to 500 m alert distances and flight initiation distances of (A) 50 m, (B) 60 m, (C) 70 m, (D) 80 m, (E) 90 m, and (F) 100m. Boxes represent the 25th and 75th percentiles, whiskers represent the 95% confidence limits, black lines within boxes represent medians, and black circles outside the whiskers represent outlier values.
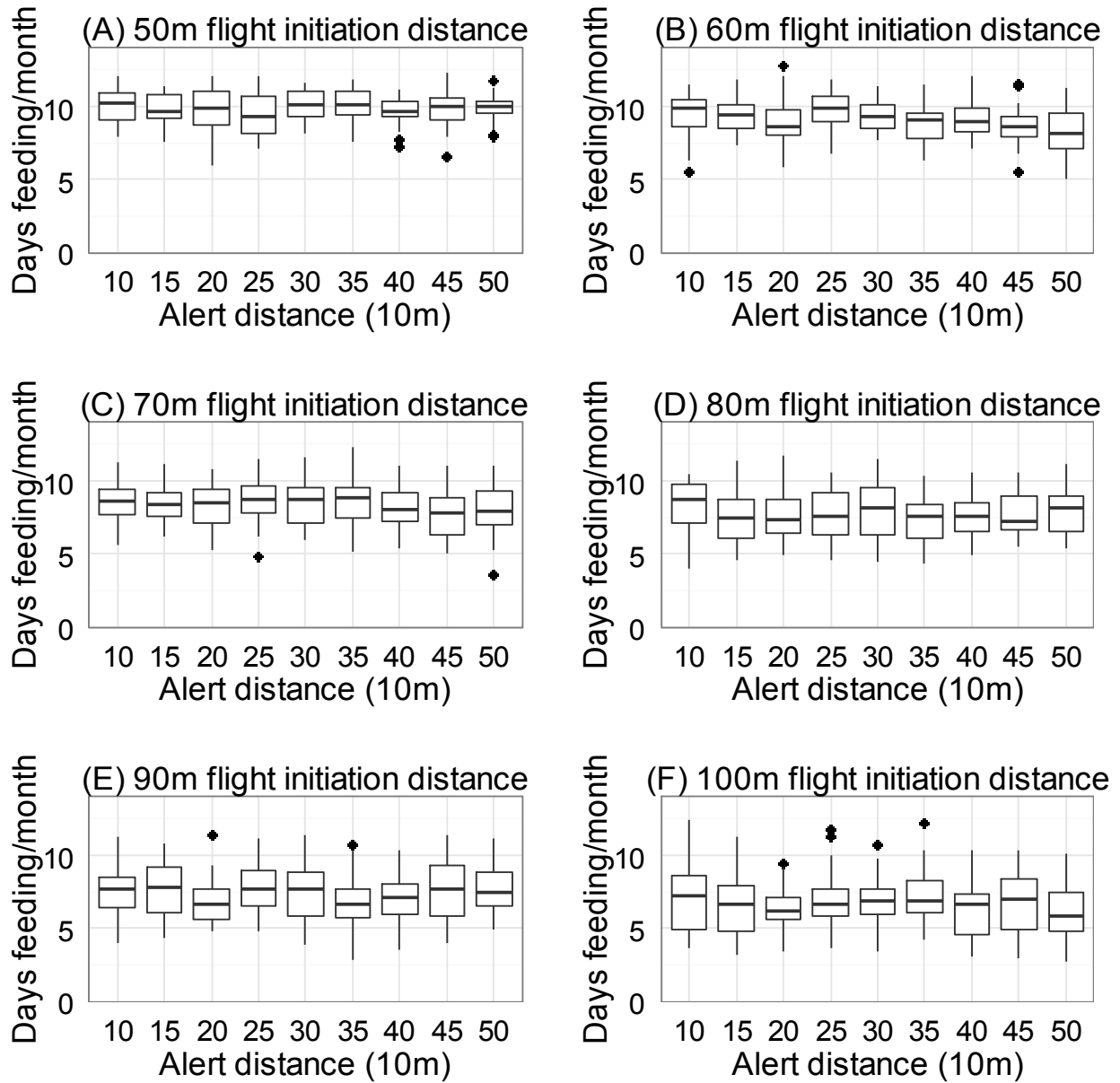
Figure 6.13: Medians of total time tiger feeding on prey per month from simulation iterations (n=30) at different flight initiation distances and alert distances (AD).
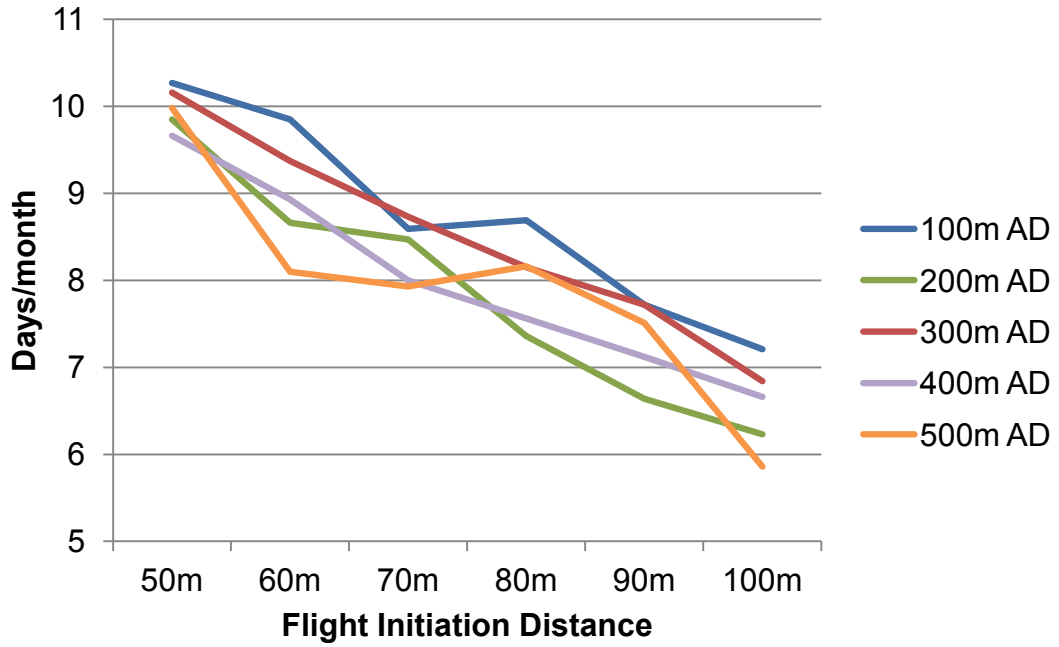
Table 6.1: Description of state variables of tiger and Sambar deer in agent-based model.

Individuals	State variables	Description	Values and units	Note
Bengal tiger	Age	Age of individual	0 - 5,400 days	Sunquist et al. (1999), Smith (1993)
	Sex	Sex of individual	1 female	
	Hunger-level	Energy level of individual	0-100	Ahearn et al. (2001)
	Starvation-level	Starvation level of individual	0-30	Ahearn et al. (2001)
Sambar deer	Age	Age of individual	0-6,120 days	Nugent et al.(2001)
	Hunger-level	Energy level of individual	0-200	Imron et al. (2011)

Table 6.2: The description of parameters and their values for the tiger in the agent-based model.

Parameter name	Description	Values	Reference
C_s	Carrying capacity for Sambar deer	8 ind/km^2	Ahearn et al. (2001)
G_s	Growth rate of Sambar deer	1 ind/year	Semiadi et al. (1994)
H_{fem}	Home-range size for female	20 km^2	Smith et al. (1987)
Ht_{rad}	Hunting radius of tigers to detect presence of prey	1,000 m^2	Imron et al. (2011)
P_c	Probability of successful hunting	25%	Ahearn et al. (2001)
T_{fs}	Time duration for feeding on Sambar deer	2-3 days	Ahearn et al (2001)
μ_{feed}	Mean rate of movement during feeding	400 m/day	Ahearn et al (2001)
μ_{hunt}	Mean rate of movement distance during hunting	1,500 m/day	Ahearn et al (2001)
μ_{rand}	Mean rate of movement distance during random movement	2,000 m/day	Ahearn et al (2001)
σ_{feed}	Standard deviation of movement during feeding	400 m/day	Ahearn et al (2001)
σ_{hunt}	Standard deviation of movement distance during hunting	1,500 m/day	Ahearn et al (2001)
σ_{rand}	Standard deviation of movement distance during random movement	2,000 m/day	Ahearn et al (2001)
D_{dist}	Displacement distance when human within flight initiation distance	300 m	Sunde et al. (1998)

CHAPTER 7

CONCLUSIONS AND SYNTHESIS

Wildlife and their habitats are important components of CHANS, as they interact with humans in numerous complex ways in today's increasingly human-dominated world. In Chapter 1, I described an integrated approach for analyzing the patterns, causes, and consequences of human-wildlife interactions in CHANS. Using this approach throughout my dissertation, I explicated several key relationships between people and globally endangered tigers in and around Nepal's Chitwan National Park, a global biodiversity hotspot. My dissertation provided new data and knowledge that answered substantive research questions such as how beliefs about tigers and their risks influence the capacity for local people to live with tigers (Chapter 2), how attitudes toward tigers are distributed in space (Chapter 3), how human activities and policies impact tiger habitat across space and through time (Chapter 4), how tigers use the landscape with respect to humans (Chapter 5), and how humans indirectly impact tigers (Chapter 6).

In Chapter 2, I developed a psychological framework that integrated past experiences with wildlife (e.g., attacks on livestock), beliefs, and perceptions as factors affecting local preferences for wildlife population size. Working with colleagues in Nepal, Michigan State University, and the University of Michigan, I developed a survey that was used to collect data on these factors from local residents in Chitwan. Structural equation modeling, which assesses hierarchical relationships, was then used to test how well the survey data corresponded with the psychological framework. In addition to beliefs about tigers (e.g., help bring tourists, keep forests healthy), I found that dissatisfaction with government management of tiger-related risks (i.e., attacks on livestock and people) and the sense of vulnerability to those risks strongly influenced local capacity to live with tigers. As such, results from Chapter 2 help identify conservation interventions that foster coexistence between people and tigers in Chitwan. Insights on how people relate to wildlife continue to emerge from various fields (e.g., anthropology, neuropsychology) and should be incorporated into the psychological framework

and tested in the field. Notably, factors related to social norms and social identity may improve

the psychological framework. Fortunately, structural equation modeling is highly flexible and

can accommodate the inclusion of new hierarchical relationships in the psychological

framework.

In Chapter 3, I used the social survey data to assess how social-cultural-economic factors

influence local attitudes toward tigers. I then used a simple but effective geostatistical tool to

examine how attitudes are spatially distributed. I found that one's position in society (i.e.,

educational level, ethnicity, and gender) shaped attitudes toward tigers more so that direct

experiences with tigers (e.g., attacks on livestock). I also found that attitudes formed spatial

clusters that were associated with geographic features. For example, more privileged groups

tended to have more positive attitudes toward tigers, which was in part because these groups

lived closer to the city where many economic and educational opportunities are located. Results

from Chapter 3 help explain why some conservation interventions fail. For example, when not

taking social processes into account, such as a caste system determining social status,

conservation interventions may be ineffectual in some regions or even lead to undesirable

outcomes (e.g., money used to incentivize conservation among local people is appropriated by

more elite groups). Also, maps of attitudes inform wildlife managers/conservationists where to

allocate their limited resources such as money and personnel to improve attitudes. The results

from Chapter 3 suggest that the intersection of geography, psychology, and ecology is a fruitful

interdisciplinary research avenue that should continue to be explored. For example, how do

ecological (e.g., dispersal of subadult animals) and social processes (e.g., land-use decisions)

interact in space to synergistically influence attitudes toward wildlife?

In Chapter 4, I combined camera trap data (collected by myself and colleagues in Nepal)

and remotely sensed data to assess spatiotemporal dynamics in tiger habitat inside Chitwan

National Park and in a multiple-use forest outside the park from 1989 to 2009. I found that the area of highly suitable tiger habitat decreased inside the park over the 20 year period, which may be associated with an increasing trend of unauthorized natural resource extraction by a rapidly growing human population that lives adjacent to the park. In contrast, land-management practices recently implemented (late 1990's and early 2000's) in the multiple-use forest outside the National Park, including community-based resource management and the prohibition of livestock grazing, has restored previously degraded tiger habitat. These results suggest that a habitat "transition" is possible if institutions are in place and policies implemented that involve local people in the conservation of local natural resources. With such institutions and policies in place, it may be possible to protect tiger habitat while also provide resource needs to local communities. Reconciling human resource needs and tiger habitat requirements is especially important for tiger conservation because a majority of the tiger's current range occurs in human-dominated, multiple-use forests outside protected areas. Moreover, the methodology used in Chapter 4 offers a straightforward way to assess habitat dynamics for wildlife species in regions around the world. To my knowledge, this is the first study to map habitat suitability and change using data from camera traps. Linking with wildlife population parameters (e.g., relationship between habitat suitability and mortality) and accommodating behavior change (e.g., seasonal changes in habitat selection) are a couple exciting possible improvements to the habitat model used in Chapter 4.

In Chapter 5, I used the camera trap data to assess the spatial and temporal activity patterns of tigers, tiger prey, and humans inside and outside the National Park. Results indicated relatively high tiger densities despite ubiquitous human presence (i.e., people on foot and vehicles) throughout the entire study site. Moreover, tigers appeared to use the same locations as people, which was unexpected. Spatial overlap between people and tigers was likely due in part

to tigers offsetting their temporal activity patterns to be much less active during the day when human activity peaked. In addition, high prey abundances and low poaching pressure facilitate spatial overlap. Measuring fine-scale spatial and temporal activity patterns of wildlife and people in human-dominated areas provides insights for developing better conservation interventions. For example, restricting human activities at certain times of the day when wildlife are most active will reduce human impact on wildlife. Like the results from Chapter 4, results in Chapter 5 suggest the possibility of supporting high densities of tigers while also providing for human resource needs. Although fine-scale spatial coexistence between people and tigers may not be ideal (e.g., more frequent negative tiger-human interactions), it may be the only practical solution in cases where the resettlement of villages or exclusion of all human activities from the tiger's habitat is socially unacceptable or infeasible. Results from Chapter 5 also suggest that other wildlife species may modify their behaviors to human presence in unpredictable ways, with implications on ecosystem dynamics. For example, when changing their temporal activity patterns in response to human disturbance predators may shift to alternative prey species, with cascading trophic effects. Thus combining data on fine-scale interactions between people and wildlife with data on ecosystem dynamics will significantly build on the research in Chapter 5.

In Chapter 6, I used an ABM to simulate specific avoidance behaviors of tigers (i.e., alert distance and flight initiation distance) to human disturbance. By varying alert and flight initiation distances, the ABM allowed me to test how sensitive tigers are to human presence in the forest. I validated model results using patterns observed from the camera trap data. I found that alert distances of 400 – 500 m and flight initiation distances of 50 – 60 m produced temporal activity patterns (measured by movement distance per hour of the day) that corresponded most closely to the empirical camera trap data. With these alert and flight initiation distances, model results also indicated that tigers may spend considerably less time feeding on prey in the

presence of people than in the absence of people. Importantly, expending more energy and eating less food in the presence of people impacts individual animal fitness, with implications on population persistence. Therefore, gathering additional empirical data on tiger alert distances and flight initiation distances (e.g., from GPS collar data) will help to calibrate future versions of the ABM and provide direction on how to feasibly reduce human impact on tigers. The research in Chapter 6 represents the first attempt that I am aware of to simulate the indirect impact of human presence on endangered wildlife using agent-based models. The model in Chapter 6 lays the groundwork for a far more complex ABM that can be used to understand complex dynamics (e.g., feedbacks, time-lags) between people, ecosystems, and tigers. By answering new substantive questions, such an ABM could better inform decision makers on how to sustain (and improve) human well-being while also conserving tigers under uncertain and dynamic future conditions. For example, do some conservation policy scenarios lead to counter-productive outcomes (e.g., surprises) in terms of tiger population size and habitat suitability? What conservation policy scenario best conserves tigers and supports livelihoods in the future?

The CHANS approach allowed me to obtain a more holistic perspective of the various interconnections between people and tigers in Chitwan, and how these interconnections change through time and how they are mediated by policies. I chose to study human-tiger interactions in Chitwan because the challenges associated with tiger conservation in Chitwan (e.g., protecting habitat, reducing human-tiger conflict) epitomize the difficulties facing tiger conservation initiatives across their 13-country range. Tiger conservation challenges are also similar to those for many imperiled wildlife species in regions around the world, such as jaguars in the Amazon Basin. Thus, the integrative and interdisciplinary approach taken in this research is an effective way to address some of the most pressing wildlife conservation challenges in a world increasingly crowded by people.

APPENDIX

Tiger Acceptance Capacity Survey

Name of interviewer: ……………………………………….   **Start time:…………**

Date: ………………..

GPS Location: UTM X: …………………..UTM Y: …………………

Name of the respondent: ……………………………………..

Age:………..Sex:………….

VDC: …………………..

Ward No: …………………….

Village: ……..……………

Now, I would like to talk to you about your interactions with Tigers and find out more about your feeling towards Tigers living in the nearby forests

1) Are there tigers in the nearby forests?

__YES
__NO → **Go to Q. No. 3.**

2) In your opinion which best describes the current presence of tigers in the nearby forests? *(choose one)*

__RARE
__SOMEWHAT COMMON
__ABUNDANT

3) How many tigers are there in the nearby forests now compared to 10 years ago?

__MUCH LESS
__LESS
__SAME
__MORE
__MUCH MORE

4) Have you read or heard of a tiger being killed nearby by authorities?

__YES
__NO

5) Have you read or heard about pets being attacked nearby by a tiger?

__YES
__NO

6) Have you read or heard about farm animals being attacked nearby by a tiger?

__YES
__NO

7) Do you know a friend or neighbor who has been threatened or attacked by a tiger?

__YES
__NO

8) Do you have a relative that has been threatened or attacked by a tiger?

__YES
__NO

9) Have you read or heard about other people being threatened or attacked nearby by a tiger?

__YES
__NO

10) Have you ever seen evidence (e.g., pugmark and/or scat) of tiger in Chitwan? (*if no skip next question*)

__YES
__NO →**Go to Q. No. 12**

11) Where were you when you saw evidence of tiger?

__YOUR VILLAGE
__NEARBY FOREST
__CHITWAN NATIONAL PARK
__ELSEWHERE (*please specify*)............................

12) Have you ever seen a tiger in the wild? (*if no, skip next question*)

__YES
__NO →**Go to Q. No. 14**

13) Where were you the last time you saw a wild Tiger?

__YOUR VILLAGE
__NEARBY FOREST
__CHITWAN NATIONAL PARK
__ELSEWHERE (*please specify*)............................

14) Do you own any farm animals?

__YES
__NO → **Go to Q. No. 18**

15) If yes, how many of these farm animals do you own?

    __BIRD
    __PIG
    __GOAT/SHEEP
    __CATTLE/BUFFALO
    __OTHER (*please specify*).........................

16) Have you ever had tiger kill your farm animals?

    __YES
    __NO → **Go to Q. No. 18**

17) If yes, how many of which animal?

    __BIRD
    __PIG
    __GOAT/SHEEP
    __CATTLE/BUFFALO
    __OTHER (*please specify*).........................

18) Other types of experiences with tigers? Please describe.

    _____

19) Have encounters between tigers and people (including threatening and attack) been occurring for a long time in Chitwan?

    __YES
    __NO

20) Has the number of problems with tigers been increasing, decreasing, or stayed the same in Chitwan?

    __INCREASING
    __DECREASING
    __SAME

21) Do you agree that Tigers are a nuisance and should be kept out of the nearby forests at all costs?

    __AGREE
    __DISAGREE

22) Do you agree that there is not enough room for both tigers and humans to live in Chitwan so tigers should leave the nearby forests?

__AGREE
__DISAGREE

23) Do you agree that Tigers have great power and humans should respect them by not disturbing them in the nearby forests?

__AGREE
__DISAGREE

24) Do you agree that your village will benefit from more tourism if tigers are in the nearby forests?

__AGREE
__DISAGREE

25) Do you agree that Tigers should stay in the nearby forests because they keep the forests healthy?

__AGREE
__DISAGREE

26) Do you agree that Tigers are an important part of your culture and should continue roaming the nearby forests?

__AGREE
__DISAGREE

27) Do you agree that Tigers were in Chitwan before humans and have the right to live in the nearby forests alongside humans.

__AGREE
__DISAGREE

28) Does it please you just knowing that tigers exist in the nearby forests?

__YES
__NO

29) Are the risks from tigers something people living in Chitwan can adapt to over time?

__YES
__NO

30) Are risks from tigers avoidable?

__YES
__NO

31) Are the risks from tigers in Chitwan understood by the government or government officials?

__YES
__NO

32) Are the risks from tigers in Chitwan being satisfactorily addressed by the government or government officials?

__YES
__NO

33) Are the people who benefit from tigers the same people who are exposed to the risks of living with tigers?

__YES
__NO

34) How worried are you about Tigers from the nearby forests will attack my pets

__VERY WORRIED
__SOMEWHAT WORRIED
__NOT WORRIED

35) How worried are you about Tigers from the nearby forests will attack my farm animals……..

__VERY WORRIED
__SOMEWHAT WORRIED
__NOT WORRIED

36) How worried are you about Tigers from the nearby forests will attack someone in my village………

__VERY WORRIED
__SOMEWHAT WORRIED
__NOT WORRIED

37) How worried are you about Tigers from the nearby forests will attack me or someone in my family………

__VERY WORRIED

__SOMEWHAT WORRIED
__NOT WORRIED

38) If there were more tigers in the nearby forests, in your opinion would it be very likely, a little likely or not likely on each of the following?

38.1) Tiger will attack my pets…….

__VERY LIKELY
__A LITTLE LIKELY
__NOT LIKELY

38.2) Tiger will attack my farm animals……..

__VERY LIKELY
__A LITTLE LIKELY
__NOT LIKELY

38.3) Tiger will attack someone in my village………

__VERY LIKELY
__A LITTLE LIKELY
__NOT LIKELY

38.4) Tiger will attack me or someone in my family………

__VERY LIKELY
__A LITTLE LIKELY
__NOT LIKELY

39) Many different feelings exist toward tigers. Which of the following comes closest to the way you feel?

__I ENJOY HAVING TIGERS IN MY AREA
__I DO NOT ENJOY HAVING TIGERS IN MY AREA

40) Which of the following comes closest to the way you feel?

__I WORRY ABOUT THE PROBLEMS TIGERS IN MY AREA MAY CAUSE.
__I DO NOT WORRY ABOUT THE PROBLEMS TIGERS IN MY AREA MAY CAUSE.

41) When a tiger becomes a man-eater what action do you think should be taken towards the tiger?

__THE TIGER SHOULD NOT BE DISTURBED
__THE TIGER SHOULD BE SCARED AWAY

__THE TIGER SHOULD BE CAPTURED AND MOVED TO ANOTHER PLACE
__THE TIGER SHOULD BE KILLED

42) When a tiger eats many livestock what action do you think should be taken towards the tiger?

__THE TIGER SHOULD NOT BE DISTURBED
__THE TIGER SHOULD BE SCARED AWAY
__THE TIGER SHOULD BE CAPTURED AND MOVED TO ANOTHER PLACE
__THE TIGER SHOULD BE KILLED

43) This question involves the presence of tigers. Please tell me if the following situations would make you take action to remove nearby tigers.

41.1) A friend tells you that he/she has seen a tiger walking in the nearby forests

__YES
__NO

41.2) You see a tiger walking in the nearby forests

__YES
__NO

41.3) You often hear about and see tigers walking in the nearby forests

__YES
__NO

44) This question involves attacks by tigers on farm animals. Please tell me if the following situations would make you take action to remove nearby tigers.

a) A farm animal from your village is attacked

__YES
__NO

b) One of your farm animals is attacked

__YES
__NO

c) More than one of your farm animals are attacked

__YES
__NO

45) This question involves human attacks by tigers. Please tell me if the following situations would make you take action to remove nearby tigers.

a) A person from this village is attacked

__YES
__NO

b) More than one person from this village is attacked

__YES
__NO

c) You or someone in your family is attacked

__YES
__NO

46) Do you think that the benefits of living near tigers are greater than, equal to, or less than the risks?

__GREATER
__EQUAL
__LESS

47) How many tigers would you prefer living in the nearby forests in the next 10 years compared to now?

__MUCH LESS
__LESS
__SAME
__MORE
__MUCH MORE

48) How important is it *to you* that there are …………….. tigers in the nearby forests in the next 10 years?

__VERY IMPORTANT
__SOMEWHAT IMPORTANT
__NOT IMPORTANT

49) Would you be happy if no tigers existed in the nearby forests?

__YES
__NO
__NOT SURE

50) Which of the following comes closest to the way you feel? Tigers in Chitwan should: *(choose one)*:

__NOT BE PROTECTED
__ONLY BE PROTECTED IN THE NATIONAL PARK
__BE PROTECTED EVERYWHERE TIGERS MIGHT GO INCLUDING THE NEARBY FORESTS

RESPONDENT INFORMATION

Now I am going to ask you some questions about your background, household characteristics, and forest use

51) Are you living here since you born?

__YES
__NO

52) How long have you lived in this house?

__

53) What option best describes your occupation?

__CROP FARMER
__FARM ANIMAL FARMER
__MIXED FARMER
__BUSINESS
__EMPLOYMENT
__OTHER (please specify) ………………………

54) What is your education level?

__

55) Within the last year, did you go in to the forest to collect fodder or firewood?

__YES
__NO **Go to Question No. 57**

56) Since last year till now, out of 365 days, approximately how many work days do you think you have spent *in the nearby forest* collecting fodder or firewood?

_____

Thank you very much for your time and cooperation! The information that you provided is very useful, valuable, and important.

Namaskar!

End time:………………..

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