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# Assessing Mammal and Bird Biodiversity and Habitat Occupancy of Tiger Prey in the Hukaung Valley of Northern Myanmar

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# ASSESSING MAMMAL AND BIRD BIODIVERSITY AND HABITAT OCCUPANCY OF TIGER PREY IN THE HUKAUNG VALLEY OF NORTHERN MYANMAR

A Thesis Presented

By

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**ABSTRACT**

ASSESSING MAMMAL AND BIRD BIODIVERSITY AND HABITAT OCCUPANCY OF TIGER PREY IN THE HUKAUNG VALLEY OF NORTHERN MYANMAR

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HLA NAING, B.S., INSTITUTE OF FORESTRY YEZIN, BURMA/MYANMAR

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Directed by Professors Todd K. Fuller and Paul R. Sievert

I used results from camera traps set for tigers (*Panthera tigris*) during 2001-2011 in the Hukaung Valley Wildlife Sanctuary of northern Myanmar to assess overall biodiversity of large mammal and bird species, and to identify differences in photo rates inside and outside of the most protected core area of the Sanctuary. A total of 403 camera stations were deployed during October-July in the dry seasons of 2001-2011, 260 inside the Core area and 143 Outside. From 10,750 trap-nights I obtained 2,077 independent photos of wildlife species and 699 of domestic animals and humans, including 35 species of wild mammals (19 carnivores, 4 primates, 1 elephant, 6 even-toed ungulates, 1 pangolin, and 4 rodents) and 16 species of wild birds. Of these, 1 is considered critically endangered, 7 are endangered, 11 are vulnerable, and 5 are nearly threatened. Some species that probably occur in the Sanctuary (e.g., arboreal or semi-aquatic mammals) were not photographed, likely because of camera placement. In total, 48 wild species were photographed in the Core area vs. only 33 at locations Outside of the core area. Generally, few photos of any domestic animal species were obtained inside the Core area, and no photos insurgents were obtained there, but many more photos of

poachers and villagers, but also park rangers, were obtained there. Increased patrol efforts may have helped maintain species presence in the Core area, but differences in photo rates between areas were likely mostly influenced by differences in elevation, slope, density of streams, trails, and roads, and perhaps vegetative cover type.

Tiger abundance is most influenced naturally by prey availability and anthropogenically by poaching. In the Hukaung Valley Wildlife Sanctuary in northern Myanmar, a major conservation area established to protect tigers, tiger presence has declined. This study was conducted to assess habitat occupancy and distribution of principal tiger prey species in the Core part of the Sanctuary by surveying for sign on 1650.9 km partitioned into 554 sampling units during November 2007 and May 2008. Using standard occupancy model in the program PRESENCE (6.2), habitat occupancy and detection probabilities were predicted and the best candidate model for each species was selected using the Akaike information criterion (AIC). By incorporating 7 environmental and 4 social covariates, the predicted habitat occupancy rates were 0.76 (SE=0.196, naïve estimate = 0.5162) for gaur (*Bos gaurus*), 0.91 (SE=0.03, naïve estimate = 0.7762) for sambar (*Rusa unicolor*), 0.57 (SE = 0.003, naïve estimate = 0.3195) for wild pigs (*Sus scrofa*) and 0.89 (SE = 0.001, naïve estimate = 0.7996) for muntjac (*Muntiacus muntjak*). Overall, shorter Euclidean distances to ranger stations and trails, decreased stream density, and broadleaved evergreen/semi-deciduous forest and relatively rare rain-fed cropland habitat occurrence positively influenced prey habitat occupancy; conversely, shorter Euclidean distances to villages, roads, and streams, higher elevations, and occurrence of mixed broadleaved and needle-leaved forest habitat negatively influenced occupancy. In addition, Euclidean distance to ranger stations, trails, and roads positively affections species detections, whereas shorter Euclidean distance to villages and streams, high elevations, and high precipitation negatively affected detections. Results indicate that all four prey species were relatively well-distributed through the Sanctuary Core area. However, comparisons with tiger and prey indices of abundance elsewhere suggest that prey density is low and would not likely support many tigers.

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## ASSESSING LARGE MAMMAL AND BIRD BIODIVERSITY WITH CAMERA TRAP PHOTOS IN THE HUKAUNG VALLEY OF NORTHERN MYANMAR

### Introduction

Although the important role of biodiversity in ecosystems and their services is commonly acknowledged, human activity has been causing rapid extinction of wild fauna and flora worldwide. Globally, one-third of wild vertebrate species declined between 1970 and 2006, especially so in freshwater ecosystems (41% decline) and in the tropics (59% decline; United Nations 2010). Myers et al. (2000) identified 25 global hotspots of eco-region in terms of species richness and endemism, and four of them (Indo-Burma, Sundaland, the Philippines and Wallacea) are in Southeast Asia. Importantly, Southeast Asian tropical forests have been seen the highest rates of deforestation, likely resulting in the loss of 75% of the original forest and 41% of its biodiversity by the end of this century (Sodhi et.al 2004).

Myanmar (formerly known as Burma; 676,577 km$^2$) encompasses a major hotspot area, is regarded as the last frontier of biodiversity in Asia, and harbors >5% of mammal species, and >10% of avifauna, in the world (Encyclopedia of the Nations 2014). Because Myanmar has been relatively isolated internationally, unusual natural and cultural diversities have been preserved. On the other hand, the baseline information with regard to wildlife conservation and protected area management is urgently needed to update future conservation planning and ecosystem management. The aim of this study is to use camera trap photos from several years of study to assess species diversity and distribution (cf., Stein et al 2008, McCarthy et al 2010) in one protected area in northern

Myanmar. I hypothesized that wildlife species diversity and abundance would be higher inside vs. outside of the most protected core area of the Sanctuary.

**Study area**

The Hukaung Valley Wildlife Sanctuary (HKVWS) is one of the largest (17,373 $km^2$) of 43 protected areas in the country (total = 49,456 $km^2$; NCEA 2009). The HKVWS (Fig. 1.1) is in the country's northernmost state (~25º23´-27º23´N and 95º33´-97º18´E) and ranges in elevation from 94 to 3,440m (Lynam et al. 2009). The Hukaung Valley is circled by steep mountain ranges in the north, east, and west the streams and rivers flowing towards the central plain of the valley combine to form a major catchment basin of the Chindwin River. The plain contains a mosaic of broadleaf forest and grassland habitats, the hilly slopes are covered with broadleaf forest, and the mountains consist of temperate broadleaf forest, coniferous forest, and shrubland (Lynam et al. 2009). The study area is in the humid subtropical climate zone, having a mean annual rainfall of approximately 2,340 mm, and mean annual minimum and maximum temperatures of 18.8 Cº and 30.0Cº, respectively. The climate is greatly influenced by monsoons, which help define three distinct seasons. Generally, the hot season runs from mid-February to mid-May, the monsoon or rainy season from mid-May to mid-October, and the cool season from mid-October to mid-February.

Indigenous people in the Hukaung Valley were primarily Naga, Kachin and Shan tribes relying primarily on shifting cultivation, non-wood forest product collection, and subsistence hunting. Compared to other areas in Myanmar, the growth of the indigenous population had been relatively low, but during the course of the camera trapping surveys, the number of temporary migrants in the Hukaung Valley employed in gold and jade mining, rattan harvesting, and agricultural businesses increased. One of the peculiarities in establishing the HKVWS is that it recognized the necessary coexistence of humans and nature, valued the existing biological and cultural diversity, and avoid undesirable issues in park management by allowing resource use in many areas.

Camera-trapping was conducted both inside and outside of the ~1,800-km² Core reserve area (Fig. 1.1) where there are no human settlements; however, some villages occur along the southern boundary of the core area adjacent to the historic Ledo Road which was built by the US Army during World War II. Forest trails, which are primarily mule tracks and footpaths along ridges and rivers, connect remote villages, and waterways are used as a secondary transportation option. Regular patrols by Sanctuary rangers occur in the Core area, in contrast to other areas of the HKVWS where patrols are infrequent.

I characterized the major differences in camera trapping sites between the Core area and Outside the core area by assessing the area within 3 km of each camera trapping site (Fig. 1.2) and for all sites within an area identifying the average or mean elevation, slope, and density of streams, trails, roads, and villages (Table 1.1), as well as the total percent of 13 land cover features over the cumulative area covered by trap sites (Fig. 1.3). Relative to the Core area, sites Outside the Core area were at higher elevations, had steeper slope, had less streams and trails but more roads, and had more Hill Forest and less Evergreen Open Forest land cover.

**Methods**

Camera-trapping in the HKVWS initially was carried out to investigate tiger (*Panthera tigris*; scientific names of all species are identified in Table 1.4) distribution and relative abundance (Lynam et al. 2009) in a variety of areas in the Sanctuary. Before beginning surveys, researchers and rangers conducted rapid assessments of potential camera trap locations and identified natural animal trails, historical wildlife corridors, streambeds, mountain ridges, saddles, mineral saltlicks, animal wallows, access routes, areas of thick vegetation such as bamboo and rattan brakes, deep rivers, and seasonally flooded wetlands. Potential trap locations and old trail networks were recorded, and logistical constraints regarding accessibility were considered. Due to the complicated and sensitive political climate among ethnic (Kachin and Naga) rebellion groups and central government, the survey teams sometimes were limited as to area accessibility, especially during the last two survey seasons (2009-2010 and 2010-2011). For example, the last ten camera traps had to be retrieved only two and half days after being set out because they were unknowingly placed between the front lines of the government army and a rebel group.

After reachable locations were indentified in a given year, a sub-set of those locations was selected and trapping stations were set up, usually at least 2 km from the next nearest station depending on the number of available camera traps and the area to be covered, but also to increase independence among traps. At each station, a passive infrared camera unit (CamtrakkerTM, Camtrak South Inc., Watkinsville, GA, and/or DeerCam with DC-300 film, Non-Typical, Park Falls, WI, USA) was attached to a tree on the side of the trail (Burton et al. 2012) at a height of 40-50cm above ground level, perpendicularly oriented to the likely direction of animal travel, and at a distance of 3.0-3.5m from the probable location of animal detection; this arrangement was used throughout the study to allow for comparison/pooling among years. Each camera trap was ready continuously (i.e., 24 hours/day) in order to capture both nocturnal and diurnal species, and took photos at 15-second intervals. Camera traps were checked periodically (three- to six-week interval) to replace batteries and rolls of film. Camera traps were left in the field for at least two weeks at the same location.

Sampling effort at a station was calculated as the number of days a camera trap was operational at that location (Burton et al. 2012). Detections of wild mammals and birds, as well as domestic animals and humans, were tallied for each station for each day. To avoid pseudo-replication, I considered as independent: 1) consecutive photographs of different individuals of the same species (for those that could be identified individually, e.g., tigers, (2) consecutive photographs of a species when separated by more than 30 min, or (3) non-consecutive photos of individuals of the same species (O’Brien et al 2003). I compared cumulative photo rates of individual species between areas with Chi-square statistics with Yates' correction test (Yates 1934) at $\alpha = 0.01$**.**

**Results**

A total of 403 camera stations were deployed during October-July (but usually December-June; Table 2) in the dry seasons of 2001-2011. In total, 260 stations were established in the Core area and 143 Outside of the core area (Figs. 1.4-1.7), resulting in 7,452 trap nights in the Core area and 3,298 trap nights Outside of the core area (average no. trap nights/station = 30.9; Table 1.3). We obtained 2,077 independent photos of wildlife species and 699 of domestic animals and humans (Table 1.3).

In terms of species richness, we captured 35 species of wild mammals and 16 species of wild birds (Table 1.4). In total, 48 wild species were photographed in the Core area vs. only 33 Outside of the core area (Table 1.3). The lower number of species recorded Outside of the core area was also reflected in species diversity curves generated from annual survey results in both the Core area, ($r^2 = 0.844$), and Outside of the core area ($r^2 = 0.608$; Figure 1.8). In addition, photos were obtained of 5 kinds of domestic animals (none Outside of the core area) and 4 categories of humans (including insurgents that were only photographed outside of the Core area; see more below).

The 35 photographed mammal species (U Tun Yin 1967) included 19 carnivores, 4 primates, 1 elephant, 6 even-toed ungulates, 1 pangolin, and 4 rodents. Only 16 of more than 430 bird species likely occurring in the Hukaung Valley (Robson 2000) were recorded, but one of them is listed in the world's 100 most threatened species, the White-bellied Heron or Imperial Heron which is the second largest heron species in the world with a total population of only 70–400 individuals (Baillie and Butcher 2012). By conservation status (Table 1.4), recorded species include 1 considered critically endangered, 7 endangered, 11 vulnerable, 5 nearly threatened, and 27 of least concern (IUCN 2013).

Statistical differences ($P<0.001$) of overall photo rates of individual wildlife species in the Core area vs. Outside of the core area were identified for 9 mammals (Table 1.5) and 1 bird (Table 1.6). Large Indian civet, crab eating mongoose, northern pig-tailed macaque, sambar deer, Malayan porcupine, and Red jungle fowl were photographed more often within the Core area, and Asian golden cat, stump-tailed macaque, rhesus macaque, and red serow were photographed more often Outside of the core area. In addition, no leopards, small Indian civets, large-spotted civets, masked palm civets, Asian elephants, hog deer (recorded only in the Core area in 2010-2011 because during that year the few traps deployed were specifically set in hog-deer habitat), Chinese pangolins, or Edward's rats were photographed Outside of the core area, and no hog badgers were photographed in the Core area (Table 1.5). Nine species of birds were only photographed inside of the Core area, and two species were photographed only

Outside of the core area, no more than 4 photos were obtained of any of these species (Table 1.6).

Relatively few photos of domestic animal species were obtained inside the Core area, but more domestic buffalo were photographed there (Table 1.7). However, many more photos of poachers and villagers, but also park rangers were obtained inside of the Core area than Outside, and photos of insurgents were obtained only Outside of the core area (Table 1.7).

**Discussion**

During the course of these consecutive camera trap surveys intended to identify tigers, 35 species of wild mammals (33 $\geq$1 kg) were confirmed to occur in the Hukaung Valley Wildlife Sanctuary. Some species that probably occur in the Sanctuary were not photographed, most likely because of camera placement intended to photograph tigers in dry land forest areas. For example, we did not record the presence of hog deer during camera trapping occurring from 2001 to 2010; however, in 2011, this species was photographed in traps specifically set in swampy habitat that is more typically used by hog deer and were traps had not been set before. According to a compendium of wild animals in Myanmar (U Tun Yin 1967) and other distribution references (Rabinowitz and Khaing 1998), large -sized ($\geq$1 kg) mammals of at least 58 species have been recorded or are purported to occur throughout northern Myanmar (Table 1.8). Many of these have specific habitat niches that were either outside the potential for “tiger cameras” in the Sanctuary to record (e.g., arboreal/gibbons; semi-aquatic/otters), or outside of the Sanctuary (e.g., high altitude/red pandas). Others are extremely rare (e.g., leaf deer) are likely were rare occurrences recorded outside of their normal range (e.g., red foxes). Nevertheless, we did document a substantial number of species, some very rarely, and the relative frequency of their occurrence probably gives us some sense of their abundance or rarity of time (Rovero and Marshall 2009), recognizing that reliability of such indices is continually of topic of discussion (Carbone et al. 2001, Jennele et al. 2002) because capture frequency might vary depending on camera location and spacing, species-specific body and home range size and behavior (e.g., Trolle and Kery 2005).

Differences in species-specific photo rates inside and outside of the core area may be due in some part to higher patrol efforts in the core area; Jenks et al. (2010) found that abundance of photographed species was higher nearer ranger stations in a national park in Thailand and recommended more patrol efforts in areas away from stations to help reduce poaching. However, differences in photo rates between areas were likely influenced by habitat differences in elevation, slope, density of streams, trails, and roads, and perhaps vegetative cover type, as is expected regarding the natural variation in species distribution.

With respect to the relatively higher photo rates of villagers and poachers in the Core area, we note that this likely is due to placement of a number of camera traps in proximity to human settlement areas along the Ledo Road; this proximity allows for easy access directly into the Core area, unlike Outside of the core area where cameras were placed in more remote, albeit less protected, settings. In addition, local hill tribes from the northern most part of the country’s remote area migrate to the southern part of the Hukaung Valley, often through the Core area, in order to look for new jobs in agriculture and mining extraction. In most every year, camera trap survey team members helped these people in need of food and medicine while on their long (~15 days walking) trip.

Overall, the various camera surveys, though not originally intended to serve as a long term monitoring survey for wildlife diversity, provide important insights into wildlife distribution and abundance, especially for an area that has had some (e.g., Zaw et al 2008), but generally little such data gathered before. In fact, our documentation of one of the most threatened bird species in the world, the White-bellied or Imperial Heron (Baillie and Butcher 2012), may be sufficient justification for continuing such surveys.

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Table 1.1. Characteristics of landscapes within a 3-km radius (28.3-$km^2$ plot) of camera trap locations in the Core study area (n = 260) and Outside the core study area (n = 143) in the Hukaung Valley of northern Myanmar during 2001-2011. Significant differences (P<0.05) indicated with an asterisk.

| | Core (1,695 km²) | | | Outside (1,950 km²) | | | |
|---|---|---|---|---|---|---|---|
| | Mean | Median | Range | Mean | Median | Range | P-value |
| Elevation (m) | 272 | 260 | 208-542 | 712 | 687 | 208-1,737 | <0.0001* |
| Slope (degrees) | 2.9 | 1.4 | 0.5-18.6 | 14.6 | 16.6 | 1.1-25.6 | <0.0001* |
| Density | | | | | | | |
| Stream ($km/km^2$) | 0.74 | 0.75 | 0.01-1.40 | 0.36 | 0.30 | 0-0.94 | <0.0001* |
| Trail ($km/km^2$) | 0.26 | 0.24 | 0-0.84 | 0.20 | 0.15 | 0-0.79 | 0.004* |
| Road ($km/km^2$) | 0.01 | 0 | 0-0.22 | 0.02 | 0 | 0 -0.27 | 0.02* |
| Village (no./100 $km^2$) | 0.19 | 0 | 0-7.07 | 0.07 | 0 | 0-3.54 | 0.14 |

Table 1.2**.** Distribution of camera trapping survey efforts in the Core study area (circles) and Outside of the core area (triangles) in the Hukaung Valley of northern Myanmar during 2001-2011.

| Year | Area | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2001-02 | Core | | | | | ● | ● | | | | |
| 2002-03 | Core | | | ● | ● | ● | ● | | | | |
| | Outside | | | | | Δ | Δ | | | | |
| 2003-04 | Core | | | ● | ● | ● | | | | | |
| | Outside | | | | | | | Δ | Δ | Δ | |
| 2004-05 | Core | | | | | | ● | ● | | | |
| | Outside | | | | | | | | Δ | Δ | Δ |
| 2005-06 | Core | | | | | | ● | ● | ● | ● | |
| | Outside | | | | | | Δ | Δ | Δ | Δ | |
| 2006-07 | Core | | | | | | ● | ● | ● | ● | |
| 2006-07 | Outside | | | | | | Δ | Δ | Δ | | |
| 2009-10 | Core | ● | ● | ● | | ● | ● | ● | ● | ● | ● |
| | Outside | | | Δ | | Δ | Δ | Δ | | | |
| 2010-11 | Core | | | | | | ● | ● | | | |
| | Outside | | | | | | | | Δ | Δ | |

Table 1.3. Annual camera trapping survey efforts and overall data accumulation for wildlife and domestic[a] species in the Core study area, and Outside of the core area, in the Hukaung Valley of northern Myanmar during 2001-2011.

| | | | | | Wildlife | | | Domestic[a] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Zone | No. of camera stations | No. of trap nights | Mean no. of trap nights per station | Total no. of photos | Total no. of independent photos [b] | Total no. of species detected | Total no. of photos | Total no. of independent photos [b] | Total no. of species detected |
| 2001-02 | Core | 25 | 884 | 35.4 | 215 | 192 | 21 | 13 | 11 | 2 |
| 2002-03 | Core | 63 | 1,079 | 17.1 | 536 | 329 | 29 | 326 | 198 | 4 |
| | Outside | 38 | 748 | 19.7 | 163 | 143 | 19 | 86 | 54 | 4 |
| 2003-04 | Core | 50 | 1,042 | 20.8 | 344 | 221 | 28 | 16 | 11 | 3 |
| | Outside | 49 | 1,069 | 21.8 | 441 | 299 | 25 | 13 | 7 | 1 |
| 2004-05 | Core | 26 | 587 | 22.6 | 154 | 120 | 24 | 27 | 17 | 3 |
| | Outside | 21 | 627 | 29.9 | 83 | 66 | 16 | 2 | 1 | 1 |

(continued)

Table 1.3. (Continued)

| | | | | | Wildlife | | | Domestic[a] | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Year | Zone | No. of camera stations | No. of trap nights | Mean no. of trap nights per station | Total no. of photos | Total no. of independent photos [b] | Total no. of species detected | Total no. of photos | Total no. of independent photos [b] | Total no. of species detected |
| 2005-06 | Core | 32 | 486 | 15.2 | 204 | 134 | 22 | 23 | 6 | 2 |
| | Outside | 17 | 260 | 15.3 | 100 | 71 | 17 | 7 | 3 | 2 |
| 2006-07 | Core | 42 | 2,056 | 49.0 | 415 | 269 | 29 | 373 | 275 | 4 |
| | Outside | 1 | 62 | 62.0 | 18 | 15 | 8 | 0 | 0 | 0 |
| 2009-10 | Core | 17 | 1,266 | 74.5 | 188 | 136 | 20 | 142 | 74 | 6 |
| | Outside | 7 | 393 | 56.1 | 63 | 51 | 8 | 14 | 7 | 3 |
| 2010-11 | Core | 5 | 52 | 10.4 | 23 | 16 | 2 | 49 | 29 | 5 |
| | Outside | 10 | 139 | 13.9 | 22 | 15 | 3 | 8 | 6 | 1 |

(continued)

Table 1.3. (Continued)

| Year | Zone | No. of camera stations | No. of trap nights | Mean no. of trap nights per station | Wildlife: Total no. of photos | Wildlife: Total no. of independent photos [b] | Wildlife: Total no. of species detected | Domestic[a]: Total no. of photos | Domestic[a]: Total no. of independent photos [b] | Domestic[a]: Total no. of species detected |
|---|---|---|---|---|---|---|---|---|---|---|
| Total | Core | 260 | 7,452 | 30.6 | 2,079 | 1,417 | 48 | 969 | 621 | 8 |
| | Outside | 143 | 3,298 | 31.2 | 890 | 660 | 33 | 130 | 78 | 4 |
| Grand total | | 403 | 10,750 | 30.9 | 2,969 | 2,077 | 51 | 1,099 | 699 | 9 |

[a]Domestic "species" include: domestic buffalos, dogs, pigs, and chickens, as well as humans categorized as insurgents, villagers, poachers, and park rangers.

[b]Independent photo: (1) consecutive photographs of different individuals of the same or different species, (2) consecutive photographs of individuals of the same species when separated by more than 30 min, or (3) non-consecutive photos of individuals of the same species (O'Brien et al 2003).

Table 1.4. Scientific and common names, and IUCN (2013) conservation status, of wild mammal and bird species identified from camera trap photos obtained during surveys in the Hukaung Valley of northern Myanmar during 2001-2011.

| Order | Family | Scientific name | Common name | Conservation status |
|---|---|---|---|---|
| Carnivora | Felidae | *Panthera tigris* | Tiger | Endangered |
| | | *Panthera pardus* | Leopard | Nearly threatened |
| | | *Neofelis nebulosa* | Clouded leopard | Vulnerable |
| | | *Pardofelis temminckii* | Asian golden cat | Nearly threatened |
| | | *Pardofelis marmorata* | Marbled cat | Vulnerable |
| | | *Prionailurus bengalensis* | Leopard cat | Least concern |
| | Canidae | *Cuon alpinus* | Dhole | Endangered |
| | Ursidae | *Ursus thibetanus* | Asiatic black bear | Vulnerable |
| | | *Helarctos malayanus* | Malayan sun bear | Vulnerable |
| | Viverridae | *Arctictis binturong* | Binturong | Vulnerable |
| | | *Viverra zibetha* | Large Indian civet | Nearly threatened |

(continued)

Table 1.4. (Continued)

| Order | Family | Scientific name | Common name | Conservation status |
|---|---|---|---|---|
| | | *Viverricula indica* | Small Indian civet | Least concern |
| | | *Paradoxurus hermaphroditus* | Common palm civet | Least concern |
| | | *Viverra megaspila* | Large-spotted civet | Vulnerable |
| | | *Paguma larvata* | Masked palm civet | Least concern |
| | Herpestidae | *Herpestes urva* | Crab-eating mongoose | Least concern |
| | Mustelidae | *Martes flavigula* | Yellow-throated marten | Least concern |
| | | *Arctonyx collaris* | Hog badger | Nearly threatened |
| | Prionodontidae | *Prionodon linsang* | Banded linsang | Least concern |
| Primates | Cercopithecidae | *Macaca arctoides* | Stump-tailed macaque | Vulnerable |
| | | *Macaca leonina* | Northern pig-tailed macaque | Vulnerable |
| | | *Macaca mulatta* | Rhesus macaque | Least concern |
| | | *Trachypithecus pileatus* | Capped-leaf monkey | Vulnerable |

(continued)

Table 1.4. (Continued)

| Order | Family | Scientific name | Common name | Conservation status |
|---|---|---|---|---|
| Proboscidae | Elephantidae | *Elephas maximus* | Asian elephant | Endangered |
| Cetartiodactyla | Bovidae | *Bos gaurus* | Gaur | Vulnerable |
| | | *Capricornis rubidus* | Red serow | Nearly threatened |
| | Cervidae | *Cervus unicolor* | Sambar | Vulnerable |
| | | *Hyelaphus porcinus* | Hog deer | Endangered |
| | | *Muntiacus muntjak* | Mauntjac/Barking deer | Least concern |
| | Suidae | *Sus scrofa* | Wild boar | Least concern |
| Pholidota | Manidae | *Manis pentadactyla* | Chinese pangolin | Endangered |
| Rodentia | Hystricidae | *Hystrix brachyura* | Malayan porcupine | Least concern |
| | | *Atherurus macrourus* | Asiatic brush-tailed porcupine | Least concern |
| | Muridae | *Leopoldamys edwardsi* | Edward's rat | Least concern |

(continued)

Table 1.4. (Continued)

| Order | Family | Scientific name | Common name | Conservation status |
|---|---|---|---|---|
| | Sciuridae | *Dremomys rufigenis* | Asian Red-cheeked squirrel | Least concern |
| Anseriformes | Anatidae | *Cairina scutulata* | White-winged duck | Endangered |
| Ciconiiformes | Ardeidae | *Ardea insignis* | Imperial heron | Critically endangered |
| | Ciconiidae | *Ciconia nigra* | Black stork | Least concern |
| | | *Ciconia episcopus* | Woolly-necked stork | Least concern |
| Columbiforme | Scolumbida | *Ducula aenea* | Green imperial pigeon | Least concern |
| Coraciiformes | Bucerotidae | *Anthracoceros albirostris* | Oriental pied hornbill | Least concern |
| Cuculiformes | Cuculidae | *Centropus sinensis* | Greater coucal | Least concern |
| Falconiformes | Accipitridae | *Circus spilonotus* | Eastern Marsh-harrier | Least concern |
| Galliformes | Phasianidae | *Pavo muticus* | Green peafowl | Endangered |
| | | *Polyplectron bicalcaratum* | Grey peacock pheasant | Least concern |
| | | *Lophura leucomelanos* | Kalij pheasant | Least concern |

(continued)

Table 1.4. (Continued)

| Order | Family | Scientific name | Common name | Conservation status |
|---|---|---|---|---|
| | | *Gallus gallus* | Red junglefowl | Least concern |
| | | *Arborophila rufogularis* | Rufous-throated partridge | Least concern |
| Passeriformes | Corvidae | *Cissa chinensis* | Green magpie | Least concern |
| | Turdidae | *Myophonus caeruleus* | Blue whistling thrush | Least concern |
| Strigiformes | Strigidae | *Ketupa zeylonensis* | Brown fish owl | Least concern |

Table 1.5. Comparison of cumulative photo rates (no. of independent photos/100 trap nights) between the Core study area (n = 7,452 trap nights) and Outside the core area (n = 3,298) for mammal species in the Hukaung Valley of northern Myanmar during 2001-2011. Significant differences (P<0.01) indicated with an asterisk.

| | Core | | Outside | | |
|---|---|---|---|---|---|
| Species | No. of independent photos | Rate | No. of independent photos | Rate | P-value |
| Tiger | 16 | 0.2147 | 2 | 0.061 | 0.122 |
| Leopard | 1 | 0.0134 | 0 | 0.000 | 0.671 |
| Clouded leopard | 38 | 0.5099 | 12 | 0.364 | 0.383 |
| Asian golden cat | 2 | 0.0268 | 21 | 0.637 | <0.0001* |
| Marbled cat | 8 | 0.1074 | 6 | 0.182 | 0.484 |
| Leopard cat | 59 | 0.7917 | 15 | 0.455 | 0.068 |
| Dhole | 33 | 0.4428 | 10 | 0.303 | 0.371 |
| Asiatic black bear | 8 | 0.1074 | 4 | 0.121 | 0.920 |
| Malayan sun bear | 31 | 0.4160 | 27 | 0.819 | 0.013 |
| Binturong | 5 | 0.0671 | 5 | 0.152 | 0.325 |
| Large Indian civet | 25 | 0.3355 | 0 | 0.000 | 0.002* |
| Small Indian civet | 11 | 0.1476 | 0 | 0.000 | 0.060 |
| Common palm civet | 39 | 0.5233 | 18 | 0.546 | 1.000 |

(continued)

Table 1.5. (Continued)

| Species | Core: No. of independent photos | Core: Rate | Outside: No. of independent photos | Outside: Rate | P-value |
|---|---|---|---|---|---|
| Large-spotted civet | 1 | 0.013 | 0 | 0.000 | 0.671 |
| Masked palm civet | 6 | 0.081 | 0 | 0.000 | 0.235 |
| Crab-eating mongoose | 44 | 0.590 | 5 | 0.152 | 0.003* |
| Yellow-throated marten | 22 | 0.295 | 9 | 0.273 | 1.000 |
| Hog badger | 0 | 0.000 | 2 | 0.061 | 0.174 |
| Banded linsang | 2 | 0.027 | 1 | 0.030 | 0.597 |
| Stump-tailed macaque | 31 | 0.416 | 59 | 1.789 | <0.0001* |
| Northern pig-tailed macaque | 33 | 0.443 | 1 | 0.030 | 0.001* |
| Rhesus macaque | 20 | 0.268 | 35 | 1.061 | <0.0001* |
| Capped-leaf monkey | 2 | 0.027 | 2 | 0.061 | 0.764 |
| Asian elephant | 10 | 0.134 | 0 | 0.000 | 0.078 |
| Gaur | 42 | 0.564 | 21 | 0.637 | 0.752 |
| Red serow | 1 | 0.013 | 11 | 0.334 | <0.0001* |
| Sambar | 119 | 1.597 | 93 | 2.820 | <0.0001* |
| Hog deer | 14 | 0.188 | 0 | 0.000 | 0.028 |

(continued)

Table 1.5. (Continued)

| Species | Core: No. of independent photos | Core: Rate | Outside: No. of independent photos | Outside: Rate | P-value |
|---|---|---|---|---|---|
| Barking deer | 371 | 4.979 | 175 | 5.306 | 0.498 |
| Wild boar | 73 | 0.980 | 31 | 0.940 | 0.920 |
| Chinese pangolin | 1 | 0.013 | 0 | 0.000 | 0.671 |
| Malayan porcupine | 122 | 1.637 | 26 | 0.788 | 0.001* |
| Asiatic brush-tailed porcupine | 45 | 0.604 | 16 | 0.485 | 0.538 |
| Edward's rat | 2 | 0.027 | 0 | 0.000 | 0.863 |
| Asian red-cheeked squirrel | 3 | 0.040 | 1 | 0.030 | 0.764 |

Table 1.6. Comparison of cumulative photo rates (no. of independent photos/100 trap nights) between the Core study area (n = 7,452 trap nights) and Outside the core area (n = 3,298) for bird species in the Hukaung Valley of northern Myanmar during 2001-2011. Significant differences (P<0.01) indicated with an asterisk.

| | Core | | Outside | | |
|---|---|---|---|---|---|
| Species | No. of independent photos | Rate | No. of independent photos | Rate | P-value |
| White-winged duck | 3 | 0.040 | 0 | 0.000 | 0.597 |
| Imperial heron | 1 | 0.013 | 0 | 0.000 | 0.671 |
| Black stork | 18 | 0.242 | 1 | 0.030 | 0.031 |
| Woolly-necked stork | 0 | 0.000 | 2 | 0.061 | 0.174 |
| Green imperial pigeon | 2 | 0.027 | 0 | 0.000 | 0.863 |
| Oriental pied hornbill | 2 | 0.027 | 0 | 0.000 | 0.863 |
| Greater coucal | 2 | 0.027 | 0 | 0.000 | 0.863 |
| Green peafowl | 4 | 0.054 | 0 | 0.000 | 0.431 |
| Grey peacock pheasant | 40 | 0.537 | 22 | 0.667 | 0.493 |
| Kalij pheasant | 38 | 0.510 | 19 | 0.576 | 0.764 |
| Red jungle fowl | 60 | 0.805 | 5 | 0.152 | <0.0001* |
| Rufous-throated partridge | 0 | 0.000 | 1 | 0.030 | 0.015 |

(continued)

Table 1.6. (Continued)

| | Core | | Outside | | |
|---|---|---|---|---|---|
| Species | No. of independent photos | Rate | No. of independent photos | Rate | P-value |
| Green magpie | 1 | 0.013 | 0 | 0.000 | 0.671 |
| Blue whistling thrush | 3 | 0.040 | 2 | 0.061 | 1.000 |
| Brown fish owl | 2 | 0.027 | 0 | 0.000 | 0.863 |
| Eastern marsh-harrier | 1 | 0.013 | 0 | 0.000 | 0.671 |

Table 1.7. Comparison of cumulative photo rates (no. of independent photos/100 trap nights) between the Core study area (n = 7,452 trap nights) and Outside the core area (n = 3,298) for domestic animal species and humans in the Hukaung Valley of northern Myanmar during 2001-2011. Significant differences (P<0.01) indicated with an asterisk.

| Species | Core: No. of independent photos | Core: Rate | Outside: No. of independent photos | Outside: Rate | P-value |
|---|---|---|---|---|---|
| Domestic buffalo | 26 | 0.349 | 0 | 0.000 | 0.001* |
| Domestic cattle | 15 | 0.201 | 0 | 0.000 | 0.0220 |
| Domestic pig | 1 | 0.013 | 0 | 0.000 | 0.6710 |
| Domestic dog | 1 | 0.013 | 0 | 0.000 | 0.6710 |
| Domestic chicken | 1 | 0.013 | 0 | 0.000 | 0.6710 |
| Poacher[a] | 135 | 1.812 | 14 | 0.424 | <0.0001* |
| Villager[b] | 357 | 4.791 | 38 | 1.152 | <0.0001* |
| Insurgent[c] | 0 | 0.000 | 19 | 0.576 | <0.0001* |
| Park Ranger[d] | 85 | 1.141 | 7 | 0.212 | <0.0001* |

[a] Person carrying hunting/fishing gear (e.g. gun snare, snare, spear, single-action rifle, shotgun, homemade gun, blanket or cloth for making a hide, fishing net, ring net, fishing rod, electrofishing equipment, poison, bow and arrow), or wild plants and/or parts of or whole animals.

[b] Person without hunting/fishing gear, or wild plants and/or parts of or whole animals, in the vicinity of villages and farmland.

[c] Person in non-state military uniform.

[d] Person in ranger uniform or otherwise known to be part of a management or research team.

Table 1.8.Wild large (≥1 kg) mammals which are believed to occur in northern Myanmar (U Tun Yin 1967a,b, Rabinowitz et.al 1999) but were not photographed from 2001-2011 in the Hukaung Valley Wildlife Sanctuary.

| Common Name | Scientific Name | Presumed distribution |
|---|---|---|
| Jungle cat | *Felis chaus* (Guldenstaedt) | Myanmar border in Kachin |
| Fishing cat | *Felis viverrina* (Bannet) | Myanmar |
| Asiatic jackal | *Canis aureus* (Linnaeus) | Myanmar and Assam, India |
| Indian wolf | *Canis lupus pallipes* (Sykes) | Northern Myanmar |
| Red fox | *Vulpes bengalensis* | Myitkyina, Kachin |
| Red panda | *Ailurus fulgens* (F. Cuvier) | Northern Myanmar |
| Slow loris | *Nycticebus coucang* (Boddaert) | Myanmar |
| Small-toothed palm civet | *Arctogalidia trivirgata* (Gray) | Myanmar border with Assam, India (Upper Chindwin R.) |
| Chinese ferret-badger | *Melogale moschata* (Gray) | Northern Myanmar, Naga Hills, Myitkyina |

(continued)

Table 1.8.(Continued)

| Common Name | Scientific Name | Presumed distribution |
| --- | --- | --- |
| Myanmar ferret-badger | *Melogale personata* (I. Groffrey) | Myanmar, Assam and Manipur (India) |
| Spotted lensang | *Priondon pardicolor* (Hoggson) | Northern Myanmar, Assam (India) |
| Common otter | *Lutra lutra* (Linnaeus) | Upper Myanmar, Myitkyina |
| Oriental small-clawed otter | *Aonyx cinerea* (Illiger) | Myanmar |
| Hoolock gibbon | *Hylobates hoolock* (Harlan) | Upper Myanmar |
| Phayre's leaf monkey | *Presbytis phayrei* (Blyth 1847) | As far north as Bhamo |
| Asemese macaque | *Macaca assamensis* (McClelland) | Northern Myanmar, Naga Hills |
| Great one-horned rhinoceros | *Rhinoceros unicornis* (Linnaeus 1766) | Bumpha Bum, Myitkyina |
| Sumatran rhinoceros | *Didermocerus sumatrensis* (Fischer) | Myanmar, Shwe-U-Daung Wildlife Sanctuary |
| Mythun | *Bos frontalis* (Lambert) | Naga hill, Kachin hills, Kachin |

North

(continued)

Table 1.8. (Continued)

| Common Name | Scientific Name | Presumed distribution |
|---|---|---|
| Banteng | *Bos banteng* (Wagner) | Kachin, Myanmar |
| Wild buffalo | *Bubalus bubalis* (Linnarus) | Assam, India; Bhamo and East Katha, Myanmar |
| Tufted deer | *Elaphodus cephalophus* (Milne-Edwards) | Northern Myanmar, Lisu |
| Musk deer | *Moschus moschiferus* (Linnaeus) | Northern Myanmar |
| Leaf deer | *Muntiacus putaoensis* | Northern Myanmar |
| Myanmar goral | *Nemorhaedus goral* (Milne-Edwards) | Myanmar Jinghpaw (Bum-ya) |

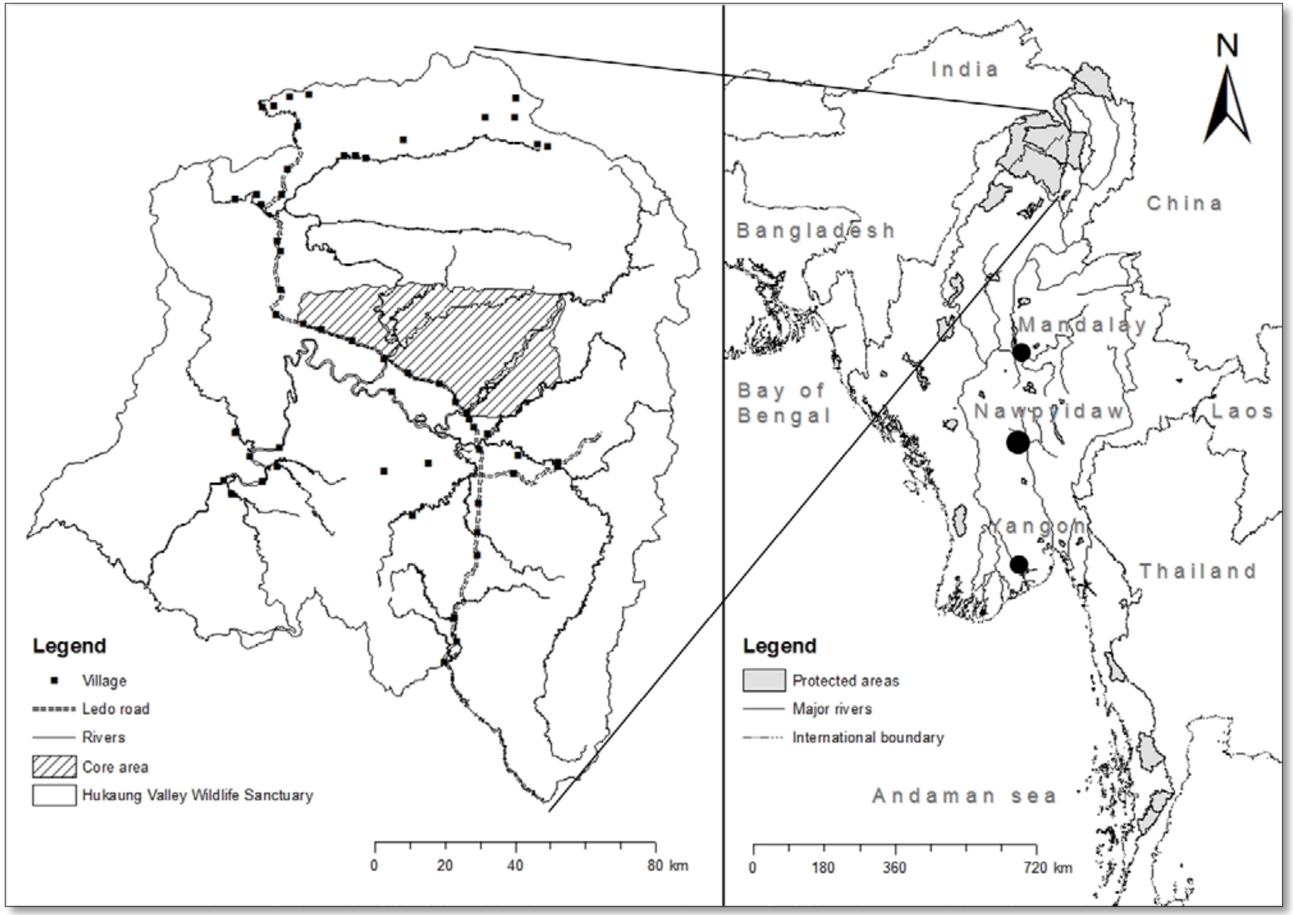



Figure 1.1 Location of Hukaung Valley Wildlife Sanctuary and Core study area (hatched) in Northern Myanmar.

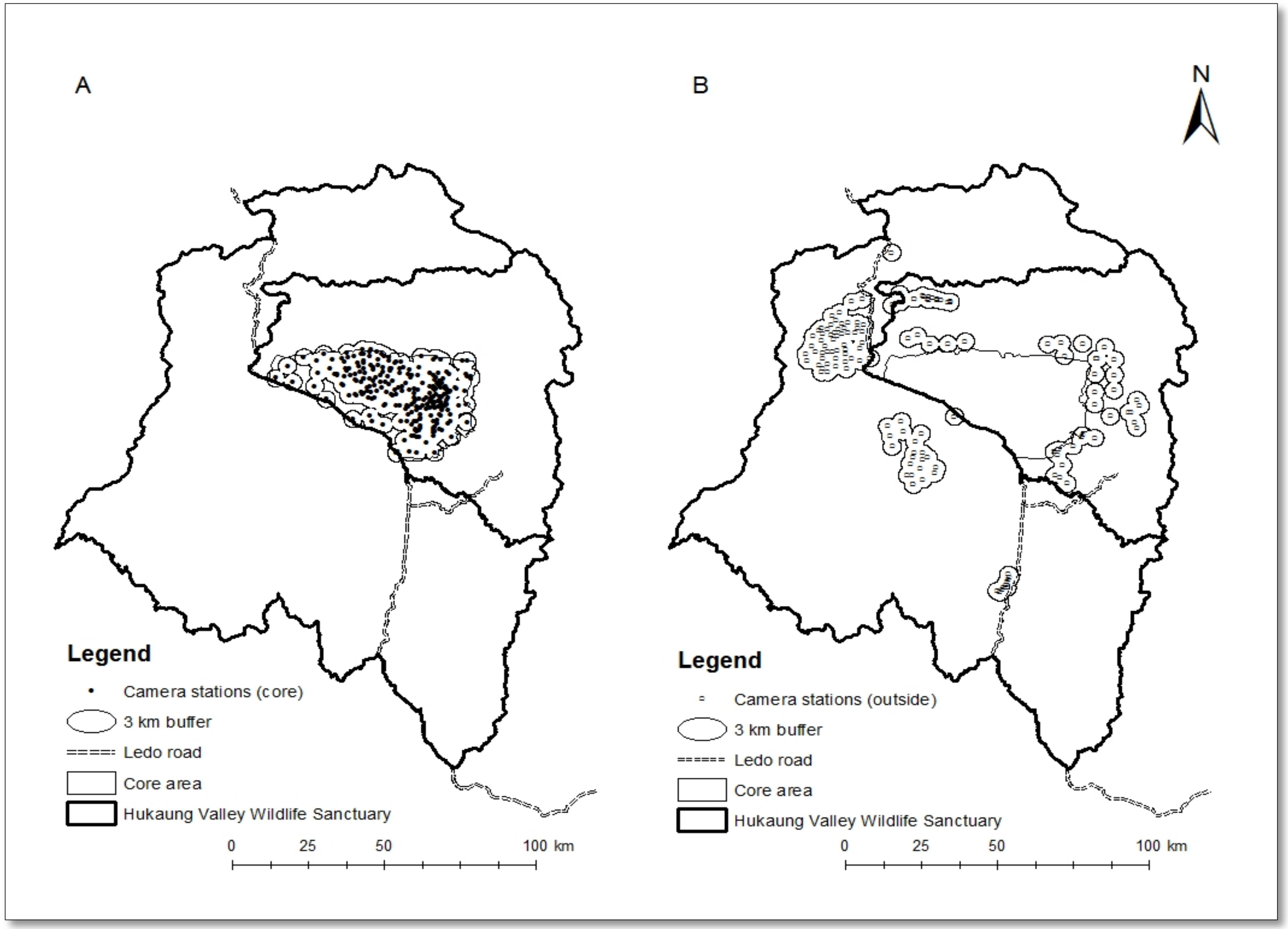
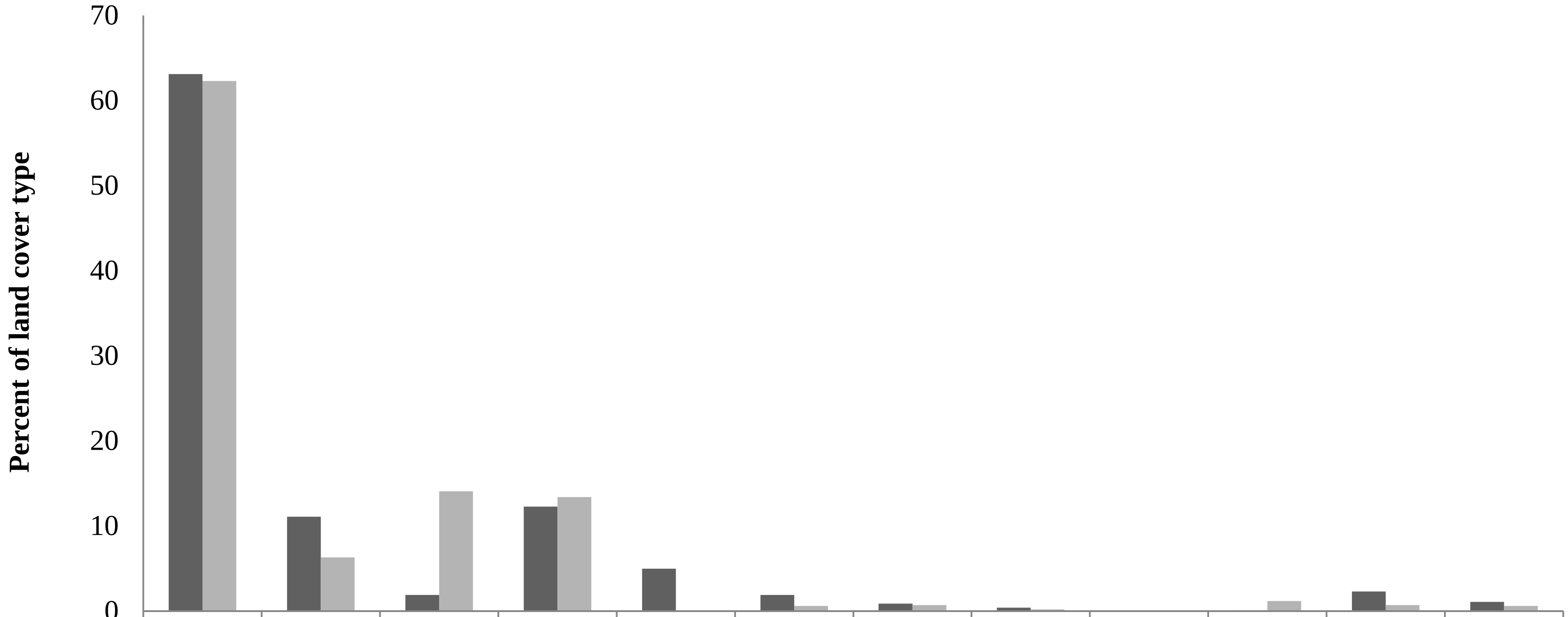



Figure 1.2. Camera stations, and the composite areas within 3 km of each station, in the Core study area (A) and Outside of the core area (B) in the Hukaung Valley Wildlife Sanctuary of Myanmar.




| | Evergreen close forest | Evergreen open forest | Hill forest | Bamboo | Rattan | Scrub land | Kaing Grass | Agriculture | Shifting cultivation | Rock | Stream bed | Water |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Core (%) | 63.1 | 11.1 | 1.9 | 12.3 | 5 | 1.9 | 0.9 | 0.4 | 0 | 0.1 | 2.3 | 1.1 |
| Outside (%) | 62.3 | 6.3 | 14.1 | 13.4 | 0 | 0.6 | 0.7 | 0.2 | 0.1 | 1.2 | 0.7 | 0.6 |

Figure 1.3 Percent of land covers type in the Core area (black) and at and near camera trap locations Outside of the core area (grey) in the Hukaung Valley Wildlife Sanctuary. [Note: This is an extraction from Landsat-7ETM+ image (2000) from UNEP.]

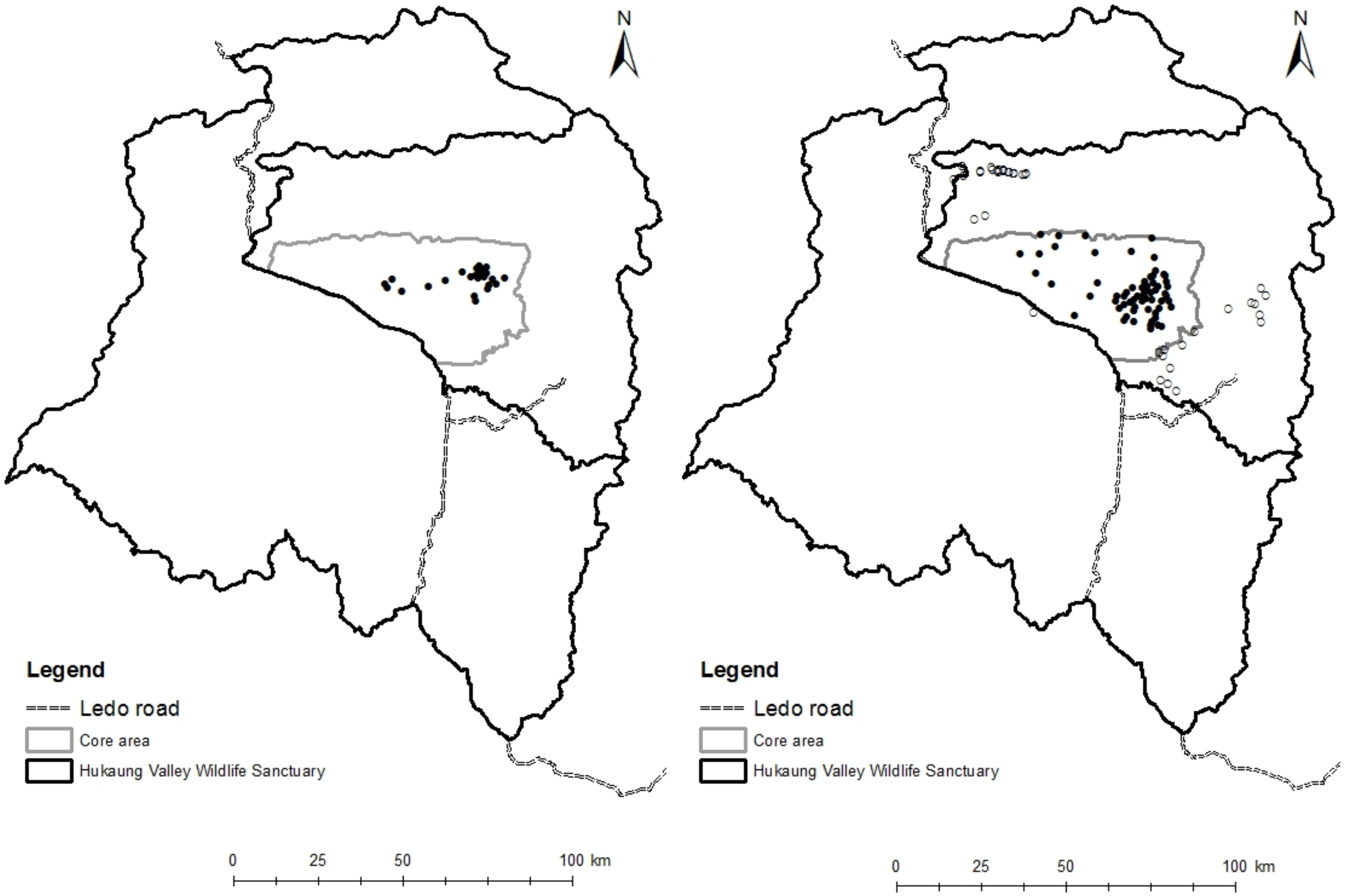



Figure 1.4. Locations of camera station in 2001-2002 (left) and 2002-2003 (right) in the Hukaung Valley Wildlife Sanctuary of Myanmar.

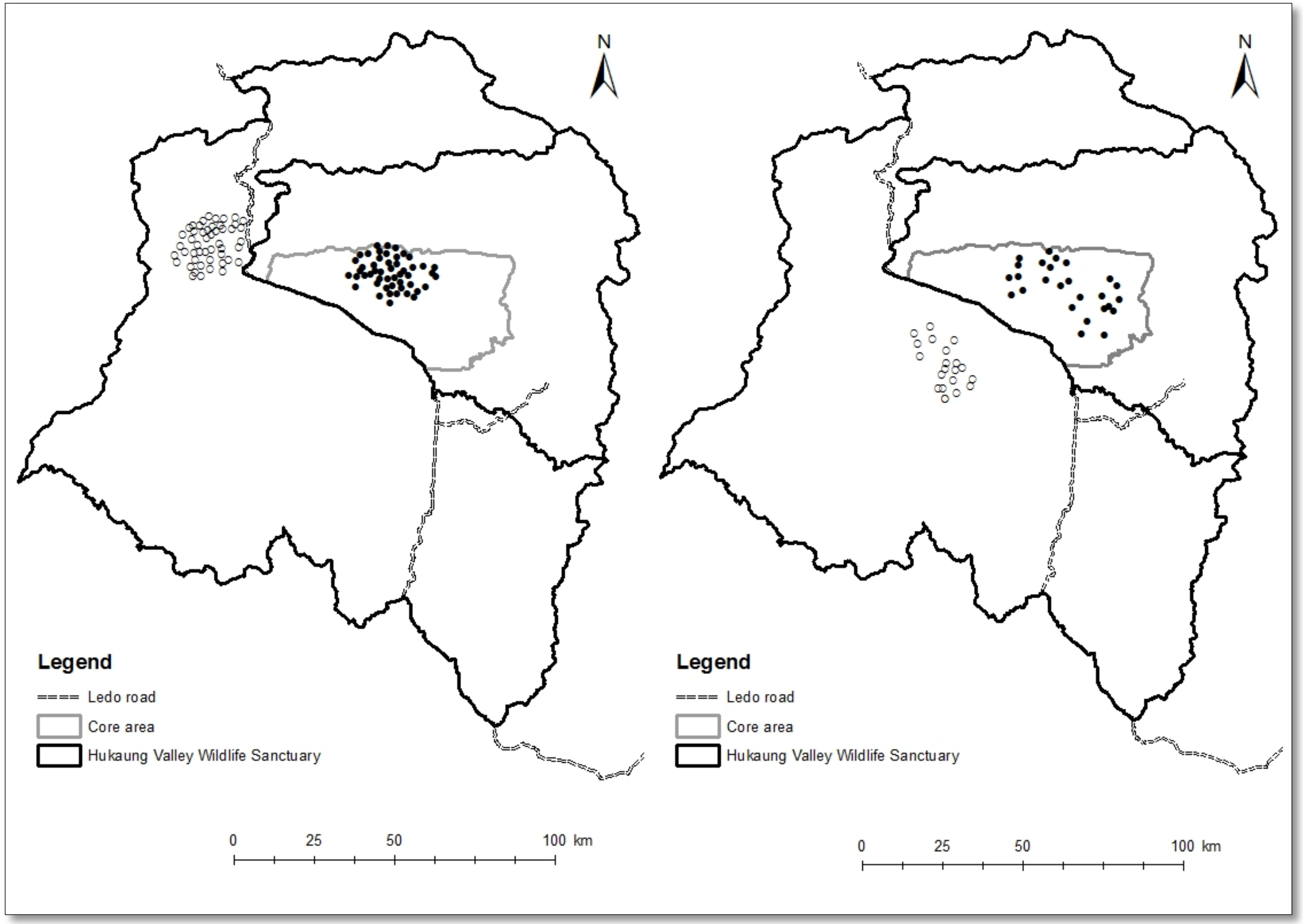



Figure 1.5. Locations of camera station in 2003-2004 (left) and 2004-2005 (right) in the Hukaung Valley Wildlife Sanctuary of Myanmar.

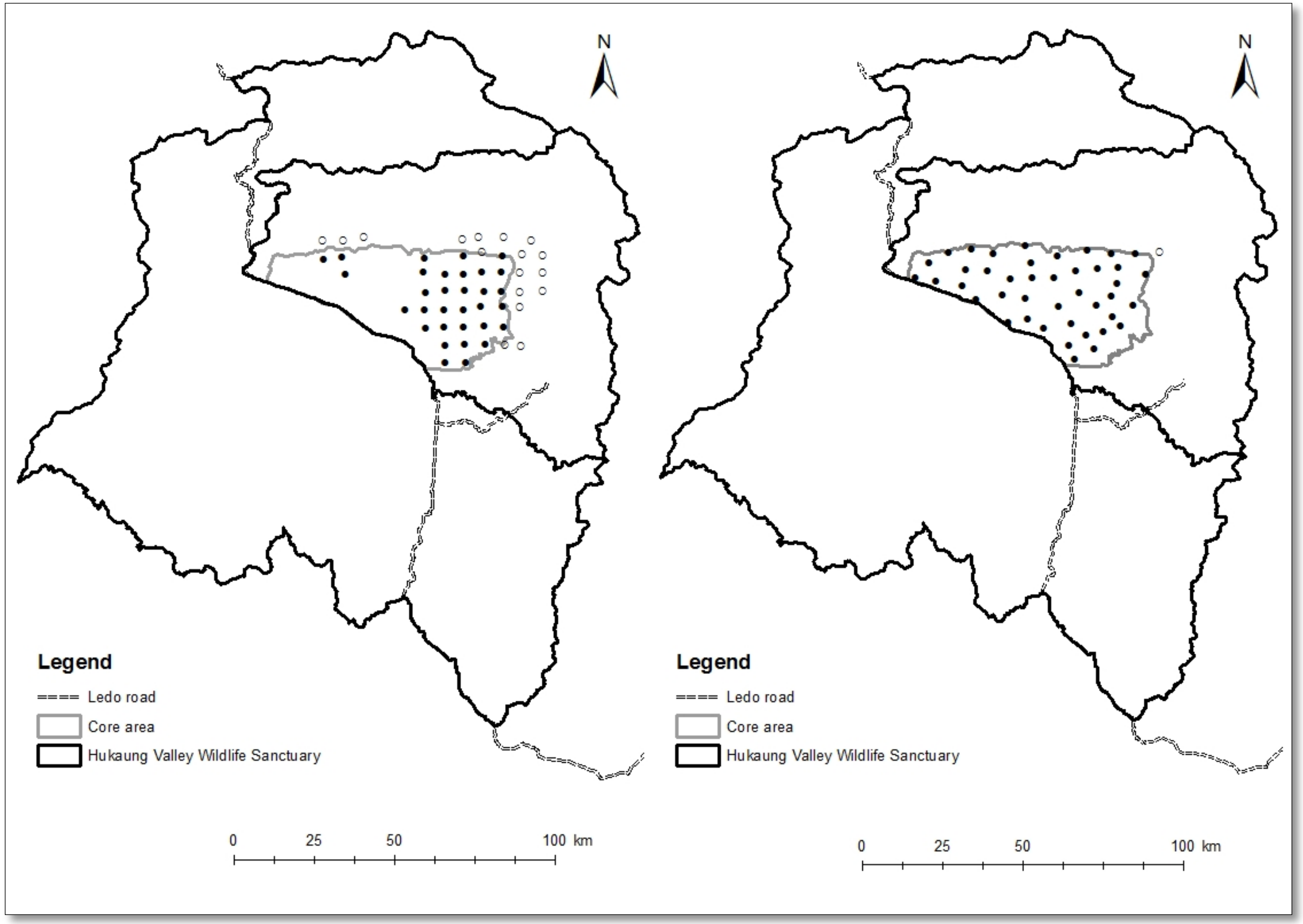



Figure 1.6. Locations of camera station in 2005-2006 (left) and 2006-2007 (right) in the Hukaung Valley Wildlife Sanctuary of Myanmar.

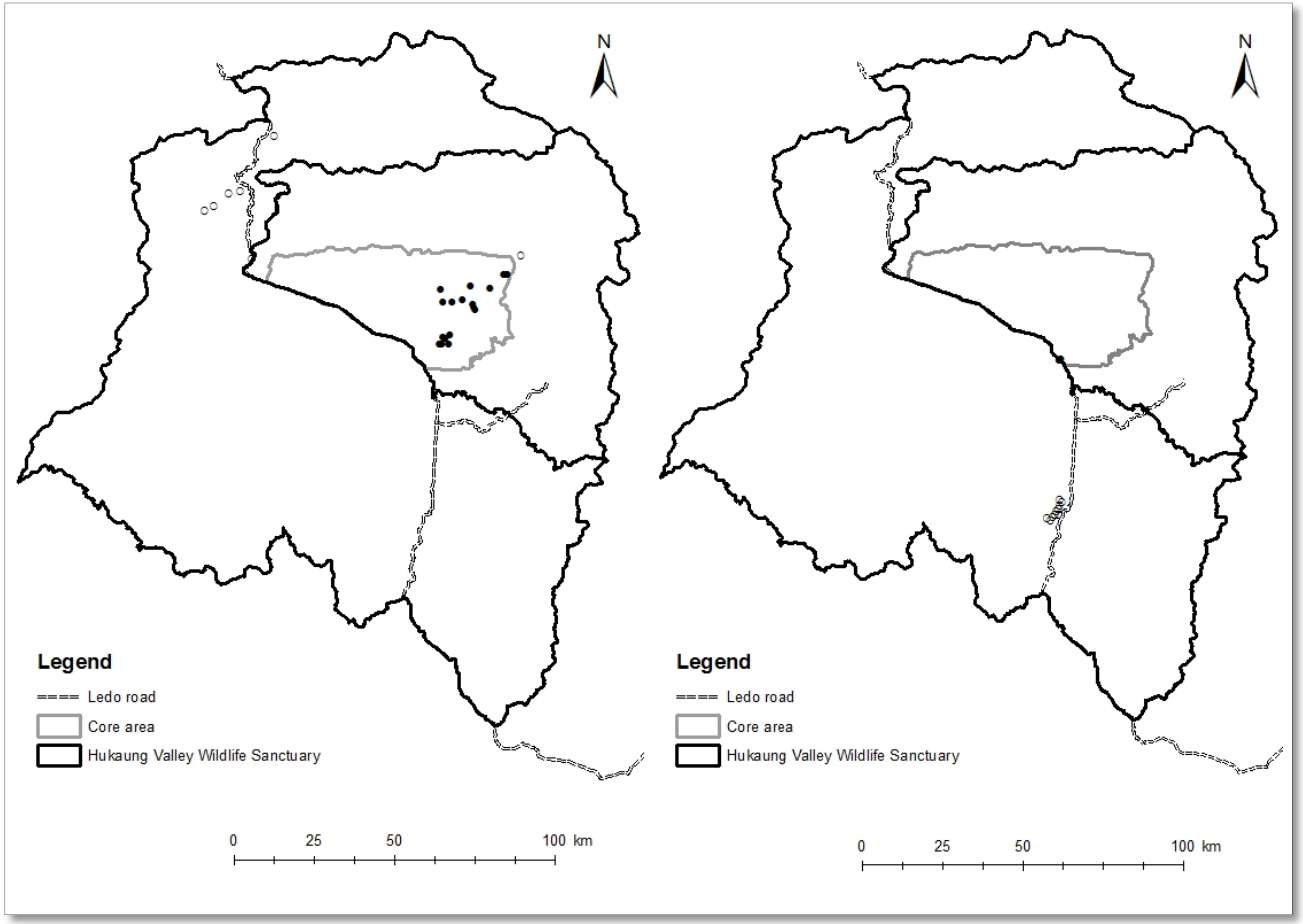



Figure 1.7. Locations of camera station in 2009-2010 (left) and 2010-2011 (right) in the Hukaung Valley Wildlife Sanctuary of Myanmar.

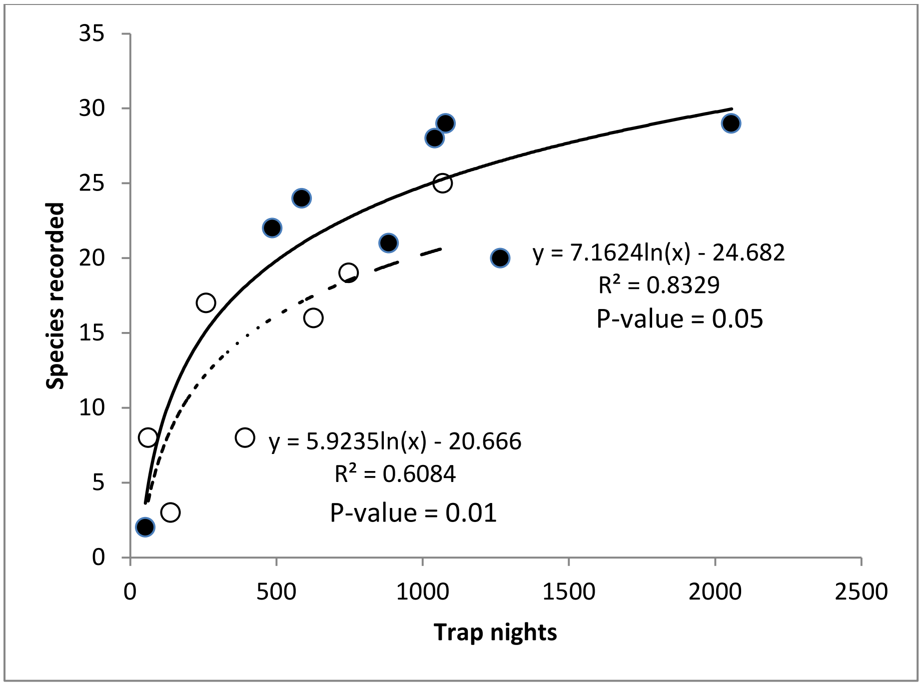



Figure 1.8. Trend lines, correlations and p-values for the relationship between number of camera trap nights per season per area (effort) versus number of species photographed (diversity) in the Core study area (solid line & solid circle) and at and near camera trap locations Outside the core area (dash line & hollow circle) in the Hukaung Valley, Myanmar.

# CHAPTER II

# HABITAT OCCUPANCY OF TIGER PREY IN THE HUKAUNG VALLEY OF NORTHERN MYANMAR

## Introduction

About 22% of 5,488 mammal species around the world are globally threatened or extinct in the wild due to habitat loss, utilization and invasive species, and about 15% of species have insufficient data to assess their conservation status (Vié, Hilton-Taylor and Stuart 2009). Tigers (*Panthera tigris* Linnaeus, 1758), for example, have debreased dramatically decreasing from 100,000 individuals in the last century to 3,200 individuals today. At the same time, tigers are also suffering a contraction of their historic range by the synergetic effects of habitat loss (about 93%; Dinerstein et al. 2006), prey depletion, and direct hunting (Karanth et al. 2004, Walston et al. 2010). Biologically, tigerscannot survive where they lack adequate prey, even though habitats seem well protected. Ungulate prey, the important determining factor of tiger population density (Karanth and Stith 1999), are also decreasing because of habitat loss and fragmentation by agricultural expansion, road construction and mining, and increased consumption due to human population growth.

There are many ways to assess population abundance, but many are difficult to employ. For example, mark-recapture methods are impractical to apply in some protected landscapes due to expense, time, and imperfect detection. Direct counting using line transect surveys (Buckland et al., 2001) is not always applicable due to low density of target species and because of habitat composition; in the Hukaung Valley of Myanmar, for example, dense vegetation like rattan and bamboo brakes, as well as other logistical constraints that limit visual sighting of species area problem. Therefore, useful methods are those that are reliable and cost effective in producing reliable data needed for effective conservation.  In some situations, indirect counting or sign surveys, along with occupancy modeling (Linkie et al., 2006; Hines et al., 2010; Karanth et al., 2011), would be a practical approach, particularly for large scale assessment.  In 2002, MacKenzie stated that no observation of species by surveyor in the surveyed site does not mean species is absent because the species may go undetected while conducting survey. The concept of MacKenzie et al. (2006) is fitted with the current situation. In this research, the distribution and proportion of habitat occupancy of principal prey species such as gaur *Bos gaurus* (C.H. Smith, 1827), sambar *Rusa unicolor* (Kerr, 1792), muntjac *Muntiacus muntjak* (Zimmermann, 1780) and wild pig *Sus scrofa* (Linnaeus, 1758) were studied in the Core study area of Hukaung Valley Wildlife Sanctuary (HKVWS) in northern Myanmar.

The main aim of the study is to assess habitat occupancy and distribution of principal tiger preys by considering natural and social governing factors for adaptive management plan of principal tiger preys.

**Study area**

The Hukaung Valley, surrounded by deep jungle and steep mountain ranges to the north, west, and east, contains Myanmar's largest expanse of tiger habitat, covering approximately 17,373 km² of semi-deciduous forest, open broadleaf deciduous forest, closed to open mixed broadleaved and needle-leaved forest, and Mosaic Forest-Scrubland/Grassland in the country's northernmost state (~25º23´–27º23´N and 95º33´–97º18´E). The site ranges in elevation from 94 to 3,440 m and contains the watershed for the upper Chindwin River which joins the mighty Irrawaddy River. The plains contain a mosaic of broadleaf forest and grassland, the hill slopes are covered with broadleaf forest, and the mountains consist of temperate broadleaf forest, coniferous forest, and shrub land (The GlobCover 2009 land cover map via *the* Economic and Social Research Institute – ESRI's ArcGIS online). The study area is in the humid subtropical climate zone, having a mean annual rainfall of approximately 2,340 mm, and mean annual minimum and maximum temperatures of 18.8 C$^{o}$ and 30.0C$^{o}$, respectively. Myanmar's climate is greatly influenced by monsoons which help define three distinct seasons. The summer season runs from mid-February to mid-May, the rainy season from mid-May to mid-October, and the winter season from mid-October to mid-February.

This study was conducted in the core area (~ 1,800 km$^2$) located in the middle HKVWS (Figure 1). There is no human settlement within this Core study area except the southern edge, the Ledo road built by the alliance during World War Two. It is the single major transportation route for the community. Local people also use foot paths along ridges and rivers, to commute their remote villages. There is no other manmade road except the Ledo. Waterways are the second major transportation option.

Historically, the local people in the Hukaung Valley were primarily Naga, Lisu, Kachin and Shan tribes. They are indigenous people who rely primarily on shifting cultivation, non-wood forest product collection, and subsistence hunting. In establishing the HKVWS, the government recognizes the existence of indigenous people and value the existing biological and cultural diversity, and to avoid undesirable issues for park management. In 2005, about half of the villages were introduced the Community-based

Natural Resource Management program. Compared to other protected areas in Myanmar, the local population growth in the HKVWS is relatively low.

**Methods**

An occupancy survey was carried out in the management-focused area of HKVWS in order to establish a robust biological monitoring system to inform Hukaung Valley management decision in tiger and prey conservation. In conducting survey, a modified cluster sampling design was used (Hines et al., 2010) and followed Tigers Forever protocols (Karanth et al., 2008, 2011). The Hukaung Valley landscape has divided into 92 large grid cells, and each has ~300 $km^2$ in size to insure that we would encompass the area of the largest home range of an adult male tiger. Among them, there are 6 large grid cells that fall in the core area (~ 1,800 $km^2$). Each grid cell includes 25 Small Grid Cells (~ 13 $km^2$), and then each of these was divided into four equal sub-grid cells (~3.25 $km^2$) (Figure 2). Within each sub-grid cell, there are altogether nine sampling destination points evenly spaced with 600 m apart. The guideline for the survey specified that each team has to pass through at least five destination points including the middle point. With this survey design, 300 m of survey line was used as a spatial replicate (Figure 3). Survey team recorded presence and absence data based on fresh tracks, pellets, and direct sightings of target species. However, in this study, only fresh footprints were used as presence-absence data in order for data consistency.

<u>Data Processing</u>

*Response variables:* During December 2007 and May 2008, presence-absence data (binary data) were collected using the occupancy survey method in the 1800-$km^2$ of HKV. Within the whole Core study area, a total of 554 out of 564 sub-grid cells (each with ten 300-m replicates) were searched, and tracks, pellets, and direct sightings were recorded. If species of interest is present, it is counted as '1'; if it is not present (absence), it is counted as '0' in every spatial replicate.

*Predictor variables*: Anthropogenic variables to be evaluated with respect to prey occurrence and detection probabilities include human disturbance frequency (see Table. 3), Euclidean distance to road, trail, ranger station, village etc.; and environmental characteristics such as elevation, slope, land cover types *(*Arino, *O* et al. *2012)*, mean monthly temperature, mean monthly precipitation (Hijmans et al. 2005), stream density and Euclidean distance to stream (Table 2.1).

Predictor data were obtained from various sources such as the National Forest Department and Wildlife Conservation Society Myanmar Program, GlobCover 2009 ESA (land cover classified as 22 types defined with the United Nations Land Cover Classification System, WorldClim (for mean monthly temperature and precipitation) and the Digital Elevation Model (SRTM90 data with 90 m resolution from USGS). Additional data from sign survey were also used. Data collected on anthropogenic and environmental factors were compiled as spatially explicit indices using ArcGIS 10.1 (ESRI, CA, USA).

Land cover types were extracted from the GlobCover 2009 via ArcGIS online using spatial analyst extension ArcGIS 10.1 (Zonal statistics as table). They were classified as 12 types in the core study area. I also calculated the exact proportion of each land cover types for each grid cell in order for the influence of each type on prey species occurrence (Figure 2.4.A and table 2.2).

The mean elevation and slope for each site were extracted from the Digital Elevation Model (SRTM90 data with 90 m resolution from USGS) using spatial analyst extension of ArcGIS 10.1 (Zonal statistics as table) (Figure 5. A and B).

Density of streams was calculated using field calculator in ArcMap in order to know the length of stream per square kilometer for each grid cell (Figure 6.A). Euclidean distance to the nearest stream is also calculated using using spatial analysis extension of ArcGIS 10.1 (zonal statistics as table) (Figure 2.6.B).

Euclidean distances of road (which is located in the southern edge of the Core study area) (Figure 2.7.A), trail (which is used by local tribes, wildlife and patrol rangers) (Figure 2.7.B) and village (which is located along the road) (Figure 2.8.A) were calculated from the mid points of site and spatial replicates in order to know their effects using spatial analysis extension of ArcGIS 10.1 (zonal statistics as table).

The location of current ranger stations was plotted and Euclidian distances plotted to estimate variation in potential effectiveness of protection (Figure 2.8.B). In each ranger station, there are altogether 6 to 10 patrol rangers, of which 3 to 6 rangers make regular patrols in their specified zone.

The mean monthly temperature (C°) and precipitation (cm) were extracted from WorldClim (Hijmans et al. 2005) because their variation is high from month to month using spatial analysis extension of ArcGIS 10.1 (zonal statistics as table) (Figure 2.9.A and B).

Exploring data, building statistical models, and making inferences

Exploratory data analysis were done using program R (R 2.15.2, 2013). During data screening, all variables were then standardized (z-scores standardization) to improve interpretation except categorical variables. Predictor variables were tested for collinearity using the Pearson (r) correlation coefficient.

Logistic regression were used to develop a single season occupancy model (McKenzie 2002) for prey occupancy and detection data from sign survey. Each species, i.e, gaur, sambar deer, barking deer and wild pig, was modeled using two logit functions: one for the probability distribution of occurrence (Ψ, 'psi'), and the other for the probability distribution of detection (p) contingent on occurrence. Program PRESENCE 6.2(Hines 2006) was used for occupancy data analysis.

In addition to standard data analyses of occurrence and detection, the following inferences were also made about populations of different species within the Core study area.

a) Correlation: The correlation between species occurrence and detection from sign surveys were determined.
b) 95% Confidence Interval: Estimates of certainty in tiger prey occurrence and detection were calculated.
c) Statistical model: From the potential candidate models, the highest ranked models were selected based on AIC.

Assumptions in a single season occupancy model

Assumptions in this occupancy survey (MacKenzie et al. 2002) are:

a) During the intensive small grid cell occupancy survey period, the site occupancy of species does not change, i.e., the site occupancy of targeted species during December 2007 and May 2008 is closed.

b) Detection probability is assumed to be constant unless the site covariates vary in the model.
c) Species observations at different sites are independent of each other and unbiased.
d) Throughout the survey season, we assume that the defined study area is closed. That is the occupancy of species in the site level has not been increased or decreased due to the affects of immigration and emigration, and colonization and extinction as well.
e) Detection in each sampling unit of the site is independent, and has no affect on the outcome of detection in the other sampling unit of the same site.
f) Response variables (species observation) are influenced by the predictor variables (i.e. environmental and anthropogenic characteristics).
g) Among predictor variables, there might be co-linear relationship like land cover and distance to stream.

Occupancy Data analysis

For occupancy data analysis, the program PRESENCE (Version 6.2) is used (Hines, 2006). First, the detection-non detection data of four species, environmental and social covariates were imported into the program PRESENCE (Version 6.2). I applied standard occupancy (single season) model (MacKenzie et al. 2002; Hines et al. 2010) which is based on two key parameters: 'site occupancy probability – Ψ (site level species occurrence probability)' and 'detection probability – p (spatial replicate level species detection probability of sites)'. I used Akaike Information Criteria (AIC) to compare and select models (Burnham & Anderson, 2002). The maximum likelihood estimates of the model parameters were derived (MacKenzie et al 2002, Hines 2006). The top candidate models were used to predict habitat occupancy of principal tiger preys: gaur, sambar, muntjac and wild pig.

In interpreting results from model selection table, it contains six columns: the 'Model' to see the name of the best model in seniority, the 'AIC' (The Akaike information criterion) for the simplest and the best fitting model (Burnham and Anderson 2004), the 'deltaAIC' for the difference between the best model/s and each other model (The best model should be ≤ 2 ∆AIC), the model likelihood to describe likelihood of the best model, the 'AIC wat' to explain the model probability and can be applied to weight decision , the 'no.Par.' to represent the number of parameters, and the last one, '-2 loglike' for a relative measure of how well the model fits the data.

The naïve occupancy estimate is calculated. It is the estimate of site occupancy which ignores detection of species, i.e., the portion of units where the species was detected at least one time. Next in the output are the design matrices that were used to fit the model to the data. Model has been fitted using the logistic link. Reading the values from "untransformed estimates of coefficients for covariates (Beta)" from the model output gives the output values, "Beta" estimates, which can be transformed to "true estimates" using the following formula.

$$Logit\ (\hat{\Psi}) = (\hat{\beta})$$

$$\hat{\Psi} = \frac{\square^{\beta}}{1 + \square^{\beta}}; p = \square^{\beta}/(1 + \square^{\beta})$$

Where $\hat{\Psi}$ 'psi'= site occupancy probability of species of interest, p = detection probability of species of interest, $e$ = mathematical constant, β = coefficient of covariates.

To calculate the odds ratio by taking the inverse-logarithm of the beta parameter, I used the following formula. As it is greater than '0', it can be interpreted that the probabilities of site occupancy and species detection are higher, for example, near ranger station than far places.

$$OR = \square^{\beta} \; or \; \mathrm{EXP}(\beta)$$

For example, β = 0.28 (Habitat D).  = EXP(0.28), OR = 1.33

In interpretation of 'Odds Ratio (OR)', it would be that the odds of occupancy at a site is 1.33 times larger for habitat D plot than the non-habitat D plot.

Where OR = Odds ratio, $e$ = mathematical constant, β = the corresponding 'beta' coefficient from covariate from the model output.

An approximate 95% confidence interval (95%CI) for odds ratio was also calculated using the following formula.

$$95\,\%\,\mathrm{CI} = (\mathrm{EXP}(\beta - 2 * \mathrm{SE}(\beta)), \mathrm{EXP}\,(\beta + 2 * \mathrm{SE}(\beta)))$$

Habitat occupancy of interest of species - The result from the individual site occupancy estimates ($\widehat{\Psi}$) of the top candidate model was the real parameter estimate or the relative suitability of the site given the model predictions; and it is used to create the habitat occupancy map of each species of interest through ArcGIS 10.1 software (ESRI, Redlands, CA).

**Results**

In total, 1650.9 km were walked and surveyed; and the detections of gaur, sambar, wild pig and muntjac were 878, 2086, 350 and 1953 repectively (total surveyed = 5503 spatial replicates * 300 m) (Table 2.4).

Based on the top candidate model result (Table 2.5 & 2.9), the potential covariates comprised in the best candidate model for gaur are distance to village, elevation, distance to trail, habitat H, habitat A and distance to stream in site occupancy probability, and distance to village in species detection probability. The naïve occupancy estimate is 0.5162 (Figure 2.10) and the best candidate model result shows that 76 % the core study area that could be occupied by gaur (SE=0.196) (Figure 2.14). Positively correlated factors on site occupancy are trail (OR = 0.92) and habitat A (OR = 12.55); on the other hand, village (Pearson's r = 0.79, OR = 1.09), elevation (OR = 0.51), habitat H (OR = 0.09) and stream (OR = 1.21) are negatively affected. Species detection is negatively affected by village (OR = 1.12) distance (Table 2.13 and 2.14).

The governing factors included in the best candidate model for sambar (Table 2.6 & 2.10) are distance to ranger station, distance to small trail, distance to stream, stream density, distance to road, elevation, precipitation in site occupancy, and, for detection, distance to small trail, distance to ranger station, distance to stream, mean monthly precipitation, elevation, distance to road, and distance to village. The naïve occupancy estimate is 0.7762 (Figure 2.11) and, according to the best candidate model, sambar could occupy 91% of the core study area (SE = 0.03) (Figure 2.15). Site occupancy was positively influenced by ranger station (Pearson's r = -0.66), trail (Pearson's r = -0.64), stream density (Pearson's r = 0.50). When it is close to stream, close to road, high elevation, high precipitation, there has been negatively affected (Table 2.13 and 2.14). For species detection probability, close to trail, near ranger station and proximity to road affect positively where as close to stream and village, high precipitation, and high elevation cause low detection rate of sambar.

The outstanding covariates that affect the distribution of wild pig (Table 2.7 & 2.11) are distance to ranger station, distance to small trail, distance to stream at the site occupancy and distance to ranger station, distance to road, distance to village, and distance to trail. The naïve occupancy estimate is 0.3195 (Figure 2.12) and, according to the best candidate model, wild pig could occupy more than half of the core study area, i.e. 57% (SE = 0.003) (Figure 2.16). The role of ranger station (Pearson's r = -0.67, OR = 0.97) and trail (Pearson's r = -0.70, OR = 0.90) are positively contributed to wild pig occupancy while stream (Pearson's r = 0.50, OR = 1.42) have negative impact on the species occurrence. And species detection rate is higher near the ranger stations (OR = 0.79), road (OR = 0.05) and trail (OR = 0.81), but it cannot be highly detected proximity to village (OR = 18.08) (Table 2.13 and 2.14).

The major influencing characteristics on muntjac (Table 2.8 & 2.12) are distance to small trail, distance to village, distance to ranger station, habitat D in site occupancy probability. The naïve occupancy estimate is 0.7996 (Figure 2.13) and the model result shows that muntjac could occupy 89% of the sore study area (SE=0.001) (Figure 2.17). The site occupancy probability is higher near ranger stations (Pearson's r = -0.58, OR = 0.90), close to trail (Pearson's r = -0.62, OR = 0.88) and in habitat D (OR = 1.33). Species habitat occupancy is higher in plots which is far from village (OR = 1.08). None of the external covariates impact on species detection, and muntjac might be generalist (Table 2.13 and 2.14).

Overall, tiger prey species occurrence was likely higher nearer ranger stations and trails, and farther from villages (Table 2.15). Occurrence of both wild pigs and sambar may have been lower near streams.

**Discussion**

Where poaching is not a limiting factor, prey biomass plays a critical role for tiger population viability (Karanth and Stith, 1999). Based on reviews of tiger food habits (Hayward et al. 2006a; Hayward et al. 2012), as many as 10 potential tiger prey species occur in the Hukaung Valley Wildlife Sanctuary. In this study, three of the four tiger prey species that are most likely important to tiger sustainability appeared to have relatively high occupancy rates (sambar >90%, muntjac almost 90%, gaur >75%), but wild pig occupancy (~50%) seemed low given that the reproductive rate of wild pigs is the highest of any ungulate (Taylor et al. 1998) and they seem quite common wherever they occur.

The factors that appear to most affect occupancy rates of these tiger prey species, distance to ranger stations and to trails, are not surprising (e.g., Jenks et al. 2012); areas nearest to ranger stations and to trails commonly used by rangers patrolling for poachers likely have increased survival value. Similarly, higher occupancy of some species in areas farther from villages and the main Ledo road suggest that proximity to humans, in general, has negative influences because of easier access for hunters and poachers (e.g., Kilgo et al. 1998). Non-anthropogenic habitat factors were not identified as primary factors affecting distribution, though occupancy seemed to increase farther from streams; perhaps streams were used a travel ways by poachers avoiding trails which are sometimes the only other ways to get through thick vegetation. Since almost of the core area was comprised of only 2 of the 12 cover types (Closed to open mixed forest - 79%; closed to open shrub land - 17%), vegetation-related variables in the models should likely be viewed with caution.

Tiger prey species appeared to occupy much of the study area and seem well distributed, especially in comparison (Table 2.15) with a very similar study in Lao PDR where occupancy rates were also high (Vongkhamheng et al. 2013). However, similar to my study area, tiger abundance was very low there, and it made me wonder if high prey occupancy was equivalent to high prey abundance. For comparative indices of prey abundance among areas with high and low tiger abundance, I examined data collected from camera-trap surveys in several areas with similar prey assemblages. In my area, I first compared photo data from an earlier period (2001-2004) when tiger population estimates were made (Lynam et al. 2008) to a later period (2005-2010) were almost no tiger photos were collected (see Chapter 1). I also tabulated data from an area in northern Myanmar where tigers had presumably been eliminated by hunting but where prey were still actively hunted (Rao et al. 2005), and with 2 adjacent areas in western Thailand where tiger abundance was quite high (Vinitporsawan 2013). The results suggest that prey abundances and tiger abundance were positively related, except where tigers were known to have been eliminated through hunting (Table 2.16). This also indicated that prey abundance in my study area was very low and likely unable to support very many tigers. In fact, during the previous 10 years it appeared that both tigers and their prey had diminished substantially in my area, perhaps because of increased poaching after 2004 that seemed to correspond with large increases in the human population related to increased mining and agricultural developments.

*Management recommendations and future research* - The management plan of Hukaung Valley Wildlife Sanctuary should be modified based on the result of the habitat occupancy and detection probabilities of the principal tiger prey species I studied. The positive key influencing factors on species occurrence should be considered when strengthening future monitoring programs. Ranger patrols should be increased (Jenks et al. 2012) even if the number of ranger stations cannot be increased in the short term. The negative drivers of prey occupancy should be taken into account in planning strategic patrol station expansion, which should be increased at least double in the core study area. For the long term, habitat management plans should be developed because there is no specific plan for habitat management in the areas as of yet. Based on the current baseline data related to biological and threat monitoring programs, a future research program should be promoted that includes a suitability analysis for new ranger stations, the interaction/conflict between livestock and wildlife (for example, wild pig and rain-fed cropland), the spatial quantity of domestic grazing, and human settlement and population growth in terms of both local people and itinerants in the Hukaung Valley. The role of world famous Ledo road should not be underestimated because it will probably be a critical East-West economic corridor for southern Asia, particularly between Myanmar's two giant neighbors, China and India.

In order to respond to probable impacts of climate change, a sustainable wildlife corridor and network system should be planned for. Fortunately, the Hukaung Valley Wildlife Sanctuary is well connected with other three wildlife sanctuaries and a national park under Northern Forest complex of Myanmar: Bum Hpabom Wildlife Sanctuary in the east, Hponganrazi Wildlife Sanctuary and Hkakaborazi National Park in the northeast. The last two are snow-capped mountain ranges linked to the Himalayan mountain ranges (Figure 2.1). In the lower part of Hukaung Valley is Htamanthi Wildlife Sanctuary, a tiger conservation protected area. Maintaining connectivity among these areas will assure a variety of habitats for wildlife into the future and, with adequate protection, may ensure viable tiger populations, as well.

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Table 2.1. Environmental and anthropogenic variables used in modeling prey distribution in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

| Variable name | Description [range of values] |
|---|---|
| Cover types (habA - habL) | 12 types (see Table 2.2) |
| Elevation (ele) | Mean altitude [203 - 554 m] |
| Slope (slp) | Mean slope [0° - 33$^o$] |
| Stream (stmD) | Stream density [0 - 3,600m/km$^2$] |
| Stream (stm) | Euclidean distance to nearest stream [0 - 3,500 m] |
| Trail (trl) | Euclidean distance to nearest trail [0 - 14,000 m] |
| Road (road) | Euclidean distance to nearest road [0 - 41,000 m] |
| Ranger station (rng) | Euclidean distance to nearest ranger station [0 - 21,000 m] |
| Village (vlg) | Euclidean distance to nearest village [0 - 42,000 m] |
| Temperature (tem) | Mean monthly temperature [14.7 - 26.1 C$^o$] |
| Precipitation (pres) | Mean monthly precipitation [16 - 243 cm] |

Table 2.2. Abundance of land cover types in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar. Habitat ID is the letter code used in modeling.

| Habitat ID | Land Cover Type | % Cover |
|---|---|---|
| A | Rain-fed croplands | 0.58 |
| B | Mosaic croplands/ vegetation | 0.22 |
| C | Mosaic vegetation/ croplands | 0.24 |
| D | Closed-open broadleaved evergreen or semi-deciduous forest | 78.91 |
| E | Closed broadleaved deciduous forest | 0.53 |
| F | Open broadleaved deciduous forest | 0.06 |
| G | Closed needle-leaved evergreen forest | 0.79 |
| H | Closed-open mixed broadleaved and needle-leaved forest | 1.14 |
| I | Mosaic forest-shrub/ grassland | 0.17 |
| J | Closed to open shrub land | 16.94 |
| K | Closed to open grassland | >0.01 |
| L | Water bodies | 0.43 |

Table 2.3. Number of sign-surveyed replicates (300m each), and number of detections of tiger prey species per land cover type in the Core study area of Hukaung Valley Wildlife Sanctuary in northern Myanmar.

| | | Land cover type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Species | A | B | C | D | E | F | G | H | I | J | L | Total |
| Replicates | | 40 | 18 | 19 | 4,311 | 22 | 2 | 34 | 73 | 17 | 945 | 22 | 5,503 |
| Detections | Gaur | 13 | 3 | 5 | 702 | 2 | 0 | 3 | 10 | 3 | 134 | 3 | 878 |
| | Sambar | 13 | 9 | 10 | 1,635 | 12 | 2 | 10 | 32 | 12 | 341 | 10 | 2,086 |
| | Wild pig | 2 | 1 | 4 | 269 | 2 | 2 | 0 | 6 | 1 | 60 | 3 | 350 |
| | Muntjac | 11 | 4 | 4 | 1,535 | 9 | 1 | 9 | 29 | 11 | 334 | 6 | 1,953 |

Table 2.4. The best candidate models for Gaur in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

| Model | AIC | ΔAIC | AIC weight | Model Likelihood | No. of parameters | - 2*Log Likelihood |
|---|---|---|---|---|---|---|
| Ψ (vlg+ele+trl+habH+habA+stm),p(vlg) | 4175.39 | 0 | 0.5893 | 1 | 9 | 4157.39 |
| Ψ (vlg+ele+trl+habH+habA+stm),p(vlg+stm) | 4175.89 | 0.50 | 0.3146 | 0.7788 | 10 | 4155.89 |
| Ψ (vlg+ele+trl+habH+habA+stm),p(.) | 4180.12 | 4.73 | 0.0379 | 0.0939 | 8 | 4164.12 |
| Ψ (vlg+ele+trl+habH+habA+stm),p(stm) | 4180.49 | 5.10 | 0.0315 | 0.0781 | 9 | 4162.49 |
| Ψ (vlg+ele+trl+habH+habA+stm+tht),p(.) | 4181.09 | 5.70 | 0.0234 | 0.0578 | 9 | 4163.09 |
| Ψ (vlg+ele+trl+habH+habA),p(.) | 4181.44 | 6.05 | 0.0196 | 0.0486 | 7 | 4167.44 |
| Ψ (vlg+ele+trl+habH+habA+stm+rng),p(.) | 4181.77 | 6.38 | 0.0166 | 0.0412 | 9 | 4163.77 |

Table 2.5. The best candidate models for Sambar in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

| Model | AIC | ΔAIC | AIC weight | Model Likelihood | No. of parameters | - 2*Log Likelihood |
|---|---|---|---|---|---|---|
| Ψ (rng+trl+stm+stmD+road+ele+pres), p(trl+rng+stm+pres+ele+road+vil) | 6196.08 | 0.00 | 0.9006 | 1.0000 | 16 | 6164.08 |
| Ψ (rng+trl+stm+stmD+road+ele+pres), p(trl+rng+stm+pres+ele+road) | 6201.24 | 5.16 | 0.0682 | 0.0758 | 15 | 6171.24 |
| Ψ (ranger+trail+stream+stmD+road+ele+pres), p(trl+rng+stm+pres+ele+road+tem) | 6202.81 | 6.73 | 0.0311 | 0.0346 | 16 | 6170.81 |
| Ψ (rng+trl+stm+stmD+road+ele+pres), p(trl+rng+stm+pres+ele) | 6227.90 | 31.82 | 0.0000 | 0.0000 | 14 | 6199.90 |
| Ψ (rng+trl+stm+stmD+road+ele+pres), p(trl+rng+stm+pres+ele+tem) | 6228.45 | 32.37 | 0.0000 | 0.0000 | 15 | 6198.45 |

Table 2.6. The best candidate models for Wild pig in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

| Model | AIC | ΔAIC | AIC weight | Model Likelihood | No. of parameters | - 2*Log Likelihood |
|---|---|---|---|---|---|---|
| Ψ(rng+trl+stm),p(rng+road+vlg+trl) | 2341.12 | 0 | 0.1342 | 1 | 9 | 2323.12 |
| Ψ(rng+trl+stm),p(rng+road+vlg+trl+stm) | 2341.49 | 0.37 | 0.1115 | 0.8311 | 10 | 2321.49 |
| Ψ(rng+trl+stm),p(rng+road+vlg+trl+pres) | 2342.11 | 0.99 | 0.0818 | 0.6096 | 10 | 2322.11 |
| Ψ(rng+trl+stm),p(rng+road+vlg+trl+tem) | 2342.17 | 1.05 | 0.0794 | 0.5916 | 10 | 2322.17 |
| Ψ(rng+trl+stm),p(rng+road+vlg) | 2342.63 | 1.51 | 0.0631 | 0.47 | 8 | 2326.63 |
| Ψ(rng+trl+stm),p(rng+road+vlg+trl+slp) | 2342.9 | 1.78 | 0.0551 | 0.4107 | 10 | 2322.9 |
| Ψ(rng+trl+stm),p(rng+road+vlg+pres) | 2343.04 | 1.92 | 0.0632 | 0.3829 | 9 | 2325.04 |
| Ψ(rng+trl+stm),p(rng+road+vlg+trl+ele) | 2343.12 | 2.00 | 0.0607 | 0.3679 | 10 | 2323.12 |

Table 2.7. The best candidate models for muntjac in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

| Model | AIC | ΔAIC | AIC weight | Model Likelihood | No. of parameters | - 2*Log Likelihood |
|---|---|---|---|---|---|---|
| Ψ (trl+vlg+rng+habD),p(.) | 6505.43 | 0 | 0.5715 | 1 | 6 | 6493.43 |
| Ψ (trl+vlg+rng+slp),p(.) | 6508.74 | 3.31 | 0.1092 | 0.1911 | 6 | 6496.74 |
| Ψ (trl+vlg+rng),p(.) | 6509.17 | 3.74 | 0.0881 | 0.1541 | 5 | 6499.17 |
| Ψ (trl+vlg+rng+tht),p(.) | 6509.28 | 3.85 | 0.0834 | 0.1459 | 6 | 6497.28 |
| Ψ (trl+vlg+rng+ele),p(.) | 6509.82 | 4.39 | 0.0636 | 0.1114 | 6 | 6497.82 |
| Ψ (trl+vlg+rng+stmd),p(.) | 6510.60 | 5.17 | 0.0431 | 0.0754 | 6 | 6498.60 |
| Ψ (trl+vlg+rng+stm),p(.) | 6510.71 | 5.28 | 0.0408 | 0.0714 | 6 | 6498.71 |

Table 2.8. Parameter estimates of coefficients of covariates for gaur from the best candidate model.

| Parameter (β) | Coefficient | Standard Error | OR | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|---|
| Intercept | -1.17 | 2.45 | 0.31 | 0.00 | 41.83 |
| psi.village | 0.09 | 0.01 | 1.09 | 1.07 | 1.12 |
| psi.elevation | -0.67 | 0.18 | 0.51 | 0.35 | 0.74 |
| psi.trail | -0.08 | 0.02 | 0.92 | 0.87 | 0.97 |
| psi.habitatH | -2.42 | 0.55 | 0.09 | 0.03 | 0.27 |
| psi.habitatA | 2.53 | 0.65 | 12.55 | 3.42 | 46.14 |
| psi.stream | 0.19 | 0.10 | 1.21 | 0.98 | 1.48 |
| p1 | -0.88 | 0.05 | 0.41 | 0.38 | 0.45 |
| p1.village | 0.11 | 0.04 | 1.12 | 1.03 | 1.22 |

Table 2.9. Parameter estimates of coefficients of covariates for sambar from the best candidate model.

| Parameter (β) | Coefficient | Standard Error | OR | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|---|
| Intercept | 2.30 | 0.42 | 10.00 | 4.30 | 23.24 |
| psi.ranger station | -0.07 | 0.02 | 0.93 | 0.90 | 0.97 |
| psi.trail | -0.06 | 0.03 | 0.95 | 0.89 | 1.01 |
| psi.stream | 0.14 | 0.18 | 1.15 | 0.81 | 1.64 |
| psi.stream density | 0.64 | 0.21 | 1.90 | 1.25 | 2.91 |
| psi.road | 0.05 | 0.01 | 1.05 | 1.02 | 1.08 |
| psi.elevation | -0.44 | 0.21 | 0.65 | 0.43 | 0.97 |
| psi.precipitation | -0.94 | 0.35 | 0.39 | 0.19 | 0.79 |
| p1 | 0.07 | 0.06 | 1.07 | 0.95 | 1.20 |
| p1.trail | -0.20 | 0.04 | 0.82 | 0.76 | 0.89 |
| p1.ranger station | -0.23 | 0.04 | 0.79 | 0.73 | 0.87 |
| p1.stream | 0.18 | 0.03 | 1.19 | 1.12 | 1.27 |
| p1.precipitation | -0.52 | 0.10 | 0.60 | 0.49 | 0.73 |
| p1.elevation | -0.30 | 0.05 | 0.74 | 0.67 | 0.82 |
| p1.road | -1.13 | 0.49 | 0.32 | 0.12 | 0.86 |
| p1.village | 1.41 | 0.50 | 4.09 | 1.51 | 11.05 |

Table 2.10. Parameter estimates of coefficients of covariates for wild pig from the best candidate model.

| Parameter (β) | Coefficient | Standard Error | OR | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|---|
| Intercept | 0.26 | 0.24 | 1.30 | 0.81 | 2.11 |
| psi.ranger station | -0.03 | 0.02 | 0.97 | 0.94 | 1.01 |
| psi.trail | -0.10 | 0.04 | 0.90 | 0.83 | 0.98 |
| psi.stream | 0.35 | 0.12 | 1.42 | 1.12 | 1.80 |
| p1 | -1.82 | 0.09 | 0.16 | 0.13 | 0.20 |
| p1.ranger station | -0.24 | 0.11 | 0.79 | 0.64 | 0.98 |
| p1.road | -3.09 | 1.38 | 0.05 | 0.00 | 0.71 |
| p1.village | 2.89 | 1.36 | 18.08 | 1.18 | 277.25 |
| p1.trail | -0.22 | 0.12 | 0.81 | 0.64 | 1.02 |

Table 2.11. Parameter estimates of coefficients of covariates for muntjac from the best candidate model.

| Parameter (β) | Coefficient | Standard Error | OR | 95% CI Lower | 95% CI Upper |
|---|---|---|---|---|---|
| Intercept | 2.06 | 0.32 | 7.88 | 4.16 | 14.93 |
| psi.trail | -0.13 | 0.03 | 0.88 | 0.83 | 0.93 |
| psi.village | 0.07 | 0.01 | 1.08 | 1.05 | 1.11 |
| psi.ranger station | -0.10 | 0.02 | 0.90 | 0.87 | 0.95 |
| psi.HabD | 0.28 | 0.12 | 1.33 | 1.05 | 1.68 |
| p1 | -0.23 | 0.03 | 0.79 | 0.75 | 0.84 |

Table 2.12. Naïve occupancy estimate, site occupancy with standard error within bracket, positively and negatively correlated influencing factors on site occupancy and species detection of gaur, sambar, wild pig and muntjac in the core study area of Hukaung Valley Wildlife Sanctuary of northern Myanmar by using standard occupancy (single season) model (MacKenzie et al. 2002; Hines et al. 2010).

| Species | Naïve estimate | Occupancy (SE) | Covariate effects indicated: Occupancy (Ψ) | Covariate effects indicated: Detection (p) |
|---|---|---|---|---|
| Gaur | 0.5162 | 0.76 (0.196) | village (+), elevation (-), trail (-), HabH (-), HabA (+), stream (+) | village (+) |
| Sambar | 0.7762 | 0.91 (0.03) | ranger (-), trail (-), stream (+), stream density (+), road (+), elevation (-), precipitation (-) | trail (-), ranger (-), stream (+), precipitation (-), elevation (-), road (-), village (+) |
| Wild pig | 0.3195 | 0.57 (0.003) | ranger (-), trail (-), stream (+) | ranger (-), road (-), Village (+), trail (-) |
| Muntjac | 0.7996 | 0.89 (0.001) | trail (-), village (+), ranger (-), HabD (+) | p (.) |

Table 2.13. Pearson's r correlation between species of interest and covariates in the core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

| Correlation | Gaur | Sambar | Wild pig | Muntjac | Elevation | Habitat A | Habitat B | Habitat D | Stream density | Road |
|---|---|---|---|---|---|---|---|---|---|---|
| Muntjac | 0.63 | 0.75 | 0.54 | | | | | | | |
| Habitat B | | | | | | 0.61 | | | | |
| Habitat C | | | | | | 0.55 | 0.62 | | | |
| Habitat J | | | | | | | | -0.89 | | |
| Stream density | | 0.50 | | | | | | | | |
| Stream distance | | | 0.50 | | | | | | -0.70 | |
| Trail distance | | -0.64 | -0.70 | -0.62 | | | | | | |
| Ranger distance | | -0.66 | -0.67 | -0.58 | | | | | | |
| Road distance | 0.80 | | | | 0.81 | | | | | |
| Village distance | 0.79 | | | | 0.82 | | | | | 0.98 |

Table 2.14. Summary of variable effects on modeling tiger prey distribution in the Core area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar. Asterisk (*) indicates top ranked variable in the best model for the species.

| Variable | Sambar | Wild pig | Muntjac | Gaur |
|---|---|---|---|---|
| Distance to ranger station | (-)* | (-)* | (-) | |
| Distance to trail | (-) | (-) | (-)* | (-) |
| Distance to village | | | (+) | (+)* |
| Distance to stream | (+) | (+) | | (+) |
| Stream density | (+) | | | |
| Distance to road | (+) | | | |
| Elevation | (-) | | | (-) |
| Precipitation | (-) | | | |
| Closed-open mixed broadleaved | | | (+) | |
| Semi deciduous forest | | | | (-) |
| Rain-fed cropland | | | | (+) |

Table 2.15. A comparison of modeled probability of site occupancy of tiger prey species from sign surveys.

| Species | This study (2001-2010) (Myanmar) | Vongkhamheng et al. (2013) (Lao) |
|---|---|---|
| Muntjac | 0.89 | 0.98 |
| Wild pig | 0.57 | 0.93 |
| Sambar | 0.91 | 0.64 |
| Gaur | 0.76 | 0.07 |
| Serow (*Capricornis milneedwardsii*) | ns[a] | 0.43 |

[a] Serow occur rarely in the area (see Chapter 1) and were not surveyed.

Table 2.16. A comparison of photographic rate (photos per 100 trap nights) of tiger prey species from camera trap surveys in tiger range.

| | This study (Myanmar) | | Rao et al. (2005) HKBZ, Myanmar | Vinitpornsawan (2013) TYNE, Thailand | HKK, Thailand |
|---|---|---|---|---|---|
| Species | (2001-04) | (2005-10) | (2002-2003) | (2010-12) | (2010) |
| Tiger | 0.5 | <0.1 | --- | 1.5 | 3.4 |
| Muntjac | 6.7 | 3.7 | 18.1 | 22.7 | 13.2 |
| Wild pig | 1.3 | 1.0 | 10.7 | 3.5 | 7.3 |
| Sambar | 2.6 | 0.5 | --- | 10.0 | 9.8 |
| Gaur | 0.3 | 0.5 | --- | 1.2 | 1.8 |
| Serow [a] | <0.1 | 0 | 5.1 | 0.2 | --- |

[a] *Capricornis milneedwardsii*

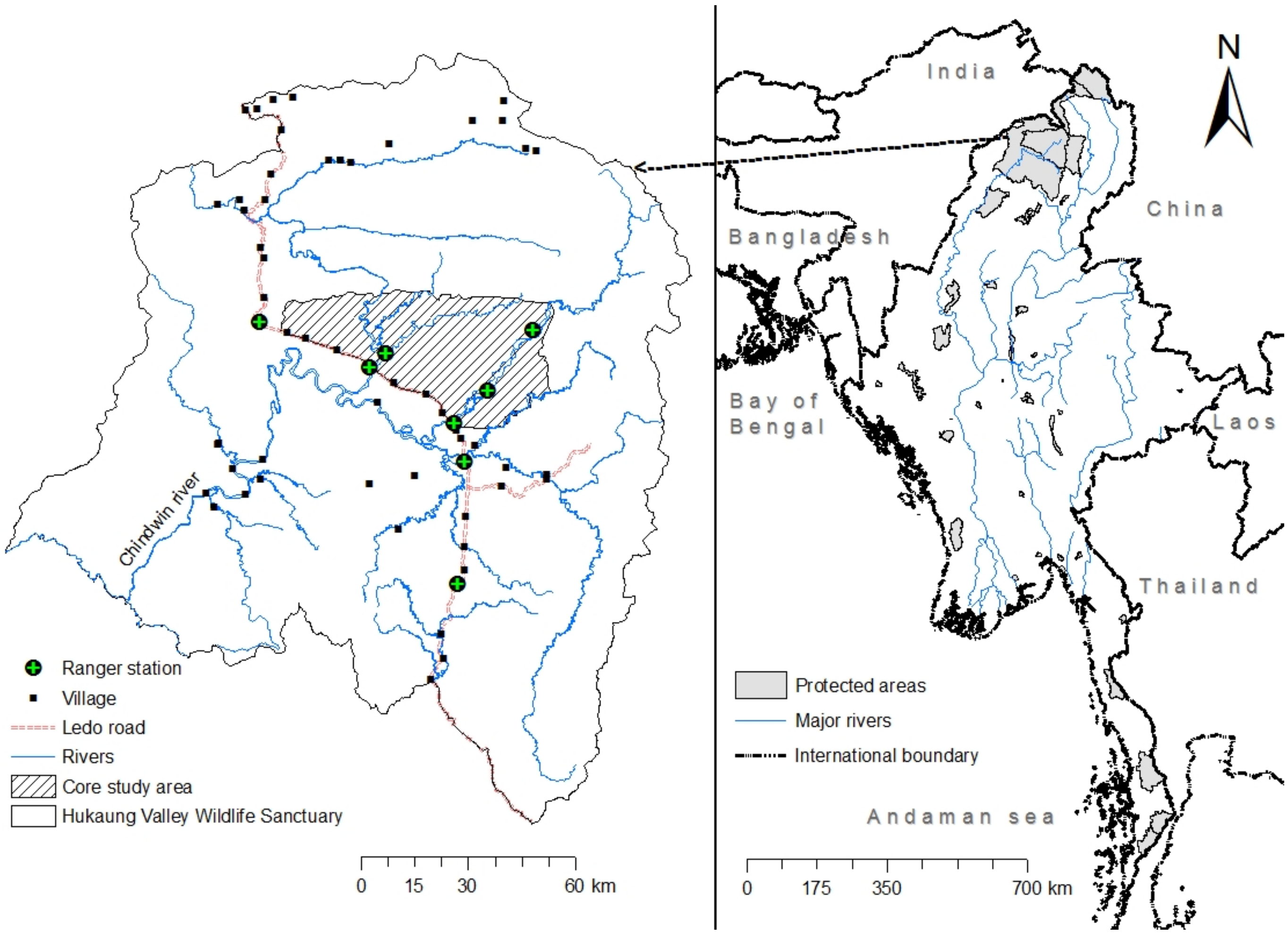


Figure 2.1. Location of Hukaung Valley Wildlife Sanctuary and Core study area (hatched) in Northern Myanmar.

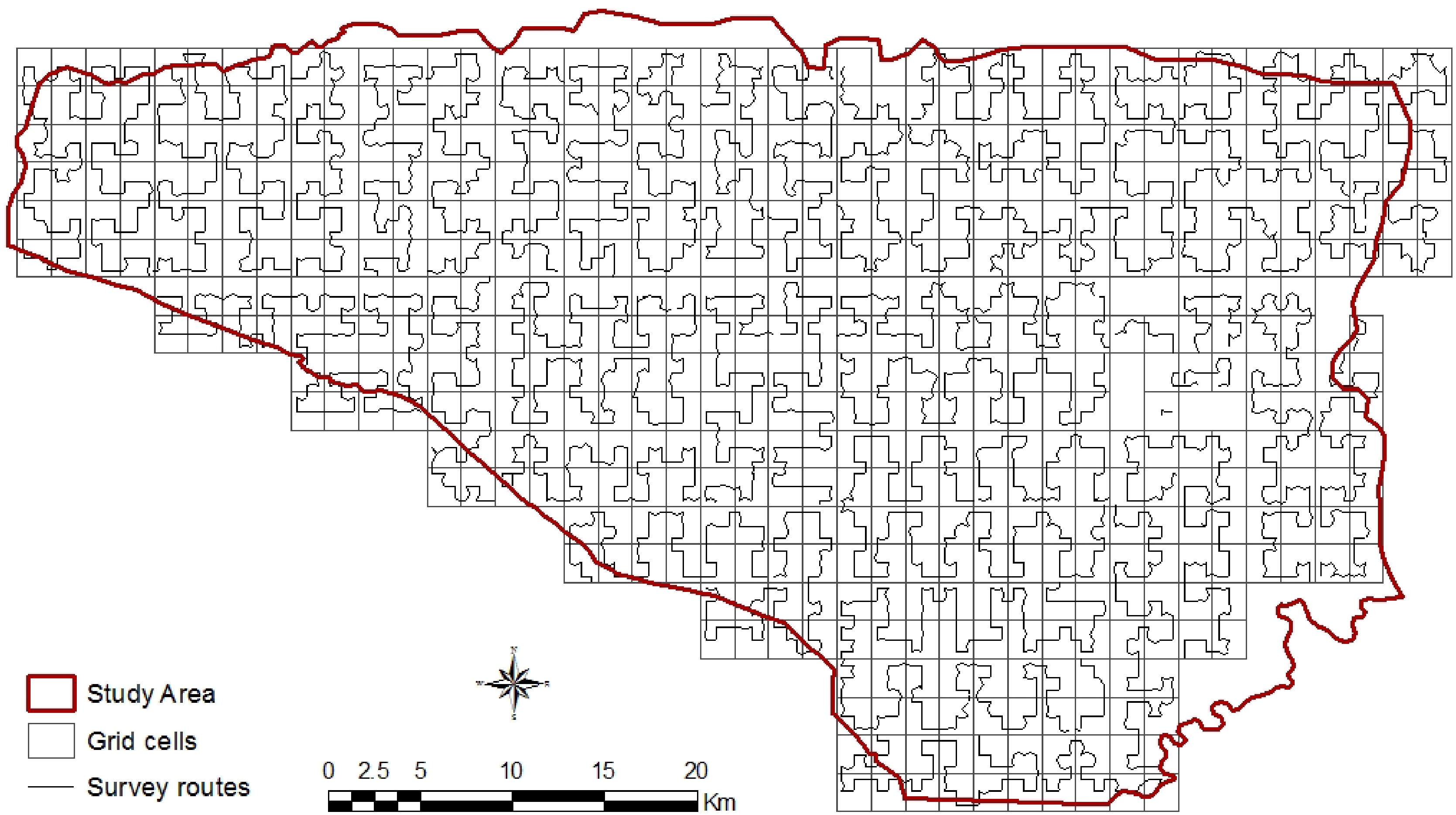


Figure 2.2. Survey routes of the occupancy survey conducted during December 2007 – May 2008 in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

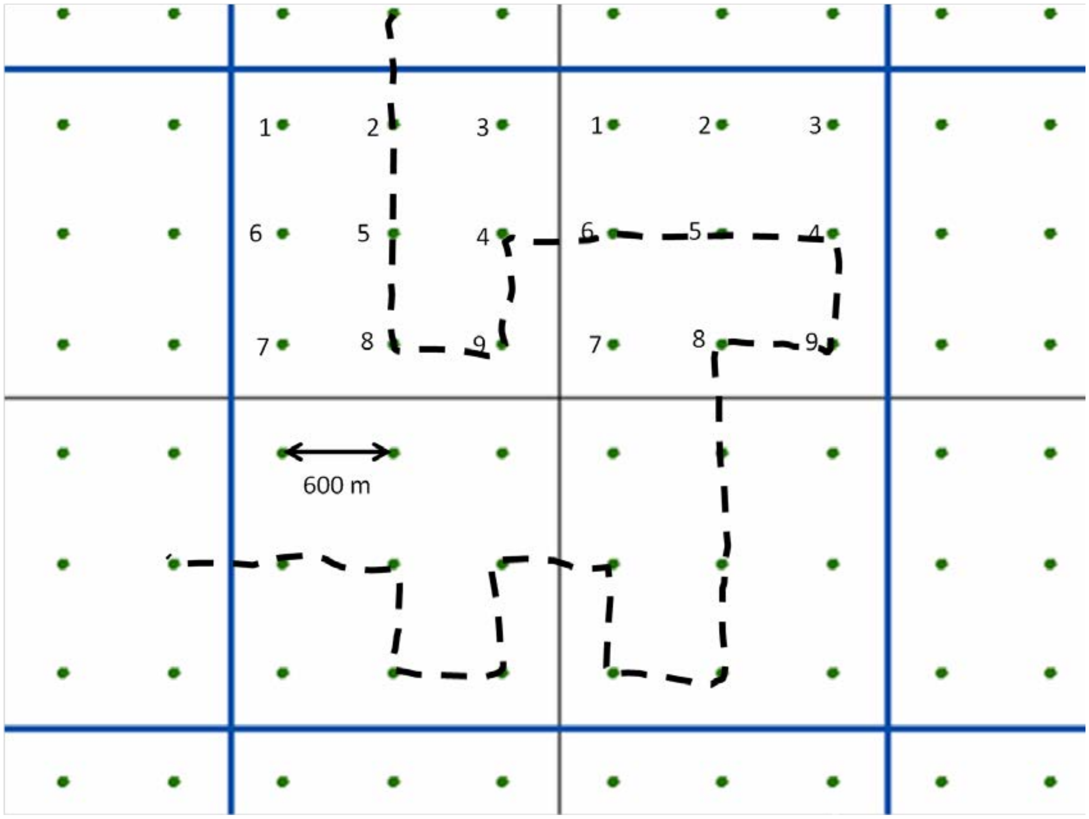


Figure 2.3. A sample survey route through 4 ~3.25 km² sub-grid cells (comprising 1 grid cell) searched for tiger prey species.

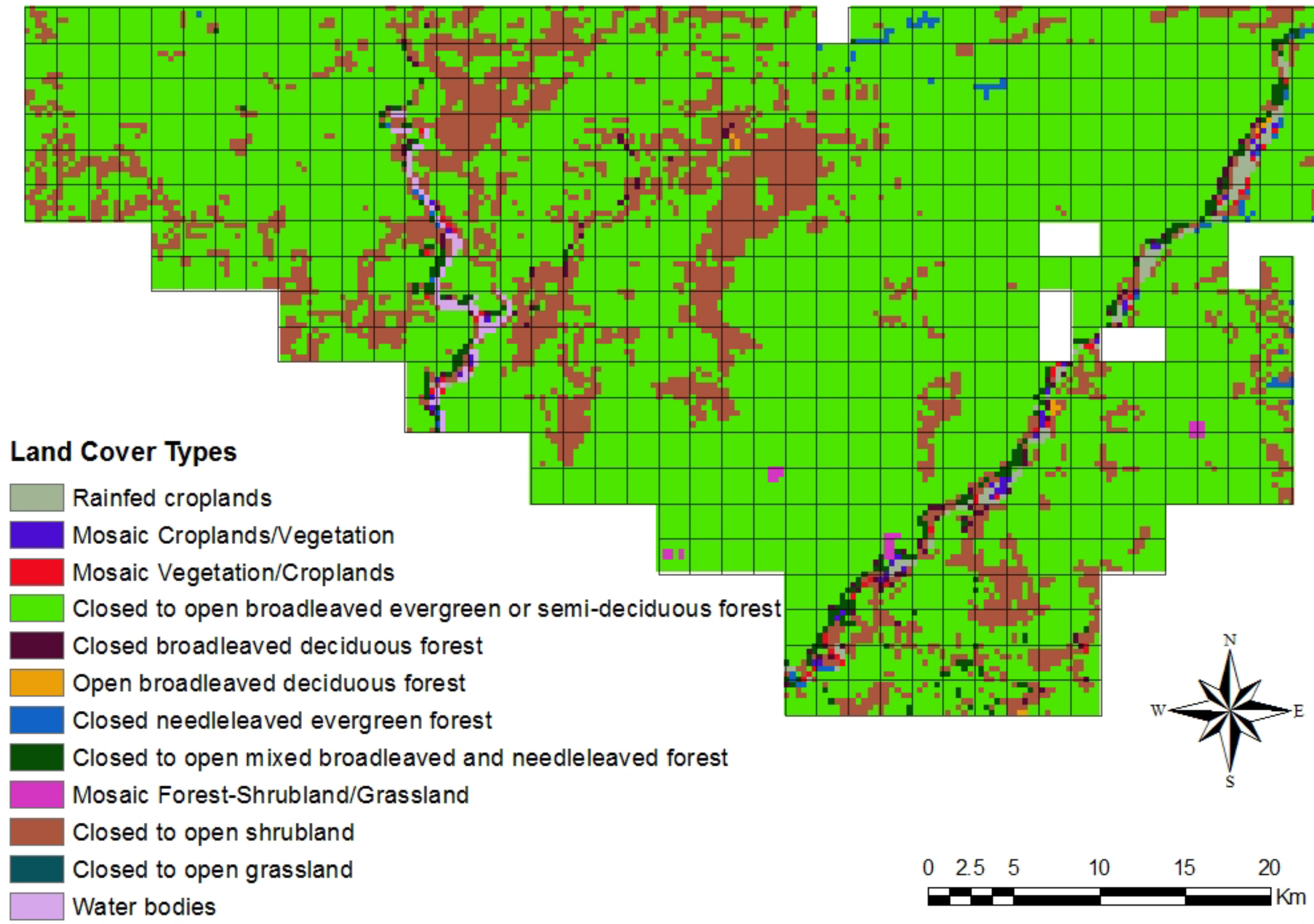


Figure 2.4. Distribution of land cover types (see Table 2.1) and used as a variable in modeling tiger prey distribution in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

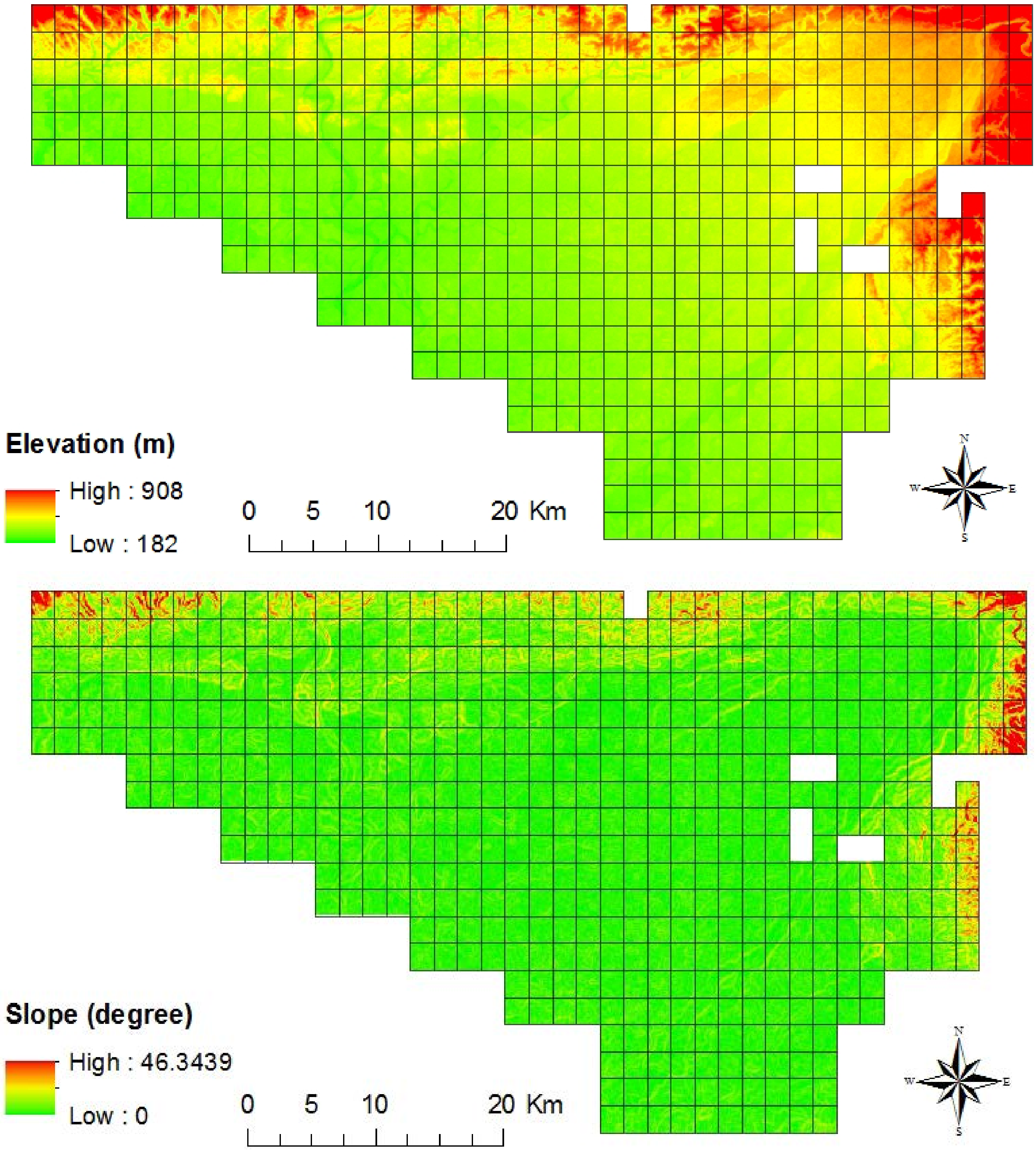


Figure 2.5. Distribution of elevation (top) and slopes (bottom) used as variables in modeling tiger prey distribution in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

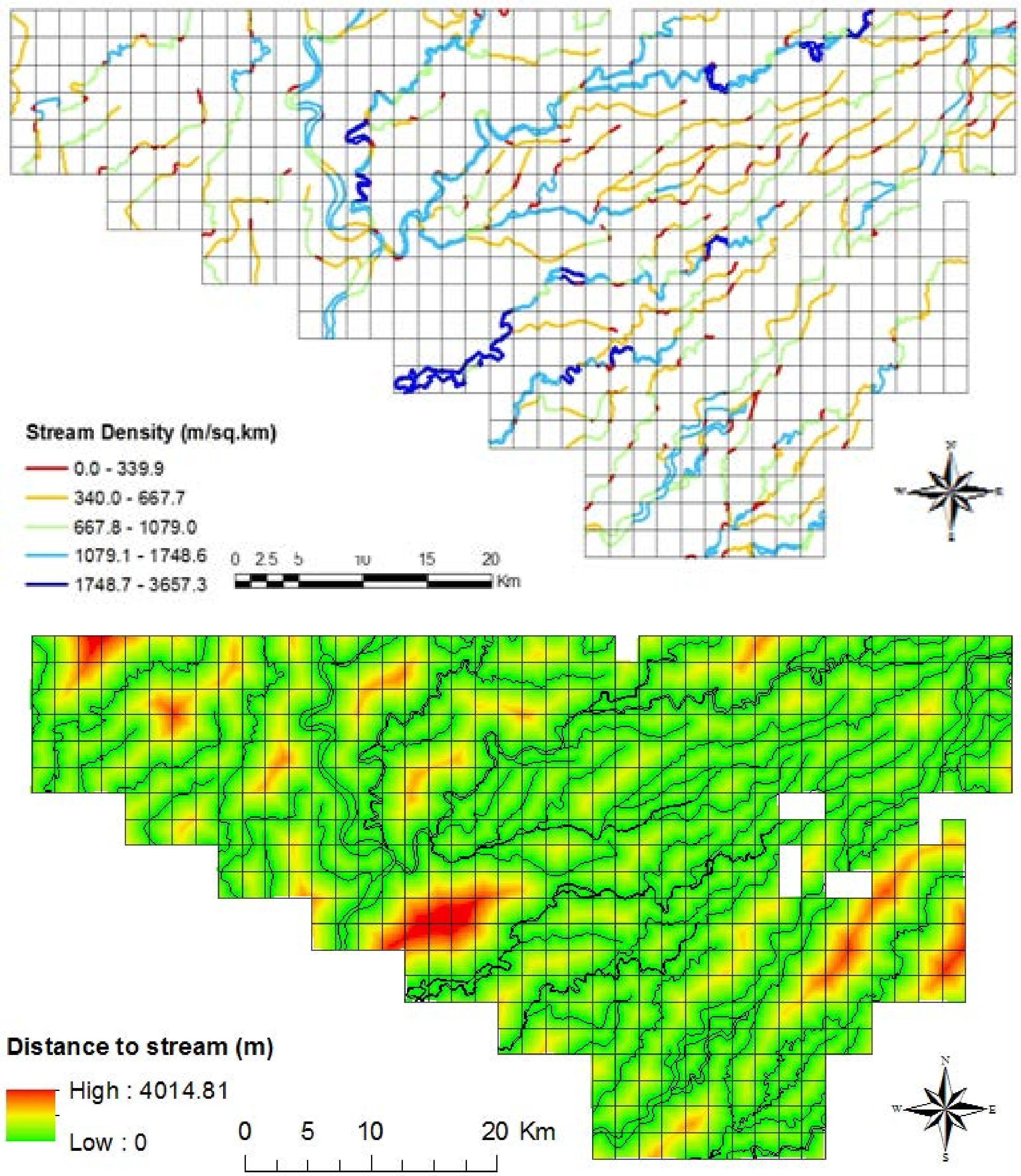


Figure 2.6. Distribution of stream density (top) and Euclidean distance to the nearest stream (bottom) used as variables in modeling tiger prey distribution in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

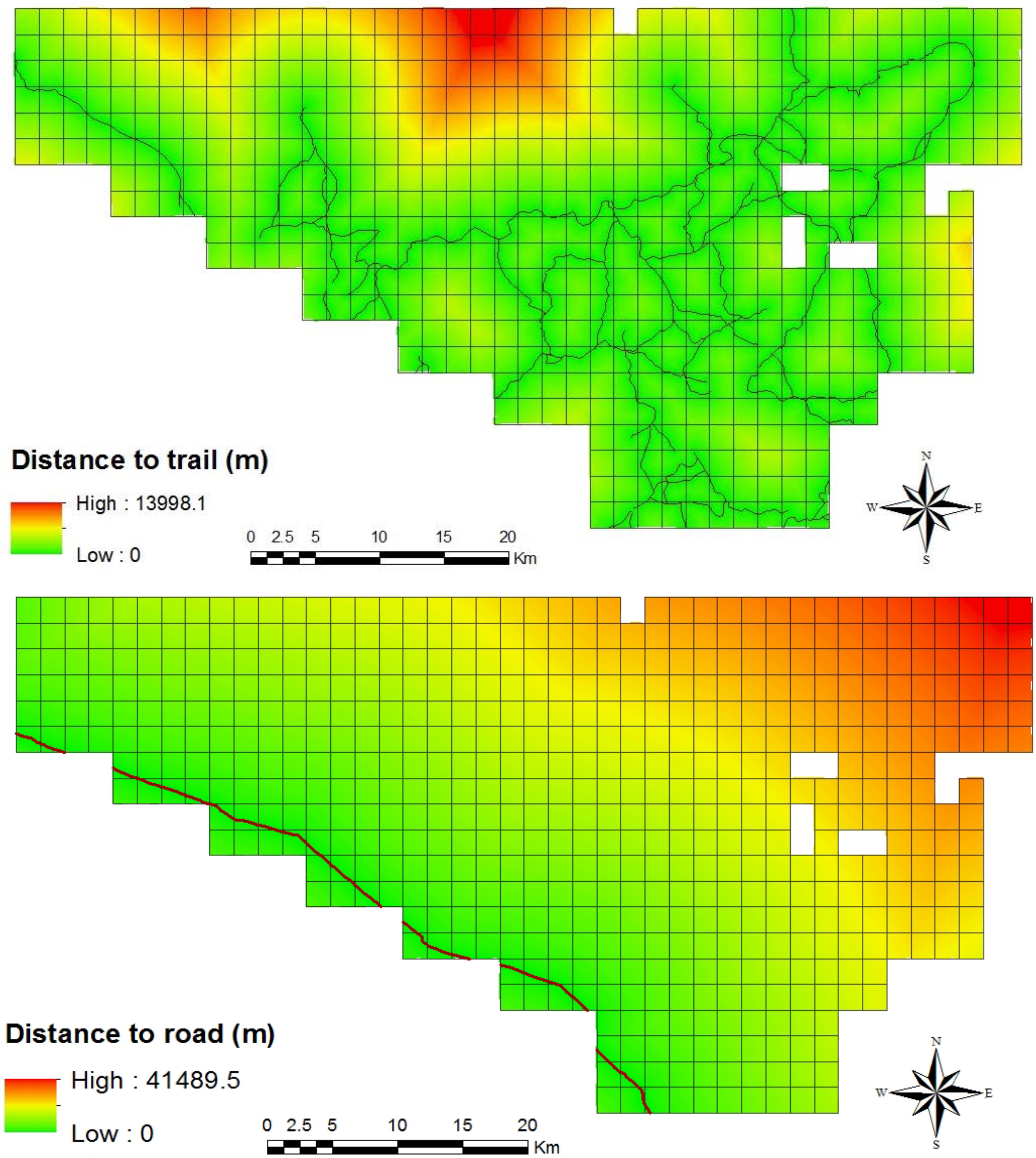


Figure 2.7. Distribution of Euclidean distances to nearest trail (top) and road (bottom) used as variables in modeling tiger prey distribution in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

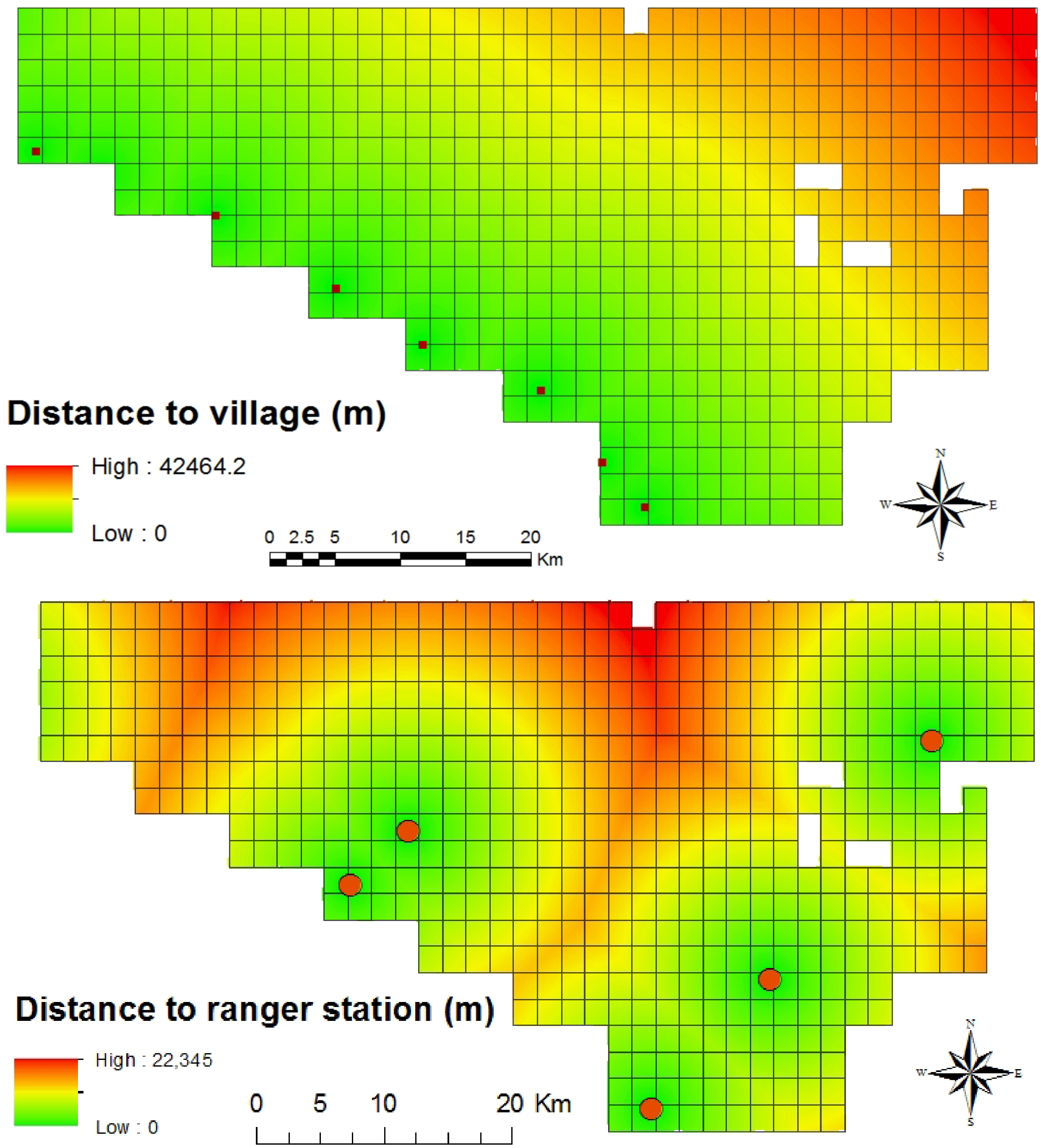


Figure 2.8. Distribution of Euclidean distance to nearest village (top) and ranger station (bottom) used as variables in modeling tiger prey distribution in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

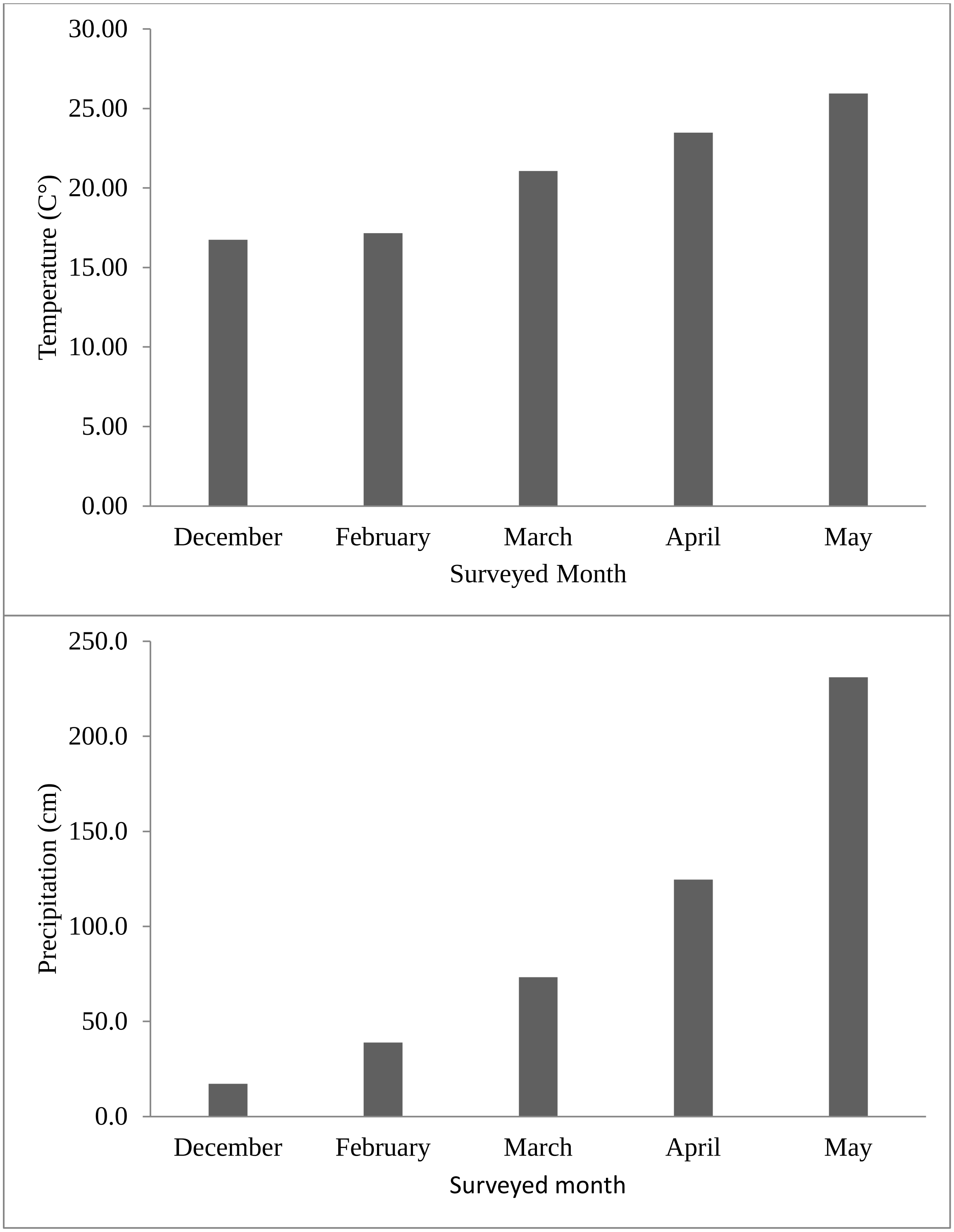


Figure 2.9. Mean monthly temperature (top) and mean monthly precipitation (bottom) during occupancy surveys conducted during December 2007 – May 2008 in the Core study area of the Hukaung Valley Wildlife Sanctuary of northern Myanmar.

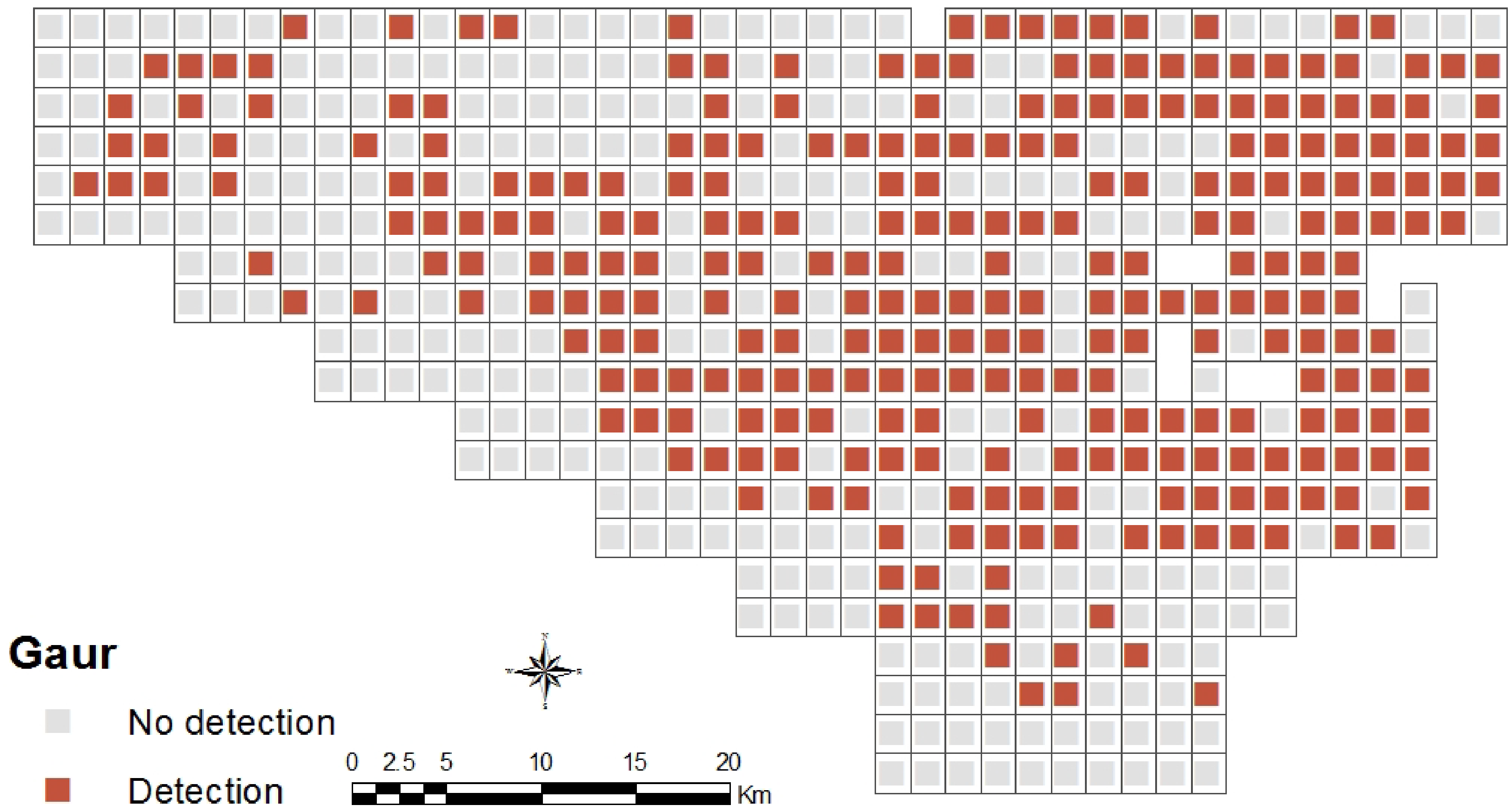


Figure 2.10. Naïve occupancy estimate of gaur based on detection non-detection approach in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

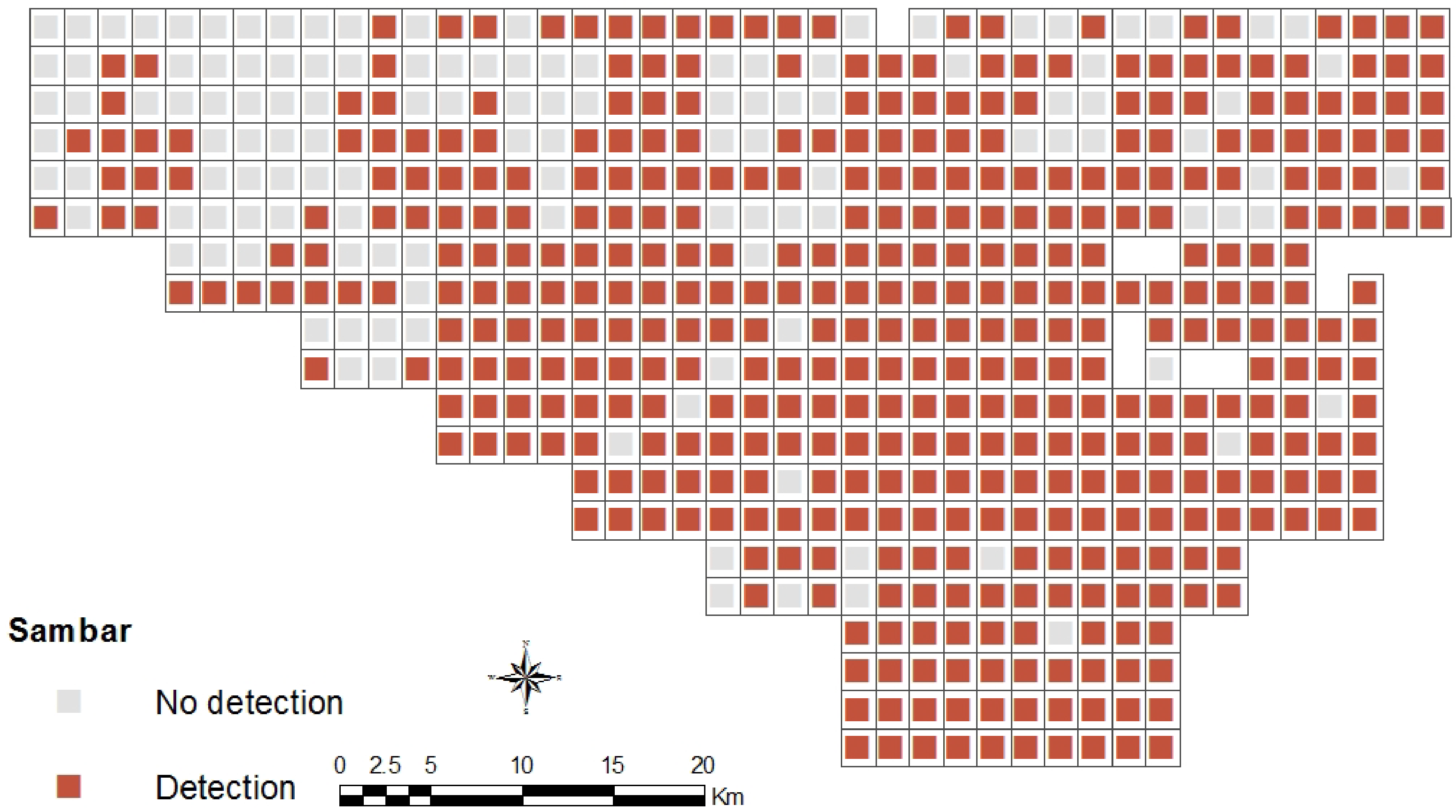


Figure 2.11. Naïve occupancy estimate of Sambar based on detection non-detection approach in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

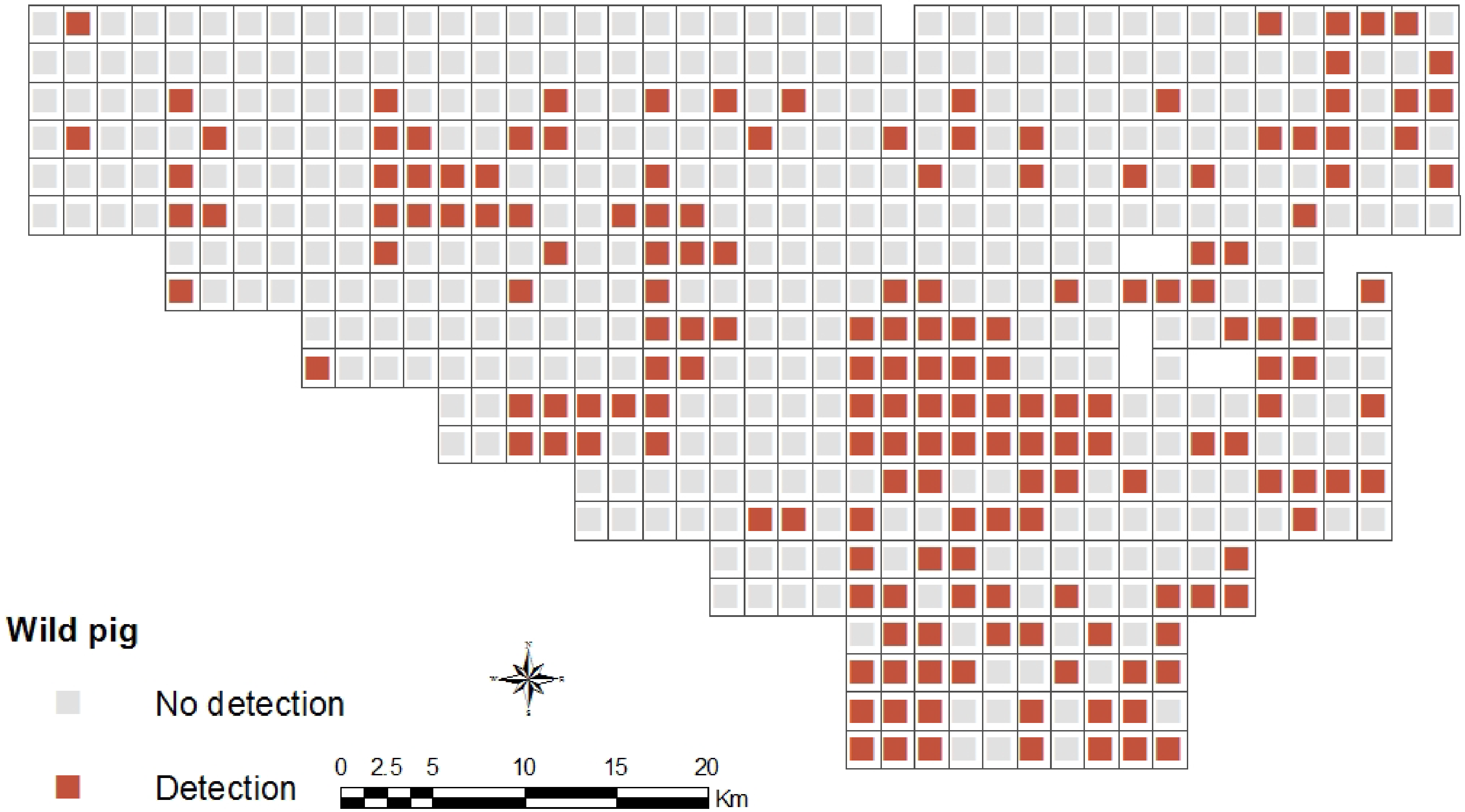


Figure 2.12. Naïve occupancy estimate of wild pig based on detection non-detection approach in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

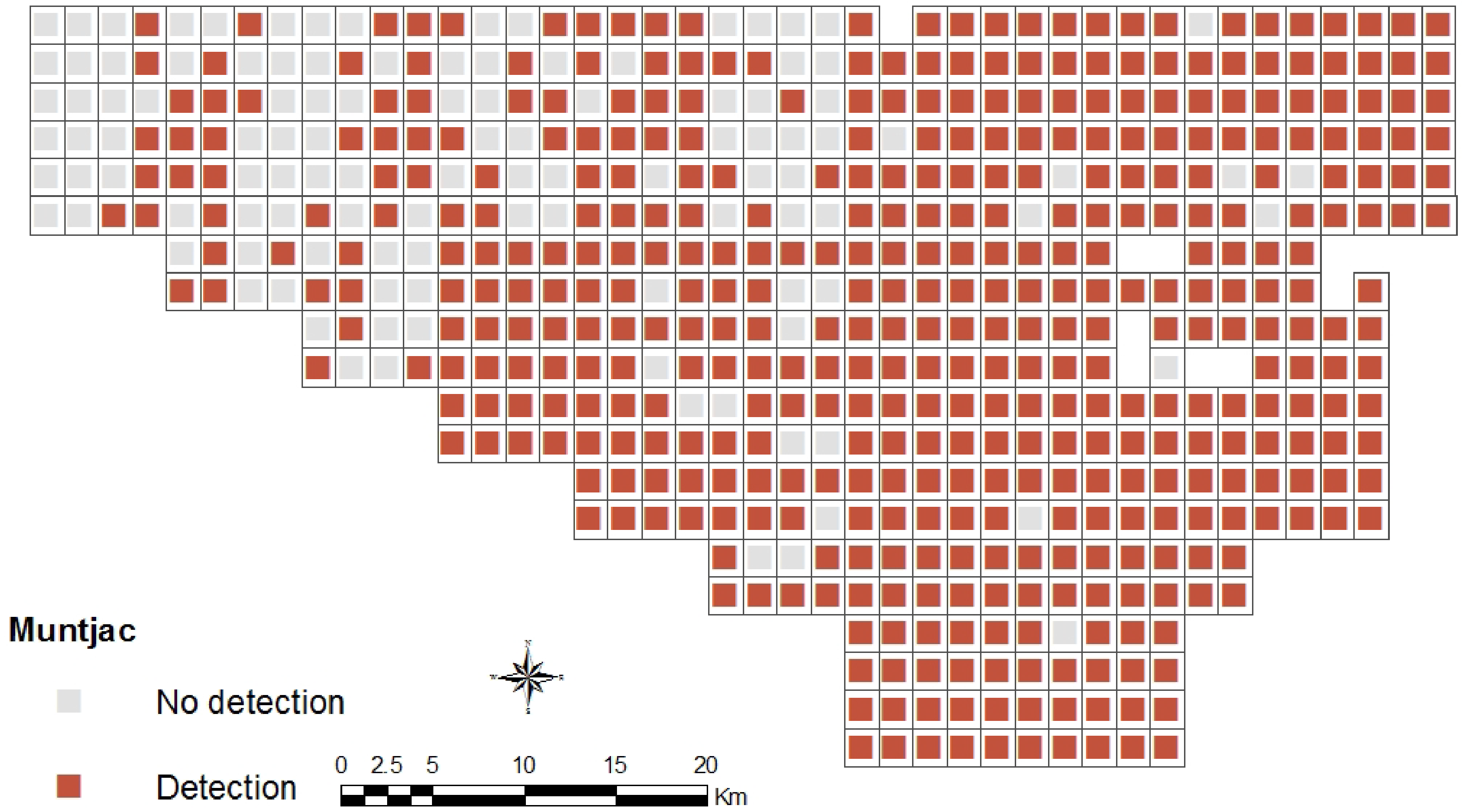


Figure 2.13. Naïve occupancy estimate of muntjac based on detection non-detection approach in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

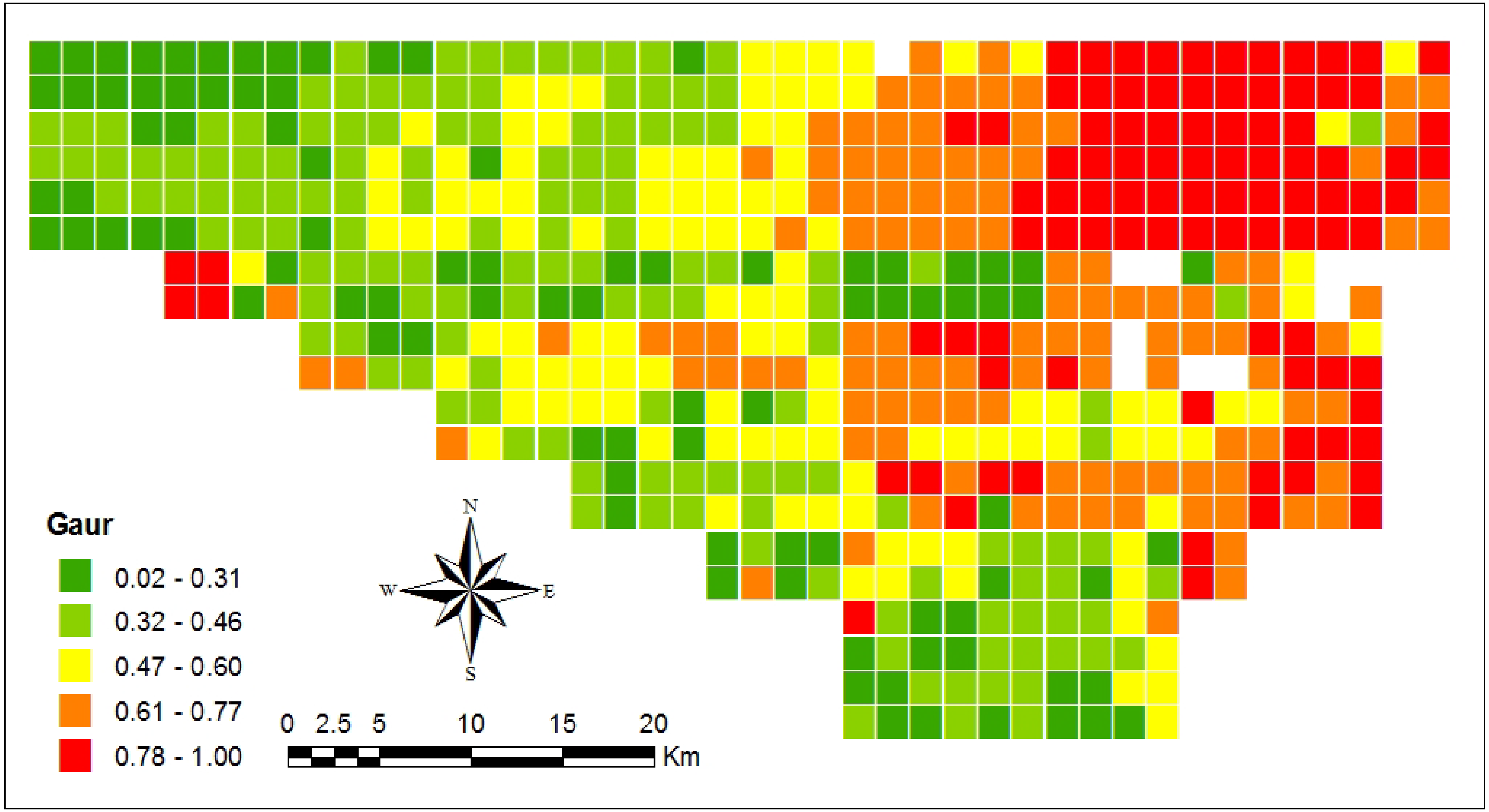


Figure 2.14. Predicted site occupancy ($\hat{\Psi}$) of gaur using standard occupancy model in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

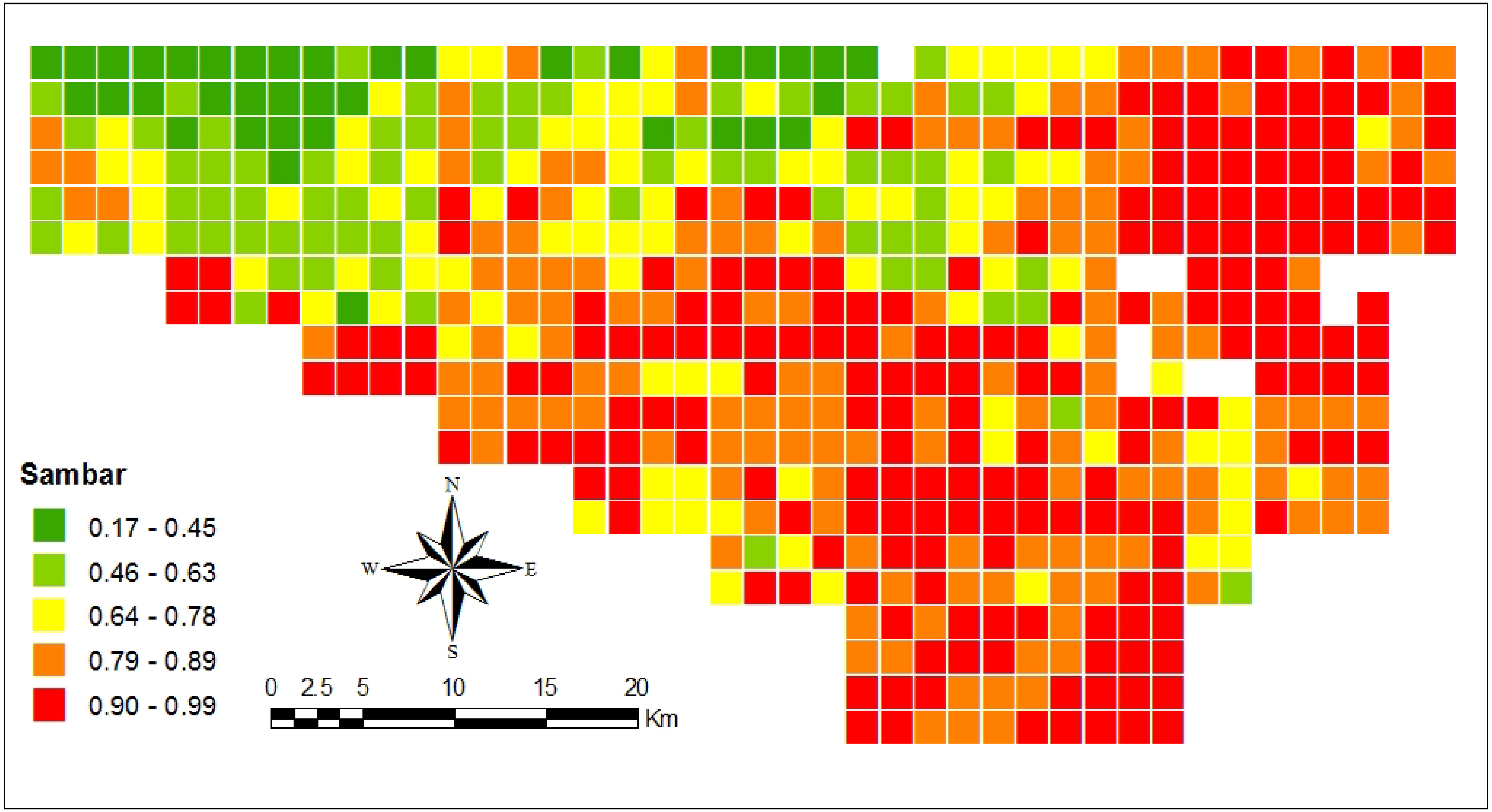


Figure 2.15. Predicted site occupancy ($\hat{\Psi}$) of sambar deer using standard occupancy model in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

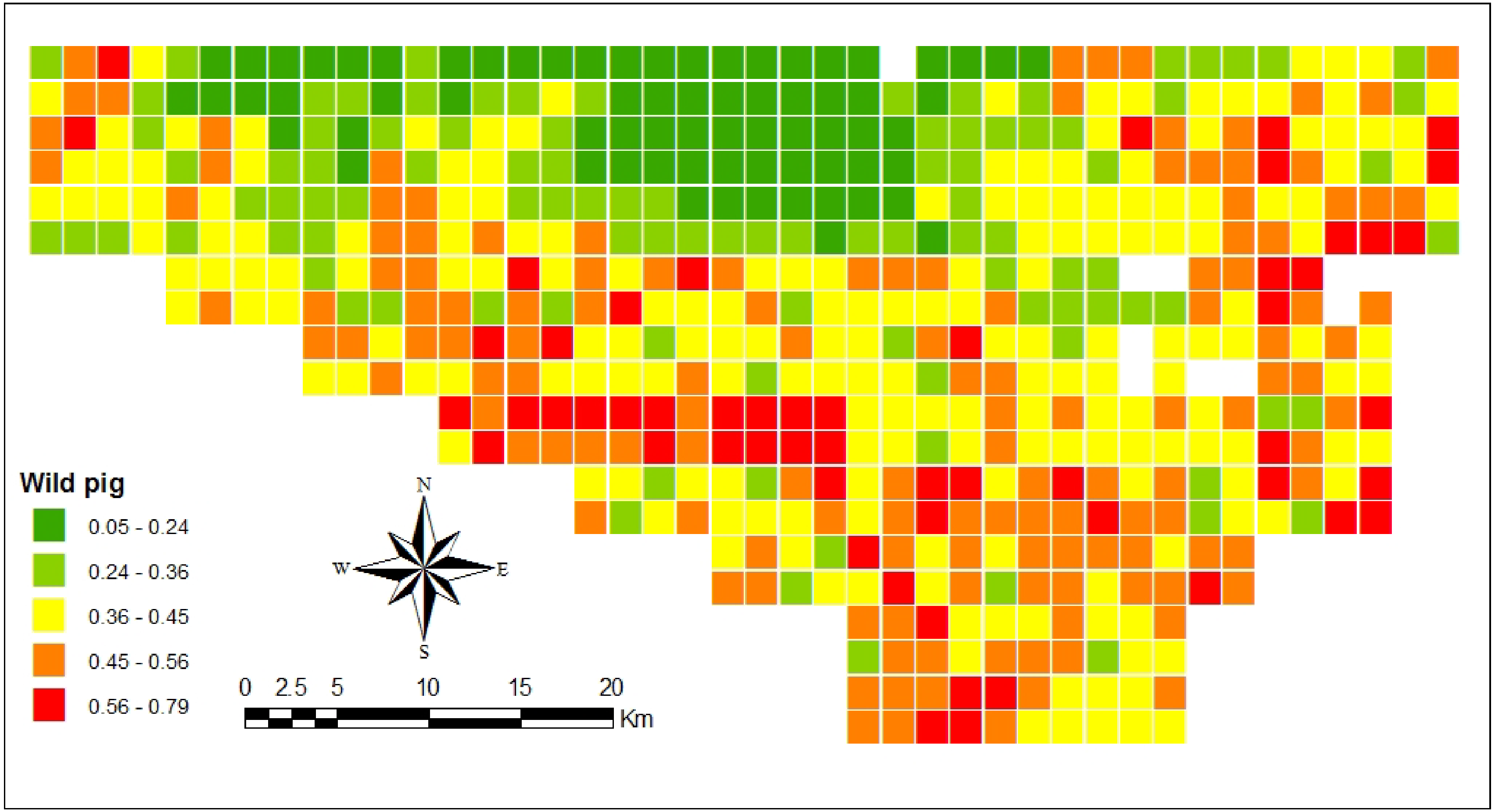


Figure 2.16. Predicted site occupancy ($\hat{\Psi}$) of wild pig using standard occupancy model in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

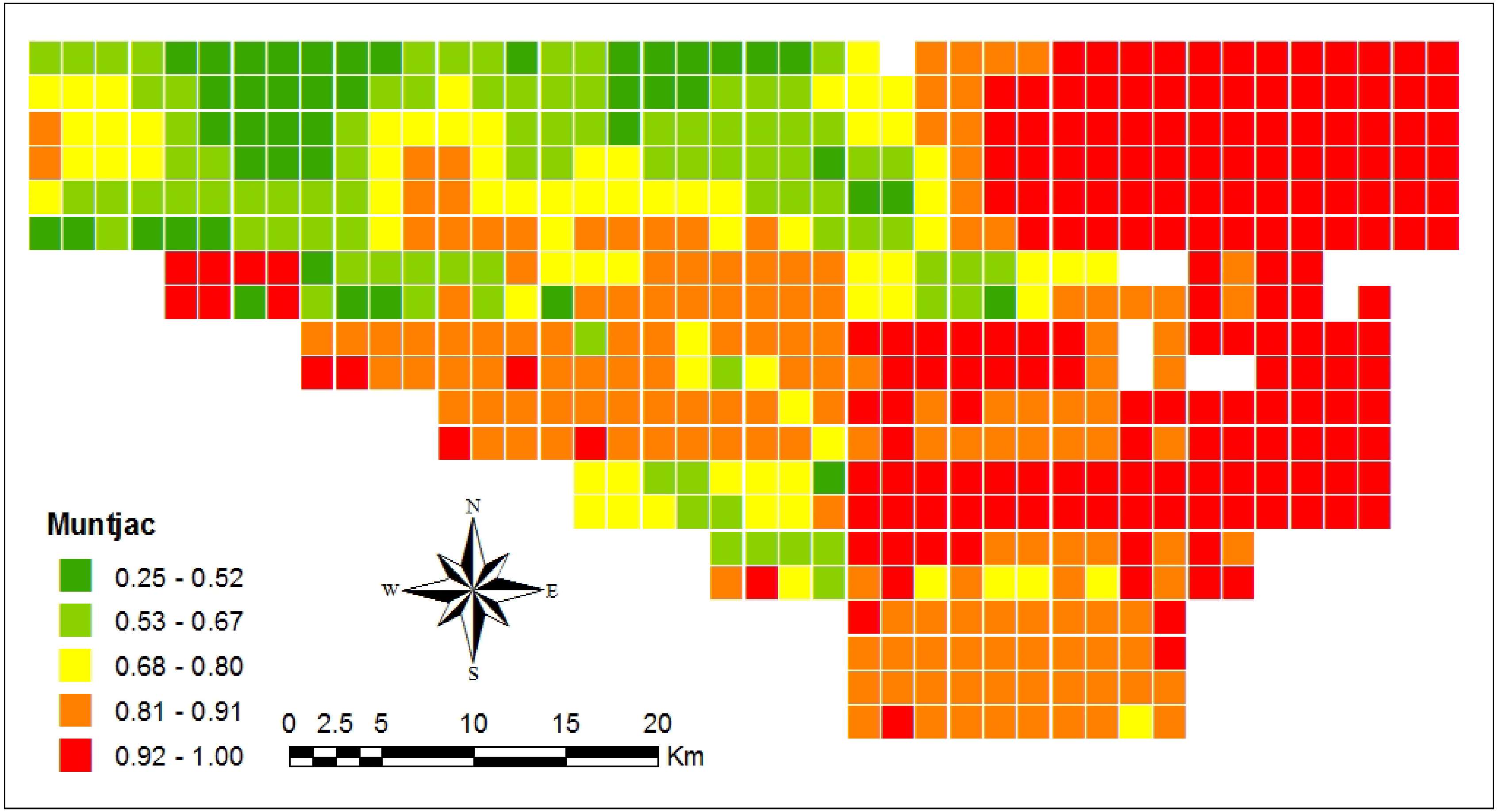


Figure 2.17. Predicted site occupancy ($\hat{\Psi}$) of muntjac using standard occupancy model in the core study area of the Hukaung Valley Wildlife Sanctuary in Northern Myanmar.

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