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Spatio-temporal analysis of dholes (*Cuon alpinus*) in Khao Yai National Park, Thailand

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Abstract. *Khoewsree N, Pla-ard M, Sukmasuang R, Paansri P, Chanachai Y, Kaewdee B, Phengthong P. 2022. Spatio-temporal analysis of dholes (*Cuon alpinus*) in Khao Yai National Park, Thailand. Biodiversitas 23: 2668-2678.* The relationship of the occurrence of key wildlife species and other wildlife in the ecosystems is complex and unique as a result of interactions between species as well as responses to complex environments. Spatio-temporal analysis of dholes (*Cuon alpinus*) in Khao Yai National Park, Thailand, aimed to study of the coexistence of the dhole with its main prey, humans, and other physical factors based on camera trapping. The temporal and spatial overlap analysis found that dholes coexist with five prey species and also with humans. The dhole also occurred with a significant positive temporal or spatial overlap with 20 other potential prey species. It was found that water sources and villages had a negative effect on the dhole's occupancy while there was a positive effect from roads, elevation, and slope. The dhole's occupancy model was most closely related to small rodent proximity. It also was found that the dhole's occupation was also related to humans. Based on the results of this study, some recommendations were developed to advocate the strict management of recreation areas. There should also be a boundary between the area of human activities and the natural forest of the area and this should include the control of illegal entry into the area from the area surrounding the national park to reduce interactions between human activities and wildlife.

Keywords: Camera trapping, Dong Phayayen-Khao Yai Forest Complex, occupancy covariate, small rodent

INTRODUCTION

Mammalian carnivores are keystone species that have a crucial role in regulating and maintaining ecosystems (Palazón 2017). The dhole is a medium-sized canid that plays an important role in the natural conditions of Asia (Charaspet et al. 2021). The dhole is perhaps one of the most misunderstood species of all time and is currently among the most threatened carnivores on the planet (Wolf and Ripple 2018). The dhole is currently the world's rarest and most endangered wild canid (Kamler et al. 2015).

The relationship of the occurrence of key wildlife species and other wildlife in the ecosystem is complex (Frey et al. 2018). Anthropogenic factors also influence intra-guild competition directly by affecting species densities or indirectly by modifying resource levels and distribution (Karanth et al. 2017). Behavioral mechanisms that allow species to coexist are not well understood. The knowledge is essential for species, population, and habitat conservation (Davis et al. 2021). It does not seem to be applicable to answer the question of negative impacts on nature, especially tourism in natural areas. This causes the deterioration to increase and this is sometimes it is difficult to fix and brings significant damage. The disappearance of important wildlife species, including the spread of epidemics from domestic livestock and free-ranging dogs to wildlife, has continued to occur in tropical conservation areas for a long time. Scientific knowledge that can be used to manage efficiently is essential.

Hayward et al. (2014) reported on the prey species of dholes in 16 study sites. A total of 35 species can be classified, with ungulate wild animals being the main prey of the dhole with a total biomass of more than three-quarters of the total prey that the dhole consumes. Khoewsree et al. (2020) reported the percentage of relative prey biomass consumed of dhole consumed as 85.33% of the ungulate species. Charaspet et al. (2020) reported on the prey species of the dhole in the three conservation areas found that the major prey species were ungulates. By the prey biomass consumed of prey, about 10-15% were small body size, including small rodents and others.

In addition to studying the prey species through spatial and temporal analysis, had been used in several studies (Rossa et al. 2021), this leads to more understanding of the interactions between dhole and prey species (Karanth et al. 2017). The influenced the probability of the appearance of dholes were environmental factors such as the distance from the village, elevation and wilderness areas (Namgyal and Thinley 2017). Sukmasuang et al. 2020 reported that the grassland was also an important factor of the dhole.

Khao Yai National Park (KYNP) was established in 1962 as one of the five conservation areas in the Dong Phaya Yen-Khao Yai forest complex, which was declared a Natural World Heritage Site in 2005 (UNESCO 2022). Highways have been developed around the areas. There are also highways that pass through the center of KYNP with a length of about 42 km, causing the trend of increasing numbers of tourists every year. There were 1.1-1.5 million tourists who visited the park per year and number of cars traveling through KYNP ranged between 2.89-4.71 hundred thousand cars per year during the last eight years (DNP 2022). In addition, communities have been developed surrounding the park and the announcement of the establishment of two new districts located north of the park, including the construction of elevated expressways or motorways. That led impact to the areas (Baker and Leberg 2018).

This study aimed to study the spatial and temporal coexistence of the dhole and potential prey as well as the physical environments. The objectives of this study were: (i) to study the spatial and temporal coexistence of dholes and prey and (ii) to study the environmental factors affecting the appearance of the dhole both in terms of physical factors and the prey species in the area.

MATERIALS AND METHODS

Study area

Khao Yai National Park (KYNP) is located between the latitude of N 14°05'0.00" to N 14°35'0.00" and between the longitude of E 101°10'0.00" and E 101°55'0.00", covering an area of 2168 km^2. Located in the Phanom Dong Rak mountain range stretching between the central and northeastern regions of Thailand and was declared as part of the World Natural Heritage Area in 2005 (UNESCO 2022) because it is an important habitat of many living things. It is home to more than 800 vertebrate species, 112 species of mammals, 392 species of birds, and more than 200 species of reptiles and amphibians (UNESCO 2022). Pla-ard et al. (2021) reported species of wildlife in the area from camera traps as the conservation status according to IUCN (2021) there were critically endangered, the Sunda pangolin (*Manis javanica*) and the Asian giant tortoise (*Manouria emys*). Three species were categorized as endangered, including the large-spotted civet (*Viverra megaspila*), dhole (*Cuon alpinus*) and Asian elephant (*Elephas maximus*). Ten species were vulnerable, including the greater hog badger (*Arctonyx collaris*), Asiatic black bear (*Ursus thibetanus*), Malayan sun bear (*Helarctos malayanus*), clouded leopard (*Neofelis nebulosa*), fishing cat (*Prionailurus viverrinus*), gaur (*Bos gaurus*), mainland serow (*Capricornis sumatraensis*), sambar deer (*Rusa unicolor*), northern pig-tailed macaque (*Macaca leonina*) and coral-billed ground-cuckoo (*Carpococcyx renauldi*). One near-threatened species is the Asiatic golden cat (*Catopuma temminckii*) and 32 species that are of least concern include for example, the Javan mongoose (*Herpestes javanicus*), crab-eating mongoose (*Herpestes urva*), and common palm civet (*Paradoxurus hermaphroditus*). Most of the forests are dry evergreen forests, moist evergreen forests, and hill evergreen forests. Some areas are covered by the grasslands formed by shifting cultivation in the past. Temperature and rainfall conditions from the Mo Singto measurement point inside KYNP showed the average temperature throughout the year is about 21°C; the highest temperature is between April and May. The highest average temperature is about 27°C and during December and January, it is the coldest season. Temperatures can drop below 10°C. The air is dry and windy. The average annual rainfall is 2338.16 millimeters per year, with the heaviest rainfall from May to October. September has the most rainfall at 426.16 millimeters. The average year-round temperature of KYNP is 21.28°C, the highest temperature in April averages 30.33°C and the lowest in January averages 12.25°C. The average relative humidity of KYNP was an average of 66% (Khao Yai National Park 2021).

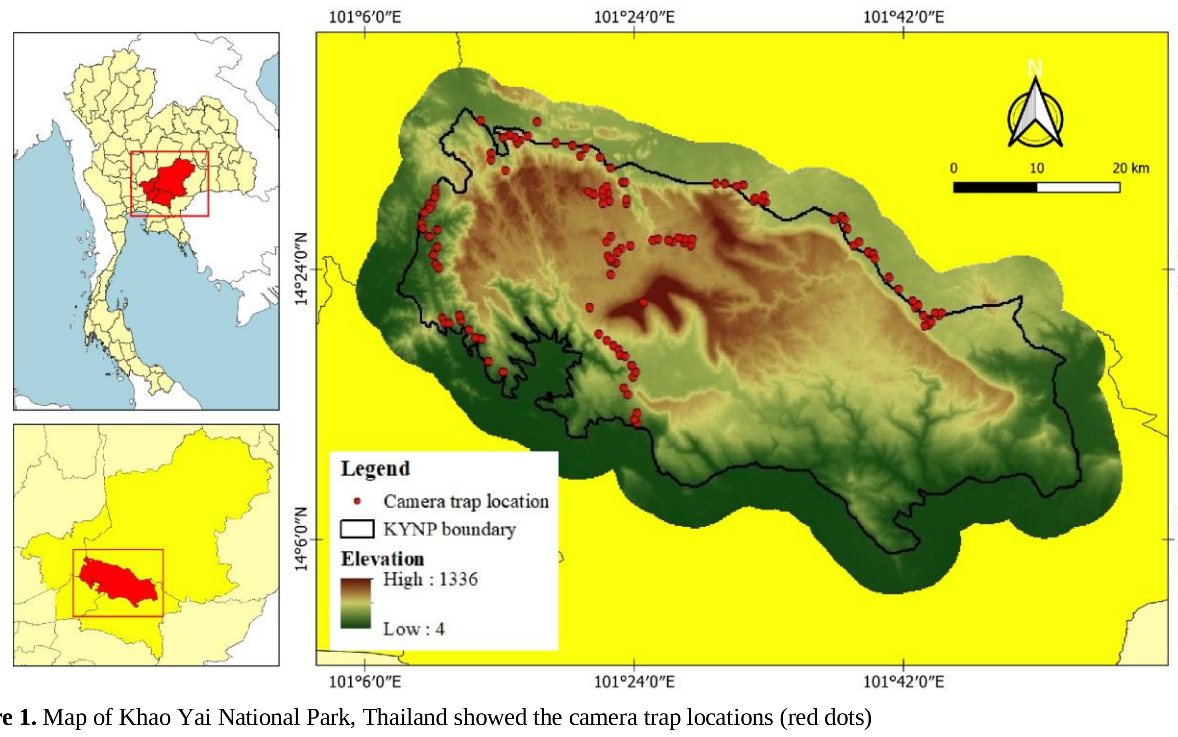

Figure 1. Map of Khao Yai National Park, Thailand showed the camera trap locations (red dots)

Procedures

This study was implemented in KYNP between November 2017 and March 2020, by using the installation of 20 automatic camera traps (Trail Camera Model Essential E3 16MP resolution) alternately including the number of the camera location. Camera traps were set up to take pictures in 115 locations, totaling 4139 trap nights. The detailed method of study was as follows: the focus was on 1 square grid on the topographic map (1: 50,000), so each square covered an area of 1 km^2. For the installation of camera traps, 1 camera was placed per 1 grid square. Camera traps were installed in areas of 15-20 grids at a time for a period of 30 days in each location and then moved to install in a new location. Typically, each camera trap installation location was more than 500 meters apart in order to independently obtain images in each grid square to reduce the probability of photographing the same animal using multiple cameras. The locations of camera traps and the study area was shown in Figure 1.

Selecting a camera trap location involves considering the suitability of each area, such as animal checkpoint path traces of carnivores. Each camera trap location was recorded with a global positioning system instrument (GPS). The camera trap was placed on about 30-40 centimeters above the ground, 3-4 meters away from the target area approximately. When motion sensors detect an animal, 3 images were taken, spaced every 10 seconds, 24 hours a day. Camera traps were set up for 30 days. After 30 days, the camera traps were moved to a new location. Photos were taken from a memory card to a computer and the images were classified with the Camera Trap Manager Program (Zaragozi et al. 2015) and imported into Microsoft Excel for further analysis.

Data analysis

Identification of the photographed species using the common name and scientific names after Lekagul and McNeely (1988) where only clearly identifiable images had the date and time shown on the photograph. Pictures with more than one species in the same image count as one event (Jenks et al. 2011) and were considered as independent figures or events. The criteria for independence of animal photographs were: (i) consecutive images of different animals; maybe of the same species or different species; (ii) consecutive images of the same animal of the same species, more than 30 minutes apart; (iii) discrete images of the same animal of the same species (O'Brien et al. 2003).

In summarizing the data for the active periods obtained from the camera trap, data were combined and classified by type by dividing the time periods between 06: 01-17: 59 as the daytime and between 18: 00-06: 00 as the night time. The values were taken to generate the data graph of the carnivores' survival times and other types of wild animals that were prey. These data are then studied to classify carnivorous wildlife according to the time shown in the photographs, which can be termed differently into five groups (van Schaik and Griffiths 1996). If the number of night shots was greater than 85%, they were grouped with a strong nocturnal pattern. The number of nighttime images between 61 and 84% was classified as having a mostly nocturnal activity pattern. At night (mostly nocturnal), the number of images during the night and during the day was between 40 and 60%, grouped with a cathemeral overlapped pattern of activity. The number of daytime images of between 61% and 84% are grouped with mostly diurnal activity patterns and more than 85% of daytime images were grouped with strongly diurnal activity patterns. To obtain spatial and temporal pattern data, camera trap positions are used to take pictures where wildlife is present (1) and not present (0), along with a record of the time when wildlife was found for each hour of the day. Number of event in each hour in the case of temporal analysis and the number of the event in each camera location of each species were used to calculate Spearman's rank correlation coefficient with dhole using SPSS 16.0 program (IBM Corp. Released 2016), both the $P \leq 0.05$ and $P \leq 0.01$ significance levels were considered.

The mean time spent with wildlife was analyzed using independent images (O'Brien et al. 2003) and a 95% confidence interval using ORIANA version 4.02 (Kovach 2011). The activity periods were analyzed using R programs (R Core Team 2021), overlap routines (Meredith and Ridout 2021) and circular packages (Agostinelli and Lund 2017) to compare the activity times of the dhole and compare between potential prey species in the Khao Yai National Park by calculating the overlap coefficient (Δ) by the Kernel density function (Ridout and Linkie 2009; Linkie and Ridout 2011).

Degree of temporal overlap was calculated, where 1 means complete overlap and 0 means no overlap. The overlap coefficient is calculated using $\Delta 1$ for small amounts of data and $\Delta 4$ for larger amounts of data greater than 50 (Ridout and Linkie 2009; Meredith and Ridout 2014). The validity of the study was obtained by calculating a 95% confidence interval of 10,000 bootstrap samples to determine the degree of overlap in time scales used according to Lynam et al. (2013), who stated that if the coefficient of overlap was ≤ 0.5, the overlap was low, between 0.5-0.75 the overlap was moderate, and if the coefficient of overlap was ≥ 0.75 that indicates that the overlay was high.

The overlap index between potential prey species based on the co-appearance information for each camera position and appearances at different times of the day and hours between the dhole and potential prey species were calculated as well as calculating the overlap index from the temporal superposition coefficient to determine the overlap with potential prey wildlife using Pianka's prey overlap index from the formula:

$$\frac{\sum_i^n P_{ij} P_{ik}}{\sqrt{\left(\sum_i^n P_{ij}^2\right)\left(\sum_i^n P_{ik}^2\right)}}$$

Where, P_{ij} is the percentage of prey species i of predator j, P_{ik} is the percentage of prey species i of predator k. Pianka's index varies between 0 (total separation) and 1 (total overlap). We used this index to enable comparisons with other studies (Zapata et al. 2003). Analysis of niche overlaps between the most common species was based on classical Pianka's index (Pianka 1973). Program R (R Core Team 2021) and SPAA-package or Species Association Analysis package)Zhang 2016) was used in the analysis.

Ecological and anthropogenic covariates

We examined covariates related to the distribution of the dhole and the physical factors: (i) elevation; (ii) distance to the nearest village; (iii) distance to the nearest road; (iv) slope; (v) distance to the nearest stream (Table 1). Package 'rgdal' was successfully unpacked and MD5 sums checked were used. We used single-season, single-species occupancy models in Program PRESENCE 2.13.10 (MacKenzie et al. 2017) to determine the relationship between covariates related to the presence of humans and main prey species and used the model with the lowest ΔAIC to determine the set of plausible models. Occupancy models suppose the camera station is closed to changes in occupancy during the survey. Our sampling occurred for one month on each occasion, which is a short time relative to the life stage of the prey species; this assumption conformed to the principles of demography (births, deaths). Some species might have overlapped with >1 camera trap station, so the occupancy estimation should be explained as site use rather than occupancy (MacKenzie 2002).

RESULTS AND DISCUSSION

Diversity of species and abundance of dholes

A total of 72 wildlife species were found based on the camera trap study, including 18 order carnivore mammals: dhole, Golden jackal (*Canis aureus*), leopard cat (*Prionailurus bengalensis*), marbled cat (*Pardofelis marmorata*), clouded leopard (*Neofelis nebulosa*), Asiatic golden cat (*Catopuma temminckii*), large spotted civet, large Indian civet (*Viverra zibetha*), common palm civet, small Indian civet, binturong (*Arctictis binturong*), crab-eating mongoose (*Herpestes urva*), Malayan sun bear, Asiatic black bear, greater hog badger (*Arctonyx collaris*), yellow-throated marten (*Martes flavigula*), smooth-coated otter (*Lutrogale perspicillata*), small Indian mongoose (*Herpestes javanicus*). Non-carnivorous wildlife includes 18 species: Asian elephant, sambar deer, northern red muntjac, wild boar (*Sus scrofa*), gaur, mainland serow, lesser oriental chevrotain, Malayan porcupine (*Hystrix brachyura*), Asiatic brush-tailed porcupine (*Atherurus macrourus*), long-tailed giant rat (*Leopoldamys sabanus*), variable squirrel (*Callosciurus finlaysonii*), gray-bellied squirrel (*Callosciurus caniceps*), Berdmore's squirrel (*Menetes berdmorei*), northern tree shew (*Tupaia belangeri*), northern pig-tailed macaque (*Macaca leonina*), common long-tailed macaque (*Macaca fascicularis*), and Burmese hare (*Lepus peguensis*). Furthermore, 34 species of ground-dwelling birds can be photographed, the most common being the Siamese fireback (*Lophura diardi*), red junglefowl (*Gallus gallus*), silver pheasant (*Lophura nycthemera*), grey-capped emerald dove (*Chalcophaps indica*), white-crested laughing thrush (*Garrulax leucolophus*), common hill myna (*Gracula religiosa*), red turtle-dove (*Streptopelia tranquebarica*), and red-wattled lapwing (*Vanellus indicus*) in chronological order. There are two types of reptiles found, namely Bengal monitor lizards (*Varanus bengalensis*) and common monitor lizards (*Varanus salvator*). The most abundant species based on camera traps recorded was gaur, 14.9%, followed by wild boar (10.94%), Siamese fireback (9.71%), sambar deer (8.98%), Asian elephant (7.44%), red junglefowl (6.9%), lesser oriental chevrotain (5.92%), northern red muntjac (5.53%), Malayan porcupine (3.72%) and dhole (3.28%) respectively. The dhole was the carnivorous animal with the highest naïve occupancy value, followed by leopard cat, large Indian civet, common palm civet, golden jackal, etc., as detailed in Table 2.

Spatial and temporal overlap

There were significant spatial and temporal overlaps of dhole with five wildlife species in the area: large Indian civet, Malayan porcupine, northern pig-tailed macaque, sambar, and wild boar. It was found that the dhole had a significant spatial overlap and there was also significant temporal overlap with potential prey species. In the case of the only significant spatial overlap, six species were found: the black-naped oriole (*Oriolus chinensis*), common palm civet, blue pitta (*Hydrornis cyaneus*), greater hog badger, greater racket-tailed drongo (*Dicrurus paradiseus*), and large-spotted civet. The result showed significant negative spatial overlap with the Asian palm civet, greater hog badger, and large-spotted civet and showed significant positive spatial overlap with the black-naped oriole, blue pitta, and greater racket-tailed drongo.

Table 1. Factors hypothesized to influence of detection probability and occupancy of the dhole in Khao Yai National Park, Thailand

Covariate	Description	Source	Reference
ROAD	Proximity to the road (m.)	GIS database	Jenks et al. (2011)
VILL	Proximity to villages (m.)	GIS database	Jenks et al. (2011)
STREAM	Proximity to the stream (m.)	GIS database	Jenks et al. (2011)
ELEV	Elevation (m. above sea level)	GIS database	Jenks et al. (2011)
SLOPE	Slope (%)	GIS database	Jenks et al. (2011)

Table 2. The abundance of dhole and other species in Khao Yai National Park, Thailand based on the 115 camera trap locations conducted between October 2017 and March 2020, a total of 4139 trap-nights

Common name	Scientific name	No. of events	No. of locations found	Naïve occupancy	RAI (%)
Carnivorous mammal					
Dhole	*Cuon alpinus*	136	22	0.19	3.28
Golden Jackal	*Canis aureus*	59	13	0.11	0.31
Leopard Cat	*Prionailurus bengalensis*	37	21	0.18	0.89
Marbled Cat	*Pardofelis marmorata*	2	2	0.01	0.04
Clouded Leopard	*Neofelis nebulosa*	2	2	0.01	0.04
Asiatic Golden Cat	*Catopuma temminckii*	1	1	0.01	0.02
Large-spotted Civet	*Viverra megaspila*	52	10	0.08	1.25
Large Indian Civet	*Viverra zibetha*	31	18	0.15	0.74
Common Palm Civet	*Paradoxurus hermaphroditus*	26	16	0.13	0.62
Small Indian Civet	*Viverricula indica*	17	8	0.06	0.41
Binturong	*Arctictis binturong*	2	1	0.01	0.04
Crab-eating Mongoose	*Herpestes urva*	19	9	0.07	0.45
Small Indian Mongoose	*Herpestes javanicus*	18	8	0.06	0.43
Sun Bear	*Ursus malayanus*	12	8	0.06	0.28
Asiatic Black Bear	*Ursus thibetanus*	11	9	0.07	0.26
Greater Hog Badger	*Arctonyx collaris*	30	11	0.09	0.72
Yellow-throated Marten	*Martes flavigula*	10	6	0.05	0.24
Smooth-coated Otter	*Lutrogale perspicillata*	3	1	0.01	0.07
Non carnivorous mammal					
Asian Elephant	*Elephas maximus*	308	72	0.62	7.44
Sambar	*Rusa unicolor*	372	52	0.45	8.98
Northern Red Muntjac	*Muntiacus vaginalis*	229	47	0.40	5.53
Wild Boar	*Sus scrofa*	453	44	0.37	10.94
Gaur	*Bos gaurus*	617	35	0.30	14.90
Mainland Serow	*Capricornis sumatraensis*	9	5	0.04	0.21
Lesser Oriental Chevrotain	*Tragulus kanchil*	26	11	0.09	5.92
Malayan Porcupine	*Hystrix brachyura*	154	35	0.30	3.72
AsiaticBrush-tailed Porcupine	*Atherurus macrourus*	2	1	0.01	0.04
Long-tailed Giant Rat	*Leopoldamys sabanus*	4	1	0.01	0.09
Rat unknow	*Rattus* spp.	1	1	0.01	0.02
Variable Squirrel	*Callosciurus finlaysonii*	14	4	0.03	0.33
Grey-bellied Squirrel	*Callosciurus caniceps*	7	6	0.05	0.16
Berdmore's Squirrel	*Menetes berdmorei*	6	2	0.01	0.14
Northern tree shew	*Tupaia belangeri*	4	3	0.02	0.09
Northern Pig-tailed Macaque	*Macaca leonina*	113	29	0.25	2.73
Common Long-tailed Macaque	*Macaca fascicularis*	2	1	0.01	0.04
Burmese Hare	*Lepus peguensis*	30	8	0.07	0.72
Bird					
Siamese Fireback	*Lophura diardi*	402	41	0.35	9.71
Red junglefowl	*Gallus gallus*	286	45	0.39	6.90
Silver pheasant	*Lophura nycthemera*	76	4	0.03	1.83
Grey-capped Emerald Dove	*Chalcophaps indica*	43	13	0.11	1.03
White-crested Laughingthrush	*Garrulax leucolophus*	36	10	0.08	0.86
Great Myna	*Acridotheres grandis*	30	3	0.02	0.72
Red Turtle-dove	*Streptopelia tranquebarica*	29	1	0.01	0.70
Red-wattled Lapwing	*Vanellus indicus*	25	4	0.03	0.60
Eastern Spotted Dove	*Spilopelia chinensis*	22	7	0.06	0.53
Thick-billed Green-pigeon	*Treron curvirostra*	18	2	0.01	0.43
Coral-billed Ground-cuckoo	*Carpococcyx renauldi*	14	8	0.06	0.33
Green-legged Partridge	*Arborophila chloropus*	11	5	0.04	0.26
Chinese Pond-heron	*Ardeola bacchus*	9	1	0.01	0.21
Green-backed Heron	*Butorides striata*	7	1	0.01	0.16
Green-billed Malkoha	*Phaenicophaeus tristis*	4	1	0.01	0.09
White-breasted Waterhen	*Amaurornis phoenicurus*	4	1	0.01	0.09
Barred Cuckoo-dove	*Macropygia unchall*	3	2	0.01	0.07
Blue Whistling-thrush	*Myophonus caeruleus*	3	1	0.01	0.07
Crested Serpent-eagle	*Spilornis cheela*	3	2	0.01	0.07
Orange-headed Thrush	*Geokichla citrina*	3	2	0.01	0.07
Red-headed Trogon	*Harpactes erythrocephalus*	3	1	0.01	0.07
Black-headed Woodpecker	*Picus erythropygius*	2	1	0.01	0.04

Blue Pitta	*Hydrornis cyaneus*	2	1	0.01	0.04
Common Green Magpie	*Cissa chinensis*	2	1	0.01	0.04
Greater Racquet-tailed Drongo	*Dicrurus paradiseus*	2	2	0.01	0.04
Asian Fairy-bluebird	*Irena puella*	1	1	0.01	0.02
Black-naped Oriole	*Oriolus chinensis*	1	1	0.01	0.02
Collared Falconet	*Microhierax caerulescens*	1	1	0.01	0.02
Common Hill Myna	*Gracula religiosa*	1	1	0.01	0.02
Western Hooded Pitta	*Pitta sordida*	1	1	0.01	0.02
Malay Night-heron	*Gorsachius melanolophus*	1	1	0.01	0.02
Shikra	*Accipiter badius*	1	1	0.01	0.02
Siberian Blue Robin	*Larvivora cyane*	1	1	0.01	0.02
Siberian Stonechat	*Saxicola stejnegeri*	1	1	0.01	0.02
Reptile					
Bengal Monitor Lizard	*Varanus bengalensis*	2	2	0.01	0.04
Common Water Monitor	*Varanus salvator*	24	8	0.06	0.57
Human activities					
Human	-	137	34	0.29	3.31
Domestic dog	-	328	38	0.33	7.92
Domestic cat	-	1	1	0.01	0.02
Domestic livestock	-	46	2	0.01	1.11

In the case of the temporal overlap, significant positive temporal overlap was found with 12 other wild animals. These were the grey-capped emerald dove, marbled cat, Siamese fireback, yellow-throated marten, leopard cat, Asiatic golden cat, white-crested laughingthrush, domestic dog, livestock or domestic cattle, red junglefowl, blue whistling-thrush (*Myophonus caeruleus*), thick-billed green-pigeon (*Treron curvirostra*), common hill myna, and binturong. There was a significant negative temporal overlap with two other species, Burmese hare and long-tailed giant rat, as shown in Table 3.

Table 3. Temporal and spatial overlaps of dhole and other animals by calculating Spearman correlation coefficient and Pianka's overlap index in Khao Yai National Park, Thailand based on camera trap data during November 2017 and March 2020, 115 camera locations, 4139 trap-nights totally (** P<0.01, * P<0.05)

Variables	Spatial correlation		Temporal correlation	
	Correlation coefficients	**Overlap index**	**Correlation coefficients**	**Overlap index**
Wild Boar	0.41**	0.58	0.56**	0.53
Grey-capped Emerald Dove	0.03 ^{ns}	0.56	0.46*	0.54
Malayan Porcupine	0.25**	0.52	-0.66**	0.21
Large Indian Civet	-0.43*	0.46	0.25**	0.2
Marbled Cat	0.09 ^{ns}	0.43	0.27**	0.16
Siamese Fireback	0.14 ^{ns}	0.33	0.58**	0.68
Human	0.32**	0.28	0.47*	0.53
Yellow-throated Marten	0.04 ^{ns}	0.27	0.28**	0.19
Leopard Cat	-0.22 ^{ns}	0.23	0.24**	0.33
Black-naped Oriole	0.21*	0.2	-0.14 ^{ns}	0.05
Asiatic Golden Cat	-0.14 ^{ns}	0.17	0.20 *	0.05
Common Palm Civet	-0.57**	0.13	0.1 ^{ns}	0.12
Binturong	0.07 ^{ns}	0.12	0.19*	0.21
Blue Pitta	0.19*	0.12	0.07 ^{ns}	0.21
Greater Hog Badger	-0.45 *	0.12	0.12 ^{ns}	0.29
Sambar	0.25**	0.12	-0.45*	0.35
Northern Pig-tailed Macaque	0.20*	0.12	0.42*	0.45
Greater Racquet-tailed Drongo	0.24**	0.1	0.00 ^{ns}	0.11
White-crested Laughingthrush	0.15 ^{ns}	0.1	0.44*	0.58
Domestic Dog	0.13 ^{ns}	0.08	0.43*	0.51
Domestic Cattle	0.09 ^{ns}	0.05	0.46*	0.42
Burmese Hare	0.01 ^{ns}	0.02	-0.51**	0.16
Large-spotted Civet	-0.57**	0.01	0.03 ^{ns}	0.17
Red junglefowl	0.03 ^{ns}	0.00	0.54**	0.21
Long-tailed Giant Rat	-0.07 ^{ns}	0.00	-0.51**	0.01
Blue Whistling-thrush	-0.05 ^{ns}	0.00	0.46*	0.45
Thick-billed Green-pigeon	-0.07 ^{ns}	0.00	0.43*	0.58
Common Hill Myna	-0.08 ^{ns}	0.00	0.44*	0.58

Temporal overlap coefficient of dholes and their prey

The temporal overlap of dholes with their prey in the area was examined. A co-analysis with a group of 8 wild prey species found that one wild animal with a high overlay coefficient (≥0.75) was the wild boar, and four others were moderately overlapped (0.5-0.75), including the northern red muntjac, northern pig-tailed macaque, sambar, and Malayan porcupine, as well as a group of small rodents. Small rodents, which included six small rodent species, were all analyzed: the long-tailed giant rat (*Rattus* spp.), variable squirrel, grey-bellied squirrel, Berdmore's squirrel, northern tree shew, and long-tailed giant rat exhibited moderately overlapped coefficients (≤0.5).

Meanwhile, the lesser oriental chevrotain and four civet species, the large-spotted civet, large Indian civet, common palm civet, and small Indian civet (*Viverricula indica*) were studied, while dholes were found to overlap with tourists. Including the people who came to do various activities, excluding officials and research studies in the park area at a high level (Δ: 0.72) as shown in Table 4.

Daily activity

Analysis of the activity time of the prey wildlife included all 4 species of civets in the same group and a small rodent group consisting of six animal species. Mostly diurnal (MD) activity had a mean activity time of 15: 06. Wild animals are potential prey for hyenas. The activity patterns in the area were mostly diurnal (MD) for 3 types: wild boar had an average activity time of 13.03, deer had an average activity time of 07: 45, and lesser oriental chevrotain had an average activity time of 10: 51 according to pictures. Two strongly diurnal (SD) activity modes appeared for macaques, with an average activity time of 12: 34, and small rodents, while two strongly nocturnal (SN) species were civets, with an average activity time of 00: 23 and Malayan porcupines which had an average activity time of 23: 22. There was one mostly nocturnal (MN) pattern for sambar deer, which had an average activity time of 23: 54 as detailed in Table 5.

Covariate occupancy of dholes and their potential prey

The appearance of dholes using the covariate of potential prey species was determined by coexistence based on the models with the lowest AIC values in each of the analytical models. A correlation was found with small rodents, including the variable squirrel, Berdmore's squirrel, gray-bellied squirrel, northern tree shew, and various rodents, followed by northern red muntjac, Malayan porcupines, civet, sambar deer, wild boar, Lesser Oriental Chevrotain and Northern Pig-tailed Macaque, respectively. It was found that spatial coexistence of dholes correlated with human presence, second only to wild boar as shown in Table 6.

Covariate occupancy of the dhole and physical factors

For the factors affecting the dhole's occupancy when considering five environmental factors, namely natural water resources, roads, villages, elevation above sea level and slope, it was found that water sources and villages and communities had a negative effect on the area occupancy of the dhole, meaning that in the areas near water sources and communities, the incidence of dholes increased.

Table 4. The calculated temporal overlaps coefficient (Δ) using Kernel density functions of dhole (n: 136) and the other species activity sampled via camera trapping during November 2017 to March 2020, in Khao Yai National Park, Thailand, (1: identical activity), with approximate 95% bootstrap confidence intervals (BCI)

Species	n	Δ	95% BCI
Wild boar	372	0.81	0.69-0.91
Northern red muntjac	229	0.72	0.60-0.84
Small rodent	36	0.72	0.50-0.91
Malayan porcupine	154	0.56	0.44-0.68
Northern Pig-tailed Macaque	113	0.58	0.45-0.70
Sambar	453	0.56	0.44-0.68
Civet	136	0.37	0.27-0.56
Lesser oriental chevrotain	28	0.36	0.15-0.58
Human (tourists and villages)	137	0.72	0.61-0.83
Domestic dog	328	0.75	0.63-0.87

Table 5. Activity periods of dhole and the other species from camera trap in Khao Yai National Park, Thailand

Species	N [1]	Mean hour (degree)	SE (degree)	%Day time (Total)	Activities pattern [2]
Dhole	143	15: 06	00: 35	76.92	MD
Sambar	453	23: 54	00: 21	18.54	MN
Wild Boar	372	13: 03	00: 12	83.20	MD
Northern Red Muntjac	229	07: 45	00: 56	60.15	MD
Malayan Porcupine	154	23: 22	00: 19	14.28	SN
Northern Pig-tailed Macaque	113	12: 34	00: 19	98.75	SD
Civet	136	00: 23	00: 21	11.76	SN
Small Rodent	36	12: 58	01: 20	91.17	SD
Lesser Oriental Chevrotain	28	10: 51	01: 21	78.57	MD
Human (tourists and villages)	137	12: 20	00: 22	83.94	MD
Domestic dog	328	10: 48	00: 15	87.56	SD

Note: 1) number of independent photos; 2) the daily activity of species was classified based on the percentage of diurnal activity (06: 00-17: 59): strongly diurnal (SD) (≥ 85%), mostly diurnal (MD) (84-61%), cathemeral (CM) (60-40%), mostly nocturnal (MN) (39-16%) and strongly nocturnal (SN) (≤15%)

Meanwhile, the dhole's occupancy of the area is in line with the roads within the area, the elevation and slope, which are positive. For locations near the road in areas with very steep slopes and in high altitude areas, dholes occupy more space in the area. In considering the most suitable equation for predicting the appearance of dholes, it was found that although physical environmental factors had a significant effect on the appearance of the dhole, the priority of the appearance of the dhole was based on the slope of the area, distance from the village, and roads, respectively, considering the AIC values, from the lowest values to the highest. But all the equations were significant (P<0.01), as detailed in Table 7 and Figure 2.

Table 6. Comparison of co-occurrence models for dhole in Khao Yai National Park, Thailand, based on camera trapping

Variable	AIC	Δ AIC	AIC wgt	Model likelihood	K	-2LL
Dhole-Small Rodent (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	153.78	0.00	1.00	1.00	17	119.78
Dhole-Northern Red Muntjac (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	490.68	0.00	1.00	1.00	17	456.68
Dhole-Malayan Porcupine (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	508.65	0.00	1.00	1.00	17	474.65
Dhole-Civet (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	514.74	0.00	1.00	1.00	17	480.74
Dhole-Sambar (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	525.52	0.00	1.00	1.00	17	419.52
Dhole-Wild Boar (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	526.83	0.00	1.00	1.00	17	492.83
Dhole-Human (tourists and villages) (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	527.13	0.00	1.00	1.00	17	493.13
Dhole-Lesser Oriental Chevrotain (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	577.79	0.00	1.00	1.00	17	543.79
Dhole-Northern Pig-tailed Macaque (ψBA, ψBa,thA,thA',thBA,thBA',thBa,thBa', pA,pB,rA,rBA,rBa,th0pi)	656.07	0.00	1.00	1.00	8	640.07

Note: AIC: Akaike's Information Criterion; Δ AIC: the relative change in AIC value compared with the top model; AIC wgt: AIC weight; K: number of estimated parameters; 2LL: 2 log-likelihood. ψ: occupancy probability; p: probability of detecting a species given only one species is present; r: probability of detecting a species given both species are present. A: dominant species is present. B: subordinate species is present. a: dominant species is absent

Table 7. Model selection for effect of covariates on occupancy probability of dhole in Khao Yai National Park, Thailand

Intercept (SE)	Estimate (SE)					Detection (SE)	AIC	P
	Stream	Road	Village	Elevation	Slope			
-0.63 (0.29)	-	-	-	-	0.20 (0.18)	-2.87 (0.29)	397.08	2.70E-22
-0.63 (0.29)	-	-	-0.11 (0.20)	-	-	-2.88 (0.29)	397.87	3.50E-23
-0.63 (0.29)	-	0.049 (0.23)	-	-	0.21 (0.19)	-2.87 (0.29)	399.03	2.33E-22
-0.67 (0.30)	-0.004 (0.22)	0.004 (0.24)	-0.27 (0.25)	0.33 (0.28)	0.15 (0.21)	-2.91 (0.30)	403.30	4.79E-21

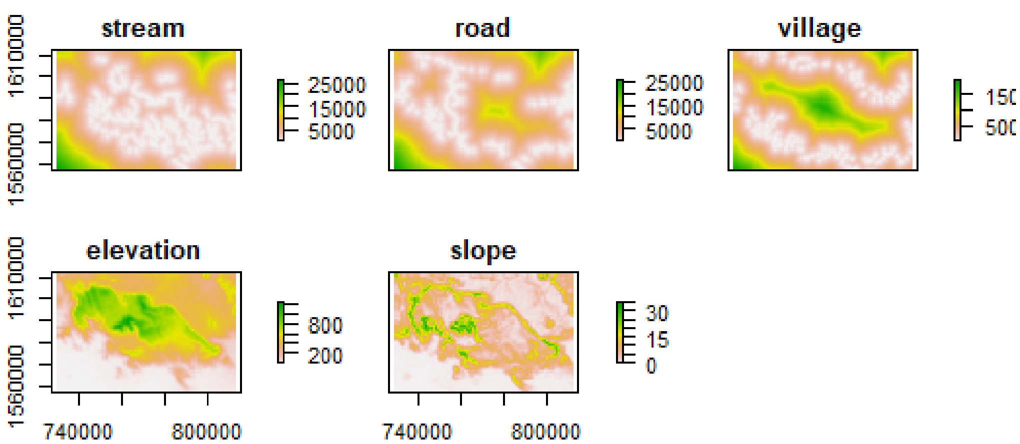

Figure 2. Raster of covariates for occupancy analysis in Khao Yai National Park, Thailand

Discussion

Coexistence of mammalian carnivores with the main prey is a behavioral adaptation between species according to the mechanism of existence in the ecosystem (Rossa et al. 2021). This study found that the dhole had a significant spatial and temporal overlap with the main prey species significantly. Kamler et al. (2012); Hayward et al. (2014); Nurvianto et al. (2015); Charaspet et al. (2020) reported prey species of dholes in the study areas based on scat analysis revealed that they also consisted of small rodents but found in small quantities. The results of this study found the abundance of six small rodent species obtained by camera traps, representing a percentage relative abundance of 0.83. Kamler et al. (2012) found that dholes in the Nam Et-Phou Louey National Reserve in Lao PDR fed on a total of 72.2 prey individuals, most of which (54.6) were small rodents, confirming the importance of small rodents in the ecosystem.

The covariate occupancy model of dholes in the area was most closely related to small rodents, followed by barking deer, porcupines, spotted civets, sambar deer, wild boar, and northern pig-tailed macaque, respectively, showing the important role of small rodents found in the area. Small rodents are prey for dholes and other carnivores found in the area, including the leopard cat, marbled cat, clouded leopard and Asiatic golden jackal, consistent with Mwebi et al. (2019), who reported that wolf and leopard excrement in Kenya consisted of small rodents amounting to 87.9-90.9% of the number found.

Chanachai (2022) reported species and populations of small rodent communities in the evergreen forest in KYNP using systematic cage traps and tags with microchips. A total of 32,555 trap nights totally were placed in the area between June 2019 and June 2020. Nine species of small rodents were captured, totaling 412 individuals of the four genera. There were 216 red spiny rats (*Maxomys surifer*), followed by 70 Indochinese ground squirrels (*Menetes berdmorei*), 44 Himalayan striped squirrels (*Tamiops mcclellandii*), 26 long-tailed giant rats (*Leopoldamys sabanus*), 22 Tanezumi rats (*Rattus tanezumi*), 20 chestnut white-bellied rats (*Niviventer fulvescens*), 22 Savile's bandicoot rats (*Bandicota savilei*), 12 northern treeshrews (*Tupaia belangeri*), and 1 short-tailed gymnure (*Hylomys suillus*) that showed the high diversity and abundance of small rodents has a notable effect on the appearance of dholes and other medium size carnivorous mammals in Khao Yai National Park.

The occupancy model of dholes showed that slope, village, and roads had the greatest effect on the appearance of dholes, in order. It was found that villages and roads were environmental factors affecting the appearance of dholes. The occupancy model showed that the slope had the greatest effect on the appearance of the dhole. Sloping areas or wilderness areas are safe areas for dholes. However, further study of the relationship of the presence of dholes with slopes should be studied. The combination of five environmental factors together were natural water resources, roads, villages, elevation above sea level, and slope. These had the least effect on the appearance of dholes based on AIC values; however, the model showed significant differences.

Thing et al. (2022) analyzed environmental factors affecting the appearance of dholes in Parsa National Park, Nepal, and found that the grassland area, wilderness area and sambar deer had a positive effect on the appearance of dholes. Meanwhile, the water source is a factor that negatively affects the appearance of the dhole, consistent with this study. Namgyal and Thinley (2017) reported another factor influencing the appearance of dholes is a village, with a percentage contribution of 61%. Closer to the community, dholes appeared more frequently, which yielded the same results as this study.

Human activities along the boundaries of the park have negatively affected the territorial possession of all carnivores (Lewis et al. 2021). Roads and walkways in the forest are included, although these are not highly exploited since they also have a high negative impact on the possession of most carnivores. In addition, the overall level of disturbance within protected areas, particularly tourism, influences carnivorous wildlife, which is more susceptible to variables caused by human disturbance. Increasing tourism in protected areas has partly transformed carnivorous communities (Baker and Leberg 2018).

Nurvianto et al. (2015) reported the impact of human activity on dholes as a significant factor. Therefore, reducing the affinity for human activities and ensuring the availability of natural prey for the dhole is a key factor in preserving the long-term survival of this carnivore in its natural habitat.

The presence of the dhole was significantly related to the distance to villages and the distance to water sources. In addition, the appearance of dholes was also correlated with the presence of small rodents. In general, populations of small rodents, especially rats (*Rattus* spp.), respond positively to human activities. In particular, the populations increase in areas with human activities or in recreational areas within national parks. Radley et al. (2021) reported rat detection probability and site occupancy were significantly higher on tourists visited compared to tourist-free areas. This may affect the changes in the behavior of carnivorous mammals which enter the tourist recreation areas within the central of the KYNP. Therefore, it is necessary to have measures for the disposal of debris and food waste in the areas that can cause wildlife behavioral changes that have both direct and indirect effects in the long term.

The temporal overlap analysis revealed that dholes overlapped with humans who entered the area with an overlap coefficient of 0.72. They also overlapped with livestock at 0.87 and overlapped with free-ranging dogs at 0.75, indicating a high risk of disease spread from livestock and free-ranging dogs encountering the wild species. Free-ranging dogs negatively interact with wildlife, mainly by predation and disease spread (Hughes and Macdonald 2013). Weng et al. (2022) reported the incursion of free-ranging dogs into protected areas. The occupancy models indicated that the presence of domestic dogs negatively affected the occurrence probability of all local species except for the yellow-throated marten. There is an urgent need for nature reserves within the area, and possibly elsewhere, to consider domestic dogs as a significant human disturbance. It is necessary to tighten the management of free-ranging dogs and other livestock in residential areas near nature reserves to avoid future human-wildlife conflicts. Kamler et al. (2020) report that the causes of the extinction of dholes in Southeast Asia are a decrease in prey, loss of habitat, and disease transmission from free-ranging dogs or free-ranging cats in the forest. Because of the pack nature of the dhole, there is a high chance of disease transmission in the whole population. This is a silent threat that is threatening the existence of the remaining carnivorous species.

Recommendations for the park management for the species conservation must be focused on tourism management in natural areas that requires measures to reduce disturbances in all dimensions, both in traveling on the highway through the middle of the area and for camping in the area where it is necessary to reduce noise and actions that cause various food odors. Disposal of food waste in areas that lead to wildlife behavioral changes in both large wild animals and small wildlife species can have both direct and indirect effects on the long-term behavior of carnivorous wildlife and long-term ecosystems. Area management, including grassland resources and saltlick operations, should be carried out away from areas of human activity to reduce the chances of wildlife coming close to human activity areas. Domestic livestock and also domestic dogs should be prohibited from entering the area should be prohibited strictly.

The study found 72 species of wildlife in the park from camera traps, with the dhole being the most predominant carnivore in the area. It was found that dholes coexisted temporally and spatially with five species, namely the large Indian civet, Malayan porcupine, northern pig-tailed macaque, sambar deer, and wild boar.

Humans, comprising tourists and some groups of villagers who go into the area illegally, also significantly coexisted both temporally and spatially with the dhole. The results also showed that the dhole had a significant positive temporal or spatial coexistence with 20 other wildlife species. In the case of temporal overlapping, it was shown that wild boar had the highest overlap coefficient, followed by northern red muntjac, small rodents, humans (tourists and villagers), Malayan porcupine, northern pig-tailed macaque, sambar deer, and lesser oriental chevrotain respectively. In the case of the physical factors that covariate negatively with occupancy of the dhole, the most significant were water sources and villages. There are positive covariates of occupancy, including roads, elevation, and slope. The present study found that the dhole's occupancy equation was most closely related to the small rodents. This pointed out the important role of small rodent groups in the ecosystem of the park, followed by northern red muntjac, Malayan porcupine, civet, northern Pig-tailed macaque, sambar deer, wild boar, and lesser oriental chevrotain respectively. Recommendations from the results of this study are as follows: strict management of recreation areas is necessary, along with the development of boundaries between human activity areas and natural areas. Wild animals must be prevented from entering the areas designated for human recreational activities. Activities that result in human-wildlife interactions must be controlled in order to avoid long-term behavioral changes due to tourism. It is also necessary to control the use of highways through national parks and to determine the number of tourists and the number of cars permitted into the areas. Speed control of car traffic should be enforced to reduce accidents with wildlife crossing, including controlling humans who go into the area illegally to collect forest products and some wildlife species poaching of some villagers who live around the national park. This includes bringing both livestock and domestic dogs to enter the area. Free-ranging dogs should be controlled to reduce interactions of the anthropogenic factor with wildlife.

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