5-2016

Gaur (*Bos gaurus*) Abundance, Distribution, and Habitat use patterns in Kuiburi National Park, Southwestern Thailand

Supatcharee Tanasarnpaiboon
University of Nebraska-Lincoln, tsree@huskers.unl.edu

GAUR (*BOS GAURUS*) ABUNDANCE, DISTRIBUTION, AND HABITAT USE PATTERNS IN KUIBURI NATIONAL PARK, SOUTHWESTERN THAILAND

by

Supatcharee Tanasarnpaiboon

A DISSERTATION

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Doctor of Philosophy

Major: Natural Resource Sciences

(Applied Ecology)

Under the Supervision of Professor John P. Carroll

Lincoln, Nebraska

May, 2016

GAUR (*Bos gaurus*) ABUNDANCE, DISTRIBUTION, AND HABITAT USE PATTERNS IN KUIBURI NATIONAL PARK, SOUTHWESTERN THAILAND

Supatcharee Tanasarnpaiboon, Ph.D.

University of Nebraska, 2016

Advisor: John P. Carroll

Population status of gaur (*Bos gaurus*), a wild cattle, in most habitats where they are present, is still unknown. As the use of camera traps in wildlife studies are widespread, I developed photographic individual identification procedures and utilized encounter histories of gaur individuals from camera trap data to estimate gaur abundance and density using the spatially explicit capture-recapture analysis. The study was conducted at Kuiburi National Park, southwestern Thailand, comprised of dry evergreen forest, moist evergreen forest, and man-modified secondary forest during November 2013- January 2015. I conducted 71 direct observations in a savannah-like habitat area to observe the numbers, as well as the sex and age ratios of gaur. The maximum number of gaur per sampling occasion observed by direct observation was 89 gaur. The ratio of young to juvenile to adult was 1.6: 1.3: 1: The sex ratio was 1.7 females to 1 male. I also set up 56 camera trap locations for the total of 8,999 trap-nights to monitor gaur numbers and distribution. Camera traps captured 841 gaur encounters in 649 trap-nights at 41 locations. Both observation methods detected herds more frequently than solitary gaur. I identified 22 females (10 adults and 12 juveniles) and 44 males (33 adults and 11 juveniles) based on multiple horn characteristics, including shapes, coloration patterns, and corrugation patterns. The average adult density from photographic capture-recapture analysis was 2.5± 1.7SE gaur/100 km^2 (95% CI = 0.8-8.2), yielding an adult abundance

estimate of 48.2 ± 2.3SE gaur (95% CI = 45.1-54.5) living in the park during the study period. The total number of gaur calculated from the age ratio ranged from 198-239 gaur. Lowland areas with human-modified secondary forest habitats, dominated by grass patches, mineral licks, and reservoirs, have a high frequency of encounters and have greater concentration of gaur than the other zones, which are mainly composed of evergreen forests and are located in mountainous areas. This study is the first to apply photographic capture-recapture data to estimate the population density and abundance of a free-ranging ungulate in Thailand. The technique holds promise for conservation and management of threatened and endangered species that are inherently difficult to sample, but it still needs validation to improve the accuracy of population parameter estimates.

ACKNOWLEDGEMENTS

My sincere thanks are dedicated to many people who assisted me along my Ph.D. career. My deep gratitude is extended to Dr. John Carroll, my committee chair, for his caring and understanding. His guidance and support are important for my success. I would like to thank Dr. Larkin Powell and Dr. George Gale for their constructive comments, suggestions in data analysis and manuscript reviewing, as well as their support and encouragement during my study. I also greatly appreciate Dr. David Marx, for his valuable comments on my dissertation.

My research project in Thailand would not be accomplished without these generous people and organizations. I thank Kuiburi National Park and Department of National Parks, Wildlife, and Plant Conservation (DNP) for permission and support to conduct the project. Thanks to all Kuiburi National Park supervisors, Mr. Prawatsart Chantep, Mr.Suriyon Phodhibundit, Mr. Preecha Wittayaphan, and Mr. Boonlue Poolnil, for coordinating assistance and for providing accommodation and logistic support. I am indebted to the staff of Kuiburi National Park, especially Mr. Jaruwat Nuchsiri, the head of the protection section, Mr. Pakpoom Aramsirirujiwet, the assistant park supervisor; Mr. Sompong Aim-oad, the head of Payang Ranger Substation; and Mr. Tanapat Preeprem, a park staff, for coordinating and helping in field work. I also thank my field assistants, Ms. Kanoktip Somsiri and Ms. Kanya Sorpimai. I am grateful to World Wildlife Fund (Thailand), Mr. Wayuphong Jitwijak, manager of elephant conservation project, and the WWF staff, who allowed me to participate in joint patrolling and provided help while I was in the remote forests. Thanks also to Dr. Robert Steinmetz, technical program specialist-biologist, for his foundational study of the wildlife

community in Kuiburi National Park and his useful comments during my study. Thanks also to Mr. Thammanoon Temchai for the permission to use the land-use database of Kuiburi National Park.

My Ph.D. study was supported by a Thai government scholarship in Science and Technology. This project was approved by the University of Nebraska-Lincoln's Institutional Animal Care and Use Committee (permit#944). This research was partially supported by a Grant-In-Aid of Research from the National Academy of Sciences, administered by Sigma Xi, The Scientific Research Society (Grant ID# G20130315163474), Siam Winery Trading Plus Co., Ltd., and University of Nebraska-Lincoln.

Thanks to the School of Bioresources and Technology, King Mongkut's University of Technology Thonburi (KMUTT) for hosting me during the time in Thailand. Thanks also to many people around me who always encourage me and make my life enjoyable, including my labmates in Conservation Ecology Groups KMUTT, Dr. Carroll's lab, and Dr. Larkin's lab; and friends and communities in Athens, Georgia; and Lincoln, Nebraska. I would also like to thank Warnell School of Forestry and Natural Resources, University of Georgia-- my home for my first three years in the USA-- for providing me the knowledge and academic foundation for my research. Special thanks to Dr. Dusit Ngoprasert, Dr. Drew Tyre, Dr. Christopher Chizinski, and Jonathan Spurgeon for suggestions in data analysis. I am also indebted the UNL writing center staff for helping me review English grammars and writing styles. Big thanks to Dr. Mattana Srikrachang for providing opportunity to work in such a wonderful place and to introduce me to those cool animals. Thanks to my past colleagues at DNP, as well as teachers and

friends in Department of Biology, Mahidol University, for motivation in wildlife ecology studies.

Finally, I would like to thank my dear parents, Mr. Meiki Sae-Koo and Mrs. Wipapon Tanasarnpaiboon, and my family, for being always supportive, understanding, and patient during my prolonged academic life.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

CHAPTER 2.

LIST OF APPENDICES

CHAPTER 1

GENERAL INTRODUCTION

SYSTEMATICS OF GAUR

Gaur *Bos gaurus* is an ungulate, which describes hoofed mammals and includes all wild cattle species belonging to the superorder Cetartiodactyla. The order Artiodactyla contains even-toed ungulates, i.e., ruminants (Suborder Ruminantia), pigs (Suborder Suiformes), hippos (Suborder Ancodonta, and camels (Suborder Tylopoda). Wild cattle including gaur belong to Family Bovidae in Suborder Ruminantia. A distinguishing characteristic of members of Bovidae is their digestive system that is comprised of three or four stomach compartments with symbiotic interactions with cellulose-digestible microorganisms. The horns of Bovids are permanent bones covered with sheaths of keratin. Bovids are diverse with approximately 140 species and are prevalent across a large geographical distribution. Bovids are found on all continents except Australia, Antarctica, and South America. Bovids are sub-divided into three tribes, and gaur is a member of the tribe Bovini, consisting of cattle, bison, yak, buffalo and saola. In the most recent morphological classification, 13 species are listed as the members in the Bovini tribe (Hassanin 2014):

1) *Bos gaurus* C. H. Smith, 1827 – guar

2) *Bos javanicus* d’Alton, 1823 – banteng

3) *Bos mutus* (Przewalski, 1883 – yak

4) *Bos primigenius* Bojanus, 1827 –aurochs

5) *Bos sauveli* Urbain, 1937 – kouprey

6) *Bison bison* (Linnaeus, 1758) – American bison

7) *Bison bonasus* (Linnaeus, 1758) – European bison

8) *Bubalus arnee* (Kerr, 1792) – Asian buffalo

9) *Bubalus depressicornis* (C. H. Smith, 1827) – lowland anoa

10) *Bubalus mindorensis* Heude, 1888 – tamaraw

11) *Bubalus quarlesi* (Ouwens, 1910) – mountain anoa

12) *Pedudoryx nghetinhensis* Dung, Giao, Chinh, Touc, Arctander & MacKinnon, 1993 – saola

13) *Syncerus caffer* (Sparrman, 1779) – African buffalo

Based on measurements of skulls and horns, two subspecies of gaur have been proposed. *Bos gaurus gaurus* lives in India, Nepal, and possibly Bangladesh whereas the other subspecies, *Bos gaurus laosiensis*, is found in Southeast Asia (Myanmar, Lao PDR, Vietnam, Cambodia, Thailand and west Malaysia) and southern China. However, the dual classification is still inconclusive because the morphological measurements are based on only a few skull samples, and there is no supporting genetic analysis (Groves and Grubb 2011, Hassanin 2014). In some instances, *Bos frontalis* (Lambert 1804) has alternatively been used as the scientific name of gaur, however, the International Commission of Zoological Nomenclature (2003), in a recent review, decided to use *Bos frontalis* only for the mithun, a domestic form of gaur.

A gaur has a high ridge on the back and white or yellow stockings on all four legs. The forehead is grayish or golden due to oil secretion, down to the level just above the eyes (Figure 1.1). A unique feature of the gaur distinguishing them from other bovini species is the oily secretion on the males' skin, which has insect repellant properties (Tran and Chauhan 2007, Ahrestani and Karanth 2014). Newborn gaur are light orange-brown and change to black after 4-5 months. Gaur body mass ranges from 440 to 941 kg. Shoulder height ranges from 145 to 197 cm. The head and body

length ranges from 249 to 330 cm. Tail length ranges from 70 to 89 cm. Morphological characteristics including horns, dorsal ridge, and muscularity are used to distinguish between males and females. Such morphological differences between sexes are visible after approximately 15 months. For example, females are not as stocky and muscular as males and have a thinner dorsal ridge. Female horns are much smaller, closer together, and pointed inwards (Lekagul and McNeely 1988, Ahrestani 2009). However, the secondary sexual traits, such as horn curvature, dorsal ridge, and muscularity are not conspicuous in the field until they reach adult age (greater than 3 years old). The estimated maximum longevity of both sexes is 25 years in captivity (Ahrestani 2009).

Gaur are social animals, and herds are a mixture of both sexes and multiple age classes. However, males may be observed as solitary individuals, or in small groups containing only males. Males also often compete to become the dominant male in the herd, especially during the breeding season (Lekagul and McNeely 1988, Prayurasiddhi 1997, Ahrestani and Karanth 2014). The timing of the annual mating and calving period varies among regions. For example, the mating season in a gaur population in central India was reported in December and January, yielding the calves in August and September (Dunbar-Brander 1923 in Ahrestani and Karanth 2014), whereas the peak rutting period of a southern India population was in November to March (Morris 1938 in Ahrestani and Karanth 2014). In Malaysia, young gaur were seen at all times except from October to December (Hubback 1937 in Ahrestani and Karanth 2014). However, recent study of a gaur population in India suggested that gaur do not have specific mating seasons because calves were seen throughout the year (Ahrestani and Prins 2011). The gestation period is approximately 9-10 months (~ 280 days). Female gaur become sexually mature at the age of three years and have

been shown to reproduce at the age of 18 years in captivity (Ahrestani 2009, Ahrestani and Karanth 2014).

GAUR BEHAVIOR AND ECOLOGY

Gaur is assumed as a nocturnal animal. They start foraging at dusk in the open areas, which provide grasses, but gaur rest and sleep almost all day in the forest until dusk. They browse on any edible leaves and young green grass. The mineral salt is also necessary for the gaur but is rarely used in dry seasons when the soil dries out. Water is also a crucial resource for gaur (Conry 1981, Lekagul and McNeely 1988, Bidayabha 2001, Ahrestani and Karanth 2014).

Gaur inhabit forests of all elevations up to 2,800 m. Habitats utilized by gaur vary by season, influenced by food and water availability. Deciduous forests and grassy openings are often used during the wet season. In contrast, they move towards evergreen forest and hilly terrain to seek forage and water during the dry season (Schaller 1967, Steinmetz 2004, Ahrestani 2009, Melletti and James Burton 2014). They eat a wide variety of vegetation, including bamboos, grasses, herbs, shrubs, vines, tree bark, and fruits. They are considered grazers but shift to browse other plants during drier periods, when grasses and bamboos are scarce (Prayurasiddhi 1997, Steinmetz 2004, Gad and Shyama 2011, Ahrestani et al. 2012). Multiple factors, such as forest types, humidity, elevation, food availability, and anthropogenic pressures may result in changes of gaur social behavior and habitat utilization patterns in both space and time (Bhumpakphan 1997, Piyapan 2000, Steinmetz 2004, Ahrestani et al. 2012). They have been reported to only inhabit the remote forested areas that are far from human activity (Lekagul and McNeely 1988, Bhumpakphan 1997). However, many recent studies have suggested that gaur can adapt to human-

disturbed habitats. For example, they frequently forage near forest edge habitats and in regenerating forests such as Khao Phaeng Ma in eastern Thailand, Kuiburi National Forest Reserve in southwest Thailand (Bidayabha 2001, Department of National Parks Wildlife and Plants Conservation 2010), and near agriculture areas in Lepar Valley, Pahang, Malaysia (Conry 1989). Their habitat use patterns also depend on sex and social structure (Conry 1989, Prayurasiddhi 1997, Steinmetz et al. 2008). In a study of the large mammal community in the Tenasserim-Dawna Mountains, Thailand, solitary bulls prefer montane forest (>1000 m elevation), while guar herds prefer mixed deciduous and semi-evergreen forest in lowlands (<1000 m elevation), which provides high quality food for gestation and lactation. Bulls use montane forest even though they contain lower-quality forage because dense habitats in montane forest may offer a refuge for bulls to avoid hunting by humans (Steinmetz et al. 2008).

Gaur are one of many prey species for large predators, especially tigers *Panthera tigris*, leopards *Panthera pardus*, and dholes *Cuon alpinus* (Schaller 1967, Karanth and Sunquist 1995, Karanth and Stith 1999, Ngoprasert et al. 2012). Studies of predator-prey interactions in Kuiburi National Park showed that an increase in the presence of tigers was positively related to predation occurrences on gaur (Steinmetz et al. 2009). Other studies of the tiger-prey relationship in India also demonstrated that gaur contribute a large portion of prey biomass for the tiger in India (Karanth and Sunquist 1995, Ahrestani 2009). The benefits of prey population recovery should maintain and increase predator populations (Karanth and Stith 1999). However, the consequences might also be negative for local villagers at the forest edge. In areas with a high density of gaur such as Indian subcontinents, crop raiding by gaur is intense and some reports exist on human injury or death by gaur attacks (Manoj et al. 2013, Prashanth et al. 2013).

Large herbivores, such as gaur, influence the plant community like landscape architects. Their foraging behaviors and movements might cause habitat modification, which facilitate seed germination and influence mortality of plants at various degrees (Ahrestani and Karanth 2014). They require a large amount and variety of plants to forage to meet the metabolic requirement of their large body size. In addition, because gaur forage on many plant forms, including fruits, they also are potential seed dispersers (Corlett 1998).

GAUR DISTRIBUTION, POPULATION STATUS, AND THREATS WORLDWIDE AND IN THAILAND

Gaur are distributed from the Indian peninsula to as far north as Nepal and east throughout mainland Southeast Asia (Figure 1.2) (Lekagul and McNeely 1988, Melletti and James Burton 2014). Their conservation status on the IUCN Redlist is listed as Vulnerable, with the estimated global population of 13,000-30,000 animals (Duckworth et al. 2008). It is now assumed that no single area has a population >1,000 individuals. Hence, the global trend in abundance has generally suggested declining populations likely due to population fragmentation from habitat loss and poaching for meat (Choudhury 2002, Duckworth et al. 2008). Even in the Indian Subcontinent, which is home to the largest gaur population, the population is highly fragmented and most subpopulations are not viable populations as a result of reduced meta-population connectivity (Choudhury 2002).

In Thailand, gaur are reported in 45 protected areas including 25 national parks and 21 wildlife sanctuaries as shown in Figure 1.3 (Department of National Parks Wildlife and Plants Conservation 2010). Srikosamatara and Suteethorn (1995) estimated that the total population size of gaur in Thailand based on various secondary

sources and short term field surveys in several national parks was 915 individuals inhabiting only 14 protected areas. Half of the gaur in Thailand was in the Western Forest Complex (WEFCOM), including Huai Kha Khaeng Wildlife Sanctuary and Thung Yai Naraesuan Wildlife Sanctuary, and the other populations scattered in other forest complexes (Figure 1.3). Gaur populations in much of Southeast Asia region have generally decreased due to poaching for trophies, habitat loss and fragmentation, and effects of human encroachment in forested habitats for settlement and agriculture (Heinen and Srikosamatara 1996, Ahrestani and Karanth 2014). In contrast, gaur populations in Thailand have increased in abundance. For example, the abundance estimates of gaur in Thung Yai Naraesuan Wildlife Sanctuary, western Thailand from tracks and signs indicated that the abundance indices of gaur gradually increased by three times over the six year study during 1999-2005 (Steinmetz et al. 2010). The prey surveys in Kuiburi National Park, southwestern Thailand, in 2006 and 2009 indicated a positive tendency in gaur occurrence and abundance (Steinmetz et al. 2009). The same trends also appeared in the other regenerating forests or buffer areas formerly utilized by humans such as Khao Phaeng Ma Forest Reserve which is contiguous to Dong Phaya Yen-Khao Yai Forest Complex (Figure 1.3) (Bidayabha 2001).

In Thailand, most of the biodiversity is restricted to protected areas, and conservation actions of natural resource management are primarily implemented in such areas. However, forested areas are still continuously encroached upon by human settlement and agriculture. Forested areas in Thailand have declined from 43 % of the country’s area in 1973 to 31% in 2013 (Department of Forestry 2013). Small and fragmented gaur populations, due to shrinking available habitats, increase vulnerability of gaur persistence. For instance, gaur might have to confront threats associated with small and declining population size, including inbreeding pressures

(Lacy 1997) and disease outbreaks (Woodroffe 1999). In addition, gaur inhabiting edge habitats, might more frequently be exposed to human threats, including poaching, being killed when raiding crops, and contagious diseases from domestic cattle.

KUIBURI NATIONAL PARK, THAILAND

Kuiburi National Park (11° 40' – 12° 10' N and 99° 20' – 99° 50' E) is located in Prachuap Khiri Khan Province in southwestern Thailand (Figure 1.4). It is a part of the Kaeng Krachan Forest Complex, which is in the Tennesarim range. It was established in 1999 and covers 969 km^2. It is a mosaic between forested and human-utilized habitats. The central part of the park is comprised of dry evergreen forest and managed-secondary forest under the Royal-Initiated Kuiburi National Forest Reserve Project (also called as ‘Payang’ or ‘Khunchorn Project’). The northern side of the park is contiguous to a military protection area, which is an ecological corridor between Kaeng Krachan National Park and Kuiburi National Park. Those areas will be officially included in the park and the total park area will become 1,057 km^2.

The climate is tropical savannah with a pronounced dry season and long wet season (Figure 1.5). Seasons can be divided into three. Rainy season starts from May to November (7 months). The cooler dry season is from December to February (3 months). The rest of the year, March to mid-May, is the hot season influenced by occasional tropical monsoons (Temchai et al. 2010). The highest temperature occurs in the months of April and May, in which temperatures can reach to 37 °C. The lowest temperature occurs in December and January, in which temperatures can be as low as 18 °C. Average annual precipitation in Prachaup Khiri Khan Province from 2009 to 2013 is 918 mm (ranges 793-1418 mm) with the average of 131 rain days

(Meterological Department 2014). The precipitation shows apparent wet and dry months. Wet periods start from May to November with average high precipitation and more rain days (Figure 1.5)

The park is characterized by steep mountainous topography incised with seasonal and perennial streams that lie at 100-300 m elevation. The highest elevation is 946 m. Kuiburi National Park land use types are comprised of a mosaic of evergreen forest, deciduous forest, secondary forest, and other habitat types that mostly are current or former human settlements (Figure 1.4). Temchai et al. (2010) classified landuse patterns across Kuiburi National Park and an adjacent ecological corridor from Landsat5 Thematic mapper (TM) and SPOT satellite images based on image processing and visual interpretation into the following categories.

1. Evergreen forests

Plant community in this forest type is not deciduous. Evergreen forest mostly covers the western part of the park and is contiguous to the evergreen forest of Myanmar.

1.1. Hill evergreen forest (HE)

This type of forest is found in small patches only on the mountain ridge at the Thailand-Myanmar border. It covers only 0.004 % of the park.

1.2. Tropical moist evergreen forest (ME1)

Tropical moist evergreen forest patches are distributed on mountains along the Myanmar border at the elevation of 500-900 m. They are found in valleys in moist areas along perennial streams or in gallery forests. This forest type covers about 14% of the park area. It is characterized by closed and complex canopy layers.

The dominant plant species at the top canopy are trees in the Family Diptercarpaceae, e.g., *Parashorea stellate* (Kai Kheio), *Dipterocarpus dyeri* (Yang

Glong), *Acrocarpus fraxinifolius* (Sadao Chang). Those trees can be 30-40 m high. The middle canopy is comprised of several species, e.g., *Aphanamixis polystachya* (Ta Seau), *Knema* sp. (Leaud Kwai), *Nephelium lappaceum* (Ngho Pa, wild rambutan). The lower canopy plant community includes palms, rattans, ferns, and herbs in the Family Zingiberaceae.

1.3. Semi-evergreen forest (ME2)

This forest type is usually a transition forest between moist evergreen forest and middle dry evergreen forest. It is located at 400-900 m elevation. These patches are sparsely distributed along the ridges at the border in the south zone of the park and in other moist evergreen forests in the central and the north zones of the park. ME2 covers 22% of the park area. The importance of this forest type is that it is the only habitat for some animals such as Malayan Tapir (*Tapirus indicus*), which inhibits only moist evergreen forests.

The plant community of the ME2 is mixed between evergreen species (70-80%) and deciduous species (less than 25%). Seasonality highly influences the plant community in ME2. In the wet season, deciduous species regrowth causes the vegetation to become denser and to contain more moisture than in the dry season. Due to such characteristics, it is sometimes called higher dry evergreen forest. Canopy structures can be divided into 3-4 layers. The top canopy layer’s height is about 30-35 m.

1.4. Middle dry evergreen forest (DE1)

Middle dry evergreen forest is prevalent in the east and the central zone of the park at elevations of 350-650 m. Some patches are also found near the streams at lower elevations of 150 m. They intersperse between semi-evergreen forest and lower dry evergreen forest. It covers about 24 % of the park.

Forest structures in DE1 can be divided into 3 layers. The top canopy is 20-25 m high, such as *Tetrameles nudiflora* (Sompong), *Erythrina subumbrans* (Thong Lang Pa), and *Mansonia gagei* (Chan Hom). The middle canopy is 10-15 m high and the lower canopy contains many species of shrub, herb, and climber.

1.5. Lower dry evergreen forest (DE2)

Lower dry evergreen forest is the unique plant community in Khaeng Krachan Forest Complex, only found in Prachuap Khirikhan and Petchaburi provinces. It is dominated by *Streblus ilicifolius* (Koi Nham), which is a thorny shrub species in the middle canopy. Canopies in DE2 are more open than in DE1. DE2 patches are located at the elevation of 100-400 m and cover 29% of the park area. Most of DE2 patches are usually adjacent to agriculture areas. DE2 is a preferred habitat for elephants.

1.6. Dry evergreen forest mixed with deciduous forest (DEMD)

Dry evergreen forest mixed with deciduous forest patches are found in the east region of the park, also adjacent to agriculture areas. They also sparsely occur on the ridges, in which the soil condition is usually dry. DEMD covers about 3% of the park area. Bamboos mixed with the deciduous plant species are common plants in this forest type.

2. Deciduous forests

Deciduous forests are generally drier than the evergreen forests. They contain deciduous plant species. Only a small proportion of deciduous forests appears in the north and the south of Kuiburi National Park. Mixed deciduous forest (MD) is the only deciduous forest type found in the park.

The mixed deciduous forest covers only 0.6% of the park. The patches are found sparsely along the slope in the southern boundary of the park at the elevation of 250-300 m. The leaves of most plants fall during the dry season.

Average canopy height of MD is 10-15 m. The lower canopy is 7-10 m high. Bamboos, such as *Thyrsostachys siamensis*, *Bambusa* spp., build up the plant community of lower canopies. Most MD patches were formerly utilized by humans.

3. Other land use types

Other land use types in Kuiburi National Park are mostly the areas formerly and currently utilized by humans. Most of them are located along the eastern boundaries of the park.

3.1. Secondary forest (SF)

Most secondary forest in Kuiburi National Park is regenerating from old human settlements and agriculture areas by either natural succession or human-modified processes. Secondary forest covers 4% of the park.

Surprisingly, secondary forest in Kuiburi National Park has become the core habitat for many charismatic mammals such as the Asian elephant (*Elephus maximus*), gaur, banteng (*Bos javanicus*), tiger (*Panthera tigris*), and leopard (*Panthera pardus*). The largest secondary forest of Kuiburi National Park is located in the central section of the park (next section below).

Plant community in secondary forest is comprised of tree plantations for habitat restoration, such as *Eucalyptus camaldulensis* (Eucalyptus tree), *Lagerstroemia* sp. (Ta Bak), and *Casuariana junghuhniana* (Son Pradiphat), *Tectona grandis* (Teak), *Leucaena leucocephala* (Kra Tin Yak). Plant species that grew up by natural forest succession include *Streblus ilicifolius* (Koi Nham), *Bridelia ovata* (Ma Ka Mong); and climbers. Some parts of these areas are managed to be grass patches, providing food resources for ungulates. There are several pioneer species in such areas, such as *Chromolaena odoratum* (Saab Seua), *Imperata cylindrical* (Ya Ka), *Lantana camara* (Pha Gra Grong). Trees are sparse.

3.2. Old clearing area (OC)

Most OC patches are formerly villages. The plant community contains weeds, agriculture plants and pioneer species such as *Streblus asper*, *Ficus fistulosa* (Fig), and *Gigantochloa hassakarliana* (bamboo). They only cover 0.1% of the park.

3.3. Bamboo forest (BB)

Bamboos grow patchily in forest gaps in ME1 and ME2 at the elevation 200-800 m. The common bamboo species found in moist evergreen forest is *Gigantochloa hasskarliana*. Bamboo patches are also sparsely in DE1 and DE2 in the eastern area of the park at 300 m. The common bamboo species in dry evergreen forest are *Bambusa* sp.(Pai Sang) and *Thyrsostachys siamensis* (Pai Ruag). Few trees emerge among bamboos. BB is about 0.2% of the park area.

3.4. Agriculture areas (AG)

Agriculture areas include both monocrop and multi-crop plantations. Most of them are located at the outside boundary of the park except one forest village, called Pamark, in the north region. Agriculture areas cover about 2% of the park area.

Important economic crops grown include pineapples, para rubber, palms, and mangoes. While the AGs along the boundaries usually are monocrops, the villagers who settled inside the park usually plant multi-crop for subsistence, such as *Areca catechu* (Mark), *Durio zibethinus* (Durian), coconuts, bananas, *Atrocarpus hetrophyllus* (Jackfruit), *Parkia speciose* (Sa Tor), and some bamboos.

3.6) Water (WT)

Most water areas that are identifiable from the satellite images are man-made reservoirs, which were built for consumption and agriculture. They cover less than 0.1% of the park area.

The Royal-initiated Kuiburi National Forest Reserve

The 50-km^2 secondary forest patch in the central zone of Kuiburi National Park, also called "Khun-chorn[1] Project" or "Payang," is the core area of the park as a home for most wildlife, and a highlight destination for tourists seeking wildlife watching in Kuiburi National Park. The Khun-chorn project was an important area for economic crop cultivation, especially pineapples. Intensive use of fertilizers and chemicals in agriculture caused forest and soil degradation and affected food resources and habitat availability for wildlife. Hence, the human-wildlife conflicts, especially crop raiding by elephants, are more severe. Subsequently, farmers commonly used poisons, illegal electric fences, and snares that result in injury and death to elephants and gaur. In responses to the rising human-wildlife conflict problems and habitat degradation, The Kuiburi National Forest Reserve Conservation and Restoration Project was established under the recommendation of His Majesty Bhumibol Adulyadej in 1997. Reforestation, changes in pineapple plantation practice, land development, and water management were implemented in area of the old plantation to mitigate the problems. With these strategies, wildlife, especially ungulates, benefit from the increase in food and resource availability and the decrease confrontation with the farmers. The losses from crop raiding decreased and the farmers who involved in tourism earned extra income to compensate for the loss.

The World Wildlife Fund (WWF-Thailand) started wildlife surveys in 2006 to monitor the predator-prey community. The study revealed that many charismatic species inhabit the Kuiburi National Park, especially in Payang, including tigers, leopards, dholes, gaur, banteng, and tapirs (Steinmetz et al. 2007). However, the occurrence of tigers was lower compared to India and in the Western Forest Complex

[1] *Khun-chorn* means 'elephant' in Thai

of Thailand, possibly due to low density of prey. As a result, the Kuiburi tiger conservation project was initiated. WWF-Thailand proposed and supported the park to increase prey density through habitat improvement and anti-poaching strategies including outreach activities to the local people and increased law enforcement by training park rangers. Three prey recovery zones were established in different areas of the park, including Hub Inthanin and Payang, located near the center of the park, and Khlong Kui near the park headquarters in the south. Payang is the only area that implemented both habitat restoration and anti-poaching strategies. Herbivores, especially elephants and gaur, benefit from the increase in food and water availability, which could cause an increase of ungulates population. Thus, with the increase in prey population, Kuiburi National Park may become a suitable habitat for large carnivores like tigers.

Additionally, WWF initiated the Elephant Conservation Project to conserve elephants and mitigate the human-elephant conflicts in the area. The actions have been supported by both private sectors, e.g. Siam Winery Trading Plus Co.Ltd., and the military, government offices (e.g., Department of National Park Wildlife and Plant Conservation, DNP), the Border Patrol Police, the local government agencies, and local communities. Together, these organizations established a conservation partnership, called POWER Kuiburi, to manage and run the campaign to improve habitats for the elephant, which is the national animal of Thailand.

JUSTIFICATION

Fundamental information about populations such as abundance estimates and population structure is needed to develop conservation strategies. Large herbivores likely respond differently to changing environmental and ecological conditions across

spatial and temporal scales (Senft et al. 1987). As a result, subpopulations may be confronted with variation of limiting factors depending on the given context within which they exist. Understanding those constraints and the general ecology of populations at multiple scales may guide wildlife and habitat management practices across a species' range.

Across the geographical distribution of gaur, the Indian population is the most well-studied; population characteristics in other countries, such as Lao PDR, Southern China, and Myanmar, remain less known, (Ahrestani and Karanth 2014). In Thailand, most of the studies were about monitoring gaur as they are a prey for tigers. Gaur population status was commonly obtained from sign surveys and gaur presence from camera trap data and roughly reported as the relative abundance index and occupancy across the landscape. Studies of gaur behavioral and other ecological aspects, including home range, movement, and diets, were concentrated only in Huai Kha Khaeng Wildlife Sanctuary in the Western Forest Complex (Srikosamatara and Suteethorn 1995, Prayurasiddhi 1997) and Khao Paeng Ma adjacent to Khao Yai National Park (Bidayabha 2001, Prayong 2014). Therefore, gaur population status in other parts of Thailand is relatively unknown and information regarding sub-populations is needed to conserve gaur across their range.

Kuiburi National Park is one of the most famous places for wildlife watching because of charismatic mammals, such as elephants, gaur, and banteng. Kuiburi National Park is promoted by local communities as a way to promote the tourism industry. Wildlife watching can generate income for the local people who were affected by elephant crop raiding. A community-owned club was established to manage the wildlife watching activities in the Payang area. The number of visitors has been gradually increasing since the park was established (Department of National

Parks 2014). Other than the wild elephants, gaur are also attractive to the tourists. Hence, understanding the behavior and ecology of gaur may also support current tourism activities.

In summary, gaur is significant from both ecological (i.e., prey species for tigers) and recreational (i.e., wildlife viewing) perspective, but still limited knowledge exists for most populations in Thailand. My study aims to provide fundamental information of gaur populations using science-based methods, which should be able to fill gaps in information about this charismatic wildlife species, and should be useful for the future management planning for both conservational and recreational purposes.

OBJECTIVES

The goal of this study is to estimate abundance and density of gaur in Kuiburi National Park using the capture-recapture methods based on multiple survey techniques. To accomplish that goal, I set up the following objectives.

1) Overview detection, number of gaur, and sex and age ratios obtained from direct observations and camera traps. Then, describe effect of habitat heterogeneity across Kuiburi National Park on the distribution of gaur (Chapter 2).

2) Develop photographic individual identification procedure for gaur (Chapter 3).

3) Estimate gaur population density based on capture-recapture analysis and extrapolate gaur abundance in the study area (Chapter 3).

LITERATURE CITED

Ahrestani, F. S. 2009. Asian Eden : Large herbivore ecology in India. Ph.D. Wageningen University. 117 pp. pp.

Ahrestani, F. S., I. M. A. Heitkönig, and H. H. T. Prins. 2012. Diet and habitat-niche relationships within an assemblage of large herbivores in a seasonal tropical forest. Journal of Tropical Ecology 28:385-394.

Ahrestani, F. S., and K. U. Karanth. 2014. Gaur *Bos gaurus* C. H. Smith, 1827. Pages 174-193 *in* M. Melletti, andJ. Burton, editors. Ecology, Evolution and Behaviour of Wild Cattle. Cambridge University Press.

Ahrestani, F. S., and H. H. T. Prins. 2011. Age and sex determination of gaur Bos gaurus (Bovidae). Mammalia: International Journal of the Systematics, Biology & Ecology of Mammals 75:151-155.

Bhumpakphan, N. 1997. Ecological characteristics and habitat utilization of Gaur (*Bos gaurus* C. H. Smith, 1827) in different climatic sites. Ph.D. (Forestry). Kasetsart University. 125 pp. pp.

Bidayabha, T. 2001. Ecology and behavior of Gaur (*Bos gaurus*) in a degraded area at Khao Phaeng-Ma, The northeastern edge of Khao Yai National Park, Thailand. M.Sc. (Environmental Biology). Mahidol University. 61 pp. pp.

Choudhury, A. 2002. Distribution and conservation of the Gaur *Bos gaurus* in the Indian Subcontinent. Mammal Review 32:199-226.

Conry, P. J. 1981. Habitat selection and use, movements, and home range of Malayan Gaur (*Bos gaurus hubbacki*) in Central Pahang, Malaysia. M.Sc. University of Montana. 120 pp. pp.

_____. 1989. Gaur *Bos gaurus* and development in Malaysia. Biological Conservation 49:47-65.

Corlett, R. T. 1998. Frugivory and seed dispersal by vertebrates in the Oriental (Indomalayan) Region. Biological Reviews 73:413-448.

Department of Forestry. 2013. Forestry statistics data.

Department of National Parks, Wildlife and Plants Conservation. 2014. Tourists statistics data. <http://park.dnp.go.th/visitor/indexstatistics.php>. Accessed 2 March 2015.

Department of National Parks Wildlife and Plants Conservation. 2010. Status of large mammals in Thailand. 302 pp.pp.

Duckworth, J. W., R. Steinmetz, R. J. Timmins, A. Pattanavibool, Z. Than, T. Do, and S. Hedges. 2008. *Bos gaurus*. *in* IUCN2010. IUCN Red List of Threatened Species.

Gad, S. D., and S. K. Shyama. 2011. Diet Composition and Quality in Indian Bison (Bos gaurus) Based on Fecal Analysis. Zoological Science 28:264-267.

Groves, C. P., and P. Grubb. 2011. Ungulate taxonomy. Johns Hopkins Univeristy Press, Baltimore, MD. 317.pp.

Hassanin, A. 2014. Systematic and evolution of Bovini. Pages 7-20 *in* M. Melletti, andJ. Burton, editors. Ecology, Evolution and Behaviour of Wild Cattle. Cambridge University Press.

Heinen, J. T., and S. Srikosamatara. 1996. Status and Protection of Asian Wild Cattle and Buffalo. Conservation Biology 10:931-934.

International Commission of Zoological Nomenclature. 2003. Usage of 17 specific names based on wild species which are pre-dated by or contemporary with those based on domestic animals (Lepidoptera, Osteichtyes, Mammalia): conserved. Bulletin of Zoological Nomenclature 60:81-84.

Karanth, K. U., and B. M. Stith. 1999. Prey depletion as a critical determinant of tiger population viability. Pages 100–113 *in* J. Seidensticker, S. Christie, andP. Jackson, editors. Riding the Tiger: Tiger Conservation in Human dominated Landscapes. Cambridge University Press, Cambridge, UK.

Karanth, K. U., and M. E. Sunquist. 1995. Prey selection by tiger, leopard and dhole in tropical forests. Journal of Animal Ecology:439-450.

Lacy, R. C. 1997. Importance of Genetic Variation to the Viability of Mammalian Populations. Journal of Mammalogy 78:320-335.

Lekagul, B., and J. A. McNeely. 1988. Mammals of Thailand. 2nd edition. Association for the Conservation of Wildlife, Bangkok. 758 pp.pp.

Manoj, K., R. Bhattacharyya, and P. K. Padhy. 2013. Forest and Wildlife Scenarios of Northern West Bengal, India: A Review. International Research Journal of Biological Sciences 2:70-79.

Melletti, M., and e. James Burton. 2014. Ecology, Evolution and Behaviour of Wild Cattle. Cambridge University Press. pp.

Meterological Department. 2014. Climatological Data of Prachaup Khirikhan station.

Ngoprasert, D., A. J. Lynam, R. Sukmasuang, N. Tantipisanuh, W. Chutipong, R. Steinmetz, K. E. Jenks, G. A. Gale, L. I. Grassman Jr., S. Kitamura, J. Howard, P. Cutter, P. Cutter, P. Leimgruber, N. Songsasen, and D. H. Reed. 2012. Occurrence of Three Felids across a Network of Protected Areas in Thailand: Prey, Intraguild, and Habitat Associations. Biotropica.

Piyapan, P. 2000. Resource partitioning of sympatric ungulates in a dry tropical of western Thailand. M.Sc. (Environmental Biology). Mahidol University. Bangkok. 83 pp. pp.

Prashanth, P. K. M., V. Kumara, and S. Thirumala. 2013. Man-Animal conflicts in protected areas, a case study of Gaur, Bos Gaurus H. Smith from the Mookambika wildlife sanctuary, Kollur, Karnataka, India. International Journal of Current Microbiology and Applied Sciences 2:466-475.

Prayong, N. 2014. Habitat Management for gaur concentration along the edge of a protected area. Ph.D. (Biology). Department of Biology, Mahidol University. Bangkok, Thailand. 109 pp.

Prayurasiddhi, T. 1997. The ecological separation of Gaur (*Bos gaurus*) and Banteng (Bos javanicus) in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Ph.D. University of Minnesota. 266 pp. pp.

Schaller, G. B. 1967. The deer and the tiger : A study of wildlife in India. The University of Chicago press. 370 pp.pp.

Senft, R., M. Coughenour, D. Bailey, L. Rittenhouse, O. Sala, and D. Swift. 1987. Large herbivore foraging and ecological hierarchies. Bioscience 37:789-799.

Srikosamatara, S., and V. Suteethorn. 1995. Populations of gaur and banteng and their management in Thailand. Nat. Hist. Bull. Siam Soc. 43:55-83.

Steinmetz, R. 2004. Gaur (*Bos gaurus*) and Banteng (*B. javanicus*) in the lowland forest mosaic of Xe Pian Protected Area, Lao PDR: abundance, habitat use, and conservation. Mammalia 68:141-157.

Steinmetz, R., W. Chutipong, N. Seuaturien, and E. Chirngsaard. 2008. Community structure of large mammals in tropical montane and lowland forest in the Tenasserim-Dawna Mountains, Thailand. Biotropica 40:344-353.

Steinmetz, R., W. Chutipong, N. Seuaturien, E. Chirngsaard, and M. Khaengkhetkarn. 2010. Population recovery patterns of Southeast Asian ungulates after poaching. Biological Conservation 143:42-51.

Steinmetz, R., N. Seuaturien, W. Chutipong, C. Chamnankit, and R. Phoonjampa. 2007. The ecology and conservation of tigers, other large carnivores, and their prey in Kuiburi National Park, Thailand.

Steinmetz, R., N. Seuaturien, W. Chutipong, and B. Poonnil. 2009. The ecology and conservation of tigers and their prey in Kuiburi National Park, Thailand.

Temchai, T., C. Chamnankid, and A. Yoosomboon. 2010. Habitat Diversity and Landuse of Kuiburi National Park and Keangkrachan-Kuiburi National Park Corridor. National Park and Protected Areas Innovation Center (Petchburi). 93.pp.

Tran, K., and K. R. Chauhan. 2007. Structural activity of bovidic acid and related coumpounds as feeding deterrents against Aedes aegypti. Biopesticides International 3:53-57.

Woodroffe, R. 1999. Managing disease threats to wild mammals. Animal Conservation 2:185-193.

FIGURES

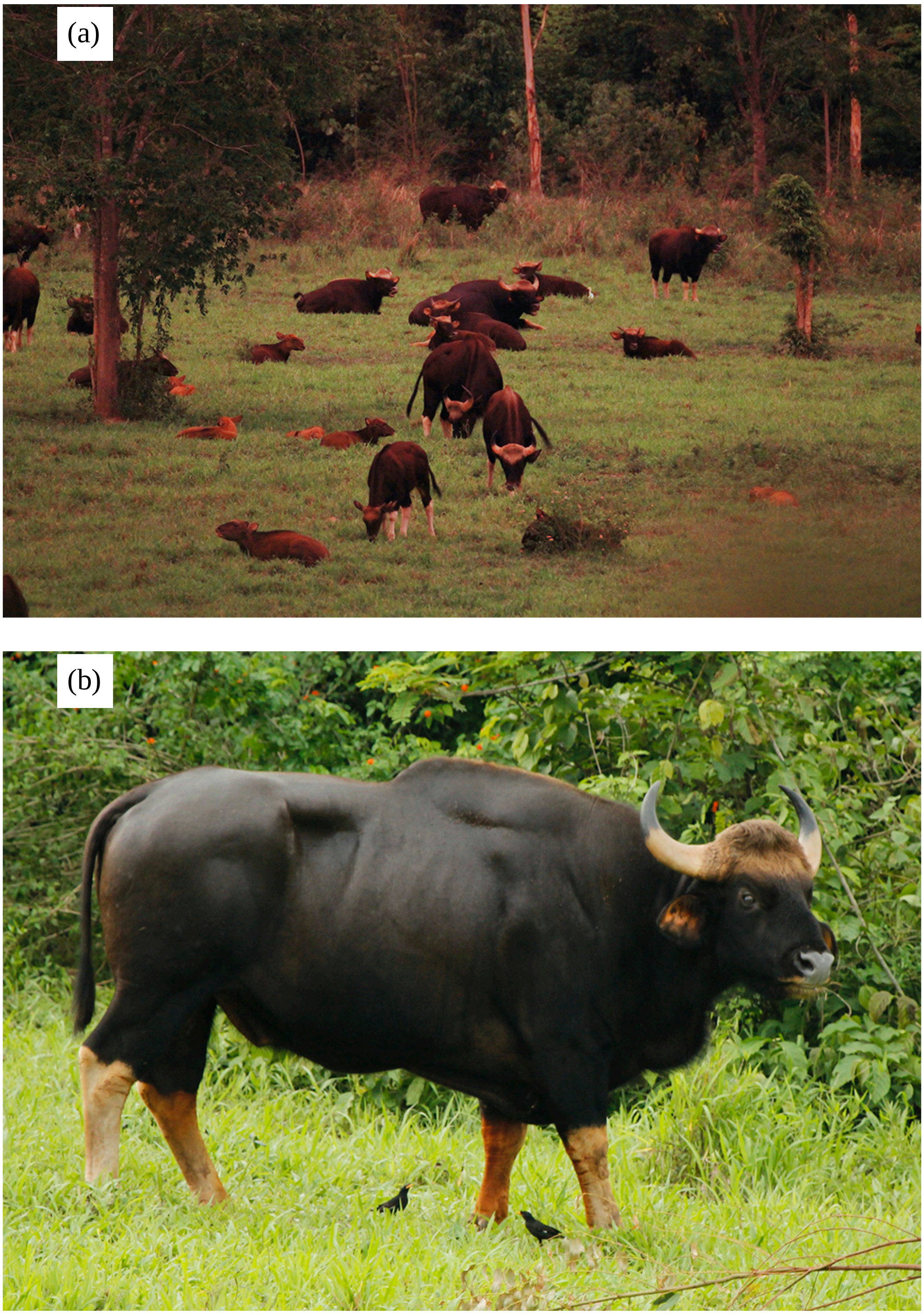


Figure 1.1. Gaur (*Bos gaurus*). (a) Gaur herd comprised of several age classes and (b) a bull gaur (courtesy photograph of bull by DNP).

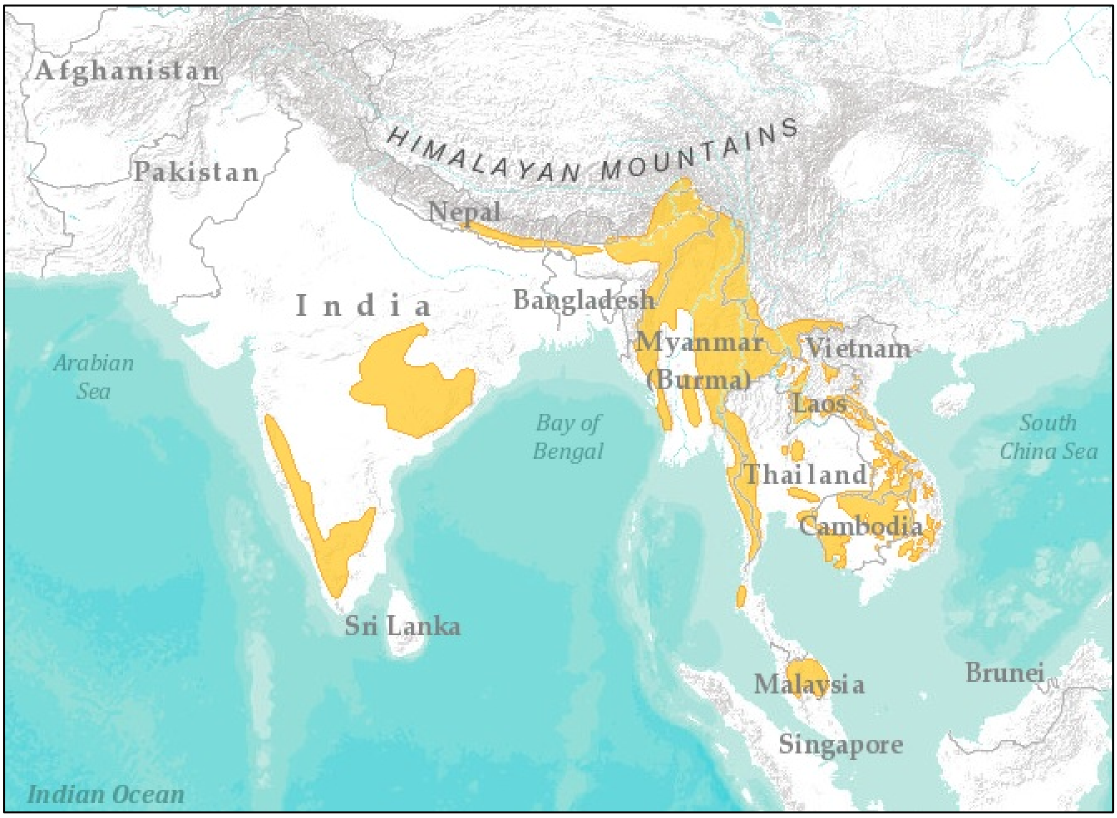


Figure 1.2. The distribution range of gaur shown in orange (From www.iucnredlist.org).

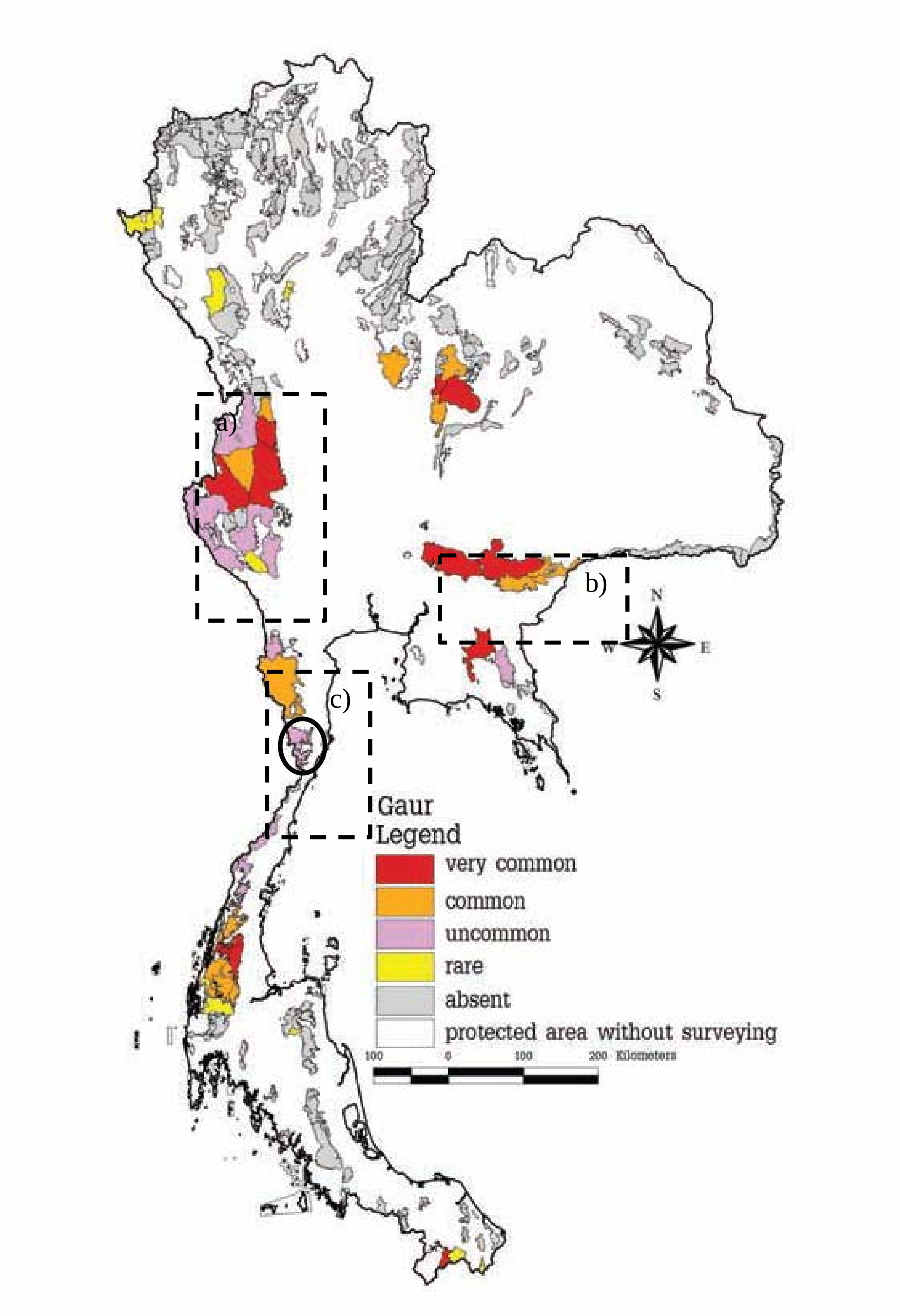


Figure 1.3. Distribution and relative abundance indices of Gaur in Thailand. (a) Western forest complex (WEFCOM), (b) Dong Phaya Yen-Khao Yai Forest complex, and (c) Khaeng Krachan forest complex, where Kuiburi National Park (circled) locates. (Department of National Parks Wildlife and Plants Conservation 2010)

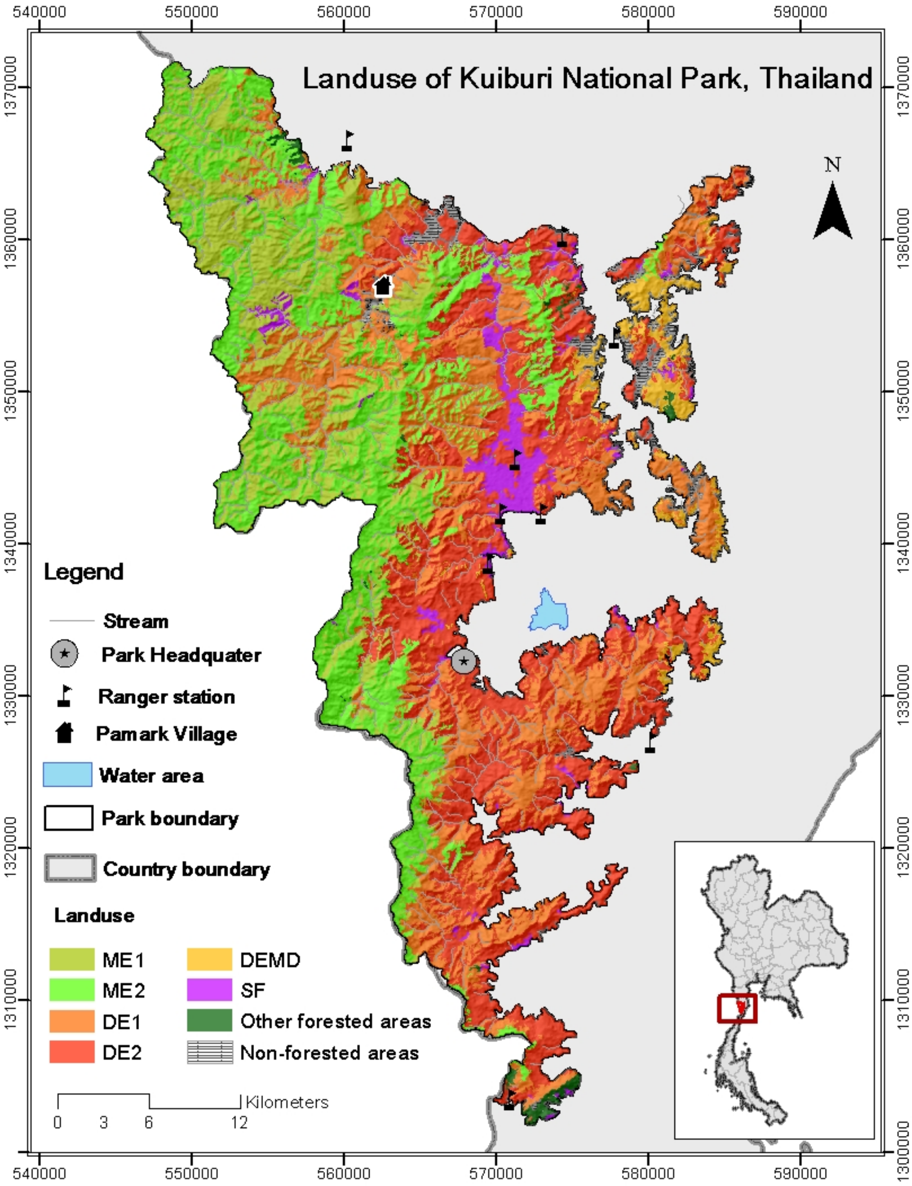


Figure 1.4. Map of Kuiburi National park showing landuse and the four prey-recovery zones proposed by Kuiburi National Park and WWF-Thailand, as well as study sites in this study (dash line circles). Landuse abbreviations: ME1- Moist Evergreen forest; ME2- Semi-evergreen forest; DE1- Middle Dry Evergreen forest; DE2- Lower Dry Evergreen forest; DEMD- Dry Evergreen forest mixed with Deciduous forest; SF- Secondary forest; Other forested areas include HE-Hill Evergreen Forest, MD- Mixed Deciduous forest, DD- Dry Dipterocarp forest , BB-Bamboo forest; Non-forested areas include OC- Old clearing area, OA- Open area, AG-Agriculture area, and WT-Water.

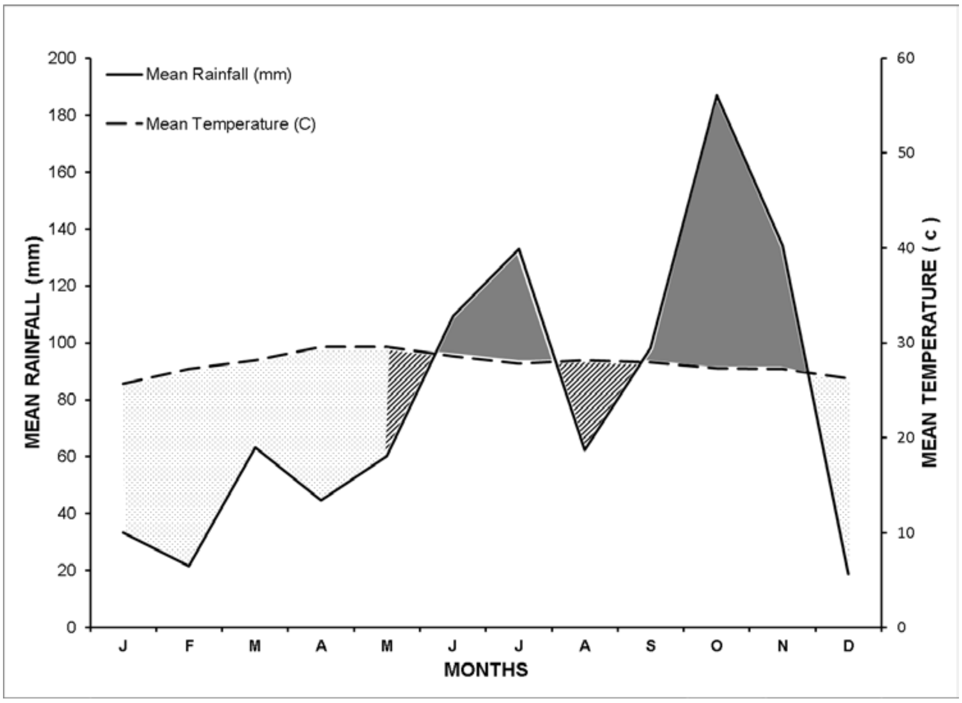


Figure 1.5. Climatic diagram of Prachuab Khiri Khan Province meteorological station during January 2009-September 2014. The dry season with relatively low rainfall is from December to April (light grey). The wet season is from May to November (dark grey area includes high rainfall period and diagonal line areas represent transition and interrupting low rainfall months).

CHAPTER 2

EVALUATION OF TECHNIQUES FOR ASSESSING GAUR

ABSTRACT

Understanding gaur ecology and response to the local environment is significant for conservation and management of habitat and wildlife community, especially tigers, because gaur are important prey species of tigers and landscape architects from grazing and browsing behavior. I used two major survey approaches to survey abundance and distribution of gaur in Kuiburi National Park, Prachuap Khiri Khan province, southwestern Thailand during November 2013-January 2015. Six focal study zones (i.e., Central 1, Central 2, Central 3, Payang, North, and South) across the park were surveyed using direct observations and camera trapping. Also, vegetation characteristics were measured in 5-m radius circular plots to describe habitat characteristics based on land use types and zones.

Direct observation in the Payang zone detected 59 gaur encounters on 52 sampling days. The maximum count was 89 gaur observed in November 2013. Average herd size per encounter observed in the dry season (20 ± 5.1SE individuals/encounter) was significantly smaller than that in the wet season (36 ± 4.3SE individuals/encounter). Camera traps were set up in 56 locations across all zones and were operated > 8,000 trap-nights. Gaur were captured in 841 encounters in 649 trap-nights (7%) at 41 locations. The overall encounter rate was 9.35 encounters per 100 trap-nights. Encounter rates in the other zones ranged 2-7 encounters/100 trap-nights, except the Payang zone with the detection of 19 encounters/100 trap-nights. The maximum encounter from camera

trapping included 56 gaur. The counts of overlapping observations between two observation approaches were independent. Gaur were photographed more frequently during the dusk and dawn periods (6.00 and 18.00 hours). The patterns were consistent across zones.

Occurrences obtained from camera trapping techniques placed over the park and abundance of gaur observed from the direct observations in the Payang zone suggested that gaur in Kuiburi National Park were highly concentrated in the Payang zone. Lowland habitats, including secondary forest surrounded by dry evergreen forest, were the main habitats for breeding herds. The abundance of food and water resources and well protection measures in the Payang zone and the adjacent areas overcome the effect of human disturbance from tourism activities. Some bulls inhabited the interior forest of the park, which dominated by the dry evergreen forest and moist evergreen forest with undulated terrain and less human disturbance. This primary population and ecological information enhances understanding of the population ecology corresponding to eh local environmental factors, such as how gaur were distributed across the landscape.

INTRODUCTION

Many sampling techniques are available for wildlife surveys, such as line transect sampling and capture-recapture methods. Researchers collect evidence of animal presence, either by direct approaches (e.g., direct sighting and capture-mark-recapture methods) or by indirect approaches (e.g., tracks and signs transects) for wildlife inventory and ecological studies of species of interest. Implication and modifications depend on the focal species, habitats, and budgets (Karanth and Nichols 2002, Conroy and Carroll 2009, O'Connell et al. 2011).

Biology and behavior of focal species influence sampling technique efficiency. Gaur are social animals, and herds contain members of both sexes and multiple age classes. The majority members of breeding herds are females, their young and juveniles. Some adult bulls lead breeding herds, but some live solitarily or form bachelor herds containing only males. Gaur do not use space randomly and often congregate around resource patches, including water holes, grass patches, or mineral licks, which are usually distributed in the forest opening. Such social behavior and habitat preference facilitate direct counts. However, direct observation for gaur confronts temporal and spatial limitations because they usually forage in the open grass patches during night times but stay near forest edges to avoid the heat from the sunlight during day times (Schaller 1967, Bidayabha 2001, Ahrestani and Karanth 2014).

One of non-invasive survey techniques that has become general practices in wildlife studies is camera trapping. Many automated cameras have a reasonable price and produce good photograph quality. They also provide lucid and permanent evidence, weather-proofing, and 24/7 operation. These features overcome limitations of human-

based observation and indirect surveys. Hence, camera trapping allows researchers to collect data on cryptic species in extensive spatial and temporal scales (Tobler et al. 2008, O'Connell et al. 2011).

Gaur is an important prey species of large carnivores in tropical forests, including tigers (*Panthera tigris*), leopards (*Panthera pardus*), and dholes (*Cuon alpinus*) (Karanth and Sunquist 1995, Karanth et al. 2004). These carnivores often prey upon young and calves. However, massive adult bulls can be killed only by tigers. Gaur biomass accounts for about 42% of prey biomass for tigers (Andheria et al. 2007). Availability of large herbivores, like gaur and deers, is a crucial factor to maintain viable tiger population because large herbivores influence carrying capacity of tigers and cub survival (Karanth and Stith 1999). Hence, diversity and availability of prey species are usually considered as an indicator of habitat suitability for carnivores.

Most gaur population abundance indices are conducted using assessment approaches, such as tracks and signs surveys (Biswas and Sankar 2002, Karanth and Nichols 2002, Karanth et al. 2004). Camera trapping and capture-recapture techniques are prevalently applied to wildlife studies, especially for carnivores. The uses of prey data obtained from camera trapping may be under-represented for prey population abudance estimations (Sollmann et al. 2013, Burton et al. 2015). Previous gaur studies concentrated in their biology, ecology of gaur, and herbivore-carnivore community rather than intension of monitoring population status. Gaur are one of common charismatic mammals in Kuiburi National Park.

This study focused on applying survey techinques to intensively monitor gaur population. The main goals of this chapter were to overview and evaluate direct

observations and camera trapping methods to survey gaur. I provided an overview of gaur population structure and behaviors, as well as described potential ecological factors (e.g., land use types and vegetation structure) influencing distribution and habitat use patterns of gaur in Kuiburi National Park. I summarized and compared descriptive statistics, behavioral and ecological aspects obtained from visual observations and camera trapping data.

STUDY AREA

Kuiburi National Park (969 km^2) is located in Prachuap Khiri Khan Province in southwestern Thailand (Figure 2.1). The park is characterized by steep mountainous topography incised with seasonal and perennial streams. Vegetation is predominantly dry evergreen forests, portions of which were logged in the past. The park is surrounded by agricultural lands, particularly pineapple plantations, except to the west where it is contiguous with extensive evergreen forest in Myanmar. Large secondary forest patches, with habitat improvement to enhance food and water availability for large herbivores, are located in the central part of the park (Steinmetz et al. 2009, Temchai et al. 2010). A park substation, named 'Payang' (Figure 2.3), is located at the center of the area to enhance wildlife protective measures and law enforcement against hunting.

Kuiburi National Park are mainly composed of eight land use types, which were re-categorized from eleven land use types defined by Temchai et al. (2010) (See Chapter 1). Forested habitats include ME1, ME2, DE1, DE2, DEMD, SF, and other forest types (OF; including BB MD, and HE) are sparsely distributed. Non-forested land uses (NF) contained agriculture areas (AG) and old clearing areas (OC) (Figure 2.1). Six focal

sampling areas were defined, called Central 1, Central 2, Central 3, Payang, North, and South (Figure 2.2 and Figure 2.3). Those areas were selected based on differences in habitat types (Figure 2.2), topography, logistical limitations, safety, protection efforts, degrees of human disturbance, and historical occurrences of gaur (Figure 2.3 and Appendix 1).

1) North zone (N)

The North zone is a deserted village surrounded by the middle dry evergreen forest, semi-evergreen forest, and moist evergreen forest. The area is closed to the ecological corridor connected to Khaeng Kra Chan National Park. Villagers of the Pamark Village visit to collect fruits, palms, and coffee beans from their plantations. Streams are perennial. The area is patrolled >3-month intervals by the joint patrol teams comprised of the park rangers, WWF researchers, soldiers, and border patrol police.

2) Central zones

The Central part of Kuiburi National Park is the widest part of the park. It contains a mosaic of habitat types and a wide range of elevation (~ 100-800 m above sea level). It has various degrees of human disturbance from tourism activity and local villagers. The region contains 4 zones.

2.1) Payang (PY)

Payang zone is a part of the park centered at Payang substation. Human-modified secondary forest, including small to medium reservoirs, grass patches, and artificial mineral licks is the dominant land uses. Wildlife watching activities from tourists are major sources of human disturbance. Previous surveys (e.g., Steinmetz 2011) and the records of the park (Kuiburi National Park, unpublished data) showed guar are

concentrated in this area. To distinguish gaur herds and their foraging ranges within this area, I divided the area into four subzones according to grass patches and man-made water sources distribution (Figure 2.4). P1 includes the southern area of the ranger station along the park boundaries. P2 covers the area to the west of the substation and is contiguous to the forest of the central zones C1. P3 is located in the north of the substation. The observation viewpoint is located in this subzone. Lastly, P4 covers the east area of the ranger station. These four subzones are assumed homogeneous habitats.

2.2) Central 1 (C1)

The zone C1, called Hub Ma Grood, is located next to the west of the Payang zone. An 800-m steep ridge to the west separates the C1 and C3. C1 area contains dry evergreen forests and a small proportion of semi-evergreen forest and secondary forest. The Pamark villagers seasonally collect non-timber products (e.g., *Parkia sp.* seeds) and opportunisticly hunt for small wildlife.

2.3) Central 2 (C2)

The zone C2, called Hub Ma Sang, is located next to the north of the Payang zone extending to the eastern boundary of the park. C2 includes the upper part of the Payang substation and the elongated lowland dry evergreen forest along the eastern park boundary, which is separated to the Payang zone by a ridge with approximately 400-600 m elevation. Pineapple plantations are located along the eastern park borders. Secondary forest in this zone is less managed. However, illegal wildlife hunting, including gaur, is occasionally reported in this area.

2.4) Central 3 (C3)

The zone C3, called Hub Inthanin, is located in the interior part of the park at the slope of the mountain ridge along the Thailand-Myanmar borders. Streams in the C3 are perennial. Middle dry evergreen forest and moist evergreen forest cover most of the C3 area (Figure 2.3) Villagers of the Pamark village collect non-timber products (e.g., *Pakia sp.* seeds) and may hunt for small wildlife.

3) South zone (S)

This zone includes riparian habitats along Khlong Kui tributaries. Dominant forest types are lower and middle dry evergreen forests. Local people rarely visit this area. Many alluvial vegetation patches appear along the perennial tributaries.

METHODS

Direct observations

Direct observations of gaur were conducted only in the Payang zone. I conducted observations at the viewpoints and included opportunistic gaur encounters while on vehicles for 2-6 consecutive days during 6.00-9.00 (AM) and 15.00-18.00 (PM) monthly using a pair of binoculars, a telescope, and digital cameras. Photographs and videos were recorded using digital cameras attached to a 70-300 mm telephoto lens to collect data on herd size and population structure. Sex and age class (i.e., calf, yearling, juvenile, and adult) of each gaur individual were determined based on relative body size and horn appearances (Table 2.1, Appendix 2).

Gaur were observed mainly at two viewpoints. The first viewpoint is located in the P3 zone and the other is at the Payang substation in the P4 zone (Figure 2.4). Large grass patches are clearly visible from a distance with less disturbance to gaur. I collected

data in 12 months during November 2013 - January 2015 (except December 2013, January and July 2014). Other exceptions included observations in May 2014 (30 April-4 May 2014), which obtained from 17-19 sites located in the grass patches from 13.00 to 18.00 (Department of National Parks, Wildlife and Plant 2014, per.comm.). I conducted the observations with about 40 staff of Department of National Parks, Wildlife, and Plant Conservation. Two to three persons per location were assigned to make observations on platforms built in trees at 5-10 m above the ground.

A sampling unit was a sampling day with 1-2 temporal replicating effort(s). An observation effort (a replicate) was defined as the observation according to daytime periods of the sampling dates, either in the morning (AM; 7-9 A.M.) or in the evening (PM; 3-6 P.M.). An independent encounter was defined as 1) individuals or herds allocated at different locations, e.g., different grass patches, 2) individuals or herds observed at different times during a particular effort, e.g., encountering near roadsides while travelling on a motorbike or in vehicles, 3) individuals or herds, regardless whether they were the same individuals or herds, observed at different observation efforts, e.g., a herd observed in the evening and the next morning at the same sites. I tallied the number of individuals over the effort. The maximum counts of the effort(s) represented a daily minimum number of gaur in the area. Sex and age classes were defined as shown in Table 2.1 and Appendix 2.

Summary statistics and comparison were compared monthly and between wet and dry seasons. Population structure indices were measured as the ratio between sexes or among age classes, such as the calves to adult females ratio and the young to adult females to adult males ratio.

Camera trapping systems

Passive infra-red digital cameras with infrared flash and T-flash were attached to trees near animal trails, mineral licks, grass patches, and reservoirs at about 0.5-1 m above ground. One to three still images and 30-second videos were recorded when the cameras were triggered (See Appendix 3 for camera settings of each camera model). Five camera models were used: 1) Moultrie M80 (EBSCO Indrustries, Inc., Birmingham, Alabama USA), 2) Scoutguard SG565 (Scoutguard, Narcross, Georgia USA), 3) StealthCam Unit Ops no glow (Stealth Cam, LLC., Grand Prairie, Texas USA), and 4) Bushnell Trophy Cam HD (Bushnell Outdoor Products, Overland Park, Kansas USA).

There were 56 camera trap locations distributed in 6 focal zones (Figure 2.4). Each location deployed 1- 4 cameras. Cameras were set up mainly to linear topographic features such as trails, streams, and ridges or near the grass patches. Camera spacing within each zone ranged from 350-2000 m, depending on topographic features, resources distribution, and relative abundance and occupancy suggested in Steinmetz et al. (2011). The camera locations were neither in random nor grid-based placements. Cameras spaced in the Payang and the North zones were closer than the others (Table 2.3). Lowland habitats with high availability of forage and water resources year-round, like the Payang zone, are more preferred habitats for gaur, especially breeding herds (Steinmetz et al. 2008). As a result, gaur inhabiting such habitats may demonstrate high site fidelity and ignore seasonal movement (Ahrestani and Karanth 2014). Closer camera spacing in the Payang zone was aimed to capture more gaur and individuals in herds, as well as their movement. Bulls occupy larger home ranges and prefer denser forest habitats (Conry 1981, Steinmetz et al. 2008, Sankar et al. 2013). Gaur outside the Payang are expected to

number fewer individuals and more solitary bulls. Wider camera trap spacing should not influence the individual detection and gaur still are able to be detected at multiple locations.

Camera traps in the Payang zones were retrieved monthly. Cameras in other regions were retrieved every 1-6 months due to logistical limitations. The camera trap effort was measured as the total trap-nights of all individual cameras from start dates to the dates of retrieval or the last date stamped on the final exposure if the cameras malfunctioned or ran out of battery power before retrieval.

An independent encounter was defined as photos of individuals at least 1 hour apart from the previous set of photographs, regardless of individuals. A 1-hour window allowed gaur members in breeding herds to enter the grass patches as I personally noted during the direct observations. The social structure was defined as herd or single. ‘Herd’ included 1) the encounters that contained at least two individuals, or 2) the encounters of only a single calf, juvenile, or female at any age classes. Date and time and the total number of individuals were recorded. Sex and age classes of individuals described in Table 2.1 were identified. I analyzed data in the Payang zone separately from the other areas in the Central region because it received intensive efforts and noticeable high historical abundance and occupancy.

Vegetation structure variables

To determine variation of vegetation structure across forest types, vegetation cover and tree density variables listed in Table 2.2 were measured in 5-m radius plots centered at the camera locations or random locations. Three to nine subplots with 20-m

spacing along the four cardinal directions (Appendix 4) at each sampling location were measured depending on the logistic constraints.

Data Analysis

Descriptive statistics of direct observations and camera trapping data was described. Variations of those statistics across spatial and temporal scales were tested using appropriate approaches, e.g., Mann-Whitney-Wilcoxon Tests, One-way ANOVA, Multivariate Analysis of Variances, and Chi-square test of Independence (Lyman Ott and Longnecker 2001) with a 95% confidence in program R (R Core Team 2015).

I tested the independence of the counts from both survey methods based on the encounters observed only during the direct observation sampling dates. Chi-square Test of Independence was used to determine the independence of the frequency of gaur encounters between direct observation and camera trapping methods.

To gain more insight into behavioral aspects of gaur, such as active time periods and relative activity across temporal scales among zones, the frequency of camera trapping encounters corresponding to the temporal and spatial scales were analyzed. Density of activity based on the kernel probability density function was calculated from intensity of encounters according to circular distribution corresponding to temporal scales and was fitted to density curves using package “overlap” implemented in R (Meridith and Ridout 2014). I set the smoothing constant for the kernel density function to 1, as was recommended by Ridout and Linkie (2009) and Meridith and Ridout (2014).

Analysis of Variance (MANOVA) was used to test whether there was any difference in the mean vector of vegetation structure variables among the land use types and focal study zones. Pillai’s trace methods were used to calculate test statistics because

of their tolerance of assumptions violation (Gotelli and Ellison 2013). Assumptions of normality and multicollinearity among predictor variables were tested using visualization of histrogram and Spearman Rank Correlation, respectively. I used $r > 0.6$ to determine the high correlation between variables. Multivariate Significant main effects (i.e., land use types and zones) were separately examined by one-way ANOVA. Statistical analysis was conducted in Program R 3.2 (R Core Team 2015).

RESULTS

Direct observations: Efforts and Detection

Of 71 direct observation efforts on 52 days during 12 months (26 efforts on 18 days in 5 dry months and 45 efforts on 34 days in 7 wet months, Table 2.3), 47 (66%) had detections, resulting in 90 detections per 100 sampling days. The average number of observations detecting at least one gaur in the dry season (54 detected observations per 100 efforts) was not different from that in the wet season (73 detected observations per 100 efforts); Pearson's Chi-squared Test: $\chi^2 = 2.7966$, 1df, n=71, P = 0.094.

The total encounter frequency over the sampling efforts was 59 encounters (15 and 44 encounters in the dry season and the wet season, respectively). The overall encounter rate was 1.13 encounters per day. The detection rates per day were 0.83 encounters per day in the dry season and 1.29 encounters per day in the wet season. The median number of individuals observed per effort was 9.5 individuals in the dry season and 37 individuals in the wet season.

Rainfall, which is one of the environmental factors used to define the seasonality, influences food distribution and availability. The average number of individual observed

per encounter each month usually ranged from 10 to 30 gaur. I observed 3 of the 5 sampling dry months with an average of less than 15 gaur per encounter. The largest herd size with more than 50 gaur per encounter was observed in November of two consecutive years when rainfall was relatively high (Figure 2.5).

Monthly average number of individuals observed per effort per day in the dry season was not significantly smaller than that in the wet season (9.64±4.2SE (n=5) and 10.69±2.44SE (n=7), respectively, Mann-Whitney-Wilcoxon Test; W=13, P=0.515). I observed two occasions of the events that two breeding herds and a single bull distributed over the Payang zone during the same sampling efforts.

Direct observation: Herd size and composition

Of 59 independent encounters, six encounters were solitary gaur (10%) (Figure 2.6). All solitary detections were observed in the wet season. Fifteen and 38 of the 53 herd encounters were in the dry and the wet season, respectively. The median herd size was 11 and 29 individuals in the dry and the wet season, respectively. The seasonal average herd size was different (19.7 ± 5.05 SE, n=15 in the dry season and 35.7 ± 4.34 SE, n=38 in the wet season; Mann-Whitney-Wilcoxon Test; W=176.5, 1 df, P = 0.033, Figure 2.7). The maximum number of individuals detected by direct observations was 89 gaur, which divided into two herds and one single bull in three different locations, in November 2013.

I was able to classify 1,332 of the 1,659 animals encountered (80%) into either a stage or sex categories. The ratio of young (including calves and yearlings): adult female: adult male was 4.5: 1.7: 1. The ratio of young: juvenile: adult was 1.6: 1.2: 1. The female: male ratio was 1.7: 1.

Camera trapping: Efforts and Detection

Gaur were detected at 41 of 56 camera trap locations during 60 sample weeks. The number of working camera locations ranged 2-23 locations per week (Figure 2.8). I observed the total of 8,999 trap-nights while gaur were detected on only 649 trap-nights (7%).

A total of 841 independent gaur encounters was observed. The overall gaur detection rate was 9.4 encounters per 100 trap-nights. However, the zone detections were varied. The Payang zone had the highest gaur detections with 19 encounters per 100 trap-nights. In contrast, gaur detections in the other zones were lower than 7 encounters per 100 trap-nights. The average detections in the Central region excluding the Payang zone were approximately 2 encounters per 100 trap-nights. The average detection in the North zone was 7 encounters per 100 trap-nights. The South zone had the average detection of three encounters per 100 trap-nights (Table 2.4).

Of the total 649 trap-nights when gaur were detected, single individual detections were 63.5 encounters per 100 trap-nights (n=412), compared to 66.1 encounters per 100 trap-nights of multiple individual detections (n=429, Figure 2.9). Single individual encounters categorized as breeding herd numbered 89 encounters. The single gaur encounter rate was 49.8 encounters per 100 trap-nights (n=323), whereas breeding herd encounter rate was 79.8 encounters per 100 trap-nights (n=518). Gaur breeding herds were observed more frequently than the single gaur in the Payang zone throughout the year. In contrast, single individual encounters were more common in other regions except the other central zones in the dry season (Figure 2.10).

Camera trapping: Herd size and herd composition

Overall average herd size was 6.5± 0.3 gaur per breeding herd encounters (ranged 1-56, n=518). Seasonal average herd size observed was not significantly different (6.6± 0.5 in the dry season and 6.5± 0.4 individuals in the wet season; Mann-Whitney-Wilcoxon Test; W=31640, 1 df, P=0.897). The largest herd contained 56 individuals and was photographed in a grass patch in the Payang zone, which was the same location as direct observations of the maximum count. The daily total maximum number of individuals observed across all camera locations was 57 gaur in two camera locations in the Payang zone in November 2014. The maximum camera locations gaur detected in a day was 7 sites (three locations in the North zone, three locations in the Payang zone, and one location in the South zone). The average herd size in the Payang zone was larger than that in the other zones (6.87± 0.37, n=456 in Payang and 4.0 ± 0.56, n=62 in other regions; Mann-Whitney-Wilcoxon Test; W=10,722, P=0.002).

I was able to identify 3,046 of 3,705 animals observed (82%) into one stage or sex category. The ratio of young: adult female: adult male was 2.8: 1.4: 1. The ratio of young: juvenile: adult was 2: 1.3: 1. The female to male ratio was 1.4:1.

Relationship between the counts by direct observation and camera trapping

During the direct observation sampling dates, camera trapping detected 80 encounters (28 records in the daylight and 52 records at night). In most of the direct observations that gaur were detected, the camera traps failed to detect any gaur. The gaur encounter from direct observation surveys were independent from those observed from camera trapping method, controlling for the daytime periods (Chi-Squared Test for independence, χ^2 = 4.813, 4 df, P=0.31; Table 2.5, Figure 2.11).

Behaviors

Temporal activity patterns

Data from camera trap photographs showed that in a 24-hour period, gaur were frequently photographed at 6.00 and 18.00. The patterns were consistent in both Payang and the other zones (Figure 2.12).

Month-wise kernel density curves showed a constant encounter density throughout the year, except in March and April (Figure 2.13 a), which were the driest period with less camera trap coverage (Figure 2.8). Gaur activities in the Payang zone were higher than the activities in the other zones, except August to October (Figure 2.13 b), which fell during the middle of the wet season, with extensive coverage of camera trap locations.

As the Payang zone had the highest concentration and detection of gaur, sub-zoning within the Payang explained herd dynamics and their movement information over small spatial scales. Sixty-week-period kernel density curves suggested that the subzone P1 showed periodically high activity during the middle of both seasons while the subzone P3 was intensively visited during the late wet season (Figure 2.14).

Intraspecific interactions

Mating and courtship behaviors

Calves were seen throughout the year. Hence, it could be inferred that there was no specific mating season. However, one camera in the Payang zone recorded a part of possible courtship behavior in February 2014. The video footage showed that a male licked a female body and repelled a juvenile that approached the female.

Sparring or fighting

Five incidents of sparring behavior seen from the camera trapping occurred only among juvenile males and adult males living in herds during May to August 2014. Three of the incidents were fighting between juveniles, the other two occurred between adults and young adults. No adult female was detected around the males in the video footage.

Interspecific interactions

Banteng (*Bos javanicus*) were occasionally observed joining the gaur breeding herds. Those herds contained 1-2 banteng. Gaur-banteng mixed herds were observed 23 of 59 encounters of direct observations (39%) or 44 encounters/100 days. In contrast, mixed herds encounters were rarely observed from the camera trapping. Mixed herd made up only 23 of 841 camera-trapping encounters (2.7 mixed herds encounters/100 gaur encounters). The mixed herd encounter rate was 3.5 encounters per 100 trap-nights that gaur were detected. Mixed herds were recorded only in the Payang zone (22 encounters) and the Central 1 zone (once). Gaur were usually observed sharing foraging grounds with other ungulates, especially elephants, which were prevalent and abundant in Kuiburi National Park.

Potential gaur predators reported in other studies that are detected in the area included Tiger (*Panthera tigris*), Leopard (*Panthera pardus*), and Dholes (*Cuon alpinus*). In India, only tigers depredate adult gaur, although they also kill juveniles or calves. Most predators prey upon calves and the younger ages (Ahrestani and Karanth 2014). However, no evidence of predation by any of these predators on gaur were observed during the study.

Vegetation structure

The total of 493 plots of 60 locations, which included six of eight land use types, i.e., DE1, DE2, ME1, ME2, NF, and SF, were sampled (Table 2.6). The total area of the sampling plots was approximately 0.004 sq.km. of the 203 sq.km focal zones (< 1 %). Pairwise Spearman Correlation showed that no multicollinearity among eight vegetation variables because all correlation coefficients were less than 0.6 (Figure 2.15).

DE1 and DE2 were dominant land use types in the focal study zones. All zones except Payang were the mosaic of dry evergreen and moist evergreen forests while the Payang zone was extensive human-modified secondary forest surrounded by dry evergreen forest (Figure 2.2).

A two-way MANOVA suggested the significant of vegetation structure variables across land use types (Pillai's trace = 0.906, $F_{5,475}$ =13.059, P< 0.001) and zones main effects (Pillai's trace = 0.947, $F_{5,475}$ = 13.781, P< 0.001), as well as the interaction term (Pillai's trace = 0.237, $F_{7,475}$= 2.075, P< 0.001), Figure 2.16. One-way ANOVA for the land use types main effect suggested that there is a significant difference of vegetation structures across land use types (Table 2.7). Tukey-HSD post hoc comparison for the main effects revealed that grass cover was significantly higher in secondary forest than other land use types. Herbaceous plants were the ground cover vegetation in all land use types. Shrub cover was lower in the non-forested land use as compared to other land use types. Bamboos, a part of gaur diet, were found in only five sampling plots in non-forested land use. Lianas and vines, providing support and denseness to the under-canopy of tropical forests, were sparsely distributed. The density of tree sizes varied across the land use types. Small-sized tree density and medium-sized tree density were relatively

low but appeared across land use types. Large-sized trees were more common in other land use types except NF and SF (Figure 2.17).

Vegetation structure variables for the zone main effect were also significantly different. I pooled zone C3 and zone N together as CN due to a small number of sample plots. Both C3 and N shared some similar characteristics. They were in similar elevation ranges (250-300 m) with undulating topography. They also had a similar ratio of dry evergreen forests to moist evergreen forests. The Payang zone was dominated by grass, with less coverage of herb than the other zones. Shrubs were common understory plants for all zones. Bamboos were patchily distributed in the CN. Lianas and vines appeared in the Payang zone in a small proportion. Densities of small trees and medium trees of each zone were similar. Large-tree density was higher in the other zones but CN and PY (Figure 2.18).

Differences among six focal zones were described based on variation in topography, elevation, levels of human disturbance, land use types, vegetation, and logistical limitation. The Central 1 was comprised of DE1, DE2, ME1, ME2, and SF, with elevation ranges from 180 to 380 m. A small proportion of secondary forest in the C1 and C2 was the extended secondary forest patches of the Payang zone and was rarely manipulated. Major habitats of C2 also contained DE1 and DE2. However, C2 was located next to pineapple plantations and at lower elevations (200-290 m). C3 and N regions were located in the interior of the park and surrounded by steep mountains. DE1 was also dominated in C1 and the north zone. Sample plots in C3 and N zones were located in the higher elevation ranges (250-300 m), with less human disturbance because logistical limitation. The majority of the C3 and N zones was covered by moist evergreen

forests. However, small patches of naturally restoring secondary forest appeared in the North zone. Vegetation plots sampled in the C3 and N zones were in similar elevation ranges of 250-300 m. The Payang zone was dominated by a large proportion of human-modified secondary forest (45%), which was mainly grass patches and small reservoirs. The main ground cover vegetation in the Payang zone was grass species (mainly *Brachiaria ruziziensis*). The Payang zone was located at low elevation ranges of 120-270 m. Human disturbance in the Payang zone came from wildlife watching activities. The Payang zone also received intensive patrol and low enforcement measures from the park to discourage hunting. The south zone included an extensive elevation range (170-570 m), containing all land use types. The eastern boundaries were located at lower elevation with moderate human disturbance from domesticated cattle and recreational camping. The inner zones contained steep ridges and extended moist evergreen forest to Myanmar. The ground cover layer of the south was comprised of herbaceous plants. The understory layer consisted of various vegetation types.

DISCUSSION

Conducting large mammal surveys can be a challenge because some of them are cryptic, shy, and dangerous, resulting in low detection or capture probability, as well as safety and welfare issues of animals and researchers for handling animals (O'Connell et al. 2011). Gaur in Kuiburi National Park are more aggregated mainly in certain parts of the park, especially the Payang zone. Both direct observations and camera trapping surveys support that gaur herds are encountered more frequently in the open habitats,

such as grass patches, which are important food resources for gaur. The population structure ratios observed by both methods are similar (Figure 2.19).

The combination of direct observations and camera trapping surveys provide an overview of the abundance and distribution of gaur in Kuiburi National Park. Large herds with > 60 individuals are periodically observed at only one open habitat location. Foraging herds contain multiple breeding herds and solitary bulls sharing the same foraging grounds. Conversely, smaller herds and solitary bulls are observed at several places. Encounters of gaur in the other zones outside the Payang are more frequently in small herds with <30 individuals.

Low detections of gaur from the camera trapping surveys are possibly due to low abundance and occupancy, as well as highly aggregated distribution of gaur in the park as reported by Steinmetz et al. (2011). However, the zone with the highest encounter rate and the largest number of individuals is the Payang zone, which is dominated by grass patches. The habitats that supply food, i.e., grass, and water resources for herbivores attract more gaur and may decrease movement distances and home range size (Conry 1981). Breeding herds, which require high nutritious and abundant food for rearing the young, more attached to such habitats than the massive bulls (Steinmetz et al. 2008). Apparent low encounter rates of the areas around the Payang zone (i.e., C1 and C2) assert the clumpiness of gaur distribution in Kuiburi National Park. There is no evidence of long migration across the park (e.g., herds or bulls in the north zone to Payang). Most gaur, especially females and juveniles, inhabit lowland deciduous and secondary forests year-round instead of switching to the moist habitats as described in the gaur population in the South India (Ahrestani et al. 2012). Other studies suggest that gaur, especially gaur

herds, prefer lowland forests and tend to avoid hilly or mountainous habitats (Conry 1981, Steinmetz et al. 2008). Gaur herds are also observed in the riverine habitats, such as the north and the south. Alluvial patches along the tributaries, which vegetation of the ground cover layer are comprised of herbs and shrubs, become the foraging ground of gaur. Although the camera traps placements and the efforts in this study are unbalanced and more focus at the Payang zone, the trend of population abundance and distribution patterns concurs with the historical records of the park and the systematic line transect surveys conducted by (Steinmetz et al. 2011).

A high ratio of calves to adult females suggests the gaur population in Kuiburi National Park is gradually increasing since the monitoring programs started in 2006. There are new areas that gaur are present. For example, gaur were not detected by the line transect surveys conducted during 2006-2010 (Steinmetz et al. 2011), but at least one bull was photographed in Central 3 (Hup Inthanin). Camera trapping surveys in this study also detected gaur breeding herds in the North zone, whereas only single gaur was reported in the past.

CONCLUSION

The direct observations and camera trapping surveys suggest that distribution of gaur in Kuiburi National Park are clumped. Eighty percent of the total encounters (including 90% of the total counts of gaur) are in the Payang zone, which is a human-modified secondary forest. Gaur are present in the other areas of the park, but in a few number. Habitat heterogeneity and anthropogenic factors may influence preferred

habitats for gaur and gaur occurrence, which influence detection probability. Hence, habitat stratification should be considered for population parameter estimations.

Camera trap surveys provide evidence of recent occupied areas in the zone Central 3, which the occurrences are not reported in the surveys during 2006-2011 (Steinmetz et al. 2014). Implementation of both survey techniques provides more information about population structure, distribution, and behaviors of gaur in various habitat types. Direct observations at the open habitats, e.g., grassland, provide large number of individuals observed but are limited by daylight, weather conditions, available observation locations, and available manpower to conduct observations in multiple locations. Camera trapping techniques are applicable to most habitat types and allow researchers to obtained information of elusive wildlife occurrence and behaviors in remote forests and larger spatial scales. However, the initial costs are high and equipment may be damaged or lost. Gaur data obtained from camera trapping suffers from low detection and less number of gaur detected, which may be problematic in statistical analysis and parameter estimations. Hence, application of the survey methods should depend on objectives of the study, habitat characteristics, and availability of manpower, budgets, and logistic constraints. For example, for group-living animals, like gaur, repeated direct observations are more practical to observe population sex and age ratios and abundance if the study area mainly contains savanna-liked habitats. In contrast, if researchers are interested in gaur density or their distribution across an extensive spatial scale with heterogeneous habitat types, camera trapping should be applied to improve population inferences, e.g., density and occupancy, when using to the mathematical modeling analysis.

LITERATURE CITED

Ahrestani, F. S., I. M. A. Heitkönig, and H. H. T. Prins. 2012. Diet and habitat-niche relationships within an assemblage of large herbivores in a seasonal tropical forest. Journal of Tropical Ecology 28:385-394.

Ahrestani, F. S., and K. U. Karanth. 2014. Gaur *Bos gaurus* C. H. Smith, 1827. Pages 174-193 *in* M. Melletti, andJ. Burton, editors. Ecology, Evolution and Behaviour of Wild Cattle. Cambridge University Press.

Andheria, A. P., K. U. Karanth, and N. S. Kumar. 2007. Diet and prey profiles of three sympatric large carnivores in Bandipur Tiger Reserve, India. Journal of Zoology 273:169-175.

Bidayabha, T. 2001. Ecology and behavior of Gaur (*Bos gaurus*) in a degraded area at Khao Phaeng-Ma, The northeastern edge of Khao Yai National Park, Thailand. Mahidol University.

Biswas, S., and K. Sankar. 2002. Prey abundance and food habit of tigers (Panthera tigris tigris) in Pench National Park, Madhya Pradesh, India. Journal of Zoology 256:411-420.

Burton, A. C., E. Neilson, D. Moreira, A. Ladle, R. Steenweg, J. T. Fisher, E. Bayne, and S. Boutin. 2015. REVIEW: Wildlife camera trapping: a review and recommendations for linking surveys to ecological processes. Journal of Applied Ecology 52:675-685.

Conroy, M. J., and J. P. Carroll. 2009. Quantitative conservation of vertebrates. Wiley-Blackwell. 342 pp.

Conry, P. J. 1981. Habitat selection and use, movements, and home range of Malayan Gaur (*Bos gaurus hubbacki*) in Central Pahang, Malaysia. University of Montana.

Gotelli, N. J., and A. M. Ellison. 2013. A Primer of Ecological Statistics. 2nd edition. Sinauer Associates Inc., MA, USA. 614 pp.

Karanth, K. U., and J. D. Nichols. 2002. Monitoring tigers and their prey: A manual for researchers, managers and conservationists in Tropical Asia. Center for Wildlife Studies, India.

Karanth, K. U., J. D. Nichols, N. S. Kumar, W. A. Link, and J. E. Hines. 2004. Tigers and their prey: Predicting carnivore densities from prey abundance. Proceedings of the National Academy of Sciences of the United States of America 101:4854-4858.

Karanth, K. U., and B. M. Stith. 1999. Prey depletion as a critical determinant of tiger population viability. Pages 100–113 *in* J. Seidensticker, S. Christie, andP. Jackson, editors. Riding the Tiger: Tiger Conservation in Human dominated Landscapes. Cambridge University Press, Cambridge, UK.

Karanth, K. U., and M. E. Sunquist. 1995. Prey selection by tiger, leopard and dhole in tropical forests. Journal of Animal Ecology:439-450.

Lyman Ott, R., and M. Longnecker. 2001. An Introduction to Statistical Methods and Data Analysis. 5th edition. Duxbury Thomson Learning, USA. 1152 pp.

Meridith, M., and M. Ridout. 2014. Overlap: Estimates of coefficient of overlapping for animal activity patterns. Version R package version 0.2.4. <http://CRAN.R-project.org/package=overlap>.

O'Connell, A. F., J. D. Nichols, and K. U. Karanth. 2011. Camera traps in Animal Ecology. Springer. 271 pp.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <http://www.R-project.org/>.

Ridout, M. S., and M. Linkie. 2009. Estimating overlap of daily activity patterns from camera trap data. Journal of Agricultural, Biological, and Environmental Statistics 14:322-337.

Sankar, K., H. S. Pabla, C. K. Patil, P. Nigam, Q. Qureshi, B. Navaneethan, M. Manjreakar, P. S. Virkar, and K. Mondal. 2013. Home range, habitat use and food habits of re-introduced gaur (*Bos gaurus gaurus*) in Bandhavgarh Tiger Reserve, central India. Tropical Conservation Science 6:50-69.

Schaller, G. B. 1967. The deer and the tiger : A study of wildlife in India. The University of Chicago press. 370 pp.

Sollmann, R., A. Mohamed, H. Samejima, and A. Wilting. 2013. Risky business or simple solution – Relative abundance indices from camera-trapping. Biological Conservation 159:405-412.

Steinmetz, R., W. Chutipong, N. Seuaturien, and E. Chirngsaard. 2008. Community structure of large mammals in tropical montane and lowland forest in the Tenasserim-Dawna Mountains, Thailand. Biotropica 40:344–353.

Steinmetz, R., N. Seuanturien, S. Srirattanaporn, and B. Poonnil. 2011. Experimental approaches towards tiger recovery in Kuiburi National Park, Thailand.

Steinmetz, R., N. Seuaturien, W. Chutipong, and B. Poonnil. 2009. The ecology and conservation of tigers and their prey in Kuiburi National Park, Thailand.

Steinmetz, R., N. Seuaturien, S. Srirattanaporn, and B. Poonnil. 2014. Research and conservation of tigers and their prey in Kuiburi National Park.

Temchai, T., C. Chamnankid, and A. Yoosomboon. 2010. Habitat Diversity and Landuse of Kuiburi National Park and Keangkrachan-Kuiburi National Park Corridor. National Park and Protected Areas Innovation Center (Petchburi). 93.

Tobler, M. W., S. E. Carrillo-Percastegui, R. Leite Pitman, R. Mares, and G. Powell. 2008. An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation 11:169-178.

TABLES

Table 2.1. Description of 4 age classes by sex based on body color, relative body size, and horn characteristics used for sex and age classification of gaur population obtained from direct observation and camera trapping in Kuiburi National Park, Thailand during November 2013-January 2015 (modified from Ahrestani 2009).

Age class	**Female**	**Male**
Calf (0-3 months)	Light orange-brown body coat, white stocking invisible	
Yearling (3-15 months)	Darker brown body coat, white stocking, < 2/3 height at the shoulder of adult female	
Juvenile (age 15-36 months)	Horns ~ 1 ft black, curve inward, white < 30%, black body coat	Black anterior body coat, horns: ~1ft spreading away from head, pointing upwards, white <50% from base
Adult (> 3 years)	Full grown- a little larger than juvenile, horns white>30% and wider with increasing age	Larger than female, more black body coat with older, dorsal ridge, horns: white > 50 %.

Table 2.2. Description of vegetation variables measured in 5-m-radius circular plots to examine seasonal variation across forest types in focal study areas in Kuiburi National Park during November 2013-January 2015.

Variables (Abbreviation)	**Description**
% cover of herbaceous plant	% of plot area covered by <1 m high, non-woody plants other than grass and bamboo.
% cover of shrub	% of plot area covered by 1-5 m high or upright multiple stem woody plants
% cover of bamboo	% of plot area covered by bamboo
% cover of grass	% of plot area covered by grass, mainly *Brachiaria ruziziensis*
% cover of lianas	% of plot area covered by lianas, vine, and climbers. Lianas, vines, and climbers are a group of plants that rooted on the ground, tangled, and use trees to reach to the canopy.
Tree density	Counts of stems of woody plants with >5 m high. The girth size at breast height (GBH) is divided into 3 classes; S (small): <32 cm, M (medium): 32-62 cm, and L (large): > 62 cm.

Table 2.3. Direct observation efforts and maximum daily gaur counts in Payang region, Kuiburi National Park, during November 2013-January 2015.

Year-Month	Date start	Date end	Number of dates	PM attempts	AM attempts	Season	Maximum daily gaur counts
2013-Nov	22-Nov-13	26-Nov-13	5	5	-	wet	89
2014-Feb	12-Feb-14	13-Feb-14	2	2	-	dry	19
2014-Mar	25-Mar-14	28-Mar-14	4	3	3	dry	10
2014-Apr	18-Apr-14	21-Apr-14	4	4	2	dry	68
2014-May	30-Apr-14	4-May-14	5	5	-	wet	81
2014-Jun	19-Jun-14	23-Jun-14	5	4	4	wet	55
2014-Aug	5-Aug-14	8-Aug-14	4	3	2	wet	82
2014-Sep	9-Sep-14	12-Sep-14	4	3	3	wet	83
2014-Oct	18-Oct-14	27-Oct-14	6	4	4	wet	81
2014-Nov	15-Nov-14	19-Nov-14	5	4	4	wet	77
2014-Dec	16-Dec-14	21-Dec-14	6	5	5	dry	7
2015-Jan	17-Jan-15	24-Jan-15	2	2	-	dry	26

Table 2.4. Camera trapping efforts measured as the number of trap-nights and gaur detection by regions and zones in Kuiburi National Park during November 2013-January 2015. Number of camera trap locations were shown in parentheses.

Region / Zone	Total trap-nights	Number of trap-nights gaur detected	Encounters/ 100 trap-nights	Camera trap convex area (km^2)	camera spacing range (average) ,*km*.
Total (56)	**8999**	**649**	**9.35**	**89.2**	**3.5-5.0 (1.2)**
Payang (24)	**3545**	**523**	**18.98**	**18.3**	**0.4-1.5 (0.6)**
P1 (8)	1022	77	9.59	-	0.4-1.5 (0.7)
P2 (6)	785	147	24.59	-	0.5-1.0 (0.6)
P3 (5)	892	192	28.59	-	0.6-0.8 (0.7)
P4 (5)	846	107	15.01	-	0.4-1.0 (0.5)
Central (17)	**3093**	**48**	**1.94**	**34.3**	**0.7-5.0 (1.5)**
C1 (8)	1402	9	0.86	5.9	0.8-1.5 (1.0)
C2 (7)	1067	34	4.03	28.4	0.7-5.0 (1.8)
C3 (2)	624	5	0.8	0.004	1.9
North (4)	**980**	**51**	**6.84**	**0.5**	**0.6-1.0 (0.7)**
South (11)	**1381**	**27**	**2.97**	**36.1**	**1.2-4.0 (2.2)**

Table 2.5. Comparison of gaur encounter frequency derived from direct observation and camera trapping in Kuiburi National Park during November 2013- January 2015. Only camera trap encounters on the direct observation sampling dates were included.

Observation period	**Methods**	**Camera trap detection**		**Total by Direct observation**
	Direct observation detection	**Detected**	**Not detected**	
AM	Detected	8	8	16
	Not detected	3	9	12
	Total by Camera trap	11	17	28
PM	Detected	11	25	36
	Not detected	8	8	16
	Total by camera trap	19	33	52
POOLED	Detected	19	33	52
	Not detected	11	17	28
	Total Direct observation	30	50	80

Table 2.6. Percent of Area cover and the number of vegetation sampling plots and the number of sampling clusters by land use types given focal study zones.The land use types present in a particular zone but were not sampled were labeled as 'NA'.

Zone	Land use	%Area	Number of clusters	Number of plots
Central 1	DE1	29.4	9	47
	DE2	31.8	6	16
	DEMD	0	0	0
	ME1	13.2	2	10
	ME2	23	2	12
	NF	0	0	0
	OF	0	0	0
	SF	2.6	NA	NA
Central 2	DE1	22.8	2	16
	DE2	41.3	2	2
	DEMD	3	NA	NA
	ME1	0	0	0
	ME2	19.4	NA	NA
	NF	2.9	NA	NA
	OF	1.5	NA	NA
	SF	9	3	18
Central 3	DE1	56.5	2	17
	DE2	0	0	0
	DEMD	0	0	0
	ME1	39.6	NA	NA
	ME2	3.8	NA	NA
	NF	0	0	0
	OF	0	0	0
	SF	0	0	0

Zone	Land use	%Area	Number of locations	Number of plots
North	DE1	47.1	3	21
	DE2	0	0	0
	DEMD	0	0	0
	ME1	3.7	NA	NA
	ME2	36.7	NA	NA
	NF	1	1	5
	OF	1.2	NA	NA
	SF	10.3	1	9
Payang	DE1	11.2	NA	NA
	DE2	42.7	9	51
	DEMD	0	0	0
	ME1	0	0	0
	ME2	0.7	NA	NA
	NF	0.2	NA	NA
	OF	0	0	0
	SF	45.2	21	135
South	DE1	20.4	3	19
	DE2	55.3	12	78
	DEMD	0.4	NA	NA
	ME1	8.7	3	17
	ME2	13.3	2	11
	NF	0.1	NA	NA
	OF	0.1	NA	NA
	SF	1.7	1	9

Table 2.7. One-way ANOVA of the mean vegetation variables for the land use types and focal study zones main effects of vegetation sampling plots across five land use types and six zones in Kuiburi National Park, Thailand. Vegetation cover variables were re-scaled to log_{10}.

Variables	Land use	Zones
Grass cover	$F_{4,483}$ = 104.6, P < .001	$F_{5,482}$ = 144.2, P < .001
Herb cover	$F_{4,483}$= 36.77, P < .001	$F_{5,482}$ = 32.44, P < .001
Shrub cover	$F_{4,483}$ = 12.35, P < .001	$F_{5,482}$ = 11.22, P < .001
Bamboo cover	$F_{4,483}$ = 5.792, P < .001	$F_{5,482}$ = 39.81, P < .001
Liana cover	$F_{4,483}$ =36.23, P < .001	$F_{5,482}$ = 36.81, P < .001
Small-tree density	$F_{4,483}$ = 4.493, P < .001	$F_{5,482}$ = 5.708, P < .001
Medium-tree density	$F_{4,483}$= 4.292, P < .001	$F_{5,482}$ = 7.066, P < .001
Large-tree density	$F_{4,483}$= 11.88, P < .001	$F_{5,482}$ = 13.28, P < .001

FIGURES

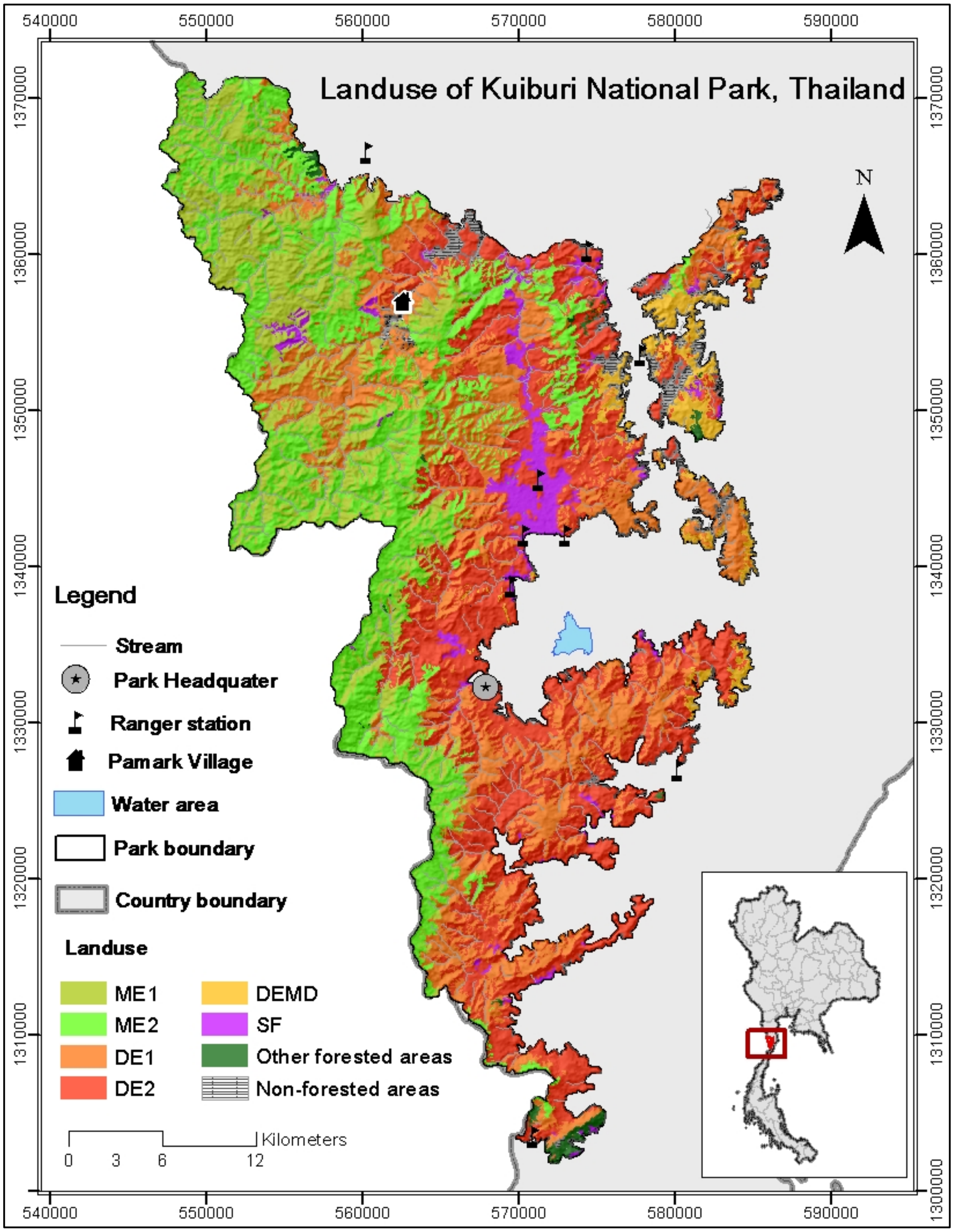


Figure 2.1. Eight Land use types of Kuiburi National Park. Land use types were re-categorized from 13 land use types according to Temchai et al. (2010).

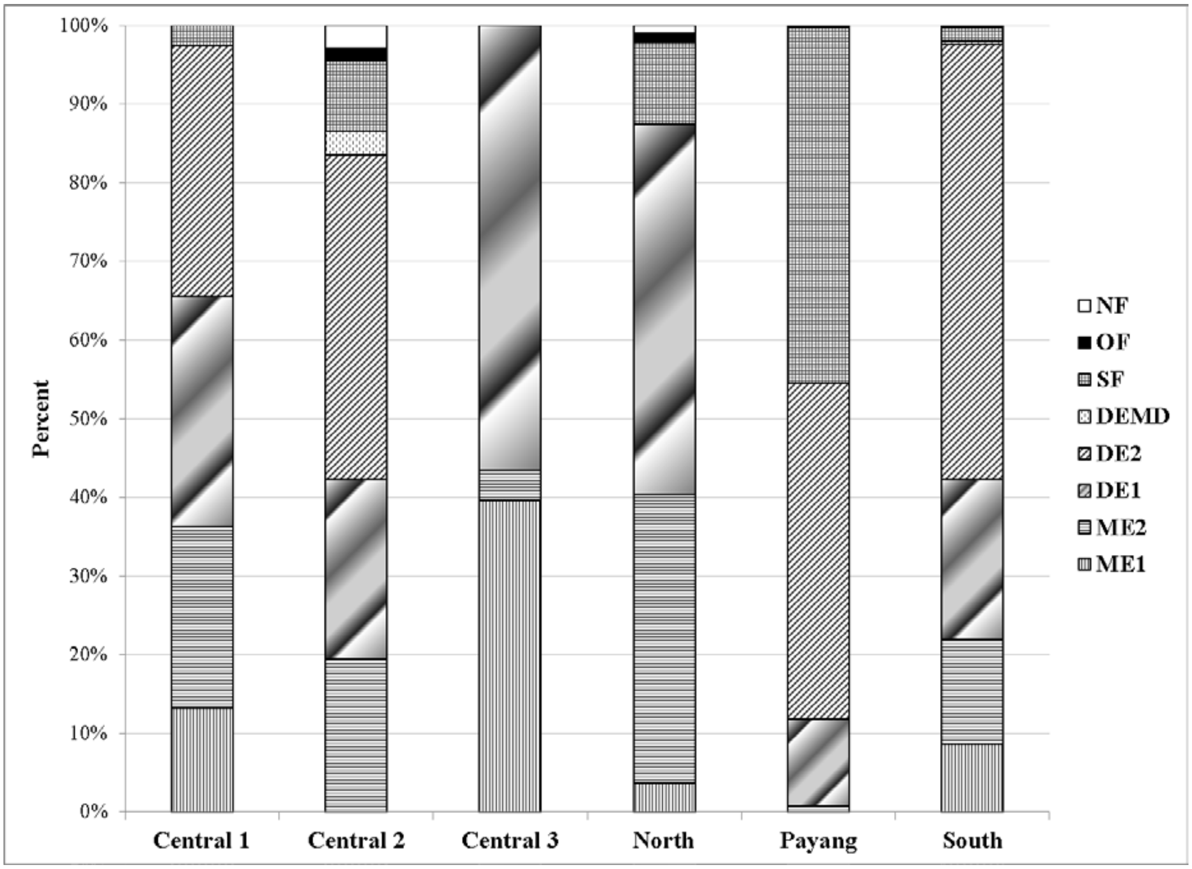


Figure 2.2. The proportion of land use types, according to zones, of focal study areas in Kuiburi National Park. The focal study areas were defined as the area within 1-km buffer of camera trap convex polygons. Land use abbreviations: ME1- Moist Evergreen Forest; ME2- Semi-evergreen Forest; DE1- Middle Dry Evergreen Forest; DE2- Lower Dry Evergreen Forest; DEMD- Dry Evergreen Forest mixed with Deciduous Forest; SF- Secondary Forest; Other forested areas (OF) include HE-Hill Evergreen Forest, MD- Mixed Deciduous Forest, DD- Dry Dipterocarp Forest , BB- Bamboo Forest; Non-forested areas (NF) include OC- Old clearing areas, OA- Open areas, AG-Agriculture areas, and WT-Water bodies.

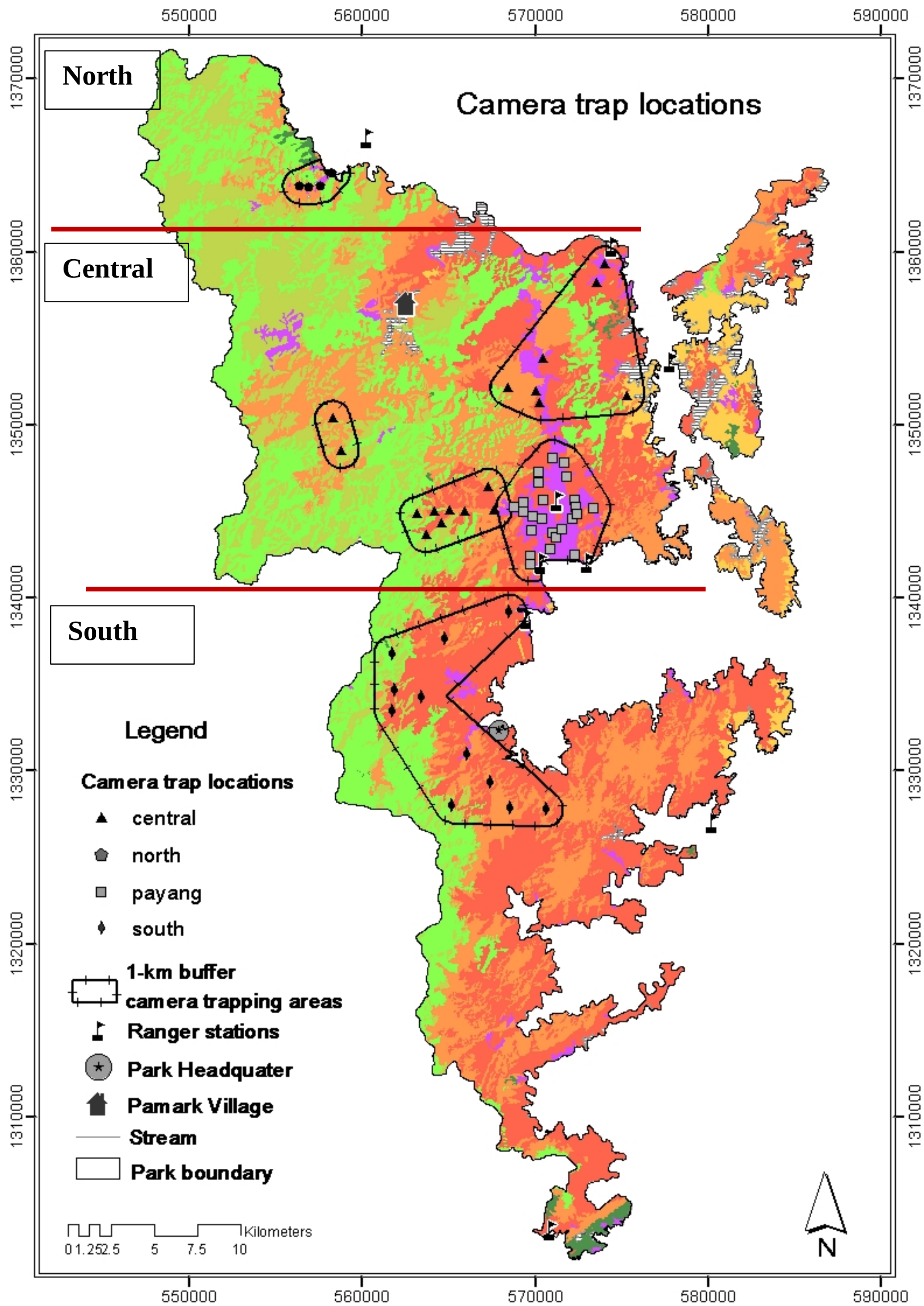


Figure 2.3. Camera trap locations (n=56) and the effective camera trapping areas, which included the area within 1-km buffer of camera locations minimum convex polygons. See Chapter 1 for land use descriptions.

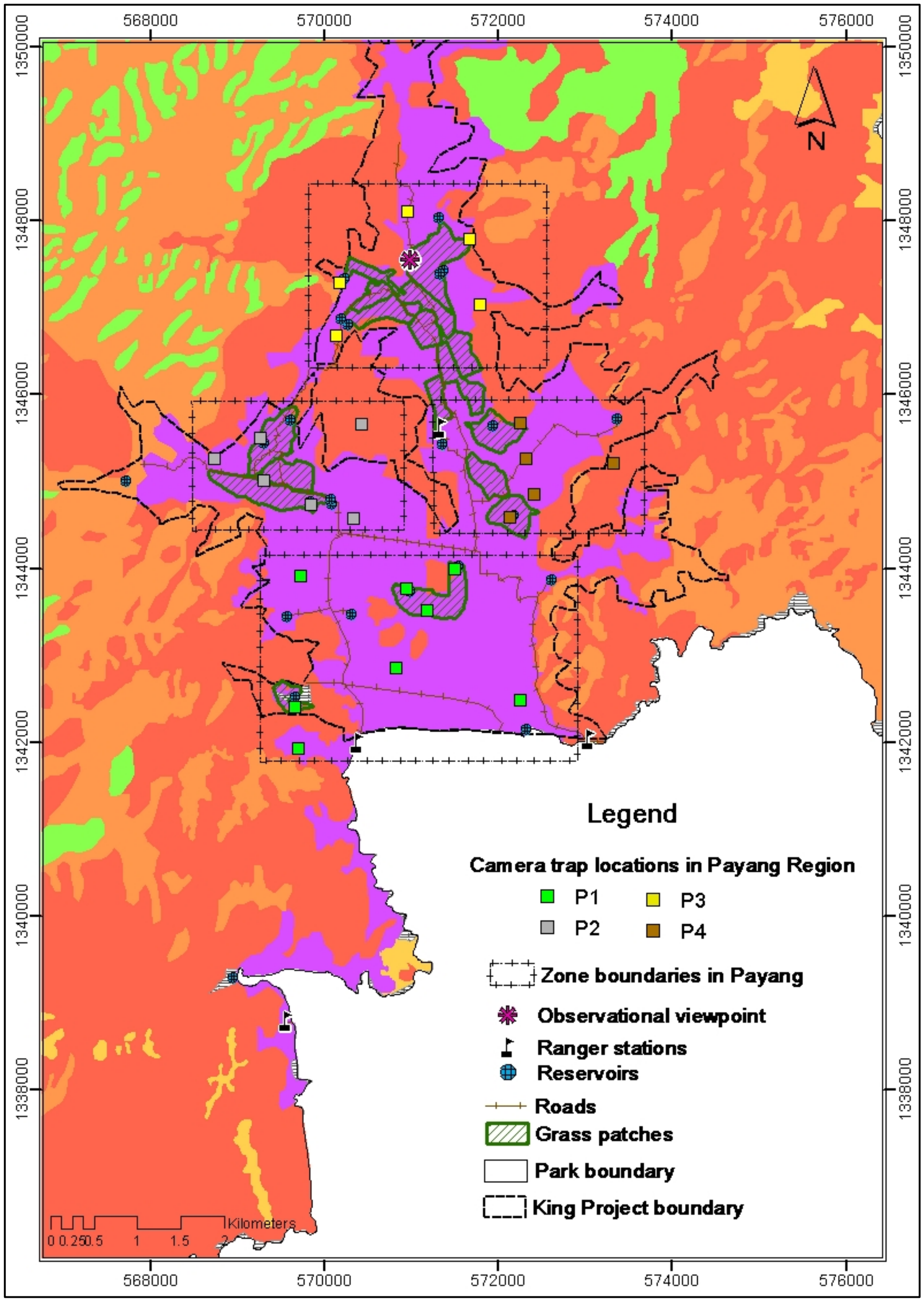


Figure 2.4. Maps of the Payang zone in Kuiburi National Park showing four subzones and camera trap locations in each subzone. A total of 24 camera trap locations were deployed in the Payang zone during November 2013-January 2015.

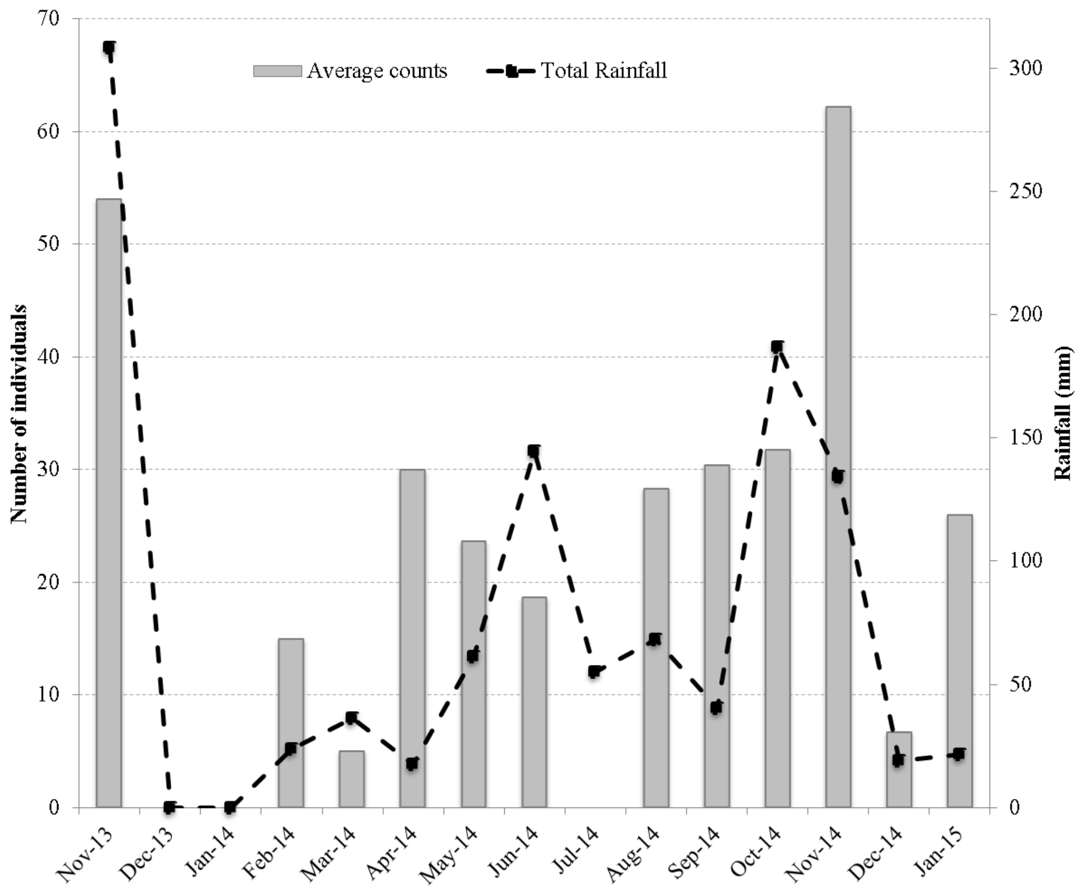


Figure 2.5. Monthly average number of individuals per encounter from direct observation in the Payang zone in a relation to the total rainfall. No observation months were empty. Average total rainfall over five years during 2009-2014 were used as the total rainfall in October 2014-January 2015 due to the lack of data in those months.

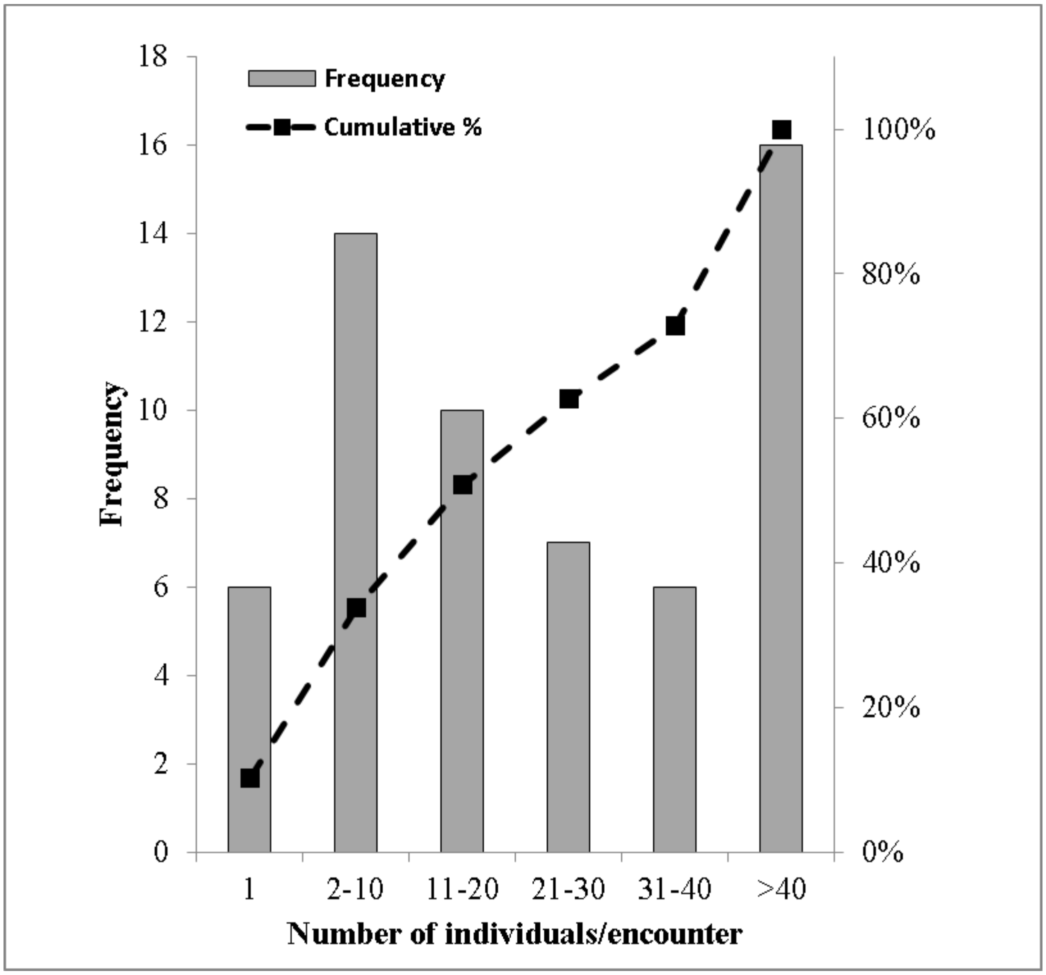


Figure 2.6. Histogram of the size of groups of solitary (bulls) and herds (at least two individuals) encounters by direct observations in Payang during November 2013-January 2015. Herd encounters were 90% of total encounters (n=59).

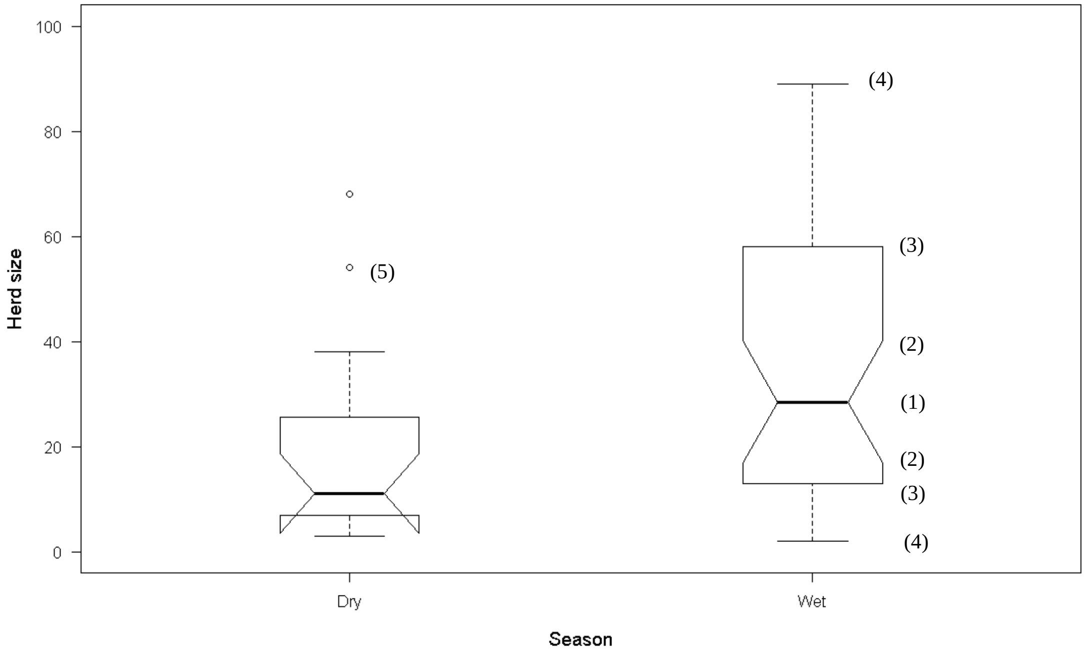


Figure 2.7. Boxplot of herd size per encounter observed in the dry and wet seasons from direct observation in Payang region, Kuiburi National Park during November 2013-January 2015 (n=53). Each box shows (1) median, (2) notches include herd size at 95% confidence level, (3) the lower (Q1) and upper (Q3) quartiles, (4) outliers of herd size, and (5) extreme outliers of herd size.

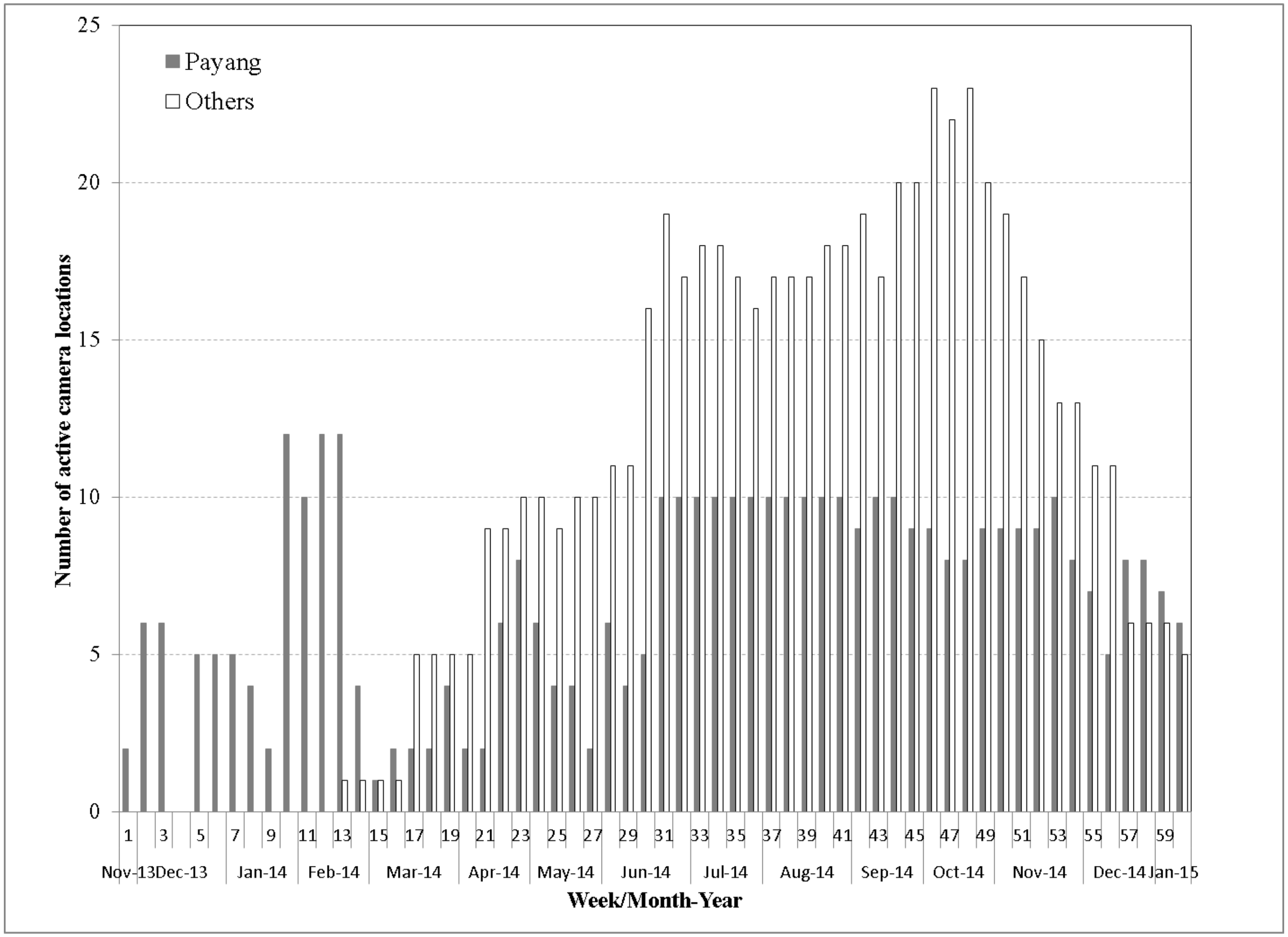


Figure 2.8. Maximum number of active camera location by week in Payang and other regions in Kuiburi National Park during 24 November 2013- 15 January 2015 (60 weeks).

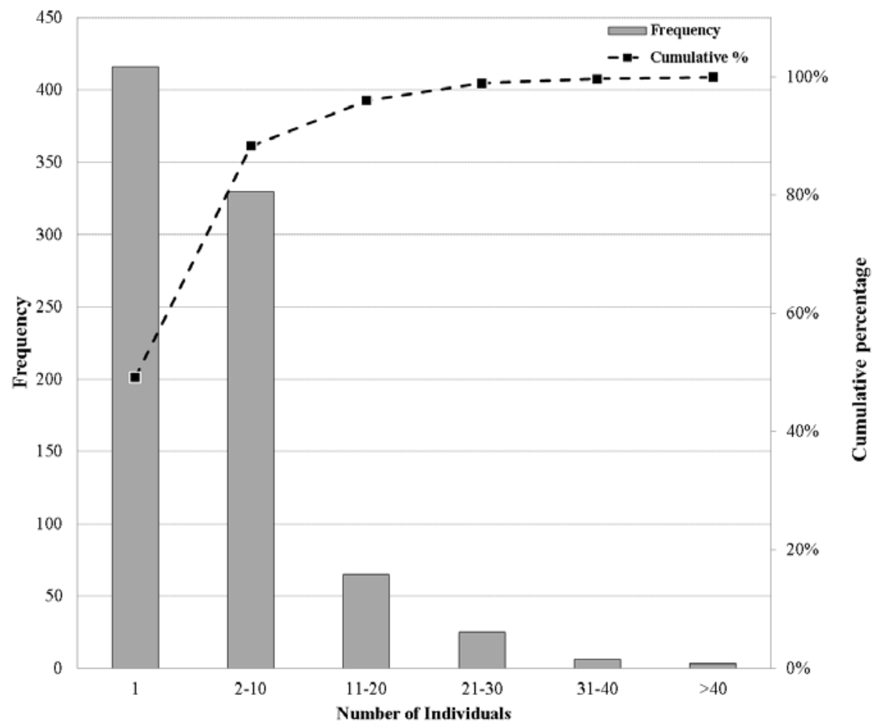


Figure 2.9. The number of individuals of an independent encounter by camera trapping in 6 focal study areas in Kuiburi National Park, Thailand during November 2013-January 2015.

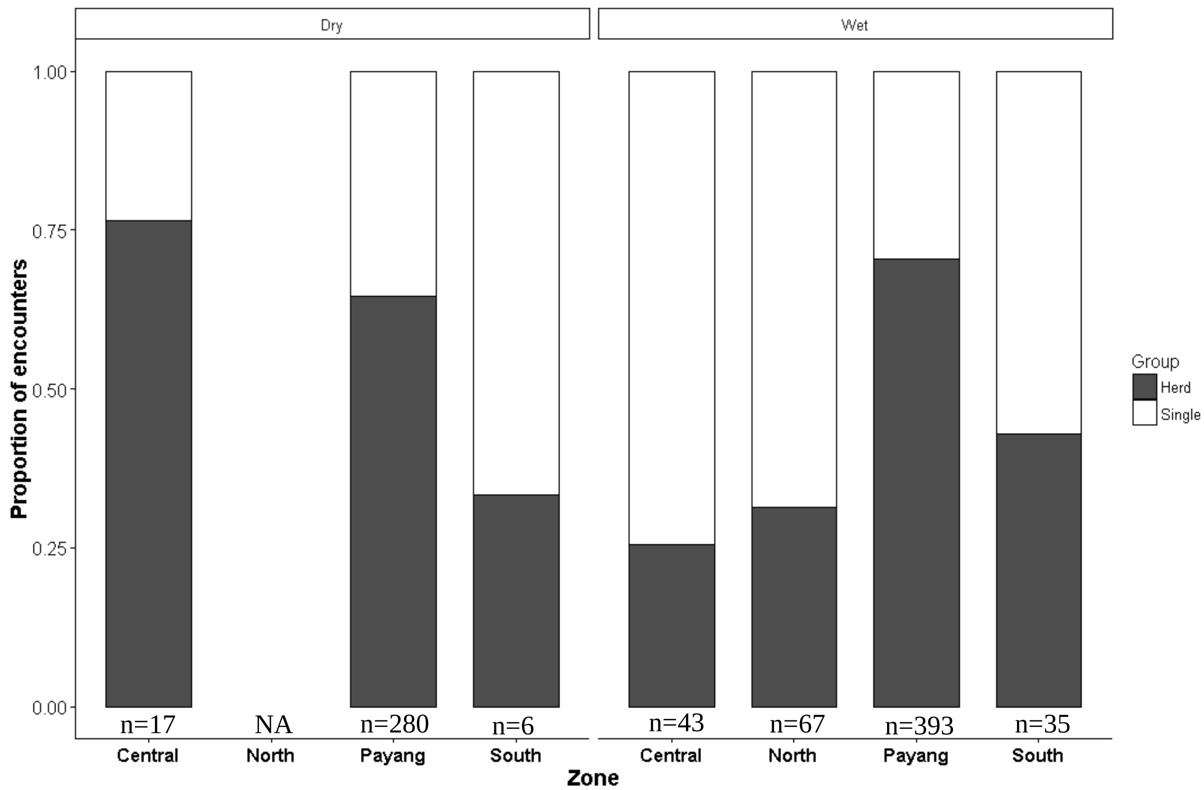


Figure 2.10. Proportion of single and herd encounters by zones (Central, North, Payang, and South) and seasons (Dry and Wet) from camera trapping in Kuiburi National Park during November 2013-January 2015. Payang zone is a lowland secondary forest with habitat improvement to enhance resource availability for ungulates and is preferred by gaur herds. The other zones are mainly composed of dry evergreen forests and moist evergreen forests and are more utilized by single gaur.

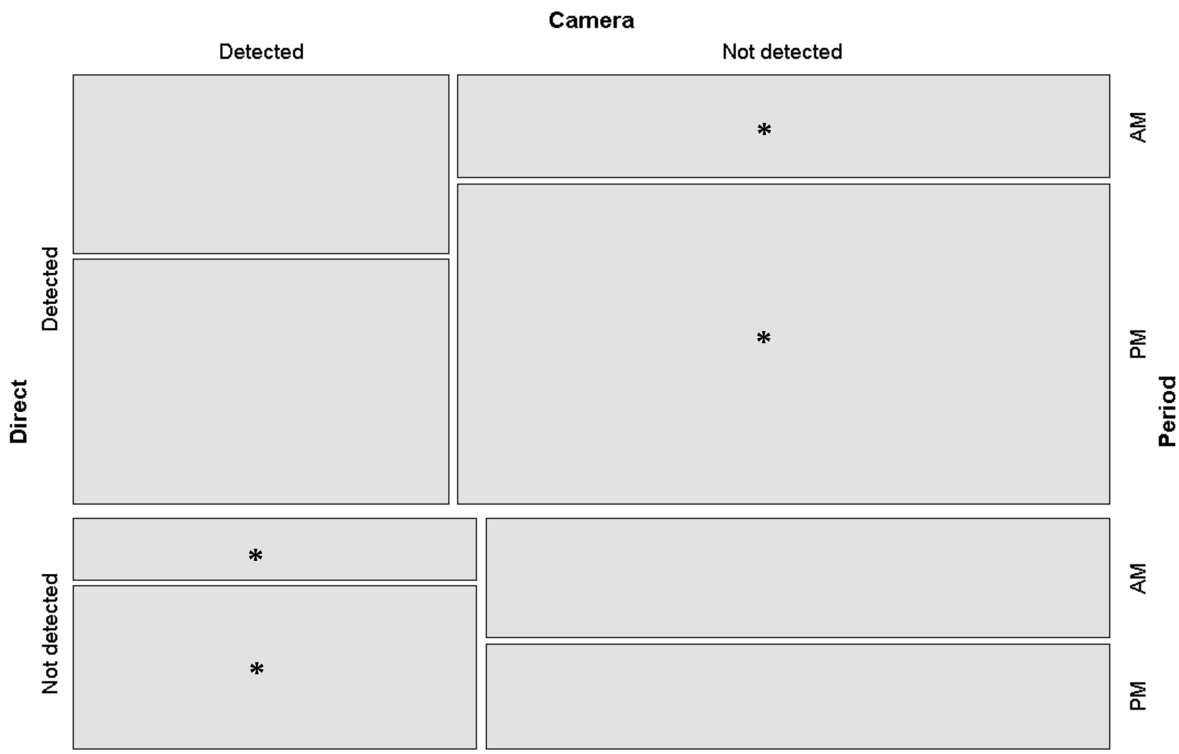


Figure 2.11. Mosaic plot comparing frequency of the gaur encounters obtained from direct observation and camera trapping, controlling for the daytime periods (AM or PM) in Kuiburi National Park during November 2013-January 2015. The detection of gaur from direct observations and camera trapping surveys during the direct observation sampling dates was independent. Proportion of non-congruent detection (e.g., gaur were detected only by either direct observations or camera traps), shown in starred boxes, was large. Camera traps failed to detect gaur when gaur were detected by direct observations.

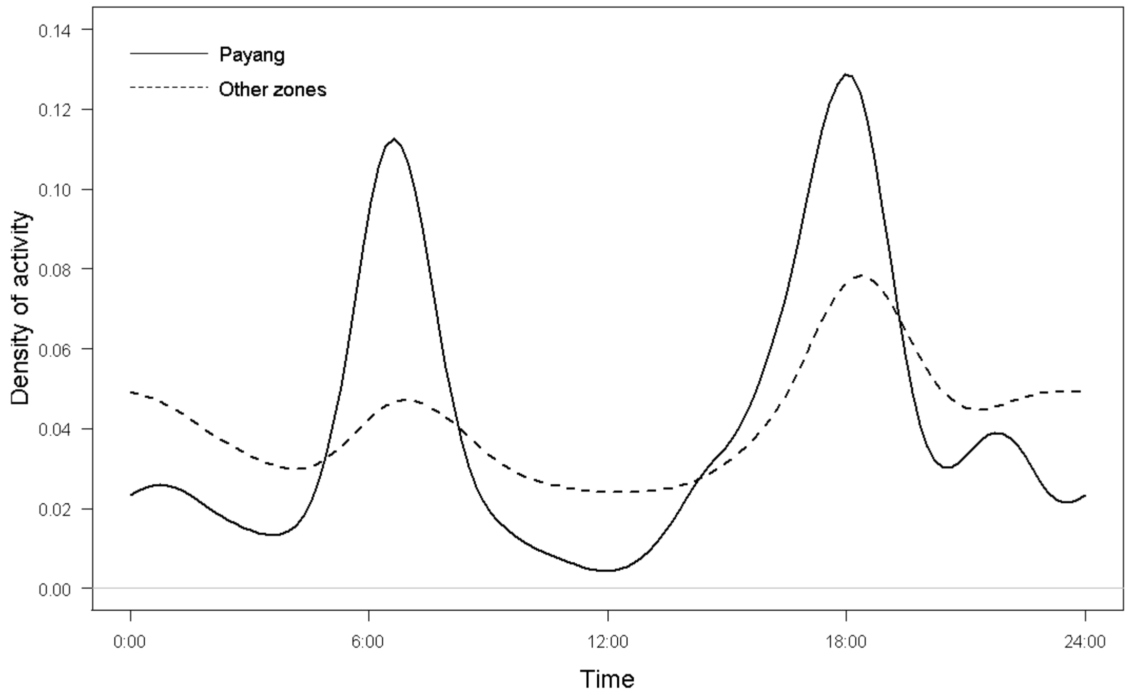


Figure 2.12. Kernel density curves showing trends of times that gaur were more often photographed by camera traps during a 24-hour period in Kuiburi National Park during November 2013- January 2015. Based on 673 encounters in the Payang zone and 168 encounters in the other zones, gaur were active at the dusk and dawn periods.

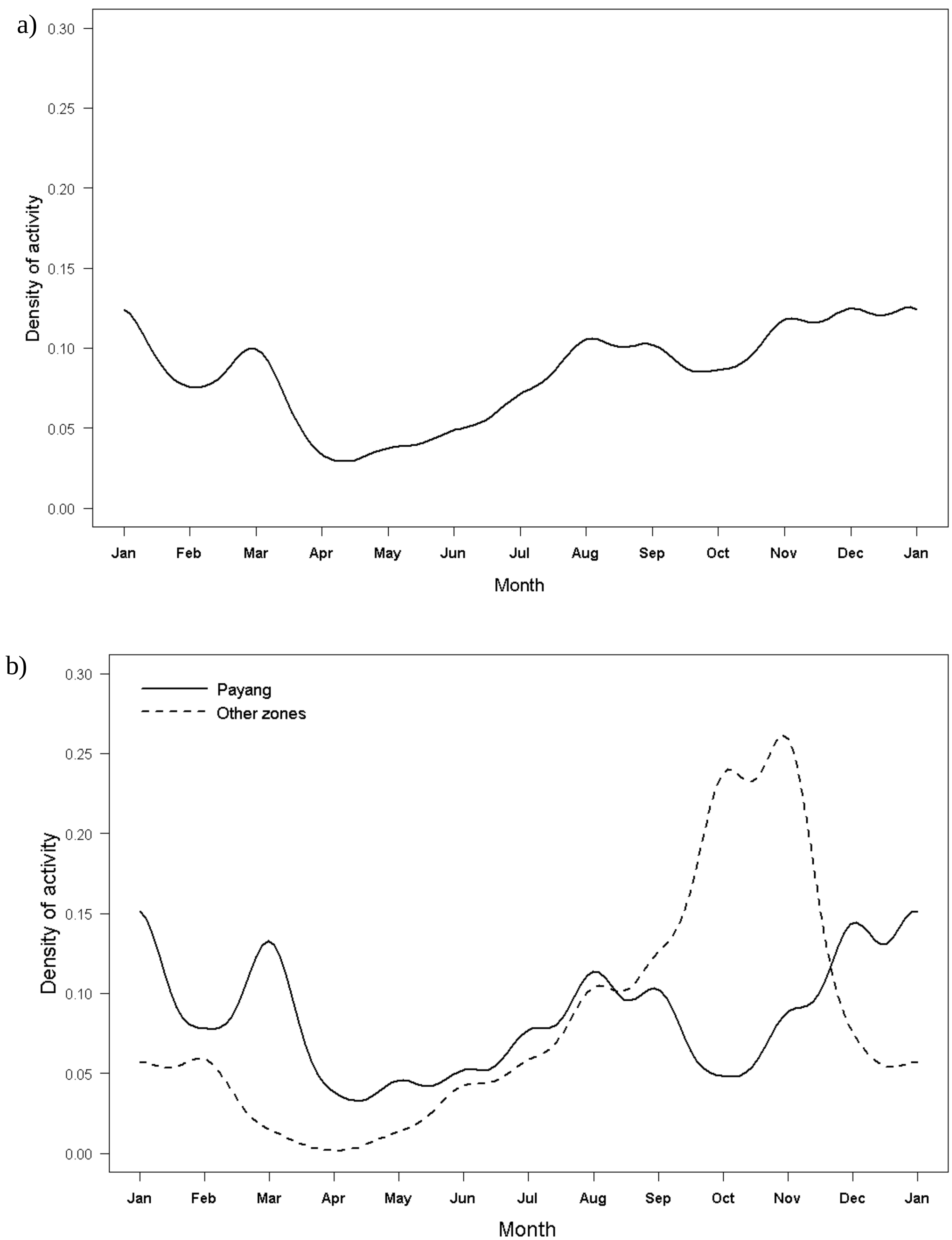


Figure 2.13. Kernel density curves showing trends in the presence of gaur captured by camera traps by month in the Payang zone and other sampling zones in Kuiburi National Park during November 2013- January 2015.a) overall data (n=841). b) Payang (n=673) and other zones (n=168).

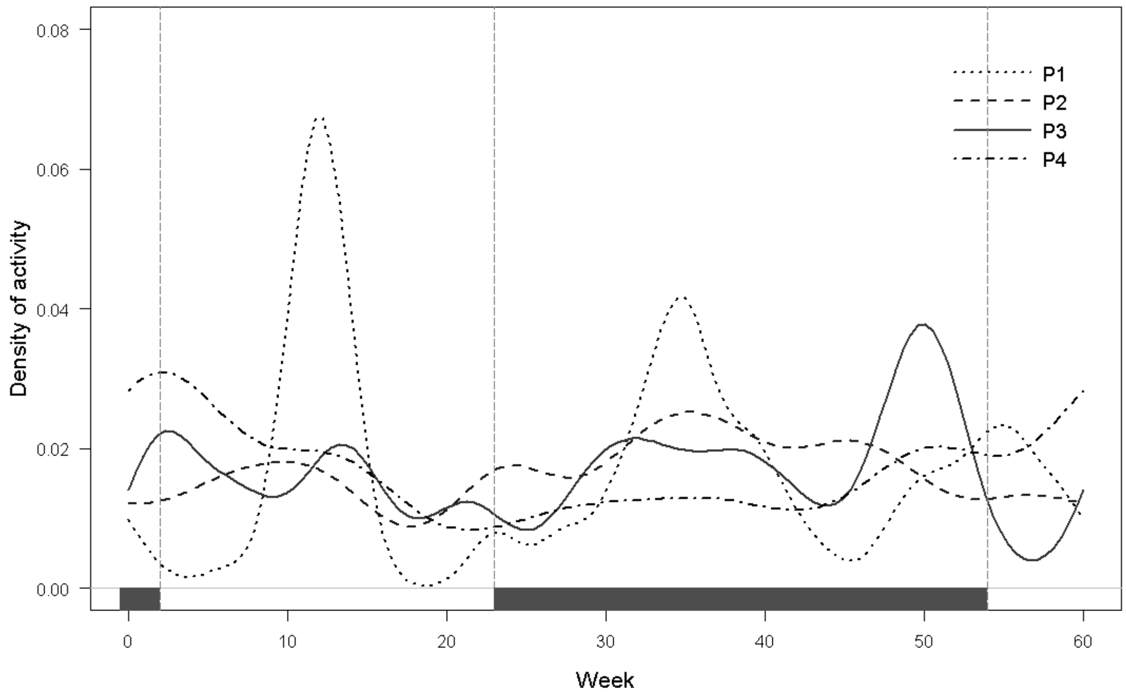


Figure 2.14. Sixty-week- period of kernel density curves of gaur captured by camera traps in 4 subzones of the Payang zone in Kuiburi National Park during November 2013-January 2015. The weeks with gray highlight bars were in the wet season. The number of encounters was 98, 193, 255, and 127 encounters for P1, P2, P3, and P4 subzones, respectively.

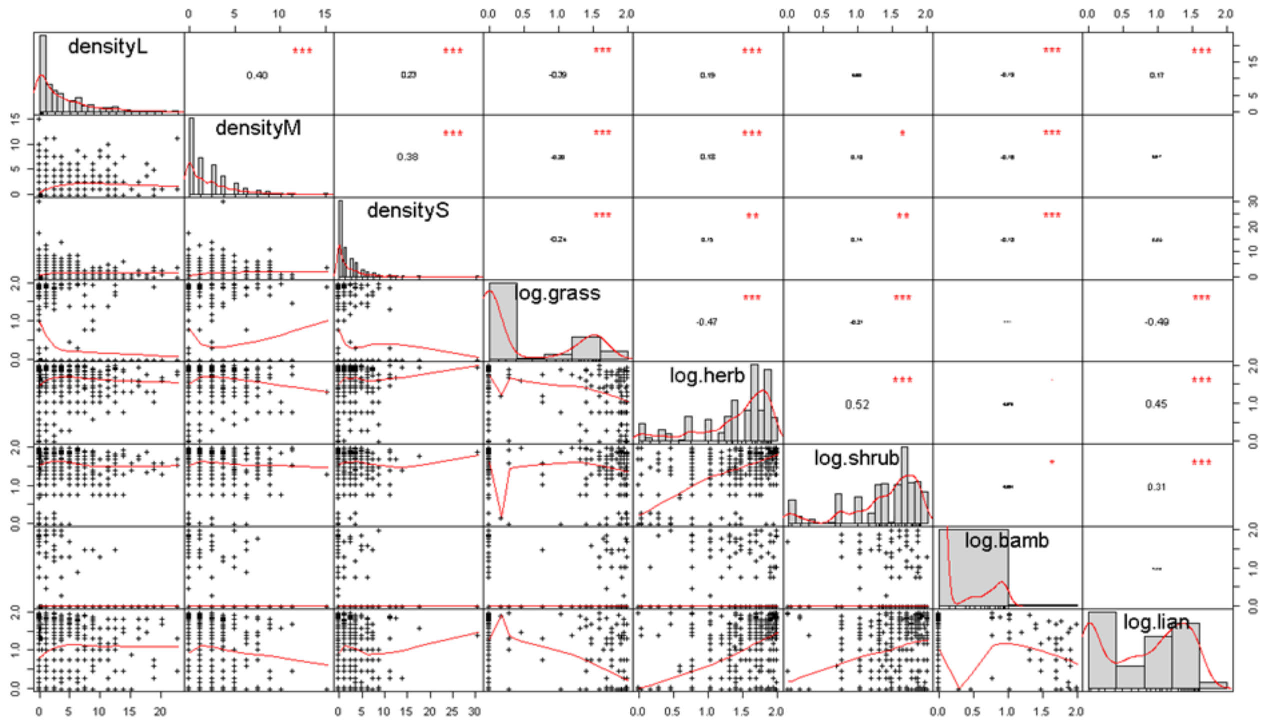


Figure 2.15. Bivariate scatter plots with fitted lines (lower panel), histograms with fitted lines (diagonal panel), and Spearman's rank correlation test (upper panel) of eight vegetation variables, including large-tree density (densityL), medium-tree density (densityM), small-tree density (densityS), grass cover (log.grass), herb cover (log.herb), shrub cover (log.shurb), bamboo cover (log.bamb), and liana cover (log.lian). Percent covers were log-transformed. Correaltion coefficients and significant levels (stars) shown in the upper panel and were scaled corresponding to correlation coefficients.

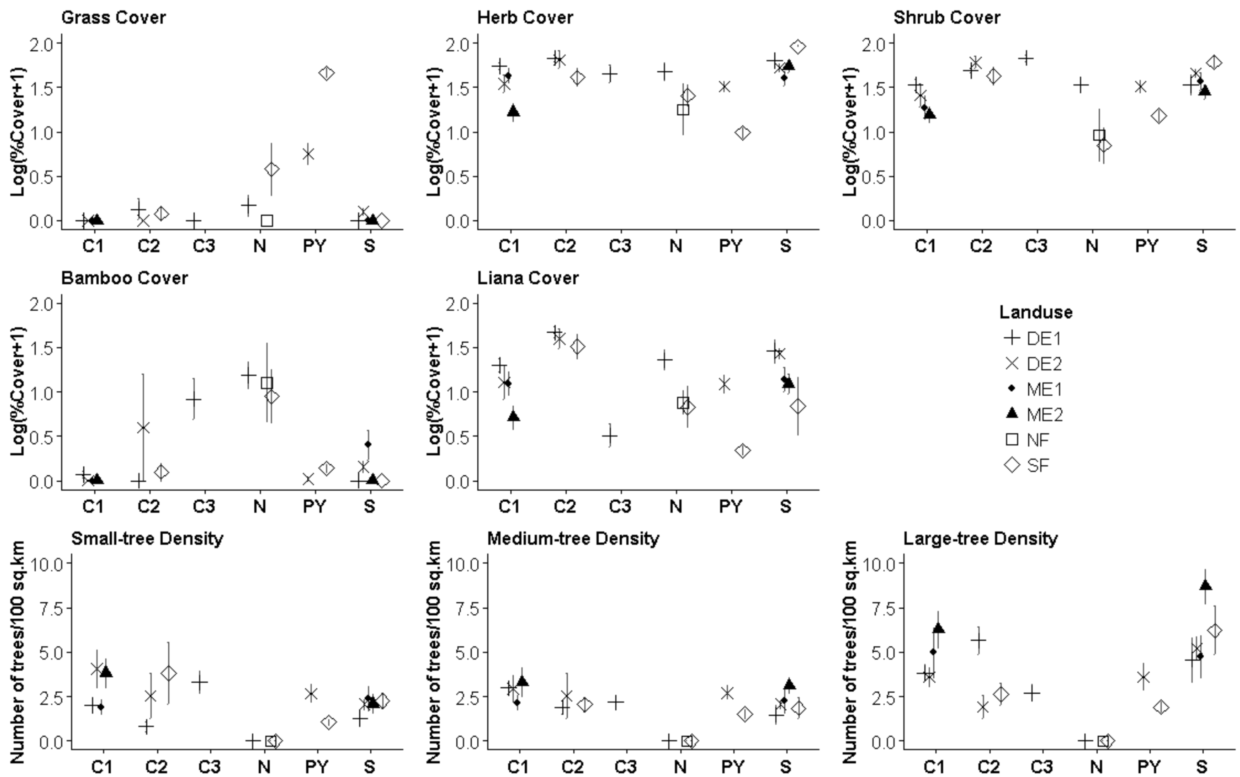


Figure 2.16. Mean ± SE of 8 vegetation variables by zones and land use types of 493 plots across Kuiburi National Park. Percent cover of vegetation were transformed into logarithmic scale by adding constant 1.*Land use types*: DE1 = Middle dry evergreen forest, DE2 = Lower dry evergreen forest, ME1= Tropical moist evergreen forest, ME2 = Semi-evergreen forest, NF= Non-forested habitats, and SF= Secondary forest. *Zone:* C1 = Central1, C2 = Central2, C3 = Central 3, N = North, PY = Payang, S = South.

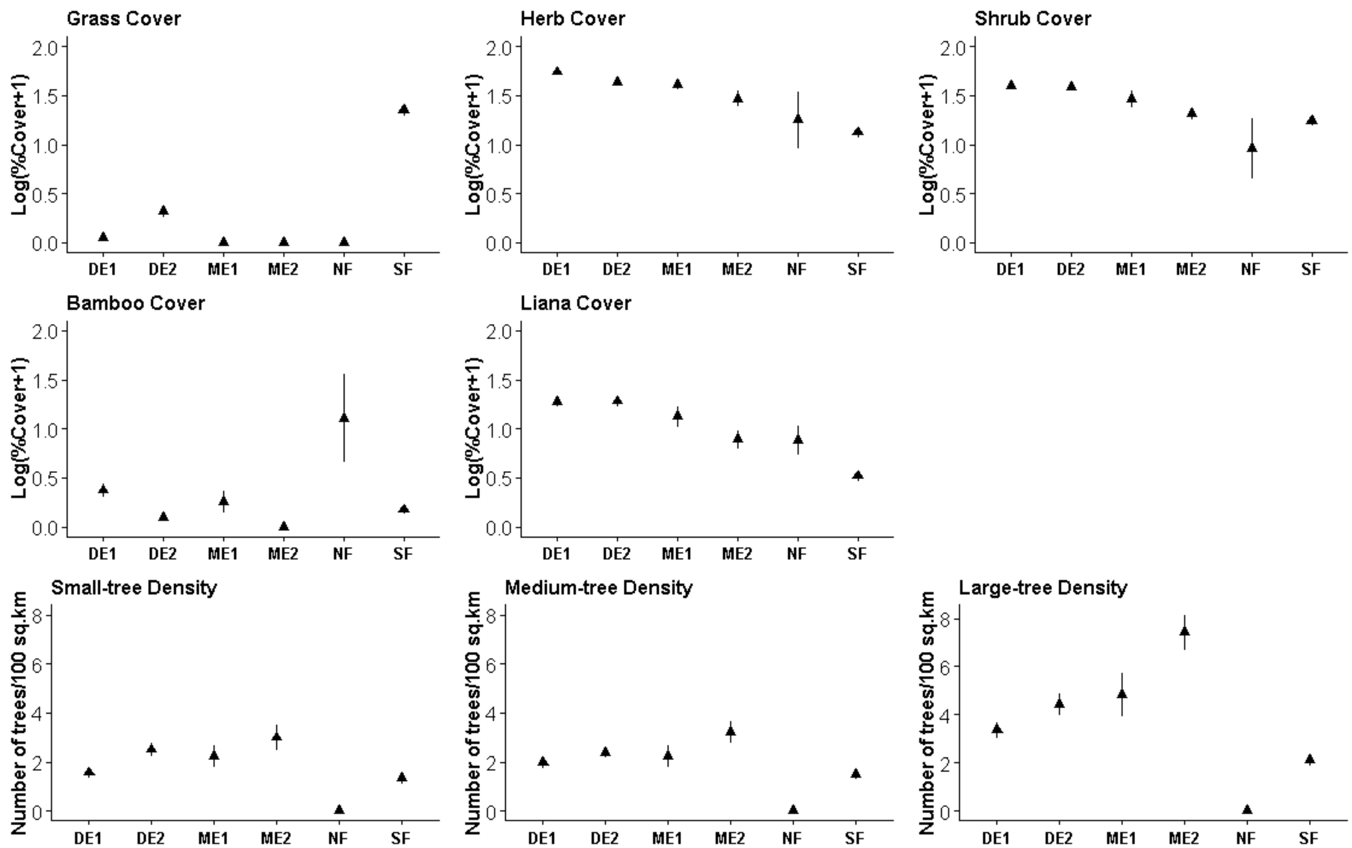


Figure 2.17. Means of 8 vegetation structure variables by land use types measured in 5-m-radius circular plots across 6 focal study areas in Kuiburi National Park during November 2013 – January 2015. *Land-use types*: DE1 = Middle dry evergreen forest, DE2 = Lower dry evergreen forest, ME1= Tropical moist evergreen forest, ME2 = Semi-evergreen forest, NF= Non-forested habitats, and SF= Secondary forest.

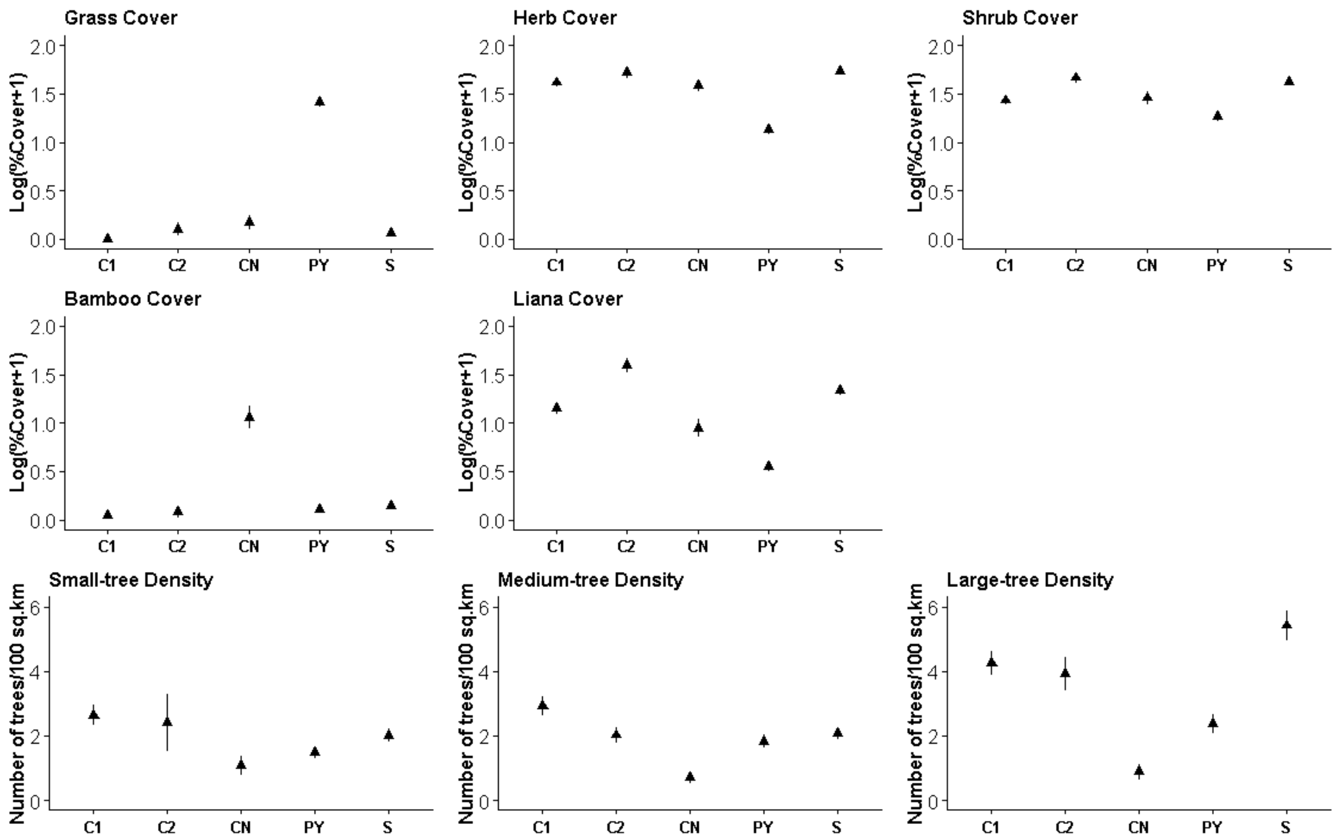
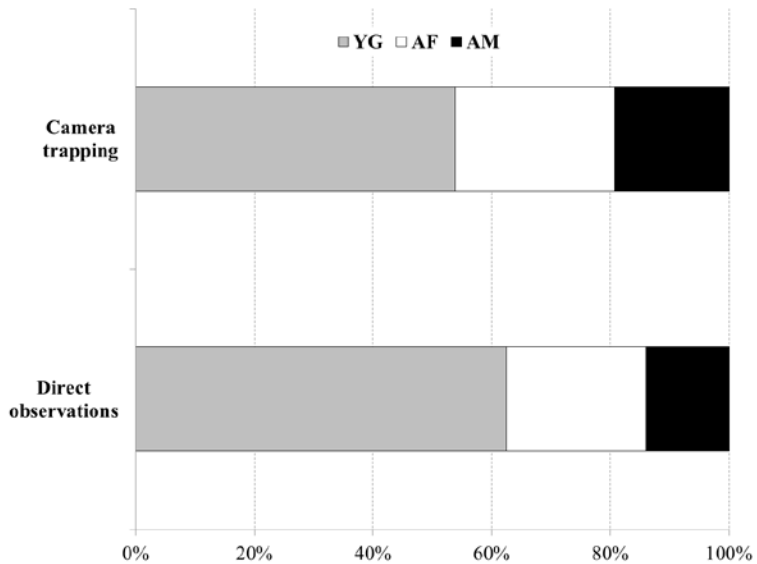
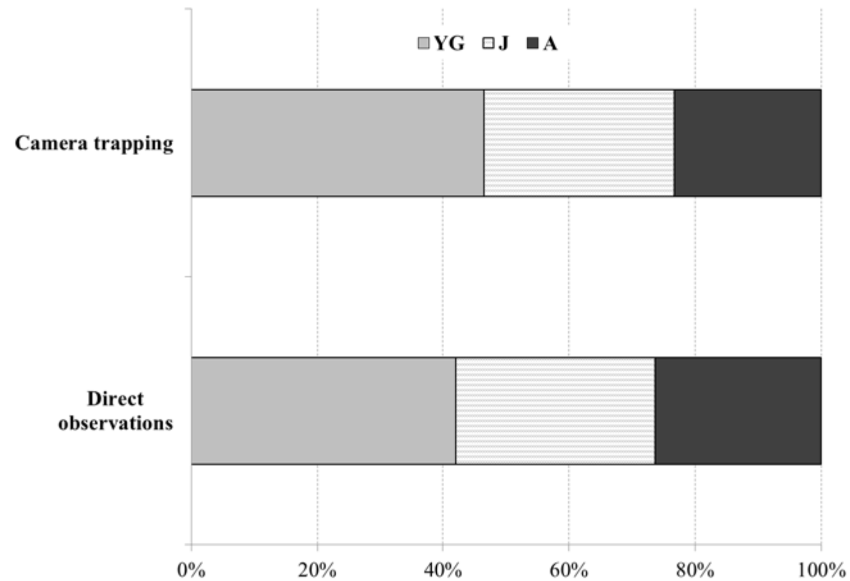


Figure 2.18. Means of 5 vegetation covers in $\log_{10}$ scale and 3 tree density variables based on GBH by zones measured in 5-m-radius circular plots across 6 focal study areas in Kuiburi National Park during November 2013 – January 2015. *Zone*: C1 = Central1, C2 = Central2, CN = Central 3 and North (pooled due to few sampling plots), PY = Payang, S = South.





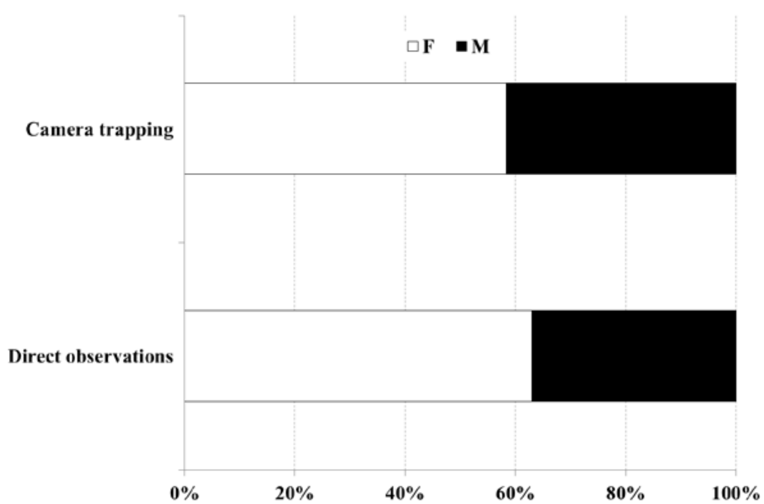


Figure 2.19. Comparison of population structure ratios obtained from direct observations and camera trapping. a) young-adult female-adult male, b) young-juvenile-adult, and c) female to male.

CHAPTER 3

ABUNDANCE AND DENSITY ESTIMATION OF GAUR USING CAPTURE-RECAPTURE

ABSTRACT

Information about population status of gaur, which is one of the herbivores influencing abundance and diversity of the carnivore community in tropical forests, is still required across their distribution ranges in part due to highly fragmented habitats that threaten their existence. Camera trap capture-recapture approaches have become widespread survey and analysis techniques used to study elusive wildlife. The goals of this study were to estimate abundance using capture-recapture methods and to make an inference of gaur density and abundance in Kuiburi National Park, southwestern Thailand. Fifty-six camera locations were set up across 6 focal zones to collect individual images for developing photographic identification protocols based on natural marks and built capture-recapture histories for density estimation using the spatially explicit capture-recapture method. I hypothesized that gaur density varied across zones. Zones were re-categorized into three zones (CN, CP, and S) based on land-use type composition, topographic features, and human disturbance. Abundance was calculated from the density estimates and extrapolated to the overall abundance based on the age ratio of pooled repeated counts obtained from direct observations and camera trapping. Sex heterogeneity of detection probability and spatial scale of movement, which is related to the home range size, was tested.

I identified 22 females (10 adults and 12 juveniles) and 44 males (33 adults and 11 juveniles) based on multiple horn characteristics, including shapes, coloration patterns, and corrugation patterns. Of these, I used capture-recapture histories of 10 adult females and 32 adult males for density estimation. The estimated density of adult gaur, averaged across zones, was 2.5± 1.7SE gaur/100 km^2 (95% CI = 0.8-8.2), resulting in the adult gaur abundance of 48.2 ± 2.3SE gaur (95% CI = 45.1-54.5). Total number of gaur calculated from an averaged age ratio ranged from 198-239 gaur. There was no evidence for the sex variation in the detection probability at home range center (g_0) and the scale of movement (σ), which may relate to home range size. The photographic identification protocol for gaur in this study allows researchers to apply capture-recapture analysis, which is a preferred method to make inferences about population parameters. However, validation for the photographic individual identification, sampling design, and modeling, is necessary to improve estimation accuracy.

INTRODUCTION

Capture-mark-recapture methods offer ability to estimate various demographic parameters, such as survival, mortality, abundance and density (Seber 1992, Schwarz and Seber 1999, Lindberg 2012). Studies in some species suggested that estimates from capture-recapture methods are more ecologically reasonable than unmarked methods (Peterson and Cederholm 1984), but see (Trolle et al. 2008). Capturing and marking animals can be done either through direct capture with physical marking or through indirect approaches, such as individual identification based on natural features or genetic materials. Individual identification techniques based on natural features are widely applied to large mammals because most large mammals are not practical to capture and most of them are under conservation concerns. Also, capturing and handling procedures require experts to protect animal welfare and human safety, and require special permission in most species and countries. In addition, automated passive cameras are less invasive survey techniques that are prevalently applied for wildlife inventory and several topics in wildlife ecology. Camera trapping techniques provide lucid and reliable evidence on animal occurrence and behavior. It is also a cost-effective method for large-scale areas and long-term monitoring programs, although the initial costs are relatively high (Rowcliffe and Carbone 2008, Tobler et al. 2008, O'Connell et al. 2011, Roberts 2011).

Spatially explicit capture-recapture modeling is a recent capture-recapture analysis methods that has become standard practice in wildlife ecology. It overcomes traditional non-spatial capture-recapture methods in that the spatially explicit capture-recapture considers spatial-process of animals’ home ranges and activity centers, which

fits the idea of trap-based studies. Spatial information of captured location and additional covariates incorporated in the models provides more ecological relevant explanations about animals' distribution and movement. Additionally, the effective sampling area concept that is integrated in the spatially explicit capture-recapture allows researchers to make a comparable inference on animal density (Royle et al. 2014). The analysis can be derived from both maximum likelihood estimation methods (Borchers and Efford 2008) and Bayesian frameworks (Efford 2004, Royle and Young 2008). The analysis is widely applied in free statistical software, like R program and WINBUGs. Spatially capture-recapture modeling can answer questions relating to animal population and landscape ecology, such as movement, landscape connectivity, and habitat utilization across landscapes (Royle et al. 2013).

Gaur are large herbivores and elusive species. Capturing them is infeasible in most circumstances because they are group-living animals, massive, and highly vigilant.. Camera trap data from this study showed that gaur move more frequently at dusk to foraging ground in opened canopy habitats and at dawn to retreat to closed canopy forests (Chapter 2). Crepuscular activity patterns observed in gaur obstruct capture procedure operation. In addition, gaur occupy a large home range and utilize various habitat types, both open and closed canopy forest. Hence, camera trapping is a suitable survey technique allowing researchers to record presences and behaviors of gaur. Current knowledge on gaur biology and ecology is based on direct observations, from track and sign surveys and telemetry data of small sample sizes. Population abundance and density are mostly extrapolated from direct counts, signs transect surveys, and occupancy from carnivore camera trap studies. Demographic information of gaur, which is the key factor

for wildlife conservation and management, is still lacking in most countries across the distribution ranges, except for India.

With increasing camera trapping surveys in wildlife studies and the advantages of spatially explicit capture-recapture modeling, the photographic capture-recapture method has usually been analyzed using the spatially explicit models (Sollmann et al. 2011, Ngoprasert et al. 2012, Rich et al. 2014). I aim to apply such an approach to estimate abundance and density of gaur in Kuiburi National Park in southwestern Thailand. I used the Automatic Photo Identification Suite (APHIS) (Moya et al. 2015) and visual investigation to develop individual identification and validation protocols for gaur. I also used capture-recapture histories to estimate gaur density using spatially explicit capture-recapture methods.

STUDY AREA

Kuiburi National Park (969 km^2) is located in Prachuap Khiri Khan Province in southwestern Thailand. The park is characterized by steep mountainous topography incised with seasonal and perennial streams. Vegetation is predominantly dry evergreen forest, portions of which were logged in the past. The park is surrounded by agricultural lands, particularly pineapple plantations, except to the west where it is contiguous with extensive evergreen forest in Myanmar. Large secondary forest patches, with habitat improvements to enhance food and water availability for large herbivores, are located in the central region of the park (Steinmetz et al. 2009, Temchai et al. 2010). A park substation, named ‘Payang’, is located at the center of the area to enhance wildlife protective measures and law enforcement against hunting. The interior of the park is hilly

terrain and mosaic between moist evergreen forest and dry evergreen forest. The climate is tropical savannah with a pronounced dry season from December to April and a long wet season from May to November (Temchai et al. 2010). Average annual precipitation in Prachaup Khiri Khan Province from 2009 to 2013 was 918 mm (ranges 793-1,418 mm) (Meterological Department 2014).

METHODS

Camera trapping systems

Passive infra-red digital cameras with infra-red flash and xenon flash were attached to trees near animal trails, mineral licks, grass patches, and reservoirs at about 0.5-1 m above ground. One to three still images and 30-second videos were recorded when animals passed the cameras (setting was varied by camera models, Appendix 3). Four camera models were used: 1) Moultrie M80 (EBSCO Indrustries, Inc., Birmingham, Alabama USA), 2) Scoutguard SG565 (Scoutguard, Narcross, Georgia USA), 3) StealthCam Unit ups no glow (Stealth Cam, LLC., Grand Prairie, Texas USA), and 4) Bushnell Trophy Cam HD (Bushnell Outdoor Products, Overland Park, Kansas USA).

There were 56 camera trap locations distributed in 6 focal zones according to geographic segregation, habitat heterogeneity and anthropogenic factors, called North, Central 1, Central 2, Central 3, Payang, and South (Figure 3.1, Chapter 2). The camera trap convex polygons encompassed the total area of 90 km^2. Each location deployed 1- 4 cameras. Cameras were set up mainly to linear topographic features, such as trails, streams, and ridges, or near the grass patches. Camera spacing within each zone ranged from 350-2,000 m, depending on topographic features, resource distribution, logistic

constraint, and relative abundance and occupancy suggested in Steinmetz et al. (2011). Closer camera spacing in the Payang zone (< 1 km) was aimed to capture more gaur and individuals in herds, as well as their movement, because gaur were more concentrated in the Payang zone than in the other zones, according to direct counts and encounter frequency and number of individuals from camera traps (See Chapter 2). Most cameras outside the Payang zone were set up 1-2 km apart because gaur were expected to number fewer individuals and more solitary bulls, which occupy larger home range and have larger movement distance (Conry 1981, Prayurasiddhi 1997, Sankar et al. 2013).

Camera traps in the Payang zone were retrieved monthly. Cameras in other regions were retrieved every 1-6 months due to logistic limitations. Camera trap efforts were measured as the total trap-nights of all individual cameras from the start dates to the dates of retrieval or the last date stamped on the final exposure if the cameras malfunctioned or ran out of battery power before retrieval.

An independent encounter was defined as photos of individuals at least 1 hour apart from the previous set of photographs, regardless of whether they were the same individuals photographed previously. A 1-hour window allowed gaur members in breeding herds to enter the grass patches, as I personally noted during the direct observations. The social structure was defined as herd or single. A herd included 1) the encounters that contained at least two individuals, or 2) the encounters of only a single calf, juvenile, or female at any age class. Date and time and the total number of individuals were recorded. Sex and age classes of individuals were identified based on relative body size to adult and coloration patterns on horns described in Table 2.1 and Appendix 2.

Data analysis

Photographic Identification

I used photographs from digital single-lens reflex (DSLR) cameras and both still images and video snapshots from camera traps with varying resolution and quality. DSLR cameras provided a resolution of 18 mega (M) pixels. Still images from camera traps had 3M and 8M pixels. Video snapshots had 640x480 or 720x400 pixels. Individual identification and photographic recaptures of the same individuals were done by the APHIS software using the spot pattern matching procedure (SPM) (Moya et al. 2015). The procedure required three reference points to delimit reference space for other spots or marked locations. For gaur, these three reference points were the tip of right horn, the tip of left horn, and the midpoint between nostrils. I used only the photographs of juveniles and adults for the individual identification because the body size and appearances at their age classes were constant or slightly changed during the one-year study period. At least 12 more points, as required by the software, were digitized to map coloration and corrugation patterns on horns and marks on ears and face. The required minimum points provided enough numbers of spot pairs for the software to calculate the similarity scores for the image matching process.

The matching process of image collection was done separately after image pre-processing and was semi-automated. The software listed candidates and corresponding similarity scores ascendant. A lower similarity score indicates a better match than a higher score. Visual inspection by users confirmed the match to one of the candidates or assigned a new individual.

I also used visual inspection to obtain additional recapture records from video footage and images that contained partial face shots or individuals with unique marks, such as broken horn tips and wounds. I recorded individuals' categorical characteristics, including relative horns balance (yes/no), completion (yes/no), presence of ear marks (presence/absence), and relative black portion on horns (0, 1-25%, 25-50%, 50-75%, and >75%) in a spreadsheet. Image quality and exposure angle of the gaur posture to the camera, which may influence digitizing and matching procedures, were also recorded. Quality of images was noted as good, fair, or poor depending on clarity of detail seen. Variation of light condition, color mode, focusing, distance from camera to object, and age class of individual gaur influenced the clarity of images. Exposure angles were defined as facing (both eyes and horn bases clearly seen), angled (eyes and horn bases partially seen), or side (only one side of the face seen).

I tested matching efficacy of the software in three aspects: 1) digitizing errors and patterns of the marking, 2) relative size of the area of interest to the background, and 3) angles of the exposure. I built sets of images of some gaur individuals. Each set was comprised of 1-3 different images of the same individuals that had different angles of exposure (direct facing, angled, and side) and each set contained 7-9 images. Some gaur individuals could have multiple sets of test images. I made seven copies of the direct facing images, which were used to test for the digitizing errors and the relative size of the area of interest to the background. The number of points digitized on these copies was the same as on the original image (CTRL, Figure 3.2a), where the points were digitized at the unique characteristics of horns and face. The next two duplicates, named DIG1 and DIG2 (Figure 3.2b), were re-digitized to account for user plotting errors. Sets of reference

points of the forth and the fifth copies were marked in grid (GRID, Figure 3.2c) and random (RAND, Figure 3.2d) patterns, respectively to test specificity of point patterns in the matching process. The sixth copy was cropped by 25% of the original size (CR25, Figure 3.2e) and the seventh copy was cropped by 50% of the original size (CR50, Figure 3.2f). The additional images with different angles of exposure (ANGL, Figure 3.2g, for angled and SIDE, Figure 3.2h, for side exposure) were available only for some gaur individuals. The number of reference points of non-facing exposure may be different from that of the direct facing images.

To understand how the similarity scores vary across a set of images and user errors during the pre-processing procedure, I conducted the score tests by recording the similarity scores of all images in the set, except the CTRL, which was used as the test photo. I calculated the coefficient of variation (CV) to measure variability of similarity scores. I calculated the average coefficient of variation (CV) of similarity scores for possible sources of the score variation, including the digitizing consistency (DIG1 and DIG2), the digitizing patterns (GRID and RAND), the distances of animals to the cameras (CR25 and CR50), and the different angles of the animal exposure to the cameras (ANGL and SIDE).

I tested the matching efficacy of the software by the rank tests. I ran matching of images in each set, except DIG1 and DIG2, to the repository that contained their other replicates, i.e., DIGT(included DIG1 and DIG2), GRID, RAND, CR25, CR50, ANGL (if applicable), and SIDE (if applicable). I recorded the ranking and the similarity scores of each pair in a spreadsheet. I summarized the percentage of number of image sets as corresponding to matching pairs included in the top 1 and top 3 ranks.

Density estimation

I used only photographic capture-recapture histories of adult gaur for density estimation. The spatially explicit capture-recapture analysis incorporates spatial distribution of individuals' activity center and detection probability according to the distances between animals and activity centers (usually referred to as home range centers). Activity centers are assumed homogeneous Poisson distribution (Borchers and Efford 2008). The parameters of the spatially explicit capture-recapture models include g_0, which is the baseline detection probability at the activity center, and σ (sigma), which describes the spatial scale of movement and is inferred to a radius from the home range center containing 95% of animal activity. Detection probability of an animal location was a declining function of g_0 and distance from animal locations to the detector.

I fitted the capture histories to the spatially explicit capture-recapture modeling through the package "secr" (Efford 2016) implemented in the program R 3.2 (R Core Team 2015). I created a mask to define an effective sampling area, which is used for density calculation, from the polygon encompassing camera trap arrays with a buffer distance that stabilizes maximum likelihood based on the null model (g_0~1, σ~1). The mask area was delimited by the park boundary. I tested detection functions of gaur detection whether it followed a half-normal or a negative exponential distribution. The detection function, with a lower AIC was selected for model fits.

I re-categorized the six focal areas into 3 zones based on gaur detection and concentration and on geographic barrier, e.g., ridges. These zones were called CP (Central 1, Central 2, and Payang zone), CN (Central 3 and North), and S (South). The capture histories of individual gaur encountered in each zone were fitted to multi-session

models using full-likelihood method. I compared the null model to the other models with assumed variation of detection probability and sigma. I hypothesized that habitat heterogeneity across zones, learned response, and site-specific behavioral response, may influence g_0, and σ. Variation of density across zones was modeled as multi-session. Learned response, which is similar to M_b in the traditional closed capture-recapture models described in Otis et al. (1978), accounts for the changes of parameters at a particular trap location (e.g., detection probability) after the first detection. Site-specific behavioral response considers changes in parameters due to behavioral response to a particular trap in a particular zone. Realized abundance of adult gaur were derived from a function in the "secr" package for each zone and were averaged across zones. Total population abundance of gaur was extrapolated from the age structure obtained from the mean of number of young (calf and yearling combined), juvenile, and adult, pooled from repeated direct observations and camera trapping, which was 2 young : 1.4 juveniles : 1 adult.

Many studies showed that gaur populations are female biased and males occupy larger home range than females (Conry 1981, Prayurasiddhi 1997, Ahrestani and Karanth 2014) (Table 3.1), which may cause variation of detection probability (g_0) and spatial scale of movement (σ) between sexes. I tested the sex-specific g_0 and σ by fitting the models with sex individual covariates based on combined capture histories across zones.

I used Akaike's Information Criterion corrected for small sample (AIC_c) to identify the most supported models (Akaike 1973). I obtained the parameter estimates, including density, g_0, and σ from the best model. If the candidate models had a dAICc <2, I used model averaging across those models to estimate the model parameters. The

Simple Monte-Carlo goodness-of-fit tests for full-likelihood models were applied to the best fitted models for 99 simulation to evaluate the model fit.

RESULTS

Photographic individual identification

From >10,000 camera-trap images, there were 230 images useable for individual identification. I added 16 high-quality images taken by DSLR cameras to the photograph collection. Among the images, 173 (70%) were photographed in the Payang zone. I identified 22 females (10 adults and 12 juveniles) and 44 males (33 adults and 11 juveniles). From these, I created dendrograms for adult individuals based on categorical characteristics for individual identification of 10 adult females (Figure 3.3) and 33 adult males (Figure 3.4 and Figure 3.5). Individual recognition process included 134 images identified by the APHIS software and 112 images identified by visual inspection.

Validation of identification

I selected 45 sets of images (16 females and 29 males), including 27 gaur individuals (8 females and 19 males). Validation tests included 45 facing images, 20 angled images and 8 side images. Various reference point patterns and angles of exposure of the same individual images were highly varied as the tested image sets had large average CVs (mean 147.7% ± 3.9%, ranged 103.5% - 223.3%, n = 45). The CV of images digitizing uncertainty (DIG1 and DIG2) averaged 11.9% ± 1.4%SE (ranged 0.2% - 46.7%, n=45). The average CV across non-specific digitizing patterns (GRID and RAND) was 41.4% ± 4.4% (ranged 2.5% - 115.6%, n = 45). The CV of cropped images (CR25 and CR50) averaged 10.9% ± 1.2% (ranged 0.2%-27.3%, n = 45). The average

CV of non-direct facing images (ANGL and SIDE) was 51.9% ±8.4 % (ranged 22.9%-74.7%, n=6). A small variation in CV of direct facing images (CTRL, DIG1, DIG2, CR25, and CR50) indicated that I accurately plotted specific reference point patterns. Non-specific digitizing patterns and non-direct exposure shots had more variation in the similarity scores. The software was not sensitive to user digitizing error and the distance of object to camera. More than 70% of the test image sets (n=45) matched to the re-digitized images in the first ranking, and all of image sets matched to the re-digitized images in the top 3 ranking (Table 3.2).

Duplicates with non-specific digitizing patterns (GRID and RAND) were not matched to the control images in the top 1 or in the top 3 ranks. More than 60% of the angled and side images matched to re-digitized direct-facing images in the top rank and matching percentages increased when the top 3 ranks were included. A high proportion of correct matching of the control images to the re-digitizing and cropped images in the higher ranks suggested that the software could recognize unique point mapping patterns with some tolerance for digitizing errors caused by users and for the relative size of the area of interest to the background caused by the varied distances from animals to cameras (Table 3.2).

Density and parameters estimation

Population density estimation and abundance extrapolation

Resighting history used in the analysis included 173 detections of 42 adults (10 adult females and 32 adult males) without repeat encounters at a particular camera trap location during the same sampling occasion. There were 20 gaur resighted at only one location and 14 of them were captured only once. Out of the total resightings, 139

resightings occurred in the CP zone. The number of camera trap locations visited on the same occasion in the CP zone was 6 camera trap locations, which was larger than the other zones (Table 3.3). The total number of individuals detected in the zone CN, CP, and S was 5, 32, and 5 guar, respectively (Table 3.3). Eight out of ten females were encountered in the CP, and the other two females were encountered in the CN zone. The number of male gaur detected in the CN, CP, and S zones was 3, 24, and 5 males, respectively. The mean distance between consecutive capture locations, pooled over individuals ($\bar{d}$) (Efford 2004), by zones was 957 m in CN, 1,024 m in CP, and 2,228 m in S. The mean maximum distance moved (MMDM), which is the average maximum distance between detections of each individual (Otis et al. 1978), was 4,164 m in CN; 3,554 m in CP; and 5,570 m in S. The detection function of null model fits the negative-exponential distribution function better than the half-normal distribution (Table 3.4).

The best model that described the variation of gaur density across zones was the learned trap responses (g_0~bk, σ~1), which implied that animals were more likely to return to particular camera locations after the first detection (Table 3.5). Population density derived from the learned trap model for CN and S zones was 0.9± 0.43SE gaur/100 km^2 (95% CI = 0.38-2.2). Estimated population density in the CP zone was 5.8 ± 1.3SE gaur/100 km^2 (95% CI = 3.7-9.0). Capture probability derived from the learned trap response model (g_0~bk, σ~1) was 0.02 ± 0.005SE (95% CI= 0.01-0.03) and the estimated scale of movement was 3,308.6± 561.2SE m (95% CI= 2,378.4-4,602.5 m). CV of the density estimates was 0.47 for the CN and S zones and 0.23 for the CP zone. The goodness-of-fit test suggested that the *bk* model fit the data (observed deviance-degree of freedom ratio = 44.88, P = 1.00). The population density, averaged across zones was 2.5±

1.7 gaur/100 km^2 (95% CI = 0.8-8.2) with CV = 0.66. The number of adult gaur calculated from the model, averaged across zones, was 48.2 ± 2.3SE gaur (95% CI = 45.1-54.5). The age ratio averaged from pooled direct observation and camera trapping was 2 young: 1.4 juveniles: 1 adult. The overall gaur abundance in Kuiburi National Park ranged 198-239 gaur.

Influence of sex on detection probability (g_0) and spatial scale of movement (σ)

I combined data across zones to examine the effect of sex on variation of g_0 and σ. The capture history included 10 females and 32 males. Male detection (n=120) accounted for 70% of the total detection (n=173). Males were more likely to utilize more extensive ranges than females because the maximum number of camera trap locations visited on the same occasion was larger for males (6 camera trap locations) than for females (2 camera trap locations) (Table 3.6). Females were more frequently encountered than males (5.3 detections per female and 3.8 detections per male, Table 3.6). Mean distance between consecutive capture location ($\bar{d}$) by sex, pooled across zones, was 863.7 m in females and 1,155.8 m in males. The mean maximum distance move (MMDM) of females was 3,286 m and that of males was 3,951 m. Learned trap response (g0~sex*bk, σ~1) and the null model (g0~1,σ~1) had ΔAICc <2 (Table 3.7). The estimates of sex-specific detection probability from model averaging was 0.03± 0.02SE (95% CI= 0.007-0.11) for females and 0.04± 0.02SE (95% CI= 0.01-0.11) for males. The estimated spatial scale of movement of both sexes was 2,766 ± 925.3SE m (95% CI= 1,461-5,237 m). The goodness-of-fit test of the best model describing sex-specific detection probability (g_0~sex*bk, σ~1), suggested the model fit observed deviance-degree of freedom ratio = 46.33, P = 1.00.

DISCUSSION

Photographic individual identification of gaur based on horn and face characteristics are possible. As a result, I can apply capture-recapture analysis to make inferences about population density and abundance of gaur.

Gaur individual identification requires multiple horn characteristics, especially shapes, coloration patterns, and corrugation patterns. However, variation of these characteristics is more obvious in adult gaur. Juveniles tend to lack unique characteristics of horn coloration and corrugation patterns and are difficult for identification.

The semi-automated software, together with visual inspection, facilitates the identification process and the organization of photos. The software recognizes the same individual regardless of user digitizing error and the distance between object to the camera, which may influence the relative size of the area of interest to the background. Gaur individual identification using the APHIS software is more sensitive to the angle of the exposure because the angled and side images lose many unique details of individuals and they are more likely not to provide enough points that the software requires. Good quality images are preferable, but inferior quality images, which are often obtained from camera traps, are also acceptable. However, inferior quality images should be used with caution and multiple shots and video footage should be included to obtain details of an individual. More reference images per individual animal improve the matching efficacy because the I^3S algorithm integrated in the software works more efficiently in matching accuracy when three reference images of an individual animal are available (Van Tienhoven et al. 2007).

In addition, non-bait camera trap stations used in this study may cause a small proportion of usable photos for identification. Selective camera trap locations or baited stations with necessary resources for ungulates, e.g., mineral licks, salt blocks, or small reservoirs should increase the number of usable images for photographic individual identification. The baited traps increase detection rates and improve density estimation when compare to the non-baited traps in a leopard population, as reported in du Preez et al. (2014). The baited traps also allow researchers to obtain images of animals in correct positioning that expose characteristics of the interest for individual identification, e.g. Ngoprasert et al. (2012) for Asian bears and du Preez et al. (2014) for leopards. However, the application of baited camera trap stations should depend on logistic limitations and threats to wildlife in the study sites. Threats from hunting should be primarily considered because more animals will be attracted to baited stations and may cause animals to be vulnerable to hunting.

Gaur detection was low across the park (ranged 0.02-0.19, see Chapter 2), even though the camera trap locations were located in the preferred habitats of gaur. Low detection probability may result in the bias of the parameter estimates and failure to represent heterogeneity in parameter estimates (Harmsen et al. 2011). Except the CP and S zones, the sampling area in the CN zone was relatively small compared to the gaur home range. However, the historical records and sign transect surveys by WWF-Thailand and the Kuiburi National Park indicated that gaur density was low outside the Payang zone and the peripheral areas (Steinmetz et al. 2014). Low detection and density estimates in the CN and S zones reflect that a fewer number of gaur inhabit these areas and each sex unequally utilized these areas. Steinmetz et al. (2008) reported that gaur had

sexual and social structure segregation of habitat utilization in Thung Yai Naresuan Wildlife Sanctuary, Thailand. Single male gaur and the bachelor group utilized montane forests more than lowland forests, while female gaur and herds were more abundant in lowland forests than in montane forests. The CN and S zones are comprised of extent moist evergreen forests and hilly terrain, while the habitat in the CP zone is located in the lowlands and is dominated by human-modified secondary forests, containing extensive grass patches, mineral licks, and small reservoirs. As a result, the CP zone become a preferred habitat for gaur, as the density estimates of gaur in the CP zone was larger than the other zones.

The current data did not suggest a difference of detection probability at the activity center of animal (g_0) and spatial scale of movement (σ) between females and males. Detection probability and the spatial scale of movement may vary between sex due to sex-specific behavior and ecology. Gaur population structure is female-biased. Females usually forage with breeding herds and prefer opened-canopy habitats containing food and water supplies (Conry 1981). In contrast, male gaur are more solitary and nomadic. Gaur telemetry studies suggest that home ranges of female gaur are smaller than those of male gaur (Conry 1981, Sankar et al. 2013). As a result, detection probability of female gaur should be larger than males', but their spatial scale of movement should be smaller than males'. Differences in the spatial scale of movement may be related to home range size (Efford et al. 2009, Efford and Mowat 2014).

Capture-recapture models are prevalently applied to population density estimation in carnivores, but are rarely adopted in herbivores (Kumbhar et al. 2013, Jůnek et al. 2015). The implication of the spatially explicit capture-recapture methods for herbivores

has partially been verified. Recently, Jůnek et al. (2015) evaluated the density estimates obtained from the spatially explicit capture-recapture and the closed capture-recapture models for a known population of the Western Derby Eland (*Taurotragus derbianus derbianus*), as well as evaluated accuracy of both methods relative to various camera trap configurations and the number of sampling occasions. The study suggests that spatially explicit capture-recapture analysis performs well in the line patterns of camera trap configuration. The simulation study suggests that the scenarios with short sampling periods tend to give overestimation of abundance. My study did not consider the effect the camera trap arrays on the parameter estimation. Although systematic trap arrays facilitate defining state-space and effective sampling area, grid arrays are not practical in most circumstances due to logistic constraints, especially in tropical forests where habitats are highly heterogeneous and usually contain undulating topography. The spatially explicit capture-recapture analysis properly handles non-grid camera trap arrays and irregular effective areas in animals living in harsh environments and remote areas, such as the wolverine (Royle et al. 2011), via several R packages, including "SPACECAP" (Gopalaswamy et al. 2014) using Bayesian methods and "secr" (Efford 2016) using the maximum likelihood method.

There are limitations and considerations of using the spatially explicit capture-recapture models for density estimation of gaur or other herbivores. First, the estimated density may be biased because the models do not account for non-independent detection, which occurs when multiple individuals are often observed in the same encounter, e.g. in group-living animals like gaur. In addition, an individual may revisit the same location multiple times within the same sampling occasion, which implies site fidelity, and habitat

preference of animals. These factors may influence detection probability and movement of animals. A modification of the spatially explicit capture-recapture models that incorporates those individual and spatial covariates should improve the density estimates (Efford and Mowat 2014).

CONCLUSION

With the widespread usage of camera trapping surveys and capture-recapture modelling to monitor population status in wildlife studies, the techniques are strictly applied in few terrestrial mammal taxa. This study extended the use of the techniques to herbivores, which are species commonly captured by camera traps. Gaur is a large herbivore that plays important roles in tropical wildlife communities, as either prey species of large carnivores or landscape architects. Gaur are common herbivores in the Kuiburi National Park, but the population status has not been monitored. The implementation of photographic capture-recapture methods for gaur density estimation is feasible. Horn characteristics, including shapes, coloration patterns, and corrugation patterns are the primary features for gaur individual identification. The software APHIS performs well in photographic individual recognition and facilitates image collection management. The software interface is simple, flexible, and user-friendly. The available matching procedures (point-based and pattern-based matching) provide opportunities to use the software for individual identification of other animals.

Gaur population density estimation using the spatially explicit capture-recapture methods suggests that gaur are concentrated at the Payang zone and the surrounding areas. The other zones, which contain a larger proportion of moist evergreen forest and

are located in mountainous areas, have lower gaur density. There is no evidence of sex-specific detection probability at the home range center (g_0) and the spatial scale of movement (σ). However, the density and parameter estimates obtained from the current data are more likely overestimated due to sampling designs (e.g., trap array configuration and trap spacing) and model parameterization (e.g., omission of trap and individual covariates).

This study is the pilot study of photographic individual identification and capture-recapture analysis for gaur. Both individual identification procedures, sampling designs (e.g., trap array configuration, minimum sampling occasions required), and model parameterization in the spatially explicit capture-recapture methods require validation and modification to obtain reliable density estimation. The technique may be implemented to monitor other free-ranging ungulates and holds promise for conservation and management of threatened and endangered species that are inherently difficult to sample.

LITERATURE CITED

Ahrestani, F. S., and K. U. Karanth. 2014. Gaur *Bos gaurus* C. H. Smith, 1827. Pages 174-193 *in* M. Melletti, andJ. Burton, editors. Ecology, Evolution and Behaviour of Wild Cattle. Cambridge University Press.

Akaike, H. Information theroy as an extension of the maximum likelihood principle., Pages 267-281 *in* Conference Information theroy as an extension of the maximum likelihood principle. B. N. Petrov, andF. Csaki.

Borchers, D. L., and M. G. Efford. 2008. Spatially Explicit Maximum Likelihood Methods for Capture–Recapture Studies. Biometrics 64:377-385.

Conry, P. J. 1981. Habitat selection and use, movements, and home range of Malayan Gaur (*Bos gaurus hubbacki*) in Central Pahang, Malaysia. M.Sc. University of Montana. 120 pp. pp.

du Preez, B. D., A. J. Loveridge, and D. W. Macdonald. 2014. To bait or not to bait: A comparison of camera-trapping methods for estimating leopard Panthera pardus density. Biological Conservation 176:153-161.

Efford, M. 2004. Density estimation in live-trapping studies. Oikos 106:598-610.

Efford, M. G. 2016. secr: Spatially explicit capture-recapture models. R package version 2.10.2. http://CRAN.R-project.org/package=secr.

Efford, M. G., D. L. Borcheers, and A. E. Byrom. 2009. Density estimation by Spatially Explicit Capture-Recapture: Likelihood-Based Methods. Pages 255-269 *in* D. L. Thomson, E. G. Cooch, andM. J. Conroy, editors. Modeling Demographic Processs in Marked Populations. Springer Science+Business Media, LLC.

Efford, M. G., and G. Mowat. 2014. Compensatory heterogeneity in spatially explicit capture–recapture data. Ecology 95:1341-1348.

Gopalaswamy, A. M., A. J. Royle, M. E. Meredith, P. Singh, D. Jathanna, N. S. Kumar, and K. U. Karanth. 2014. SPACECAP: A program to estimate animal abundance and density using Bayesian Spatially-Explicit Capture-Recapture Models. R package version 1.1.0.

Harmsen, B. J., R. J. Foster, and C. P. Doncaster. 2011. Heterogeneous capture rates in low density populations and consequences for capture-recapture analysis of camera-trap data. Population Ecology 53:253-259.

Jůnek, T., P. Jůnková Vymyslická, K. Hozdecká, and P. Hejcmanová. 2015. Application of Spatial and Closed Capture-Recapture Models on Known Population of the Western Derby Eland (Taurotragus derbianus derbianus) in Senegal. Plos One 10:e0136525.

Kumbhar, A., C. L. Prabhu, J. K. Yogesh, P. Francies, G. Patwardhan, Q. Qureshi, and Y. Jhala. 2013. Application of Photographic Capture-Recapture Sampling for Estimating Abundance of Indian Mouse Deer Moschiola indica. World Journal of Zoology 8:388-391.

Lindberg, M. 2012. A review of designs for capture–mark–recapture studies in discrete time. Journal of Ornithology 152:355-370.

Meterological Department. 2014. Climatological Data of Prachaup Khirikhan station.

Moya, O., P. L. Mansilla, S. Madrazo, J. M. Igual, A. Rotger, A. Romano, and G. Tavecchia. 2015. APHIS: A new software for photo-matching in ecological studies. Ecological Informatics 27:64-70.

Ngoprasert, D., D. H. Reed, R. Steinmetz, and G. A. Gale. 2012. Density estimation of Asian bears using photographic capture–recapture sampling based on chest marks. Ursus 23:117-133.

O'Connell, A. F., J. D. Nichols, and K. U. Karanth. 2011. Camera traps in Animal Ecology. Springer. 271 pp.pp.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical Inference from Capture Data on Closed Animal Populations. Wildlife Monographs:3-135.

Peterson, N. P., and C. J. Cederholm. 1984. A Comparison of the Removal and Mark-Recapture Methods of Population Estimation for Juvenile Coho Salmon in a Small Stream. North American Journal of Fisheries Management 4:99-102.

Prayurasiddhi, T. 1997. The ecological separation of Gaur (*Bos gaurus*) and Banteng (Bos javanicus) in Huai Kha Khaeng Wildlife Sanctuary, Thailand. Ph.D. University of Minnesota. 266 pp. pp.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/.

Rich, L. N., M. J. Kelly, R. Sollmann, A. J. Noss, L. Maffei, R. L. Arispe, A. Paviolo, C. D. De Angelo, Y. E. Di Blanco, and M. S. Di Bitetti. 2014. Comparing capture-recapture, mark-resight, and spatial mark-resight models for estimating puma densities via camera traps. Journal of Mammalogy 95:382-391.

Roberts, N. J. 2011. Investigation into survey techniques of large mammals: surveyor competence and camera-trapping vs. transect-sampling. Bioscience Horizons 4:40-49.

Rowcliffe, J. M., and C. Carbone. 2008. Surveys using camera traps: are we looking to a brighter future? Animal Conservation 11:185-186.

Royle, J. A., R. B. Chandler, R. Sollmann, and B. Gardner. 2013. Spatial capture-recapture. Academic Press. 612 pp.pp.

_____. 2014. Spatial Capture-Recapture. Elsevier Inc., Massachusetts, USA. 577 pp.

Royle, J. A., A. J. Magoun, B. Gardner, P. Valkenburg, and R. E. Lowell. 2011. Density estimation in a wolverine population using spatial capture–recapture models. The Journal of Wildlife Management 75:604-611.

Royle, J. A., and K. V. Young. 2008. A hierarchical model for spatial capture-recapture data. Ecology 89:2281-2289.

Sankar, K., H. S. Pabla, C. K. Patil, P. Nigam, Q. Qureshi, B. Navaneethan, M. Manjreakar, P. S. Virkar, and K. Mondal. 2013. Home range, habitat use and food habits of re-introduced gaur (*Bos gaurus gaurus*) in Bandhavgarh Tiger Reserve, central India. Tropical Conservation Science 6:50-69.

Schwarz, C. J., and G. A. F. Seber. 1999. Estimating Animal Abundance: Review III. Statistical Science 14:427-456.

Seber, G. A. F. 1992. A Review of Estimating Animal Abundance II. International Statistical Review / Revue Internationale de Statistique 60:129-166.

Sollmann, R., M. M. Furtado, B. Gardner, H. Hofer, A. T. A. Jácomo, N. M. Tôrres, and L. Silveira. 2011. Improving density estimates for elusive carnivores: Accounting for sex-specific detection and movements using spatial capture–recapture models for jaguars in central Brazil. Biological Conservation 144:1017-1024.

Steinmetz, R., W. Chutipong, N. Seuaturien, and E. Chirngsaard. 2008. Community structure of large mammals in tropical montane and lowland forest in the Tenasserim-Dawna Mountains, Thailand. Biotropica 40:344–353.

Steinmetz, R., N. Seuanturien, S. Srirattanaporn, and B. Poonnil. 2011. Experimental approaches towards tiger recovery in Kuiburi National Park, Thailand. 71 pp.

Steinmetz, R., N. Seuaturien, W. Chutipong, and B. Poonnil. 2009. The ecology and conservation of tigers and their prey in Kuiburi National Park, Thailand.

Steinmetz, R., N. Seuaturien, S. Srirattanaporn, and B. Poonnil. 2014. Research and conservation of tigers and their prey in Kuiburi National Park. 80 pp.

Temchai, T., C. Chamnankid, and A. Yoosomboon. 2010. Habitat Diversity and Landuse of Kuiburi National Park and Keangkrachan-Kuiburi National Park Corridor. National Park and Protected Areas Innovation Center (Petchburi). 93.pp.

Tobler, M. W., S. E. Carrillo-Percastegui, R. Leite Pitman, R. Mares, and G. Powell. 2008. An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation 11:169-178.

Trolle, M., A. J. Noss, J. L. P. Cordeiro, and L. F. B. Oliveira. 2008. Brazilian Tapir Density in the Pantanal: A Comparison of Systematic Camera-Trapping and Line-Transect Surveys. Biotropica 40:211-217.

Van Tienhoven, A., J. Den Hartog, R. Reijns, and V. Peddemors. 2007. A computer-aided program for pattern-matching of natural marks of the spotted raggedtooth shark Carcharias taurus (Rafinesque, 1810). Journal of Applied Ecology In press.

TABLES

Table 3.1. Home range size and daily movement of gaur in other studies.

References	Study site	Method	Season	Home range size[a] (km^2)	Daily movement distance (km)	Distance between activity center (km)
Conry (1981) and Conry (1989)	Central Pahang, Malaysia	Telemetry	Seasonality not apparent	Adult male: 137.3[b] (20.8)[c]	Adult male: 1.5 (0.2-4.2)[e]	NA
				Yearling female: 52.1 (17)[d]	Yearling female: 1.2 (0-3.9)[e]	
				Yearling male: 29.9 (10.1)[d]	Yearling male: 0.6 (0-2.6)[e]	
Prayurasiddhi (1997)	Huai Kha Khaeng Wildlife Sanctuary, western Thailand	Telemetry	Wet	Herd: 39.1±12.9SD (21.3-58.1, n=7)	Herd: 2.7±0.6SD (1-5.1)	5±3.5SD (0.6-8.9, n=6)
				Adult male: 45.2	Adult male: 2.4	
			Dry	Herd: 27.3±8.1SD (19-39.3, n=5)	3.3±1.4SD (1.2-5.7)	7.4±5.6SD (0.5-12.9, n=6)
			Annual	65.5±27.8SD (n=5)	NA	NA
Bidayabha (2001)	Khao Pheang Ma, northeastern Thailand	Direct observation	Wet	0.92±0.74SD[f]	0.6-1.0	NA
			Dry	1.17±0.5SD[f]	NA	NA
			Annual	approx. 6	NA	NA

References	Study site	Method	Season	Home range size[a] (km^2)	Daily movement distance (km)	Distance between activity center (km)
Sankar et al. (2013)	Bandhangarh Tiger Reserve, India	Telemetry re-introduced guar	Summer	290 (M=231,F=161)	NA	NA
			Monsoon	137.1 (M=111,F=136)	NA	NA
			Winter	155 (M=98, F=152)	NA	NA
			Overall	Female: 200 (32-169) Male:: 255 (135-142)	NA	NA

a. Home range size determined by Minimum Convex Polygon method
b. Home range includes a travel corridor, which is the mountains.
c. Most widely distance of home range
d. Maximum distance between two locations
e. range of daily movement
f. average monthly area used by gaur

Table 3.2. The matching matrix of the rank tests for gaur individual identification. The percentages of the number of image sets with corresponding matching combinations (e.g., control-digitizing, control-grid points) based on 45 direct facing images of 27 gaur individuals, 20 angled images, and 8 side images were shown. The software successfully recognized the direct facing images, regardless of digitizing error and variation of distance from camera to animal. Most of non-direct facing images, which lack some unique individual information, also matched to the direct facing images.

Ranking	Test photos	% of image sets matched						
		Re-digitizing	Grid points	Random points	25% cropped	50% cropped	Angled	Side
Top 1	**Control (n=45)**	**71.1**	0	0	6.7	22.2	0	0
	25% cropped (n=45)	**80**	0	0		20	0	0
	50% cropped (n=45)	**80**	0	0	20		0	0
	Angled (n=20)	**60**	0	0	5	35		0
	Side (n=8)	**75**	0	0	0	12.5	12.5	
Top 3	**Control**	**100**	0	0	**100**	**100**	0	0
	25% cropped	**100**	26.7	28.9		**100**	40	2.2
	50% cropped	**100**	20	35.6	**100**		42.2	2.2
	Angled	**100**	0	0	**100**	**100**		0
	Side	**100**	12.5	12.5	50	**87.5**	37.5	

Table 3.3. Capture-recapture statistics for gaur in three focal zones of Kuiburi National Park, Thailand during November 2013 – January 2015. n=individuals detected on each occasion; u = individuals detected for the first time on each occasion; f = capture frequencies or individuals detected exactly j times, when j = occasion; M(t+1) = cumulative number of individuals detected; detections = number of detections, including within-occasion recapture; detectors visited = number of camera locations, at which at least on detection was recorded.

Occasion (Week)	**Number of camera locations available**	**CN**						**CP**						**S**					
		n	**u**	**f**	**M (t+1)**	**detect-ions**	**detectors visited**	**n**	**u**	**f**	**M (t+1)**	**detect-ions**	**detectors visited**	**n**	**u**	**f**	**M (t+1)**	**detect-ions**	**detectors visited**
1	7	0	0	1	0	0	0	2	2	10	2	2	2	0	0	3	0	0	0
2	7	0	0	1	0	0	0	8	7	5	9	10	2	0	0	1	0	0	0
3	7	0	0	1	0	0	0	1	0	4	9	1	1	0	0	0	0	0	0
4	6	0	0	1	0	0	0	0	0	4	9	0	0	0	0	1	0	0	0
5	6	0	0	0	0	0	0	1	0	1	9	1	1	0	0	0	0	0	0
6	5	0	0	0	0	0	0	0	0	2	9	0	0	0	0	0	0	0	0
7	5	0	0	0	0	0	0	2	2	1	11	2	2	1	1	0	1	1	1
8	5	0	0	0	0	0	0	1	0	0	11	1	1	0	0	0	1	0	0
9	3	0	0	0	0	0	0	0	0	1	11	0	0	0	0	0	1	0	0
10	13	0	0	0	0	0	0	2	0	1	11	2	1	0	0	0	1	0	0
11	13	0	0	0	0	0	0	5	2	1	13	5	4	0	0	0	1	0	0
12	13	0	0	1	0	0	0	5	2	0	15	5	2	0	0	0	1	0	0
13	13	0	0	0	0	0	0	2	0	1	15	2	2	0	0	0	1	0	0
14	13	0	0	0	0	0	0	3	2	1	17	4	2	0	0	0	1	0	0
15	6	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	1	0	0
16	7	0	0	0	0	0	0	1	0	0	17	1	1	0	0	0	1	0	0
17	7	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	1	0	0
18	11	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	1	0	0

Occasion (Week)	Number of camera locations available	CN						CP						S					
		n	u	f	M (t+1)	detect-ions	detectors visited	n	u	f	M (t+1)	detect-ions	detectors visited	n	u	f	M (t+1)	detect-ions	detectors visited
19	10	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	1	0	0
20	13	0	0	0	0	0	0	1	1	0	18	1	1	0	0	0	1	0	0
21	13	0	0	0	0	0	0	3	0	0	18	3	2	0	0	0	1	0	0
22	18	0	0	0	0	0	0	3	2	0	20	3	2	0	0	0	1	0	0
23	18	0	0	0	0	0	0	4	0	0	20	4	3	0	0	0	1	0	0
24	18	0	0	0	0	0	0	1	0	0	20	2	2	0	0	0	1	0	0
25	18	0	0	0	0	0	0	3	0	0	20	3	2	0	0	0	1	0	0
26	18	0	0	0	0	0	0	0	0	0	20	0	0	2	1	0	2	2	1
27	21	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	2	0	0
28	20	0	0	0	0	0	0	4	1	0	21	5	2	0	0	0	2	0	0
29	20	0	0	0	0	0	0	3	0	0	21	3	3	0	0	0	2	0	0
30	25	0	0	0	0	0	0	4	2	0	23	4	3	0	0	0	2	0	0
31	29	1	1	0	1	1	1	8	0	0	23	9	6	0	0	0	2	0	0
32	28	2	1	0	2	2	1	2	1	0	24	2	2	0	0	0	2	0	0
33	28	1	0	0	2	1	1	4	1	0	25	4	3	0	0	0	2	0	0
34	28	0	0	0	2	0	0	3	0	0	25	3	3	0	0	0	2	0	0
35	28	0	0	0	2	0	0	2	0	0	25	2	2	0	0	0	2	0	0
36	28	0	0	0	2	0	0	5	0	0	25	5	4	0	0	0	2	0	0
37	27	1	0	0	2	1	1	0	0	0	25	0	0	0	0	0	2	0	0
38	27	1	0	0	2	1	1	0	0	0	25	0	0	0	0	0	2	0	0
39	31	3	1	0	3	4	2	1	1	0	26	1	1	0	0	0	2	0	0
40	31	0	0	0	3	0	0	2	0	0	26	2	2	0	0	0	2	0	0
41	28	3	2	0	5	3	1	3	0	0	26	3	2	0	0	0	2	0	0
42	30	1	0	0	5	1	1	1	1	0	27	1	1	0	0	0	2	0	0

Occasion (Week)	Number of camera locations available	CN						CP						S					
		n	u	f	M (t+1)	detect-ions	detectors visited	n	u	f	M (t+1)	detect-ions	detectors visited	n	u	f	M (t+1)	detect-ions	detectors visited
43	30	2	0	0	5	2	1	0	0	0	27	0	0	1	1	0	3	1	1
44	30	0	0	0	5	0	0	1	0	0	27	1	1	0	0	0	3	0	0
45	33	2	0	0	5	2	1	2	0	0	27	2	2	0	0	0	3	0	0
46	33	3	0	0	5	4	2	1	0	0	27	1	1	0	0	0	3	0	0
47	34	1	0	0	5	1	1	0	0	0	27	0	0	3	2	0	5	4	2
48	33	1	0	0	5	1	1	4	1	0	28	5	3	2	0	0	5	2	1
49	33	0	0	0	5	0	0	6	2	0	30	8	3	0	0	0	5	0	0
50	31	0	0	0	5	0	0	2	0	0	30	2	2	0	0	0	5	0	0
51	29	0	0	0	5	0	0	8	0	0	30	9	3	0	0	0	5	0	0
52	25	0	0	0	5	0	0	5	1	0	31	5	4	0	0	0	5	0	0
53	25	0	0	0	5	0	0	0	0	0	31	0	0	0	0	0	5	0	0
54	22	0	0	0	5	0	0	1	0	0	31	1	1	0	0	0	5	0	0
55	21	0	0	0	5	0	0	2	0	0	31	2	1	0	0	0	5	0	0
56	21	0	0	0	5	0	0	2	1	0	32	2	2	0	0	0	5	0	0
57	20	0	0	0	5	0	0	1	0	0	32	1	1	0	0	0	5	0	0
58	14	0	0	0	5	0	0	2	0	0	32	2	2	0	0	0	5	0	0
59	14	0	0	0	5	0	0	1	0	0	32	1	1	0	0	0	5	0	0
60	12	0	0	0	5	0	0	1	0	0	32	1	1	0	0	0	5	0	0
Total	1162	22	5	5	5	24	15	129	32	32	32	139	95	9	5	5	5	10	6

Table 3.4. Comparison of models with different distribution functions describing detection probability. Model fit of the half-normal detection function was compared to the negative exponential detection function applied to null models (g_0~1, σ~1) using capture-recapture history of gaur in Kuiburi National Park, Thailand, during November 2013 – January 2015. Detection function, which describes detection probability at a particular camera trap location as a declining function of the detection probability at home rang center (g_0) and distances from a camera to activity center, fitted the negative exponential distribution better than the half-normal distribution. ΔAIC_c is the absolute difference in the Akaike's information criterion (AIC) value adjusted for small sample sizes (AIC_c) between the best-fit model and the model under consideration, w_i is the Akaike weight, which provides a measure of relative support for each model.

Detection function	**Number of parameters**	**Log(Likelihood)**	**AIC**	**AIC_c**	**ΔAIC_c**	**w_i**
Negative Exponential	2	-904.379	1812.758	1813.065	0	1
Half-normal	2	-926.499	1856.997	1857.305	44.24	0

Table 3.5. Models from spatially explicit capture-recapture methods for gaur across three zones of Kuiburi National Park, Thailand. The detection function of all models followed negative exponential distribution function. ΔAIC_c is the absolute difference in the Akaike's information criterion (AIC) value adjusted for small sample sizes (AIC_c) between the best-fit model and the model under consideration, w_i is the Akaike weight, which provides a measure of relative support for each model. Model parameters include; g_0 = detection probability at the activity center of an animal and σ = spatial scale of movement.

Model name	Model	Number of parameters	Log Likelihood	AIC	AIC_c	ΔAIC_c	w_i
Learned trap	g_0~bk, σ~1	4	-894.80	1797.60	1798.68	0.00	0.93
Learned trap by zones	g_0~1, σ~zones*bk	8	-891.68	1799.36	1803.73	5.05	0.07
Null model	g_0~1, σ~1	2	-904.38	1812.76	1813.07	14.39	0
Learned response by zones	g_0~1, σ~zones*b	8	-904.24	1824.48	1828.84	30.16	0
Zone variation in detection	g_0~zones, σ~1	5	-922.86	1855.72	1857.39	58.71	0
Learned response	g_0~b, σ~1	4	-926.62	1861.24	1862.32	63.64	0
Zone variation in detection and sigma	g_0~zones, σ~zones	7	-922.83	1859.65	1862.95	64.27	0

Notes: Model descriptions

- Learned trap response (~bk): trap-specific behavioral response of animals, hence, animals are more likely to return to particular camera locations after first detection
- Learned trap response by zones (~zone*bk): trap-specific behavioral response varies by zones
- Learned response (~b): overall behavioral response, e.g., change in detection probability after the first encounter. This model is equivalent to M_b in the non-spatial closed capture-recapture.
- Learned response by zones (~zone*b): behavioral response varied by zones
- Zone heterogeneity (~zones): variation in detection or sigma among zones.

Table 3.6. Capture-recapture statistics by sex of adult gaur in Kuiburi National Park, Thailand during November 2013 – January 2015. n=individuals detected on each occasion; u = individuals detected for the first time on each occasion; f = capture frequencies or individuals detected exactly j times, when j = occasion; M(t+1) = cumulative number of individuals detected; detections = number of detections, including within-occasion recapture; detectors visited = number of detectors, at which at least on detection was recorded.

Occasion (Week)	Number of camera locations available	Female						Male					
		n	u	f	M (t+1)	detect -ions	detectors visited	n	u	f	M (t+1)	detect-ions	detectors visited
1	7	0	0	3	0	0	0	2	2	11	2	2	2
2	7	4	4	2	4	6	2	4	3	5	5	4	1
3	7	1	0	0	4	1	1	0	0	5	5	0	0
4	6	0	0	1	4	0	0	0	0	5	5	0	0
5	6	1	0	0	4	1	1	0	0	1	5	0	0
6	5	0	0	2	4	0	0	0	0	0	5	0	0
7	5	1	1	0	5	1	1	2	2	1	7	2	2
8	5	1	0	0	5	1	1	0	0	0	7	0	0
9	3	0	0	0	5	0	0	0	0	1	7	0	0
10	13	0	0	1	5	0	0	2	0	0	7	2	1
11	13	1	0	0	5	1	1	4	2	1	9	4	3
12	13	2	0	0	5	2	1	3	2	1	11	3	2
13	13	2	0	0	5	2	2	0	0	1	11	0	0
14	13	1	0	1	5	2	2	2	2	0	13	2	1
15	6	0	0	0	5	0	0	0	0	0	13	0	0
16	7	1	0	0	5	1	1	0	0	0	13	0	0
17	7	0	0	0	5	0	0	0	0	0	13	0	0
18	11	0	0	0	5	0	0	0	0	0	13	0	0
19	10	0	0	0	5	0	0	0	0	0	13	0	0

Occasion (Week)	Number of camera locations available	Female						Male					
		n	**u**	**f**	**M (t+1)**	**detect -ions**	**detectors visited**	**n**	**u**	**f**	**M (t+1)**	**detect- ions**	**detectors visited**
20	13	0	0	0	5	0	0	1	1	0	14	1	1
21	13	0	0	0	5	0	0	3	0	0	14	3	2
22	18	1	1	0	6	1	1	2	1	0	15	2	1
23	18	0	0	0	6	0	0	4	0	0	15	4	3
24	18	0	0	0	6	0	0	1	0	0	15	2	2
25	18	2	0	0	6	2	1	1	0	0	15	1	1
26	18	0	0	0	6	0	0	2	1	0	16	2	1
27	21	0	0	0	6	0	0	0	0	0	16	0	0
28	20	1	0	0	6	2	2	3	1	0	17	3	2
29	20	1	0	0	6	1	1	2	0	0	17	2	2
30	25	0	0	0	6	0	0	4	2	0	19	4	3
31	29	4	0	0	6	4	2	5	1	0	20	6	6
32	28	0	0	0	6	0	0	4	2	0	22	4	3
33	28	1	0	0	6	1	1	4	1	0	23	4	3
34	28	1	0	0	6	1	1	2	0	0	23	2	2
35	28	0	0	0	6	0	0	2	0	0	23	2	2
36	28	2	0	0	6	2	1	3	0	0	23	3	3
37	27	0	0	0	6	0	0	1	0	0	23	1	1
38	27	0	0	0	6	0	0	1	0	0	23	1	1
39	31	2	2	0	8	2	2	2	0	0	23	3	2
40	31	0	0	0	8	0	0	2	0	0	23	2	2
41	28	2	1	0	9	2	2	4	1	0	24	4	3
42	30	0	0	0	9	0	0	2	1	0	25	2	2
43	30	0	0	0	9	0	0	3	1	0	26	3	2

Occasion (Week)	Number of camera locations available	Female						Male					
		n	u	f	M (t+1)	detect -ions	detectors visited	n	u	f	M (t+1)	detect-ions	detectors visited
44	30	0	0	0	9	0	0	1	0	0	26	1	1
45	33	0	0	0	9	0	0	4	0	0	26	4	3
46	33	1	0	0	9	1	1	3	0	0	26	4	3
47	34	0	0	0	9	0	0	4	2	0	28	5	3
48	33	2	0	0	9	3	2	5	1	0	29	5	4
49	33	3	1	0	10	4	2	3	1	0	30	4	2
50	31	1	0	0	10	1	1	1	0	0	30	1	1
51	29	1	0	0	10	1	1	7	0	0	30	8	3
52	25	2	0	0	10	2	2	3	1	0	31	3	3
53	25	0	0	0	10	0	0	0	0	0	31	0	0
54	22	1	0	0	10	1	1	0	0	0	31	0	0
55	21	2	0	0	10	2	1	0	0	0	31	0	0
56	21	1	0	0	10	1	1	1	1	0	32	1	1
57	20	0	0	0	10	0	0	1	0	0	32	1	1
58	14	0	0	0	10	0	0	2	0	0	32	2	2
59	14	0	0	0	10	0	0	1	0	0	32	1	1
60	12	1	0	0	10	1	1	0	0	0	32	0	0
Total	**1162**	**47**	**10**	**10**	**10**	**53**	**40**	**113**	**32**	**32**	**32**	**120**	**90**

Table 3.7. Models from spatially explicit capture-recapture methods described influence of sex to detection probability and spatial scale of movement of adult gaur in Kuiburi National Park, Thailand. The detection function of all models followed negative exponential distribution function. ΔAIC_c is the absolute difference in the Akaike's information criterion (AIC) value adjusted for small sample sizes (AIC_c) between the best-fit model and the model under consideration, w_i is the Akaike weight, which provides a measure of erelative support for each model. Model parameters include; g_0 = detection probability at the activity center of an animal and σ = spatial scale of movement.

Model name	Model	Number of parameters	Log Likelihood	AIC	AICc	ΔAIC_c	w_i
Learn trap by sex on detection	g_0~sex*bk, σ~1	6	-875.99	1763.98	1766.38	0	0.66
Null model	g_0~1, σ~1	3	-880.53	1767.06	1767.69	1.32	0.34
Sex variation in detection and sigma	g_0~sex, σ~sex	5	-901.15	1812.30	1813.96	47.59	0
Sex variation in sigma	g_0~1, σ~sex	4	-903.89	1815.78	1816.86	50.49	0
Sex variation in detection	g_0~sex, σ~1	4	-909.51	1827.01	1828.10	61.72	0
Learn response by sex on detection	g_0~sex*b, σ~1	6	-907.86	1827.73	1830.13	63.75	0

Notes: Model descriptions

- Learned trap response by sex (~sex*bk): trap-specific behavioral response of animals varied by sex, hence, females and males may have different site fidelity and have different probability of returning to particular locations after the first detection.

- Influence of sex on detection and sigma (~sex): difference of detection probability and spatial scale of movement between females and males.

- Learned response by sex (~sex*b): behavioral response varied by sex.

FIGURES

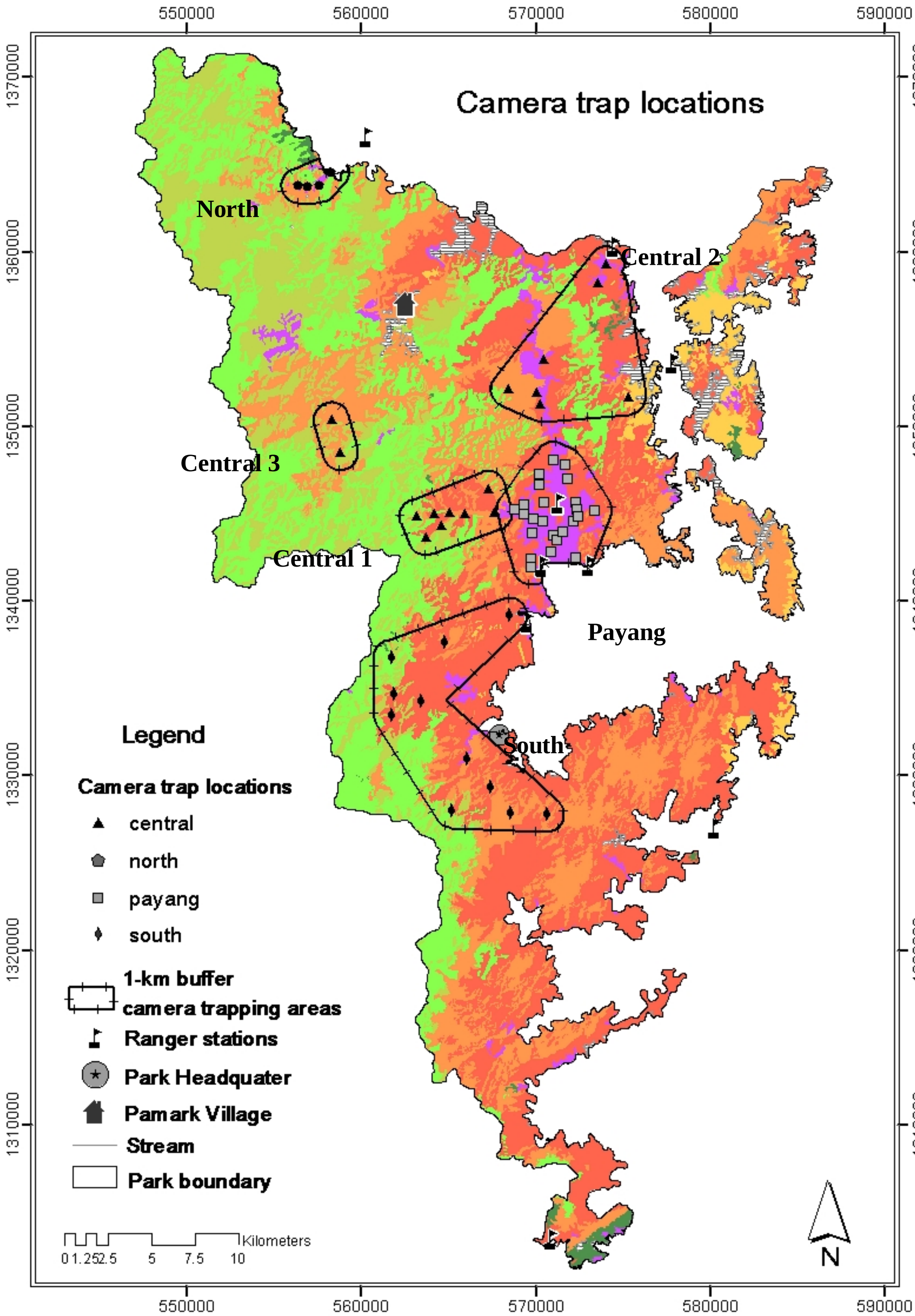


Figure 3.1. Camera trap locations and the effective camera trapping areas with 1-km buffer from minimum convex polygon of camera locations. (See legends and descriptions of landuse in Figure 1.2).

a) Control (CTRL)

b) Re-digitizing (DIG1 and DIG2)

Figure 3.2. An example of image sets that was used in the matching efficacy validation of the APHIS software. Direct facial shot images (a-e) are duplicates. Angled (f) and side (g) exposure are optional.

c) Grid digitizing (GRID)

d) Random digitizing (RAND)

Figure 3.2. (continued)

e) Crop 25%

f) Crop 50%

Figure 3.2. (continued)

g) Angled exposure (ANGL)

h) Side exposure (SIDE)

Figure 3.2. (continued)

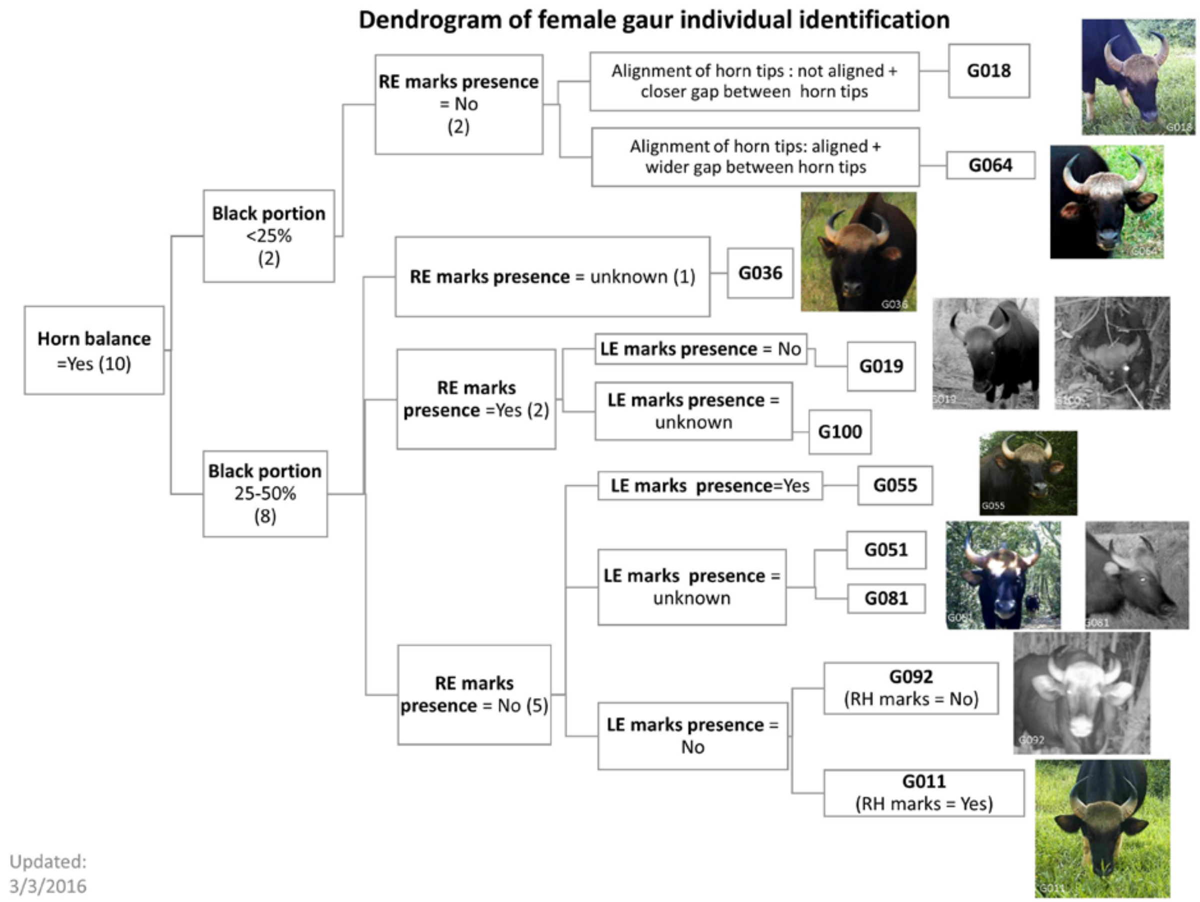


Figure 3.3. Dendrogram of 10 female gaur in Kuiburi National Park, Thailand identified from image collection photographed during November 2013 – January 2015. Horns of selected females are complete in length and shape. Horn coloration patterns and marks on ears and horns were used for individual identification. RH : Right horns, LH: Left horns, RE: Right ear, LE: Left ear.

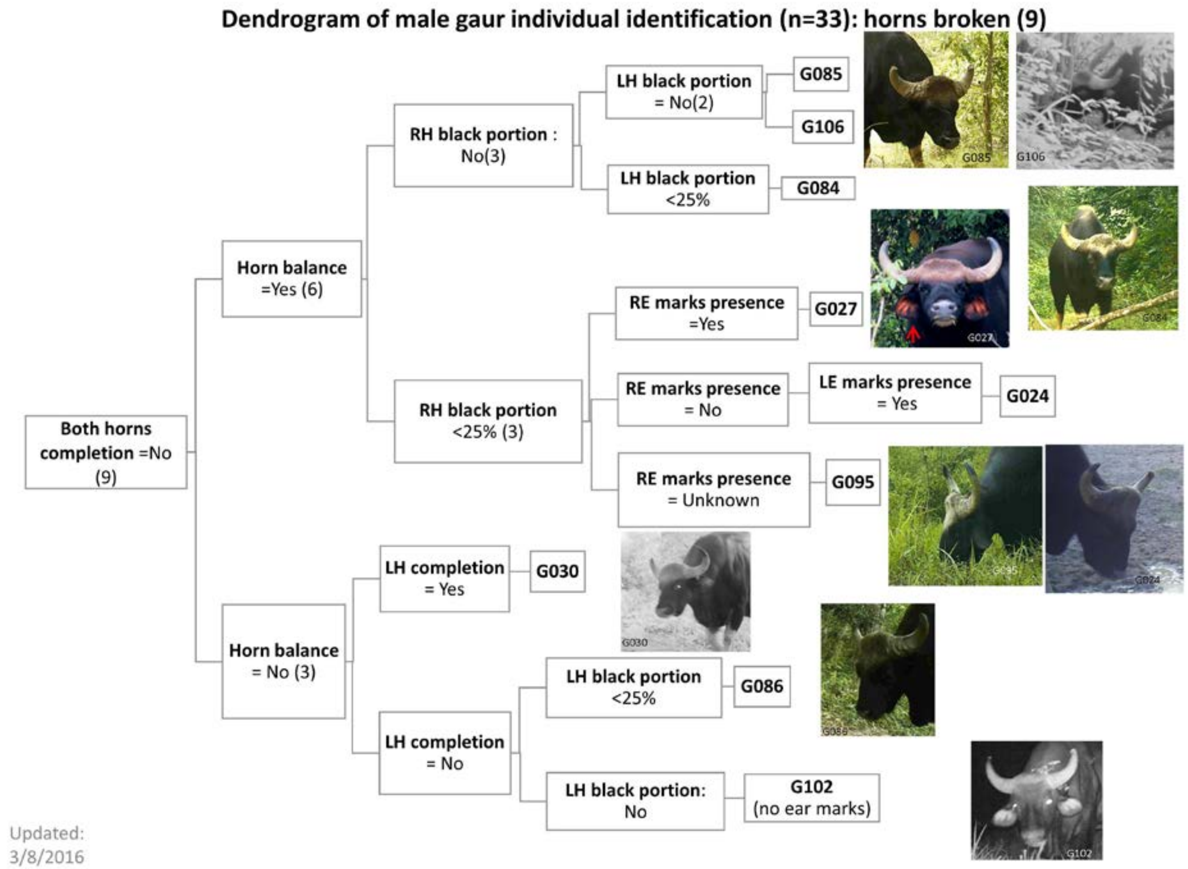


Figure 3.4. Dendrogram of male gaur with horns broken (n=9) in Kuiburi National Park, Thailand identified from image collection photographed during November 2013 – January 2015. Individual males with broken horns can be identified based on shape and length of each horns, coloration on horns, and marks on ears. RH : Right horns, LH: Left horns, RE: Right ear, LE: Left ear.

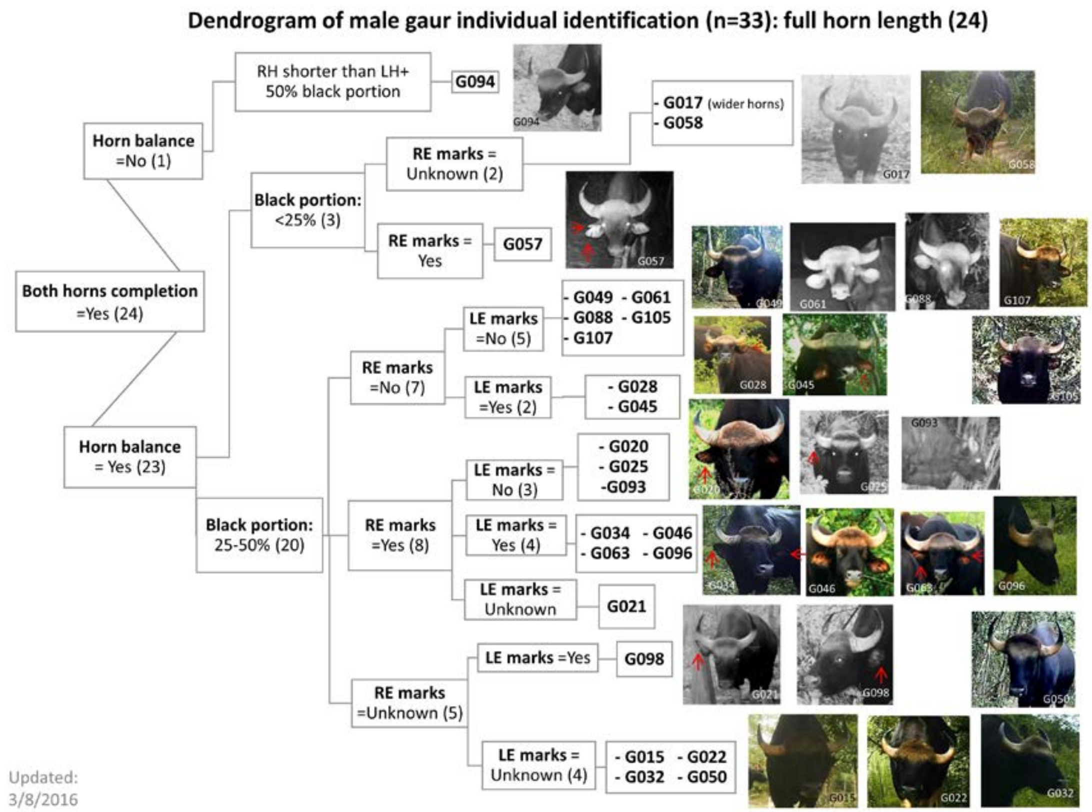


Figure 3.5. Dendrogram of male gaur with horns unbroken in Kuiburi National Park, Thailand identified from image collection photographed during November 2013 – January 2015. Individual males with complete horn shape have pointed horn tips. Criteria used to individual identification are length of both horns, coloration patterns on horns, and marks on ears. RH : Right horns, LH: Left horns, RE: Right ear, LE: Left ear.

CHAPTER 4

SYNTHESIS AND IMPLICATION OF GAUR POPULATION STUDY AND MANAGEMENT

POPULATION STATUS OF GAUR IN KUIBURI NATIONAL PARK, THAILAND

Kuiburi National Park is a home for much charismatic wildlife, such as the Asian elephant, gaur, banteng, leopards, and tigers (Steinmetz et al. 2014a). Habitat suitability modeling suggests that Kuiburi National Park contains medium to high suitable habitats for gaur (Department of National Parks Wildlife and Plants Conservation 2010a). Secondary forests, which were restored with human modifications and management, provide suitable habitats of ungulates. Direct observations and camera traps suggest that the Payang zone has a high concentration of gaur. Lowland habitats with plenty of food supply through habitat management and well protection measures result in successful population recovery and recruitment of charismatic mammals like elephants, gaur, and banteng. Wildlife watching and tourism-related services becomes a source of income for local villagers, who are trained as guides or offer transportation services.

Gaur require heterogeneous habitats for other purposes, e.g., dispersion, seasonal short-distance migration, or avoiding humans and predators. In Kuiburi National Park, gaur utilize secondary forest, dry evergreen forest, and moist evergreen forests. Most gaur are aggregated in the Payang zone, which is mainly comprised of secondary forests surrounded by dry evergreen forests. Evergreen forests, generally located in the interior part of the park, are not major habitats for breeding herds, but for males. Gaur inhabiting

remote forests are more vulnerable to poaching because patrolling occurs less frequently in remote forests due to logistic constraints and insufficient park rangers.

Based on the spatial capture-recapture modeling, the average adult gaur density in Kuiburi National Park was 2.5 ± 1.6 SE and the total number of gaur calculated from the age ratio was 198-239 gaur. Estimated density of gaur in the Payang zone is 6 times larger than the other zones. Although the camera trap arrays were set up only in gaur habitats with small effective sampling areas, other evidence from Steinmetz et al. (2014a) and patrols indicate clumped distribution patterns. Gaur breeding herds, which are comprised of a large proportion of gaur population, are more aggregated in the Payang zone. A large ratio of young to adult and female-biased population structure suggests that gaur population in Kuiburi National Park is increasing. This trend persists since the prey population has been monitored since 2006, implied by in gradually increasing occupancy and abundance (Steinmetz et al. 2014b).

The density obtained from the study is not comparable to the other populations because of the difference in sampling methods and analysis methods. Gaur density obtained from the distance sampling in the Western Forest Complex, including Huai Kha khaeng Wildlife Sanctuary and Thung Yai Naresuan Wildlife Sanctuary during 2006-2010 ranged from 0.3-1.6 gaur/100 km^2. Gaur density was relatively smaller than other sympatric major tiger's prey species, including muntjac, sambar, wild pig, and banteng (Wildlife Conservation Society 2014). However, the distribution and preferred habitats of gaur in many studies are similar. Based on tracks surveys in the Western Forest Complex, gaur tracks are more abundant in Savanna-like habitat and evergreen forest (Wildlife

Conservation Society 2014). In Kuiburi National Park, gaur highly concentrate in savanna-like habitats, i.e., Payang zone.

Threats to gaur population from humans are unapparent but still exist in Kuiburi National Park. There was only one case of gaur poaching for trophies during the study's period. However, anti-poaching measures- both legislation and outreach, still need to be implemented because habitat alteration and fragmentation may cause gaur to be more frequently exposed to humans and result in behavioral changes. Gaur may increase in tolerance to human disturbance and are together with domestic animals. In such situations, gaur are more vulnerable to diseases infection from domestic cattle. During the study period, 30 gaur died from the foot-and-mouth disease outbreak. Hence, this population needs to have long-term monitoring together with disease controls. Also, gaur in the wild may lose their genetic diversity due to inbreeding within a fragmented population or mating with the domestic cattle.

TECHNICAL APPLICATION ON GAUR AND UNGULATES STUDIES

Sign transect surveys and distance samplings are common survey techniques and data analysis for ungulates. It is a practical technique for wildlife inventory in the extensive landscape (Silveira et al. 2003). However, assumptions violation, e.g., closed population assumptions and errors in distance measurement, can easily occur due to animal behaviors or sampling errors and may cause bias in density and other demographic parameter estimates (Royle et al. 2014).

In the past few decades, camera trapping survey techniques are prevalent and have become common practice in wildlife studies. Camera traps not only provide lucid

evidence of animal occurrence, but their ability to operate in all environments and habitats also serve the opportunities to study rare and elusive animals (Thompson 2004, Tobler et al. 2008, O'Connell et al. 2011). The major analysis for abundance, density and population parameters estimations are relative abundance index, occupancy, and capture-recapture. For most species with unmarked individuals, relative abundance index (RAI) and occupancy are more commonly used because they utilize a simple form of data, e.g., presence/absence. Relative abundance indices, even though they are simple, but they do not account for imperfect and varied detection. Both ecological and sampling-related factors, e.g. different detection between animals due to animal size and behaviors, cause inference bias (Sollmann et al. 2013). Occupancy is one of the camera trap data analysis that utilizes latent information from the camera trap data to describe the distribution patterns of animals across the landscape or obtained abundance estimates. This method is widespread in many taxa, including ungulates, birds, and small mammals. Occupancy supports more ecologically relevant explanations on species occurrence and community composition and does not require marked populations. However, critical assumptions of the analysis, such as closed population and constant detection across sites, are difficult to follow. The violation of assumption leads to biased estimates of occupancy, detection, and abundance. Photographic capture-recapture is more intensively applied to carnivores, such as tigers, leopard, bears, than other taxa. The strength of capture-recapture is that it provides robust estimates for marked or identifiable species. The capture-recapture methods are limited to only species that contain a variation of unique characteristics among individuals, e.g. pelage patterns (Karanth 1995, Jackson et al. 2006, Wang and Macdonald 2009, Ngoprasert et al. 2012) and spot patterns (Meekan et al. 2006,

Kumbhar et al. 2013). Few species of ungulates adopted the photographic capture-recapture, including Mouse deer *Moschiola indica* (Kumbhar et al. 2013), Western Derby Eland *Taurotragus derbianus derbianus* (Jůnek et al. 2015), Bison *Bison bison* (Merkle and Fortin 2014), and tapirs *Tapirus* spp. (Trolle et al. 2008, Traeholt and Mohamed 2009).

This study is the pilot study to apply photographic capture-recapture techniques on gaur, which may be applicable to other ungulates. Horn characteristics, such as shape, coloration, and corrugation, combining with other marks, e.g., marks on ears and body, can be used to identify individuals. However, the techniques are restricted to only adult gaur because those characteristics are more varied than the juveniles. Young gaur lack variation of identifiable features and their features change rapidly. Semi-automated identification approaches using a matching software and visual inspection may be more practical to study wild ranging animals. In species with low detection, baited traps is an option to obtain more usable photos and increase detection rate.

The efficient survey techniques for ungulates, which usually live in a group and inhabit heterogeneous habitats like gaur, are difficult to determine. Camera trapping technique are less effective to capture the demographic structure of the entire population (e.g., sex and age ratio) because their limitation in the field of view and sex- and age-biased detection, but camera traps can be applied to all environment and habitat conditions and in extensive spatial and temporal scales. Direct observations in open areas or resources, e.g. grass patches, mineral licks, or small reservoirs, are favorable for population structure, but constraints on habitat types, man-power, and observation duration. As a result, monitoring of gaur population status requires a combination of

several survey techniques to collect demographic information, including sex and age ratio, abundance, and density. The use of multiple survey techniques, such as using the age ratio obtained from repeated aerial surveys and capture-recapture analysis, for density estimation is applied to other free-ranging animals, such as bison (Merkle and Fortin 2014).

The estimates from this study may be biased due to study designs, such as inconsistent sampling period and trap placement. I did not include other covariates which may influence detection probability in the spatially explicit capture-recapture models, such as the number of trap-nights and camera trap spacing. The spatial explicit capture-recapture models are more likely to overestimate abundance when applied to herbivores as suggested in the study of a known population of Western Derby elands (Jůnek et al. 2015). Photographic individual identification procedure may be insufficient and inaccurate due to the small photo collection. Both photo individual identification and population parameter estimation need validation to improve the accuracy of population parameter estimates. However, information obtained from this study is still useful for Kuiburi National Park, either in wildlife conservation or habitat management perspectives.

WILDLIFE MANAGEMENT IMPLICATION

Wildlife and forest management and conservation planning in Thailand focus on conserving wildlife and remaining forested areas using protected area systems (Department of National Parks Wildlife and Plants Conservation 2010b, Trisurat et al. 2010). Umbrella species, which usually include rare and large mammals that play

significant ecological roles and indicate the health of wild ecosystems, were priority species for conservation and management actions. Conservation of those umbrella species required large-scale habitat management and relevant ecological factors necessary to maintain species, e.g. other species that interact with umbrella species and their suitable habitats. The tiger is in the spotlight for conservation issues in Thailand and worldwide because it is the largest carnivores and the top predator in tropical forest ecosystems. Prey abundance is one of the most important factors to maintain and increase tiger population (Karanth and Stith 1999, Karanth 2003, Karanth et al. 2004). Thailand Tiger action plan (2010-2022) proposes to recover wild ungulates in tiger habitats as one of the priority actions to increase tiger population (Department of National Parks Wildlife and Plants Conservation 2010b). Reliable and accurate density estimation methods for ungulates are necessary to monitor prey species population for tiger conservation. Gaur is considered as a high-quality prey for gaur and can be depredated only by adult tigers. Hence, the forest that contained gaur in tiger diet list may indicate healthy ecosystem.

Preferred habitats of gaur and most ungulates are lowland forests containing foraging grounds and water resources. Such habitats are usually adjacent to human habitations, previously utilized by humans, or located on the edge of protected areas. Proper habitat management regimes can increase suitable habitat availability for ungulates and other wildlife, as well as enhance the economy of local communities through tourism business. The Payang zone in Kuiburi National Park and Khao Phaeng Ma Reforestation, formerly degraded habitats, are examples of the successful habitat management with the aims of wildlife conservation (Department of National Parks Wildlife and Plants Conservation 2010a, Prayong 2014, Steinmetz et al. 2014b).

However, natural succession alters plant community through time, causing habitats less prefer for ungulates. In-situ experiments to increase open habitats by selective cutting trees in regenerating forests showed that gaur occurrence and concentration in the managed areas increased when compared to the unmanaged areas (Prayong 2014). Hence, habitat improvement and maintenance are required periodically to preserve ideal habitats for gaur and other large herbivores. Participation of local communities and stakeholders from several sectors are also necessary for long-term wildlife and habitat management in a human-dominated landscape.

LITERATURE CITED

Department of National Parks Wildlife and Plants Conservation. 2010a. Status of large mammals in Thailand. 302 pp.pp.

_____. 2010b. Thailand tiger action plan 2010-2022. Ministry of Natural Resources and Environment, Bangkok, Thailand. 55 pp.

Jackson, R. M., J. D. Roe, R. Wangchuk, and D. O. Hunter. 2006. Estimating Snow Leopard Population Abundance Using Photography and Capture-Recapture Techniques. Wildlife Society Bulletin 34:772-781.

Jůnek, T., P. Jůnková Vymyslická, K. Hozdecká, and P. Hejcmanová. 2015. Application of Spatial and Closed Capture-Recapture Models on Known Population of the Western Derby Eland (Taurotragus derbianus derbianus) in Senegal. Plos One 10:e0136525.

Karanth, K. U. 1995. Estimating tiger Panthera tigris populations from camera-trap data using capture—recapture models. Biological Conservation 71:333-338.

Karanth, K. U. 2003. Tiger ecology and conservation in the Indian subcontinent. Journal of the Bombay Natural History Society 100.

Karanth, K. U., J. D. Nichols, N. S. Kumar, W. A. Link, and J. E. Hines. 2004. Tigers and their prey: Predicting carnivore densities from prey abundance. Proceedings of the National Academy of Sciences of the United States of America 101:4854-4858.

Karanth, K. U., and B. M. Stith. 1999. Prey depletion as a critical determinant of tiger population viability. Pages 100–113 *in* J. Seidensticker, S. Christie, andP. Jackson, editors. Riding the Tiger: Tiger Conservation in Human dominated Landscapes. Cambridge University Press, Cambridge, UK.

Kumbhar, A., C. L. Prabhu, J. K. Yogesh, P. Francies, G. Patwardhan, Q. Qureshi, and Y. Jhala. 2013. Application of Photographic Capture-Recapture Sampling for Estimating Abundance of Indian Mouse Deer Moschiola indica. World Journal of Zoology 8:388-391.

Meekan, M., C. Bradshaw, M. Press, C. McLean, A. Richards, S. Quasnichka, and J. Taylor. 2006. Population size and structure of whale sharks (Rhincodon typus) at Ningaloo Reef, Western Australia. Marine Ecology Progress Series 319:275 - 285.

Merkle, J. A., and D. Fortin. 2014. Likelihood-based photograph identification: Application with photographs of free-ranging bison. Wildlife Society Bulletin 38:196-204.

Ngoprasert, D., D. H. Reed, R. Steinmetz, and G. A. Gale. 2012. Density estimation of Asian bears using photographic capture–recapture sampling based on chest marks. Ursus 23:117-133.

O'Connell, A. F., J. D. Nichols, and K. U. Karanth. 2011. Camera traps in Animal Ecology. Springer. 271 pp.pp.

Prayong, N. 2014. Habitat Management for gaur concentration along the edge of a protected area. Ph.D. (Biology). Department of Biology, Mahidol University. Bangkok, Thailand. 109 pp.

Royle, J. A., R. B. Chandler, R. Sollmann, and B. Gardner. 2014. Spatial Capture-Recapture. Elsevier Inc., Massachusetts, USA. 577 pp.

Silveira, L., A. T. A. Jácomo, and J. A. F. Diniz-Filho. 2003. Camera trap, line transect census and track surveys: a comparative evaluation. Biological Conservation 114:351-355.

Sollmann, R., A. Mohamed, H. Samejima, and A. Wilting. 2013. Risky business or simple solution – Relative abundance indices from camera-trapping. Biological Conservation 159:405-412.

Steinmetz, R., N. Seuaturien, S. Srirattanaporn, and B. Poonnil. 2014a. Research and conservation of tigers and their prey in Kuiburi National Park. 80 pp.

Steinmetz, R., S. Srirattanaporn, J. Mor-Tip, and N. Seuaturien. 2014b. Can community outreach alleviate poaching pressure and recover wildlife in South-East Asian protected areas? Journal of Applied Ecology 51:1469-1478.

Thompson, W. L. 2004. Sampling rare or elusive species: concepts, designs, and techniques for estimating population parameters. Island Press. 413 pp.

Tobler, M. W., S. E. Carrillo-Percastegui, R. Leite Pitman, R. Mares, and G. Powell. 2008. An evaluation of camera traps for inventorying large- and medium-sized terrestrial rainforest mammals. Animal Conservation 11:169-178.

Traeholt, C., and M. S. b. Mohamed. 2009. Population estimates of Malay Tapir, Tapirus indicus, by camera trapping in Krau Wildlife Reserve, Malaysia. Tapir Conservation 18:12-20.

Trisurat, Y., R. Alkemade, and P. Verburg. 2010. Projecting Land-Use Change and Its Consequences for Biodiversity in Northern Thailand. Environmental Management 45:626-639.

Trolle, M., A. J. Noss, J. L. P. Cordeiro, and L. F. B. Oliveira. 2008. Brazilian Tapir Density in the Pantanal: A Comparison of Systematic Camera-Trapping and Line-Transect Surveys. Biotropica 40:211-217.

Wang, S. W., and D. W. Macdonald. 2009. The use of camera traps for estimating tiger and leopard populations in the high altitude mountains of Bhutan. Biological Conservation 142:606-613.

Wildlife Conservation Society. 2014. Recovering wild tigers in Thailand's western forest complex. 39 pp.

APPENDICES

Appendix 1. Photographs of habitats in six focal areas of study in Kuiburi National Park, Thailand.

a) Payang zone

b) Central zones

Central 1: Hub Ma Grood

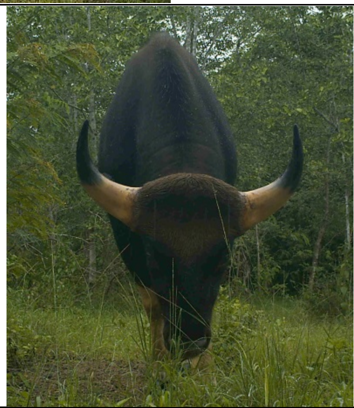
Central 2: Hub Ma Sang

Central 3: Hub Inthanin

c) North zone

d) South zone

Appendix 2. Photographs of gaur in each sex and age class.

Age class	Female	Male
Calf (0-3 mo)		
Yearling (3-15 mo)		
Juvenile (15-36 mo)		
Adult (> 3 years old)		

Appendix 3. Camera trap models and setting schemes used in the camera trapping surveys for gaur in Kuiburi National Park, Thailand during November 2013 – January 2015.

Model	**Scoutguard SG565**	**Moultrie M-80**	**StealthCam Unit Ops no glow**	**Bushnell Trophy Cam HD**
Flash Type	Xenon flash	Infra-red	Infra-red	Infra-red
Capture mode	VIDEO - record only video during the day but still images during the night	VIDEO - record both still images and video	VIDEO - record only videos	HYBRID -record both still images and videos
Photo quality	8MP	3MP	8 MP	8MP
Video quality	VGA(640x480@16fps)	HIGH (720x400 @24fps)	HIGH (1280x720@30fps)	VGA (640x480@18fps) or HD (1280x720@18fps)
Video length	30 sec.	30 sec (during the day) - camera default setting records 10 sec for night-shots)	30 sec.	30 sec.
Photo delay	1 sec	- 15 sec	N/A	1 sec
Multi-shot	N/A	2 or 3 photos	3 photos	2 or 3 photos

Appendix 4. Vegetation sampling plots layout. Nine 5-m radius circular plots along the four cardinal directions centered at the camera locations or random locations. Each subplots was 20-m apart.