

Spatial and Temporal Habitat Use by the Main Prey Species of Tigers in Two Protected Areas of Thailand's Southern Western Forest Complex

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ABSTRACT

Tigers (*Panthera tigris*) have disappeared from over 90% of their historical range, and extant populations face habitat loss, direct poaching, and prey depletion in otherwise suitable habitats. In Thailand, tiger numbers continue to decline due to prey depletion, yet a few strongholds remain. Recently, tigers have been detected in the Southern Western Forest Complex (sWEFCOM), following intensification of conservation efforts. However, there is still a lack of primary data on the status of tigers and their prey in the sWEFCOM. To fill this knowledge gap, we conducted camera trapping surveys between 2019 and 2020 in Khuean Srinagarindra National Park (KSR) and Salakphra Wildlife Sanctuary (SLP). Located near a tiger source population in Thungyai Naresuan and Huai Kha Khaeng, these areas are potential areas for tiger recovery. In particular, our study assessed the status of prey, a prerequisite to the persistence and recovery of tigers. Based on relative abundance indices, time overlap and occupancy models, we analysed the effect of anthropogenic and ecological factors on the spatial and temporal habitat use of the main prey species. We highlight that anthropogenic factor impacted species-specific habitat relationships. Mainly, shifts in ungulate temporal and spatial habitat use was linked to human activities. These relationships, however, differed between the two protected areas. As tiger recovery depends on prey recovery, we suggest that increased conservation law enforcement and greater engagement with villages within and adjacent to protected areas are essential to minimising unsustainable resource use practices that currently affect prey.

1. INTRODUCTION

Thailand's Western Forest Complex (WEFCOM) is the largest remaining tract of forest in mainland Southeast Asia and is currently home to the largest known population of Indochinese tigers (*Panthera tigris corbetti*) (DNP, 2010a; WEFCOM, 2004). The WEFCOM lies at the heart of the Dawna Tenasserim mountain range that straddles the border with Myanmar and includes the Kaeng Krachan Forest Complex to the south. The Thung Yai-Huai Kha Khaeng (TY-HKK) World Heritage Site, established in 1991, covering an area of approximately 6,000 km², constitutes the core of the WEFCOM (WEFCOM,

2004; UNESCO, 2020). In 2005 the government of Thailand established an intensive patrolling system to protect and recover its most significant source of wild tigers in Huai Kha Khaeng Wildlife Sanctuary. Duangchantrasiri et al. (2016) conducted photographic capture-recapture from 2006 to 2012 to estimate tiger abundances annually and reported an increase in abundance from 35 to 58 tigers, with high individual survival (ranging from 79.60% to 95.50%), and substantial recruitment of 25 individuals. In large part, this increase is attributed to better management and protection of ungulate species, the tiger's main prey within the protected area, and the intensification of

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patrols and wildlife protection efforts. Consequently, the increase in tiger density during this period appears to have created the need for tigers to disperse to other forested areas adjacent to the wildlife sanctuaries (Phumanee et al., 2021a). In light of some reports from Khuean Srinagarindra National Park (KSR) and Salakphra Wildlife Sanctuary (SLP) south of TY-HKK, it is critical to assess the potential for these sites to support tiger recovery (Panthera, 2018).

Tigers are large carnivores and prey primarily on ungulates within the weight range of 10 to 250 kg (Hayward et al., 2007). However, over 50% of ungulate species that tigers prey upon are threatened, and over 80% of these species have declining population trends on account of habitat loss and degradation, being hunted for human consumption, and coming into conflict with agriculturalists due to damages to crops (Wolf and Ripple, 2016; Wolf and Ripple, 2017). Hence, understanding the status of prey at sites constitutes a crucial first step in evaluating the site's potential to support tiger recovery and suggest appropriate interventions to meet recovery objectives. In the TY-HKK World Heritage Site (WHS), a broad assemblage of ungulates are present, ranging from muntjac (18 kg) to gaur/banteng (600-1,200 kg). And, studies report the tigers' diet is primarily composed of large prey (with 89.80% biomass consumed being banteng, sambar, gaur, and domestic water buffalo). In contrast, small prey species (<100 kg) in the tiger's diet was 10.20% (Simcharoen et al., 2018). However, studies highlight that prey occupancy outside the WHS is low, especially for large ungulates (Duangchatrasiri et al., 2019). Therefore, it is critical to understand the status of prey outside of the WHS to evaluate the sites recovery potential (Harihar et al., 2018). With Phumanee et al. (2020) and Phumanee et al. (2021b) highlighting that the status of prey to the north of the WHS is poor, we aim to assess the status of prey to the south in the protected areas of KSR and SLP to inform tiger population recovery efforts. For the most part, both KSR and SLP are surrounded by settlements, with a few relatively large communities also existing within the boundaries of the protected areas. Furthermore, data from the DNP (2019) confirmed the occurrence of offenses directly affecting the population of wildlife in the study area (19 cases in KSR and two cases in SLP), which indicates that species may be threatened at these sites from anthropogenic influences. Furthermore, Lahkar et al. (2020) report that chronic anthropogenic disturbances such as unsustainable natural resource

harvesting have a detrimental effect on ungulate populations, with a consequence on carnivore populations as well, and Amornitiyangkul et al. (2022) report that human activity near villages in protected areas has a negative effect on wildlife populations. Therefore, understanding the nature of human-wildlife relationships is essential when considering conservation measures and natural resource management policies. Currently, no scientific studies having been conducted to examine the spatial and temporal influence of humans on the prey species of tigers in the sWEFCOM. Therefore, understanding the impacts of human disturbances and interactions with carnivores and their prey is vital to formulate appropriate conservation action in the region (Widodo et al., 2022).

Since SLP may be a potential recovery site for breeding populations and KSR may provide critical connectivity between TY-HKK and SLP, this study aims to understand the determinants of prey species occurrence and behavior in relation to ecological and anthropogenic factors. As part of our assessment of the status of prey in these two protected areas, we estimated the relative abundance indices, time activity and occupancy of the tigers' main prey and the influence of anthropogenic and ecological factors on their spatial and temporal distribution.

2. METHODOLOGY

2.1 Study area

This study was carried out in two protected areas, Khuean Srinagarindra National Park (KSR) and Salakphra Wildlife Sanctuary (SLP), located in the West of Thailand (Figure 1). The rainy season runs from May to October, with an average rainfall of 1,628.8 mm/year. The highest temperature is around 44-45°C in April. The minimum temperature is about 8-9°C in December. With an average temperature of approximately 27°C.

KSR, established in the early 1980s, is bisected by a large reservoir, covering an area of 1,532 km² (15.80% of the NP); 76.22% of the national park is forested, consisting of 56.06% mixed deciduous forest, 7.30% bamboo forest, 6.43% dry-dipterocarp forest, 5.64% dry-evergreen forest, 0.78% evergreen forest, and 1.41% grassland and natural forest restoration (WEFCOM, 2004). The remaining 7.98% comprises agricultural lands and communities. There are 42 villages within the National Park boundaries with 1,716 households and approximately 8,415 people, most farmers (WEFCOM, 2004). The

reservoir construction caused a large-scale relocation of local communities from the flooded plain to higher areas. The displacement and subsequent expansion of communities in the higher regions, as well as related agricultural and subsistence activities such as farming, livestock grazing and hunting, has caused a decrease

in the occurrence of wildlife species in the area and potentially constricting connectivity (Knight and Cole, 1995; Suttidate et al., 2021). Important perennial watersheds flow into KSR Reservoir, including large basins such as the Mae Klong River and Huai Kha Khaeng Stream.

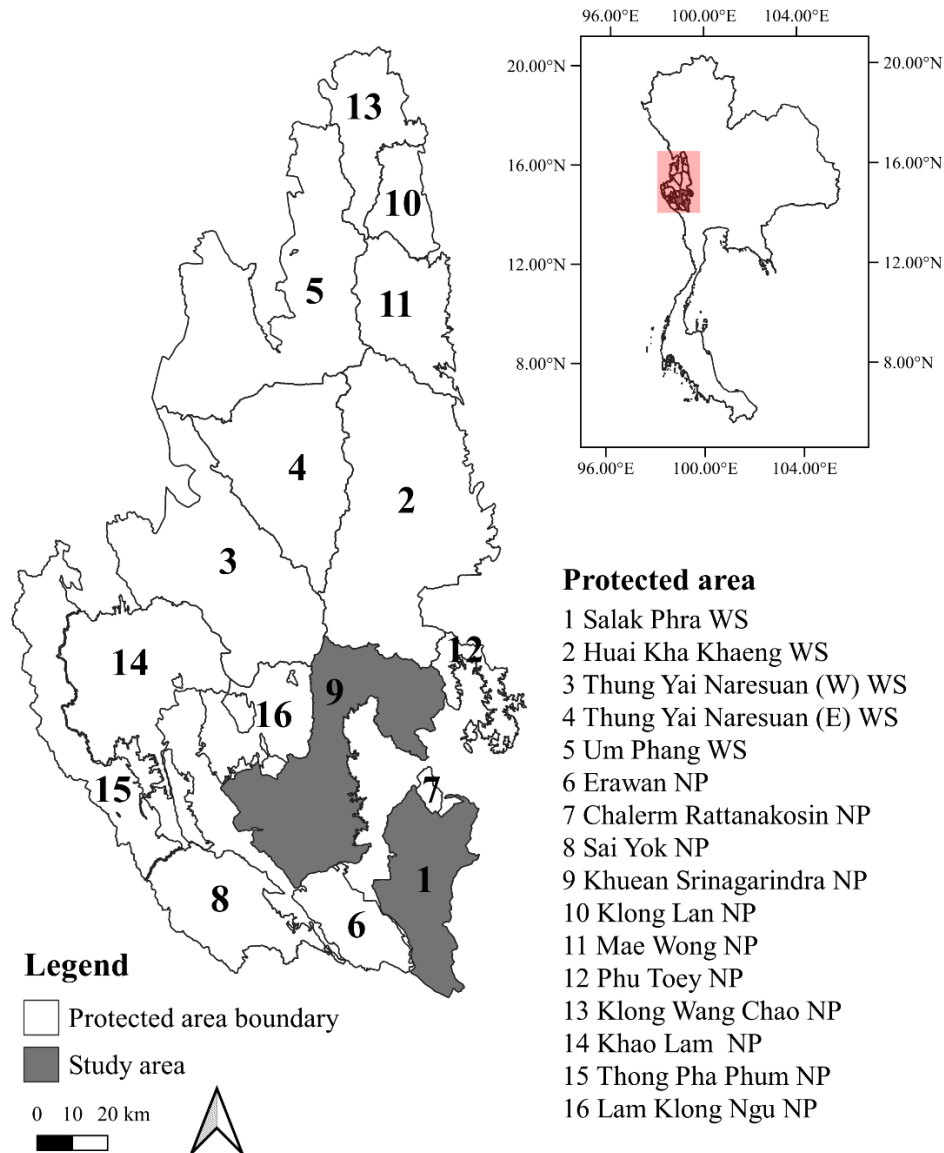


Figure 1. Protected areas in the Western Forest Complex (WEFCOM) in West Central Thailand

SLP, Thailand's first wildlife sanctuary, established in 1965, forms the southernmost tip of the Western Forest Complex, and covers an area of approximately 858.55 km², consisting of 60% mixed deciduous forest, 30% dry-dipterocarp forest, and 10% dry-evergreen forest (WEFCOM, 2004). Seven villages with 833 households and 3,483 individuals are located inside the sanctuary. Within the 3-km buffer from the boundary, there are 17 villages with 937 households and 3,937 individuals (WEFCOM, 2004).

Critical perennial watersheds flow through SLP, including Huai Sadong, Huai Lam Esu, Huai Mae Lamoon, and Huai Mae Plasoi. SLP supports, gaur, sambar, muntjac, and wild pig. Additionally, banteng was locally extinct in SLP, and a reintroduction program was carried out between 2015 and 2016 to repopulate the park (Chaiyarat et al., 2020). While tigers inhabited SLP historically, no photographic evidence was recorded until 2014. However, a camera trap study, using similar methods to those used in the

World Heritage Site and carried out by the Zoological Society of London (ZSL) in collaboration with the DNP and Panthera, confirmed the presence of one female tiger. Cross-referencing with the Khao Nang Ram research stations tiger database revealed that this individual had dispersed from HKK, travelling over 130 km. This dispersal likely occurred through Khuean Srinagarindra National Park (KSR). In 2015, ZSL and Panthera collaborated with the DNP to survey the Northeastern part of KSR and identified three tigers, one of which, a young male, had also dispersed from HKK. The other two tigers, both females, had not been identified previously in HKK and were, therefore, new records for Thailand. In 2019 and 2022, surveys were replicated in KSR and SLP, respectively. Based on previous research studying the dietary preferences of tigers in HKK (Simcharoen et

al., 2018), wild ungulates represent the main prey for tigers, with five species comprising the majority of wild tigers' diet in Thailand, banteng (*Bos javanicus*), gaur (*Bos gaurus*), sambar (*Rusa unicolor*), northern red muntjac (*Muntiacus vaginalis*), and the wild pig (*Sus scrofa*). Hence in this study, we assess the status of these species from camera trapping surveys.

2.2 Camera trap survey

We conducted systematic camera trap gridded surveys in sWEFCOM covering an area of 572 km² in north KSR and 557 km² in SLP, respectively, placing camera traps to optimize detections of tigers and their prey. The surveys were carried out in KSR from January to May 2019 with 76 camera trap stations and in SLP from November 2019 to February 2020 with 69 stations (Figure 2).

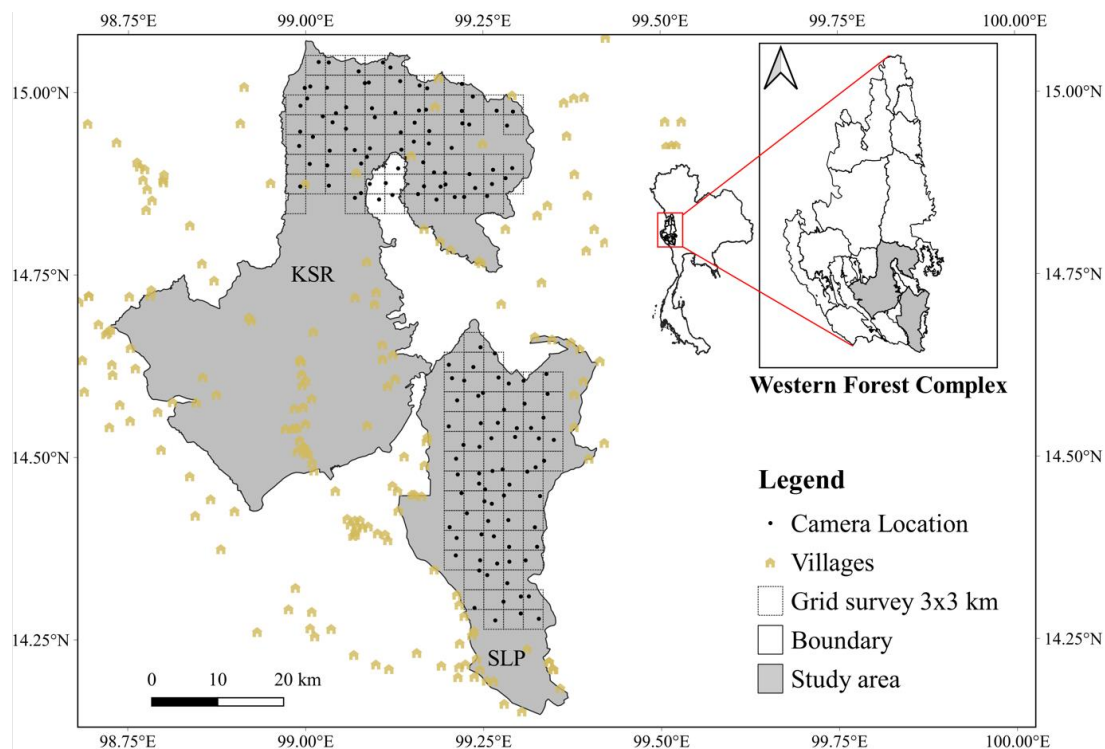


Figure 2. Camera trap stations in Khuean Srinagarindra National Park (KSR) from January to May 2019 and Salakphra Wildlife Sanctuary from November 2019 to February 2020, the map also shows the 9 km² grid cells (gray-filled squares) that were surveyed.

While the two surveys were not undertaken simultaneously, they were carried out in the same year in the dry season and, therefore subject to similar seasonal conditions and diurnal patterns. Although the effective trapping period was approximately 90 days for each survey, the remoteness and steepness of the terrain in KSR required longer deployment and collection periods when compared to SLP.

Camera trap stations consisted of a pair of motion-triggered PantheraCam V-series camera traps positioned opposite each other and fixed approximately 40-50 cm above the ground. Cameras were set to have a minimum of 15 seconds between trigger events and were continuously active during the survey period. To maximize the probability of detecting our target species, camera-trap stations were

placed in a grid 3×3 km along dirt roads, streams, animal trails and routes commonly used by tiger and their prey. Camera traps were mounted on trees located 3-5 m from the trail, clearing vegetation that might obstruct the camera's field of view. We did not use any baits to attract wildlife. Camera traps were not moved during the individual surveys.

After collecting the images from camera traps, we categorized the photos using Panthera's "Camera trap File Manager" software (Olliff et al., 2014). First, we identified the animal species in each image, referring to Francis (2019). If a species could not be identified, the image was categorized as "unidentified species". Next, all images of the same species captured within 30 min were grouped into independent events, following the principle described by O'Brien et al. (2003). Finally, a photo with multiple individuals of the same species in the frame were counted as single detection for that species.

2.3 Data analysis

2.3.1 Photographic capture rate index (PCRI)

For each station, we calculated the photographic capture rate index (PCRI) using independent event captures of individuals of the same species taken at more than 30 minutes time intervals (O'Brien et al., 2003). We then divided the number of independent event captures obtained at each trap by the number of camera trap nights and expressed the estimate per 100 trap nights (Carbone et al., 2001). Finally, PCRI values of each camera trap were calculated and mapped using the open-source software QGIS. To create the map and assess the difference in PCRI of prey species between KSR and SLP, we summarized species-specific PCRI of each area. We finally

visualised the magnitude of the capture rate with higher rates of capture shown as larger dots.

2.3.2 Temporal activity

We used the 'overlap' package (Ridout and Linkie, 2009) in the program R to fit kernel density functions to times of observations of human and five prey species and to estimate the coefficient of overlapping, a quantitative measure the continuous ranging from 0 (no overlap) to 1 (identical activity patterns). The coefficient is defined as the area under the curve. Confident intervals for coefficients of overlap were calculated by 1,000 bootstraps.

2.3.3 Influence of ecological and anthropogenic factors on species occupancy

- Ecological and anthropogenic covariate

We examined the effects of ecological and anthropogenic covariates to explain the probability of occupancy in each grid. Across the two PAs we included (a) distance to closest village, (b) average distance to closest road, (c) distance to closest stream, (d) distance to park boundary, (e) distance to reservoir, (f) human PCRI, (g) elevation, (h) NDVI, and (i) distance to closest patrol path, all factors shown in Table 1. All distances, except for roads were calculated from the centroid of each grid. We suppose that all species might occur nearby water (survey in the dry season) and further from anthropogenic factors (poaching pressure is higher closer to villages) (Phumanee et al., 2020). NDVI is a remotely sensed measure for vegetation productivity, nitrogen content, and other aspects of high-quality food for herbivores and is widely used to predict herbivore distribution and abundance (Pettorelli et al., 2011).

Table 1. Factors hypothesized to influence of detection probability and occupancy of prey species in sWEFCOM, Thailand

Covariate	Description	Source
a	Distance to closest village	WEFCOM (2004)
b	Average distance to closest road	WEFCOM (2004)
c	Distance to closest stream	WEFCOM (2004)
d	Distance to protected area boundary	WEFCOM (2004)
e	Distance to reservoir	WEFCOM (2004)
f	Human PCRI	Camera trap data
g	Elevation	Google engine (Gorelick et al., 2017)
h	NDVI	Google engine (Gorelick et al., 2017)
i	Distance to closest patrol path	SMART patrol database

- Unmarked occupancy model

Capture data for the main prey species was formatted into detection/non-detection data format with 14 occasions, with each occasion representing one week time. If a species was detected in one or more days of the week, it was recorded as detected (1), else it was recorded as not-detected (0) for the particular occasion. For SLP, data was available from 4/11/2019 to 5/02/2020 (14 weeks) for 69 sites. Accordingly, data for KSR was truncated to 14 weeks (15/01/2020 to 22/04/2020) and included 70 sites. Each site was represented by a grid of 3×3 km², and sites from both protected areas were combined in a single occupancy analysis as data was scarce for PA specific models. Effort, in terms of the number of days each camera trap was active during the study period, was used as a covariate to explain heterogeneity in detection probability.

Ten models were set up independently for each site to explain occupancy and detection probabilities for the different species. The first five models included (a) null model with no covariates for either occupancy or detection probability (NULL), (b) a full model with all covariates used to explain occupancy, (c) a habitat model including only covariates for habitat characteristics, i.e., distance to stream and elevation, (d) an environment model including NDVI, and (e) a human intervention model including covariates a, b, d, f, and i. The second set of five models were the same, with detection probability additionally being modelled as a function of effort.

Highly correlated variables (Pearson's correlation coefficient ≥ 0.7) were checked for and removed before further analysis. Variables 'distance to reservoir' and 'NDVI' were removed for KSR, while variables 'NDVI' and 'distance to road' were removed for SLP. However, since NDVI was the only variable used to explain occupancy in 'environment' models, it was only removed from the 'full' models. All covariates were centre scaled. All analyses were

conducted in R using the package 'unmarked' (MacKenzie et al., 2002).

Models were ranked according to their AIC values and weights. However, all models were averaged for further inference on occupancy, detection probability and effect sizes of covariates on them. Site-wise occupancy and site/occasion-wise detection probabilities were estimated using the 'predict' function in R, which were used to calculate mean occupancy and detection probability values for each species at each site.

3. RESULTS AND DISCUSSION

3.1 Survey effort and photo captured rate

3.1.1 Khuean Srinagarindra National Park (KSR)

Our survey in KSR had 75 camera stations (one location did not yield data because the cameras were stolen), totalling 8,751 camera trap nights. No tigers were detected during this survey. However, Panthera's previous survey revealed a tiger to have been photographed at TY-HKK. This indicates that the tigers from TY-HKK disperse toward KSR. The main prey animals detected included gaur, banteng, sambar, muntjac, and wild pig. According to the event per 100 camera trap nights, wild pig was the most detected species, with 3.77 events per 100 camera trap nights, followed by muntjac, gaur, sambar, and banteng with 3.57, 0.38, 0.30, and 0.15 events per 100 trap nights, respectively (Table 2). The majority of captures were of small prey species while large prey capture rates were low, especially banteng. Capture records indicated that banteng occurred in a small area covered by seven camera stations close to each other. Sambar was primarily distributed along the edge of the reservoir. Gaur was found mainly in the upland areas adjacent to the TY-HKK forest. We found small prey species (wild pigs and muntjac) distributed throughout the area.

Table 2. Number of photo capture event per 100 trap nights in KSR and SLP

Species	KSR		SLP	
	No. of capture event	No. of event per 100 trap nights	No. of capture event	No. of event per 100 trap nights
Gaur	33	0.38	47	1.07
Banteng	13	0.15	3	0.07
Sambar	26	0.30	209	4.77
Muntjac	312	3.57	356	8.12
Wild Pig	330	3.77	382	8.71

3.1.2 Salakphra Wildlife Sanctuary (SLP)

We placed 69 camera stations in part of SLP, totalling 4,384 camera trap nights. Three tigers were found and, comparing the tiger individual with the DNP tiger database, we found that two tigers dispersed from the TY-HKK World Heritage Site, and one tiger had never been detected previously. However, we detected gaur, banteng (reintroduced species), sambar, muntjac, and wild pig amongst ungulate species. The wild pig was the most detected species with 8.71 events per 100 camera trap nights, followed by muntjac, sambar, gaur, and banteng were 8.12, 4.77, 1.07, and 0.07 events per 100 camera trap nights, respectively. Banteng were detected at two locations, one at the release site of the reintroduction, and another to the south of the protected area, suggesting the spread of the population. Sambar was detected in

flat areas located in the middle PA. Muntjac and wild pig were distributed throughout the site.

Overall, most prey species at SLP had a higher capture rate than KSR. The number of banteng found in both areas was low. In addition, based on the camera trap image data, a calf of banteng was detected. The two smaller prey (wild pig and muntjac) were common throughout both areas. Similarly, in another protected area in WEFCOM, wild pig and muntjac were the most commonly detected than large prey, observed >50% of camera locations, sambar <22%, and gaur <19% (Phumanee et al., 2020). Additionally, strong habitat protection in some protected areas has resulted in more gaurs occurring near the borders of the protected area (Prayoon et al., 2021), explaining the distribution of gaur in the upper area adjacent to HKK (Figure 3).

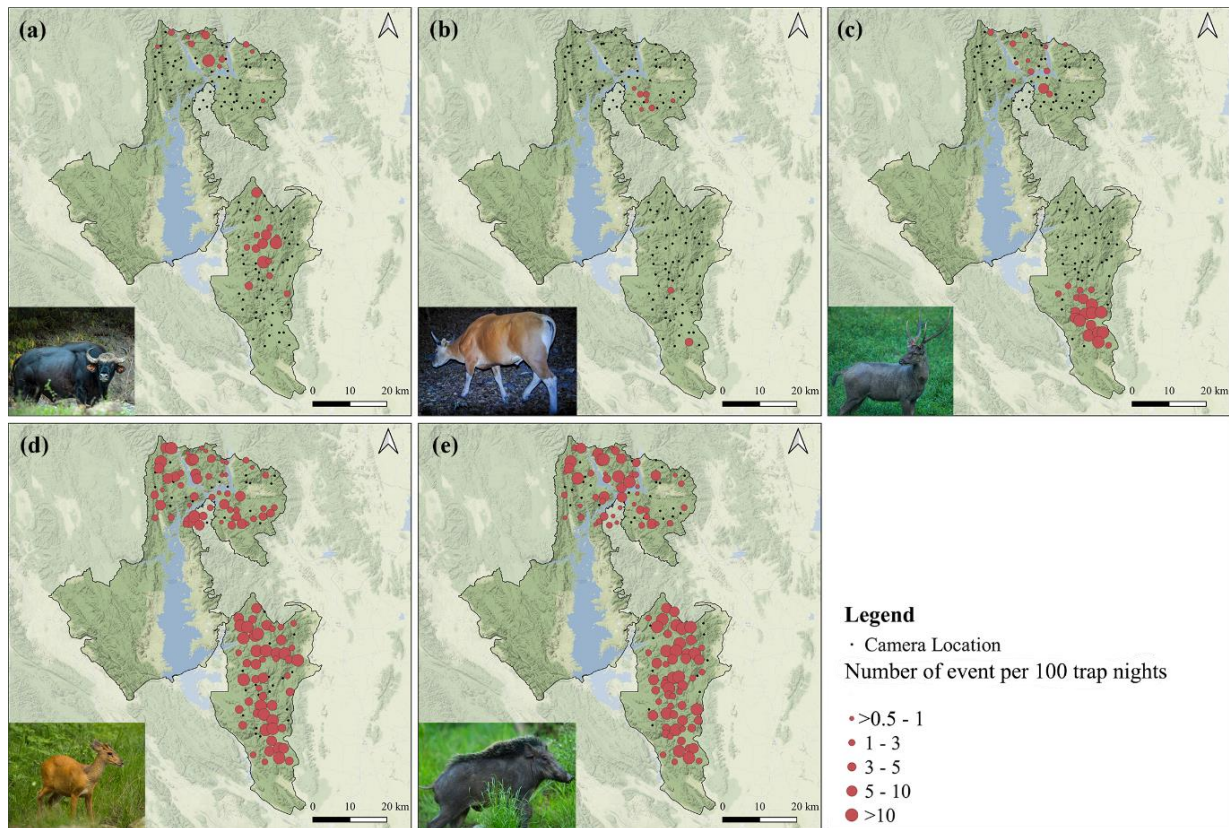


Figure 3. Photographic capture rate index (PCRI) of prey species in KSR and SLP including: (a) gaur, (b) banteng, (c) sambar, (d) northern red muntjac, and (e) wild pig

3.2 Temporal activity

In our study areas, the peak of human activity was recorded at mid-day, as illustrated by the dotted line in Figure 4. The shaded area in Figure 4 represents the estimated temporal overlap in activity for humans and prey species. Camera trap data has revealed the widespread movement of people throughout the

protected areas. In KSR, large prey species, gaur, banteng, and sambar, were more active during the hours of darkness compared to smaller species such as muntjac and wild pig, whose peak activity periods were during the day. In SLP, sambar, muntjac, and wild pig showed similar temporal activity patterns to their conspecifics in KSR, while gaur and banteng

appeared to be active day and night. As a result, the species with the highest temporal overlap with humans in both areas is the wild pig, (KSR; 0.763 (0.70-0.82) and SLP; 0.607 (0.51-0.70)), while sambar was the species with the lowest temporal overlap in both areas, (KSR; 0.439 (0.29-0.60) and SLP; 0.194 (0.11-0.28)).

In Khao Yai National Park, [Khoewsree et al. \(2020\)](#) found that sambar mainly was active during the night while most human, muntjac, and wild pig activity was recorded during the daylight hours resulting in low temporal overlap, similar to the findings of this study. Furthermore, [Johann et al. \(2020\)](#) reported that large areas with low levels of human disturbance were linked with higher daytime activity of wild pigs than smaller areas with relatively higher levels of disturbance. Similarly, [Ohashi et al. \(2013\)](#) also reported human activity in the

Southwestern part of Tochigi, Japan, significantly affected the activity patterns of wild pigs. Additionally, in a study of the spatial and temporal distribution of leopards and their prey in Thailand's Western Forest Complex, [Saisamorn et al. \(2019\)](#) reported that sambar and banteng were nocturnal while wild pig and muntjac were diurnal.

Our results indicate that gaur activity in KSR peaks around 00:00, while in SLP, the peak period is around 18:00. Similarly, [Vinitpornawan and Fuller \(2020\)](#) also found similar patterns of activity, with most detections between 17:00 and 18:00 and 59% of overall gaur activity in the daytime. Their study recorded most human activity around noon, with only a few detections after 18:00 hours, causing overlaps of activity with nocturnal wildlife species.

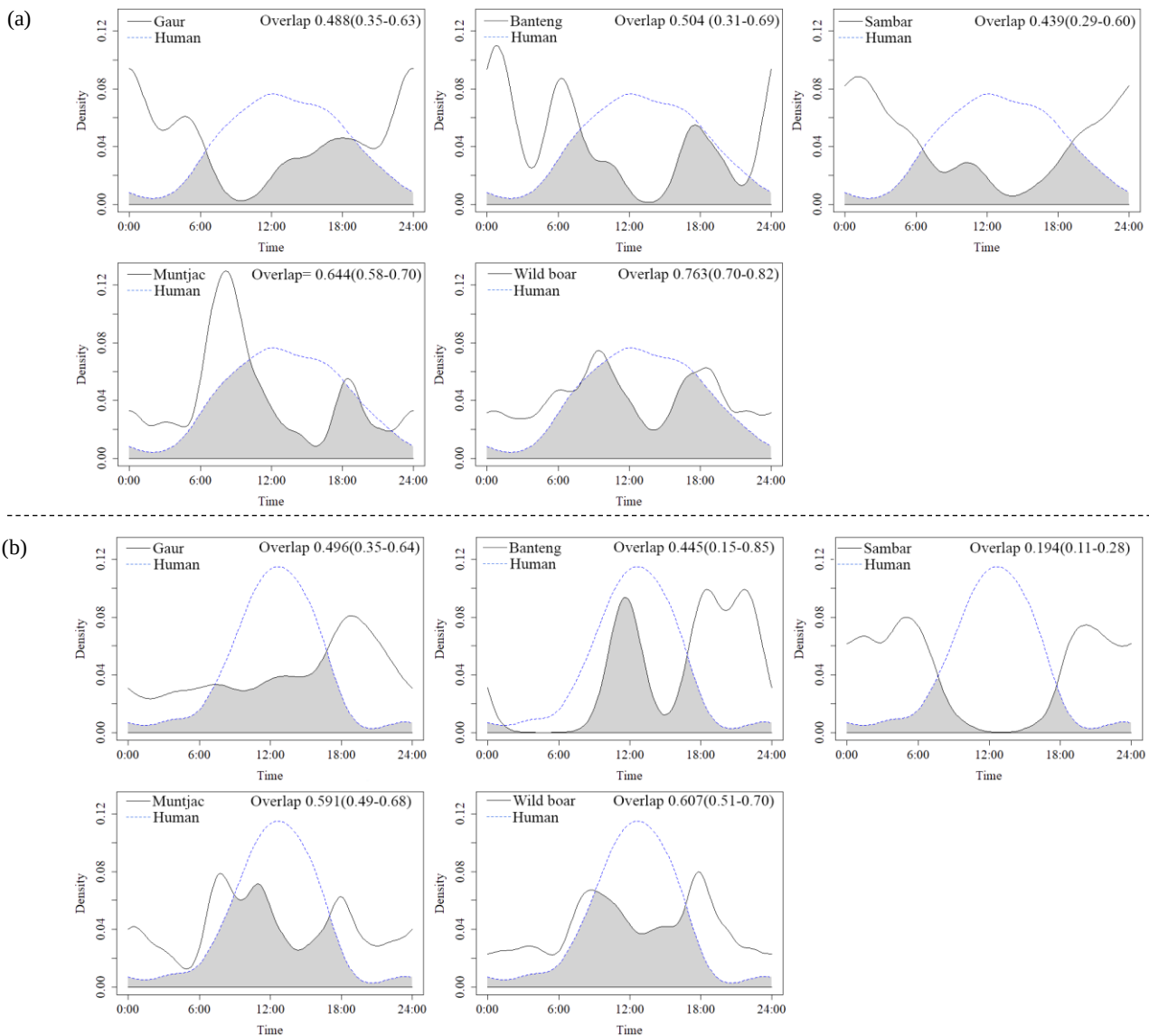


Figure 4. Time overlaps plot of human and tiger's prey species in (a) KSR and (b) SLP, the estimated overlap is shown by the grey area.

3.3 Influence of covariates on occupancy model

3.3.1 Gaur

The model averaged estimate of gaur occupancy across the two protected areas was 29% (Table 3). The top model included human influence covariates with distance to closest patrol path and road having the most significant effect (Table S1 and S2). Differing from studies in HKK, [Jornburom et al. \(2020\)](#) reported the best model for gaur is higher elevation and avoidance of shallow slope areas within a 1 km buffer of streams. In addition to this, [McShea](#)

[et al. \(2011\)](#) reported that gaur in Thailand required grassland and open areas of moist evergreen, dry evergreen, semi-evergreen, and mixed deciduous forests. [Paansri et al. \(2022\)](#) however found that gaur was detected in both open and closed forests.

In the past, both study areas had a greater distribution of gaur ([Srikosamatara and Suteethorn, 1995](#)). Currently, there is a threat to the population from hunting. Around and within both areas there are human settlements and this might be causal to the relationship.

Table 3. Detection probability and occupancy estimates of prey species in KSR and SLP, Thailand, 2019-2020

Species	Detection probability			Occupancy probability		
	Mean	2.50%	97.50%	Mean	2.50%	97.50%
Gaur	0.11	0.07	0.11	0.29	0.01	0.98
Banteng	0.08	0.03	0.08	0.10	0.07	0.14
Muntjac	0.27	0.10	0.30	0.77	0.74	0.82
Sambar	0.31	0.13	0.33	0.23	0.00	0.94
Wild pig	0.29	0.05	0.32	0.73	0.08	1.00

3.3.2 Banteng

The model averaged estimate of banteng occupancy was low (10%) across the two PAs (Table 3). Banteng detections in our study were likely too few to run the model effectively (Table S1 and S2). [Jornburom et al. \(2020\)](#) simulated a map of predicted occupancy for banteng in WEFCON in the absence of poaching, and estimated ~6,400 km² of ecologically suitable habitat that could support reintroduction of banteng in other protected areas and reports banteng used low elevations and low slopes. Furthermore, Mae Wong National Park confirms the return of banteng after an absence of over 40 years, likely dispersed from HKK ([Phoonjampa et al., 2021](#)).

Three replications of camera trap surveys in KSR since 2016 have confirmed that banteng is present in only one relatively small area of the protected area. In SLP, Banteng were distributed throughout the park, however, there were no reports of sightings for more than 30 years (personal communication with park rangers). Therefore, banteng was reintroduced in 2015. Currently, the reintroduced population of 13 have increased to 19 and is concentrated near the release area. With improved protection, this population is expected to increase.

3.3.3 Sambar

The model averaged estimate of sambar occupancy across the parks is 23% (Table 3). Habitat

covariates such as distance to reservoir, elevation and NDVI had a significant relationship on the occupancy suggesting that sambar was far the reservoir, at lower elevation and in more open habitats (Table S1 and S2). Our results are similar to that reported from HKK, where occupancy of sambar was negatively correlated to elevation, with the majority of detections distributed in lower altitude grasslands ([Simcharoen et al., 2014](#)). [Duangchatrasiri et al. \(2019\)](#) found that livestock was negatively correlated with tiger and sambar occupancy in HKK. Furthermore, [Paansri et al. \(2021\)](#) found that sambar occupancy was directly related to grass biomass and also avoided human disturbance factors. From our study, sambar avoid the reservoirs. This might be because the KSR reservoir area has a traffic of villagers' boats, fishing, and livestock. Livestock grazing in forested areas was expected to negatively impact ecosystems and wildlife, such as competition for forage, pollution of water resources. ([Chaiyarat and Srikosamatara, 2009](#)).

3.3.4 Northern red muntjac

The model averaged estimate of occupancy from the muntjac is 77% across the two PAs (Table 3). The human influence model was top ranked suggesting that (although non-significant) human capture rate negatively influenced muntjac occupancy (Table S1 and S2). Similar to a study in Mae Wong-Khlong Lan National Park in northern WEFCON,

none of the variables in the top model set were statistically significant, (Phumanee et al., 2020). Likely as muntjac has non-specific habitats and can be detected in all forest types, agricultural areas, and abandoned farm (DNP, 2010b). The negative correlation with photo capture rate of human shows that muntjac although widely distributed are susceptible to human influence.

3.3.5 Wild pig

Model averaged occupancy estimate of wild pig across the two PAs was 73% (Table 3). The top models included human influence covariates, particularly noting higher occupancy away from roads and the reservoir (Table S1 and S2). Consistent with studies of ungulates in Mae Wong and Khlong Lan, where wild pig was associated with avoidance of villages (Phumanee et al., 2020). The wild pig is a resilient species, distributed throughout the area. It has the highest reproduction rate among ungulates and therefore a high resilience to hunting pressure (Gaillard et al., 1993; Steinmetz et al., 2010) and is a habitat generalist (Spitz and Janeau, 1995).

While our study provides an assessment of species occupancy in the sWEFCOM, these estimates are relatively lower compared to HKK (Duangchatrasiri et al., 2019). Tiger occupancy is strongly influenced by prey availability and often choose larger ungulates as diet (sambar, gaur, and banteng) (Simcharoen et al., 2018). Given large prey occupancy was low in KSR and SLP this may limit the recovery of tigers and conservation measures should therefore focus on mitigating the factors that limit the presence of large tiger prey (Duangchantrasiri et al., 2016).

4. CONCLUSION

This study provides evidence of the impact of ecological and anthropogenic factors on the spatial and temporal habitat use patterns of the tigers' wild prey across KSR and SLP, and emphasizes the importance of initiating and maintaining conservation measures to support prey recovery to ensure the recovery of tigers. To be more specific, we first demonstrate that the abundance indices of prey (PCRI) across the two protected areas indicate that small prey appear to be more abundant than large prey. Nevertheless, large prey species, such as sambar and gaur, registered higher PCRI estimates in SLP than in KSR, suggesting that the site might be a better habitat for tigers. Secondly, we demonstrate through the analysis of time activity patterns that most prey

avoided periods of high human activity. At both protected areas, this was most prominent among the large prey animals, gaur and sambar. While the smaller prey, which are more abundant, overlap more widely with human activity. Finally, the results of our occupancy analysis confirm that small prey (muntjacs and wild pigs) occupy more area than large prey (sambar, gaurs, and bantengs), demonstrating the importance of large prey recovery if tiger recovery is to be supported across the PAs.

The results of this study and other similar analysis suggest that most tiger prey species tend to avoid anthropogenic activity. The detection in the southern WEFCOM of at least two tigers having dispersed from the Thungyai Naresuan-Huai Kha Khaeng World Heritage Site has highlighted the importance of sWEFCOM for the long-term viability of tiger populations in Thailand. Our results will also help protected area managers better understand the ecological and anthropogenic factors affecting ungulate, allowing them to make more informed decisions regarding the management and regulation of the protected areas.

- Management implications

Many studies have shown that the abundance of tigers often depends on the health and abundance of large ungulates. Sambar, banteng, and gaur composed 95.10% of biomass of these kills in HKK (Pakpien et al., 2017). It can be noticed that tigers tend to choose large prey (>100 kg). Based on our surveys within KSR and SLP, populations of large prey species should be of concern. Strengthening efforts should be made to protect the remaining small red bull populations and to preserve the area. Since communities are settled throughout around KSR and SLP, human activities impacting wildlife distribution and abundance should be regulated through a combination of patrolling and community engagement aimed at reducing, where possible, spatial and temporal overlap between human activities and wildlife. There should be a zoning arrangement for villagers who come to use forest resources to reduce disturbances in wildlife habitats, including livestock. At present, the outbreak of lumpy skin disease affects both domestic and wild cattle in Thailand (Arjkumpa et al., 2021). There should be surveillance for diseases transmitted from domestic animals to wild animals. Wildlife conservation depends on habitat maintenance (Reed, 2004). KSR connects to HKK and are suitable for gaur population. Most suitable gaur habitat was

connected to large patches (Prayoon et al., 2021). Therefore, it should be managed to reduce the threat in order to support population of gaur that spread from nearby areas. To increase the large ungulate populations throughout the area, salt lick sources need attention, because the tiger's prey is herbivorous, causing sodium and other nutrient deficiencies. (Emmons and Stark, 1979). Furthermore, the presence of salt licks in WEFCOM is associated with gaur and other ungulate species (Jornburom et al., 2020; Phumanee et al., 2020). Finally, these studies should provide information that can be used by management for the establishment of conservation areas to develop plans to conserve gaur and banteng to support tiger habitat.

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