

# Mapping the distribution of dholes, *Cuon alpinus* (Canidae, Carnivora), in Thailand

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## Abstract

No recent attempt has been made to survey dhole distribution, or to estimate remaining population numbers. We surveyed 15 protected areas in Thailand with camera traps from 1996 to 2010. We used the photo locations of dholes (n=96) in the maximum entropy (MaxEnt) model along with six environmental variables to model current dhole distribution, as well as species predictive occurrence layers for sambar, red muntjac, wild boar, tiger, and leopard. The MaxEnt model identified

the predicted probability of the presence of leopards and sambar as positive and the most important variables in modeling dhole presence, indicating that maintaining a sufficient prey base may be the most important factor determining continued survival of dholes. Roughly 7% of the total land area in Thailand is potentially suitable for dholes. However, surveys to date have focused on protected areas, which make up just a third of the potential suitable areas for dholes. Only in four protected areas do they occur across the entire landscape, suggesting that in the majority of places where they occur, habitats are not uniformly suitable. Using the model, we identified several potential areas where dholes have not been reported, and therefore status surveys are needed, and where future research of the species might be focused.

**Keywords:** *Cuon alpinus*; MaxEnt; maximum entropy modeling; Southeast Asia; species distribution modeling.

## Introduction

The dhole *Cuon alpinus* (Pallas 1811) is a medium-sized social canid that once occurred over a wide geographic range from the Tian-Shan and Altai Mountains in central Asia and easternmost Siberia to India and Indochina (Cohen 1978, Durbin et al. 2004). Although listed as endangered [International Union for Conservation of Nature and Natural Resources (IUCN) 2008], little is known about current dhole population sizes and distribution across its current geographic range. India is thought to be the current stronghold for dholes, although existing information on the species primarily stems from Johnsingh's 1976–1978 field study in Bandipur and his 1985 census of dholes using questionnaire surveys (Johnsingh 1981, 1985), which only covered as far east as Myanmar and is now out of date. In an attempt to map the dhole's range in 1993, Stewart (1993) conducted interview surveys across Southeast Asia but was unable to locate dholes in Thailand. The most up-to-date distribution map of this species was compiled from status reports for the 2004 Canid Action Plan; however, this map contains huge tracts of localities with unconfirmed or unknown dhole status (Durbin et al. 2004). No recent attempt has been made to survey dhole distribution or to estimate remaining population numbers.

Our study intends to use established distribution modeling tools to develop and test the first ever distribution map for dhole, an endangered canid species, in Thailand. The results from our research are meant to assist conservation decision makers for prioritizing geographic areas for future dhole surveys, research, management, and conservation. To achieve this, we developed a new and unique approach that

incorporates distribution models of prey and competitor species to significantly increase the predictive power of our distribution models (Anderson et al. 2002, Singh et al. 2009). As Thailand has one of the most extensive protected area systems in the region (Pattanavibool and Dearden 2002), understanding the dholes' distribution in this country should have significant conservation benefits. Our modeling efforts will also advance current understanding of the ecology of dhole and the factors that control this species' geographic distribution in Thailand. Finally, we believe that our approach could be translated to better explore the status and distribution of dhole throughout its geographic range.

Several factors may influence patterns of dhole distribution, including vegetation and landscape structure, food availability, competition with other carnivores, and human population levels (e.g., Morris 1925, Prater 1965, Barnett et al. 1980, Johnsingh 1983). However, a lack of understanding of specific influences on dholes of different environmental and human factors is an impediment to managing their populations in Asian protected areas.

Vegetation type does not seem to constrain dhole distribution as they occur across a wide range of land cover types, including tropical dry and moist deciduous forest, evergreen and semi-evergreen forests, low scrub interspersed with bamboo, grasslands, and alpine steppe (e.g., Peplow 1947, Barnett et al. 1980, Johnsingh 1981, 1983); dholes even inhabit open country in Ladak and Tibet (Prater 1965). Johnsingh (1981) suggested that dholes may prefer open forest to dense forest and the moist deciduous forests of India may represent optimal habitats (Phythian-Adams 1949). In an Indian study that applied occupancy models to data from country-wide experts, the best model for predicting dhole occupancy included covariates for evergreen, temperate, and deciduous land cover with low and mid elevations (Karanth et al. 2009). However, it is possible that dholes' apparent vegetation preferences are actually the result of prey distributions and avoidance of competing predators (Johnsingh 1981).

Dhole prey selection varies throughout the range, but they often tend to focus on medium to large ungulates. Sambar (Kerr 1792) (*Rusa unicolor*), Wild boar (Linnaeus 1758) (*Sus scrofa*), Tahrs (C.H. Smith 1826) (*Hemitragus jemlahicus*), Muntjac (*Muntiacus* spp.), Chital (Erleben 1777) (*Axis axis*), Markhors (Wagner 1839) (*Capra falconeri*), Musk deer (*Moschus* spp.), and Goral (*Naemorhedus* spp.) have all been recorded among dhole prey items (e.g., Morris 1925, Prater 1965, Barnett et al. 1980, Johnsingh 1983). Yet, in Mudumalai Wildlife Sanctuary in India, hares and rodents comprised 46% of the dholes' diet (Barnett et al. 1980), while in Taman Negara National Park in Malaysia, 78% of dhole scats contained mouse deer [(F. Cuvier 1822) (*Tragulus napu*) and (Osbeck 1765) (*Tragulus javanicus*); Kawanishi and Sunquist 2008]. This indicates that dholes may be able to rely on smaller prey items in areas where ungulate populations have declined.

Dholes are sympatric with tigers (Linnaeus 1758) (*Panthera tigris*), leopards (Linnaeus 1758) (*Panthera pardus*), and jackals (Linnaeus 1758) (*Canis aureus*) throughout Southeast Asia (Johnsingh 1992) and with wolves (Linnaeus 1758)

(*Canis lupus*) in China and India (Johnsingh and Yoganand 1999), begging the question of whether dholes compete with other carnivores for shared prey. Johnsingh (1992) identified 13 parameters that enabled tiger and dholes to coexist, and partitioning of prey selection was identified as the top factor (Karanth and Sunquist 2000). Although prey partitioning may enable coexistence of tigers and dholes, interguild predation, i.e., direct predation of the smaller by the larger carnivore, may lead to greater separation. In our case, this would mean the distribution and abundance of larger, potentially competing carnivore species may restrict dhole habitat selection (Woodroffe and Ginsberg 2005). Examples of this include cases where dholes have been killed by tigers and attacked by leopards (e.g., Johnsingh 1983, Karanth and Sunquist 2000, Lynam et al. 2001), indicating both larger carnivores may be behaviorally dominant over dholes. Moreover, Venkataraman (1995) argues that dholes need to be aggressive toward leopards as a defense against leopard attacks on dholes.

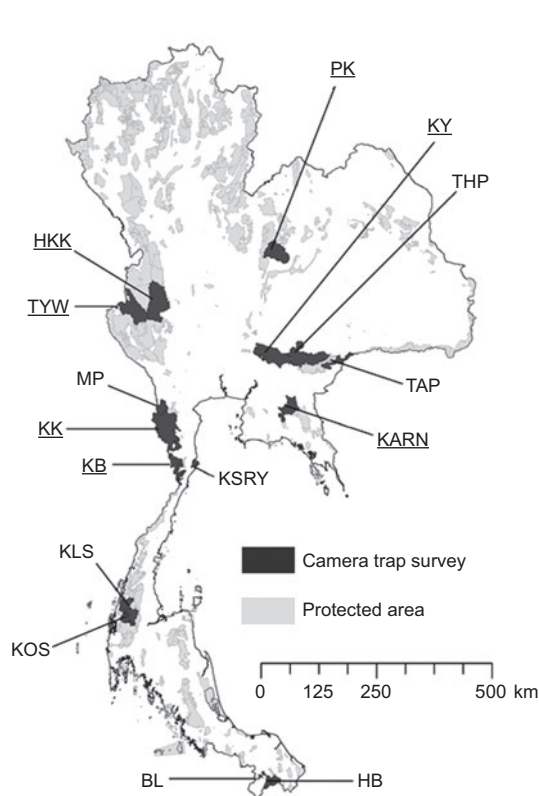
Other dhole habitat considerations include suitable denning sites and proximity to water (Inverarity 1901, Prater 1965), although no study has suggested that den sites are a limiting resource. Dholes are known to hunt sambar by driving them into water bodies (Johnsingh 1983). Dhole distribution may be inversely related to human distribution because the species is sometimes persecuted as livestock predators, prey populations are often reduced by humans, and domestic dogs may transmit diseases (Durbin et al. 2004).

Dholes overlap with other large carnivores throughout their range; however, they probably play a unique ecological role that is not functionally redundant with the roles of other carnivores (Woodroffe and Ginsberg 2005). This implies that dholes have their own unique impacts on prey species and ecosystem processes, and that their conservation is important for maintaining ecological function and community integrity. To explore this influence and better elucidate the ecological role of dholes, managers first need to understand where the species occurs and why. We used data collected from 1996 to 2010 from 15 protected areas to assess potential factors affecting the distribution of dholes in Thailand. Our goals were to (1) confirm the presence of dholes in protected areas in Thailand, (2) identify environmental factors associated with dhole occupancy, (3) predict which areas within the country are within the species' potential distribution, (4) evaluate the efficacy of protected areas in providing sufficient area for viable dhole populations, and (5) identify areas for future research efforts on this endangered species.

## Materials and methods

### Input data

From 1996 to 2010, camera traps were deployed at 15 protected areas within Thailand: Bang Lang National Park (BL), Hala-Bala Wildlife Sanctuary (HB), Huai Kha Kaeng Wildlife Sanctuary (HKK), Kaeng Krachan National Park (KK), Khao Ang Rue Nai Wildlife Sanctuary (KARN), Khao Sam Roi Yod National Park (KSRY), Khao Sok National Park (KOS),



**Figure 1** The study locations included 15 protected areas within Thailand: Bang Lang National Park (BL), Hala-Bala Wildlife Sanctuary (HB), Huai Kha Kaeng Wildlife Sanctuary (HKK), Kaeng Krachan National Park (KK), Khao Ang Rue Nai Wildlife Sanctuary (KARN), Khao Sam Roi Yod National Park (KSR), Khao Sok National Park (KOS), Khao Yai National Park (KY), Klongsaeng Wildlife Sanctuary (KLS), Kuiburi National Park (KB), Maenam Pachi Wildlife Sanctuary (MP), Phu Khieo Wildlife Sanctuary (PK), Ta Phraya National Park (TAP), Thap Lan National Park (THP), and Thung Yai Naresuan-West Wildlife Sanctuary (TYW). Dholes were detected at underlined sites.

Khao Yai National Park (KY), Klongsaeng Wildlife Sanctuary (KLS), Kuiburi National Park (KB), Maenam Pachi Wildlife Sanctuary (MP), Phu Khieo Wildlife Sanctuary (PK), Ta Phraya National Park (TAP), Thap Lan National Park (THP), and Thung Yai Naresuan Wildlife Sanctuary-West (TYW; Figure 1). In total, individual cameras were set at 1174 sites, and accumulated 48,130 trap nights with a mean of 41 trap nights per camera. Camera trap sites were not baited and placed a minimum of 0.5 km apart at elevations ranging from 0 to 1351 m (mean 428 m). All cameras were operational 24 h per day, and recorded time and date for each exposure. Cameras were placed ~50 cm from the ground and close to trails, stream beds, and ridges where wildlife signs (i.e., foot prints and scats) were present to maximize the chances of capturing an animal.

### Habitat variables

We used six environmental variables across Thailand, together with the predicted occurrence of three prey species, and the

predicted occurrence of potential competitors (tigers and leopards), to model dhole distribution. For assessing the potential distribution of prey and competitor species, independent probability of occurrence models were developed using maximum entropy (MaxEnt). Following the modeling procedure for dholes described below, we first produced predicted occurrence layers for three prey species (*Sambar*, *Red muntjac*, and *Wild boar*) on the basis of locations where the species were photo-trapped. The predicted occurrence layers are a surrogate for prey availability or abundance. The resulting layers were included as predictor variables in the tiger, leopard, and dhole models. Additionally, the output layer for *Tiger* and *Leopard* was included as a variable for the dhole model. Presence records used for training included sambar ( $n=124$ ), red muntjac ( $n=271$ ), wild boar ( $n=184$ ), tiger ( $n=80$ ), and leopard ( $n=100$ ). We are assuming that the inclusion of prey and competitors linked with environmental variables (Anderson et al. 2002, Singh et al. 2009) will result in a better spatial representation of the distribution of dholes, which cannot be substituted by only using environmental variables. Because MaxEnt does not use a statistical regression, but an optimization, collinearity and correlation of variables are not used in the theoretical analysis of MaxEnt. It is therefore more stable regarding correlated variables (Elith et al. 2011) and unnecessary to create separate abiotic and biotic models.

Annual precipitation (1950–2000) and elevation was obtained from the WorldClim database (version 1.4, <http://www.worldclim.org>). General country-wide land cover categories and distances to nearest protected area edge, village, and stream were obtained using ArcMap 9.3 from shape files provided by the Thailand Department of National Parks, Wildlife, and Plant Conservation. Distance to nearest edge was measured from all grid points within a protected area to the boundary, with areas outside of protected areas being assigned a zero value. We consolidated land cover categories from 25 to 14; they were entered as a categorical variable in the model and included agriculture, bamboo, beach forest, dry dipterocarp forest, dry evergreen forest, eucalyptus plantation, grassland, hill evergreen, mixed deciduous forest, moist evergreen forest, pine forest, secondary growth forest, teak plantation, and other.

### Distribution modeling

Locations at which dholes were photo-trapped ( $n=96$ ) were the source of data for MaxEnt (Phillips et al. 2006). MaxEnt estimates a frequency distribution by finding the distribution that is closest to uniform, constrained by the average values for a set of variables taken from the target distribution (Phillips et al. 2006). We used MaxEnt because it performs better than other presence-only modeling techniques (Elith et al. 2006), especially with low numbers of occurrence locations (Papes and Gaubert 2007). This method has been used to develop habitat suitability models for a range of mammals (e.g., DeMatteo and Loiselle 2008, Monterroso et al. 2009, Wilting et al. 2010, Jennings and Veron 2011).

All environmental layers were projected to the Indian 1975 UTM zone 47N to match their coordinates, clipped

to the extent of the boundary of Thailand, resampled to the same cell size of 30 arc-seconds ( $\sim 1 \text{ km}^2$ ), and entered with the occurrence data into MaxEnt version 3.3.3 (<http://www.cs.princeton.edu/~schapire/MaxEnt>). We set the program to run 500 iterations with a convergence threshold of 0.00001, a regularization multiplier of 1, a maximum of 10,000 background points, the output grid format as “logistic,” algorithm parameters set to “auto features,” and all other parameters at their default settings (Phillips and Dudik 2008). The model was trained using a mask to include surveyed protected areas only because we only sampled camera-trap locations. The final distribution map resulted from the model projecting into all of Thailand, including protected areas where we collected no data and outside of protected areas. The model was trained using a mask to include surveyed protected areas only because we only sampled camera-trap locations for prey, competitors, and dholes within protected areas. In this way, our background sample excluded areas that have not been searched (Elith et al. 2011). While extrapolation beyond the area where the data was collected often is an issue in distribution modeling, MaxEnt has consistently performed very well in such applications. We experimented with different threshold values; however, this tends to lead to significant overprediction. On the basis of our experience and published literature, we feel justified in our approach. The outputs also are parsimonious and can serve as a first hypothesis for areas where we may find additional dhole populations or may want to consider potential sites for dhole restoration and recovery. We had the program randomly withhold 25% of the presence locations to test the performance of each model.

Model performance was assessed by the area under the curve (AUC) of the receiver-operating characteristic (ROC) plot (Liu et al. 2005). We calculated standard errors and confidence intervals for each of the models using ROCR (Sing et al. 2009), vcd (Meyer et al. 2010), and boot (Canty and Ripley 2010) packages in R v2.11.1 (R Development Core Team 2010). The data were jackknifed to evaluate each variable’s importance in explaining the observed distribution. The percent contribution of each variable was calculated on the basis of how much the variable contributed to an increase in the regularized model gain as averaged over each model run. To calculate variable permutation, for each variable in turn, the values of that variable on training presence and background data were randomly varied and the resulting change in training AUC is shown normalized to percentages (MaxEnt Tutorial; <http://www.cs.princeton.edu/~schapire/MaxEnt/>). To delineate areas with better than random prediction of dhole presence, we used *a priori* prevalence values (96 dhole detection locations out of 1174 total sampling locations) as the “presence” threshold (0.08 detection). In a review of 12 approaches for choosing a threshold of occurrence, Liu et al. (2005) ranked this prevalence approach as one of the most robust.

## Results

Distribution models for sambar, red muntjac, wild boar, tiger, leopard, and dhole performed well based on the moderately

high ( $>0.80$ ) AUC values (Swets 1988; Table 1). Distance to protected area edge (*Edge*) and annual rainfall (*Rain*) had the highest predictive power for all prey species (Table 2). The probability of presence for prey was higher at lower rainfall locations and at distances closer to the interior of protected areas (graphs not shown).

The variables with the highest percent contribution and permutation importance for the dhole model were *Leopard* and *Sambar* (Table 2). The jackknife test of variable importance shows the highest gain when the variable *Sambar* is used in isolation, which therefore appears to have the most useful information by itself (Figure 2). However, the variable that decreases the gain the most when it is omitted is *Leopard*, which indicates this variable has the most information that is not present in the other variables (Figure 2). The variables *Leopard*, *Sambar*, *Stream*, and *Red muntjac* make up almost 90% of the contribution for the dhole model, and all of the variables are positively correlated with predicted dhole presence (Table 2, Figure 3).

We generated a map (predicted probability of occurrence; Figure 4) of potential dhole distribution in Thailand. The highest dhole probability of presence was projected to be  $<500 \text{ m}$  elevation (graph not shown). The land cover categories with the highest predicted probability of dholes as calculated in MaxEnt included grasslands (predicted dhole presence of 60%), mixed deciduous forest (57%), dry dipterocarp forest (49%), dry evergreen forest (47%), and hill evergreen forest (29%; Figure 5). The model predicted  $<10\%$  probability of occurrence of dholes in all other land cover types. The total area predicted to be potential habitat for dholes was  $34,404 \text{ km}^2$ , which is roughly 7% of the total area in Thailand (Figure 6).

Thirty percent of this potential habitat for dholes falls within current protected areas. If we exclude all land outside of protected areas, the total potential habitat for dholes is  $10,461 \text{ km}^2$  or 2% of Thailand (Figure 6). To further refine the potential habitat, we excluded patches that are too small to support a dhole pack. Grassman et al. (2005) found dholes in PK to have ranges of 12.0 and  $49.5 \text{ km}^2$ . Therefore, we counted only contiguous patches of predicted habitat  $>50 \text{ km}^2$ . The remaining 31 patches have the potential to support 161 dhole home ranges of  $50 \text{ km}^2$  on the basis of our rough assumptions. However, 58% of those patches might sustain fewer than three packs (Figure 7). From the model, we identified four protected areas [Khlung

**Table 1** Model of predicted species occurrence output from MaxEnt; performance measured by the AUC of the ROC plot, standard error (S.E.), and 95% confidence interval (95% CI).

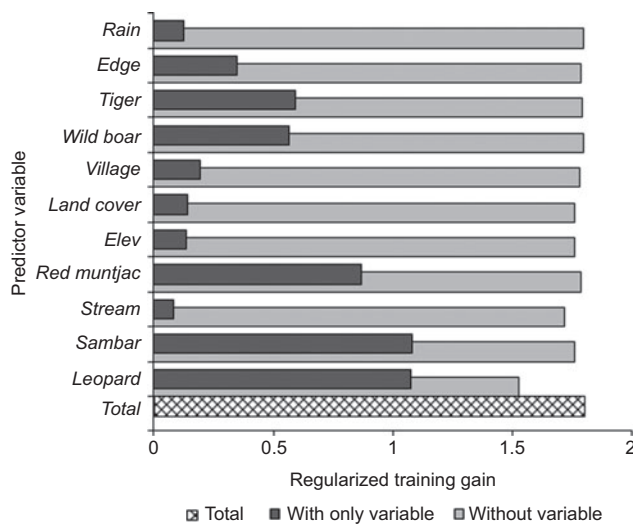
MaxEnt model	AUC	S.E.	95% CI
Sambar	0.883	0.025	0.827–0.927
Red muntjac	0.827	0.022	0.782–0.880
Wild boar	0.827	0.026	0.772–0.874
Tiger	0.715	0.060	0.589–0.843
Leopard	0.929	0.040	0.827–0.981
Dhole	0.932	0.033	0.850–0.993

**Table 2** Estimates of relative percent contribution (RC) and permutation importance normalized to percentages (PI) for variables used in MaxEnt modeling of species distributions in Thailand.

Variables	MaxEnt model											
	Sambar		Red muntjac		Wild boar		Tiger		Leopard		Dhole	
	RC	PI	RC	PI	RC	PI	RC	PI	RC	PI	RC	PI
<i>Leopard</i>											37.6	39.2
<i>Sambar</i>							35.0	2.9	29.7	3.7	36.8	25.3
<i>Stream</i>	2.1	0.7	2.4	3.2	10.2	4.9	5.2	0.5	0.7	0	8.5	5.0
<i>Red muntjac</i>							7.5	2.1	7.0	0.4	6.9	10.5
<i>Elev</i>	10.7	10.8	11.2	6.1	10.1	9.7	2.3	1.8	2.5	3.5	4.0	3.8
<i>Land cover</i>	14.1	9.1	9.8	9.7	14.8	8.4	16.4	31.9	26.9	22.1	2.5	8.3
<i>Village</i>	10.7	24.9	6.6	13.7	4.1	12.8	13.9	18.1	5.0	4.1	1.3	2.4
<i>Wild boar</i>							16.7	16.3	10.8	27.0	1.2	0
<i>Tiger</i>											0.7	0.5
<i>Edge</i>	35.1	26.4	29.2	33.6	19.2	33.7	0.5	1.5	1.5	1.0	0.4	4.1
<i>Rain</i>	27.4	28.1	40.7	33.7	41.6	30.6	2.6	25.0	15.8	38.2	0.2	0.9

MaxEnt, maximum entropy; *Edge*, distance of species presence to protected area boundary (m); *Elev*, elevation (m); *Land cover*, categorical land cover type; *Rain*, annual rainfall (mm); *Stream*, distance of species presence to nearest stream (m); *Village*, distance of species presence to nearest village (m); *Sambar*, *Red muntjac*, *Wild boar*, *Leopard*, *Tiger*, predicted layer of occurrence from MaxEnt modeling for each species. Variables are in italic.

Wangchaow National Park (KW), Salakpra Wildlife Sanctuary (SP), Khao Ang Rue Nai Wildlife Sanctuary (KARN), and Pang Sida National Park (PS)] where dholes may range across almost the entire protected area and that include patches >50 km<sup>2</sup> (Figure 8).



**Figure 2** Jackknife analyses of individual predictor variables important in the development of the full model for dholes in relation to the overall model quality or the “regularized training gain.” Black bars indicate the gain achieved when including only that variable and excluding the remaining variables; gray bars show how much the gain is diminished without the given predictor variable. *Edge*, distance to protected area boundary (m); *Elev*, elevation (m); *Land cover*, categorical land cover type; *Rain*, annual rainfall (mm); *Stream*, distance to nearest stream (m); *Village*, distance to nearest village (m); *Sambar*, *Red muntjac*, *Wild boar*, *Leopard*, *Tiger*, predicted layer of occurrence from MaxEnt modeling for each species.

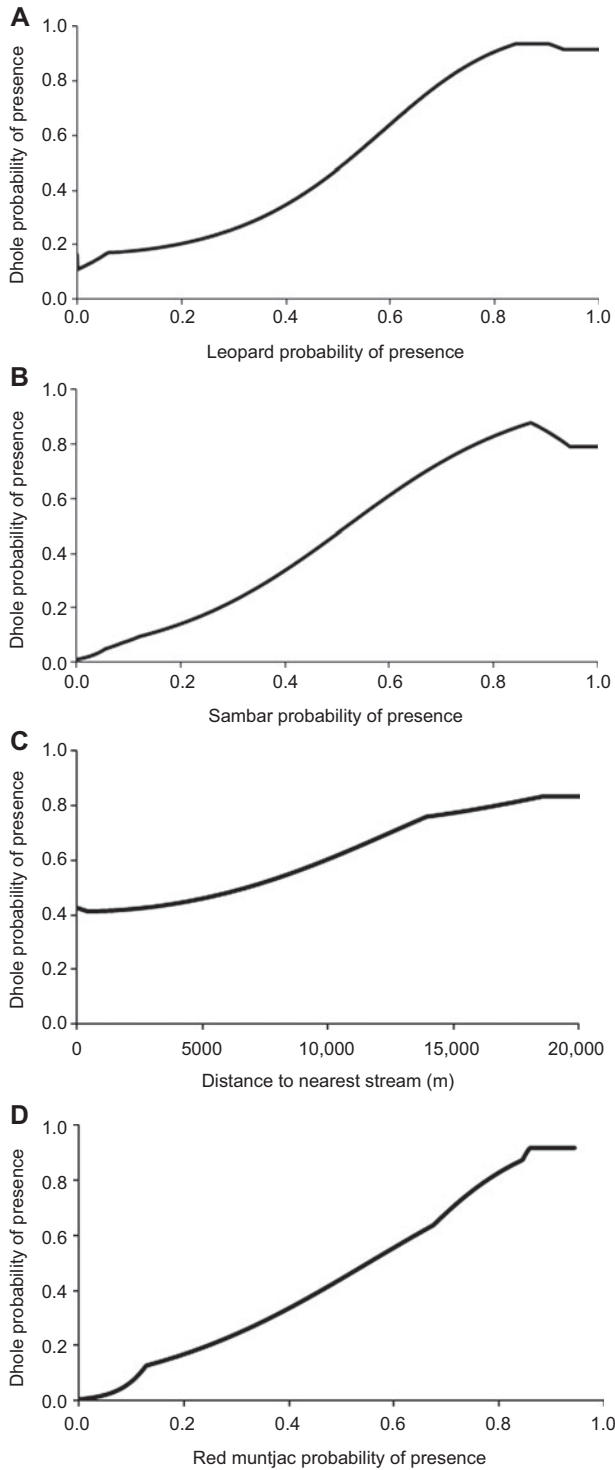
## Discussion

Identifying areas of high habitat suitability for dholes lays the foundation for planning future research and conservation initiatives. Our MaxEnt results are a step toward highlighting areas of suitable habitat for dholes. We extrapolated our predictions to the whole of Thailand to identify areas that may be suitable for dholes but were previously disregarded. We incorporated competitors because interactions may skew dhole distribution despite environmental suitability and prey availability. While we recognize the potential circularity of the model because we used the same environmental variables to develop distribution models that were surrogates for prey availability and competitor presence, we elected to proceed because so little is known about dholes and we thought it was important to include these covariates, limited as the data may be. Not surprisingly, prey availability (*Sambar* and *Red muntjac* combined) explained 44% of the species’ predicted occurrence.

The probability of presence for prey was higher at lower rainfall locations and at distances closer to the interior of protected areas. These findings are dissimilar to Ngoprasert et al. (in press) who found sambar and wild boar associated with higher rainfall. However, they found red muntjac associated with areas far from forest edges.

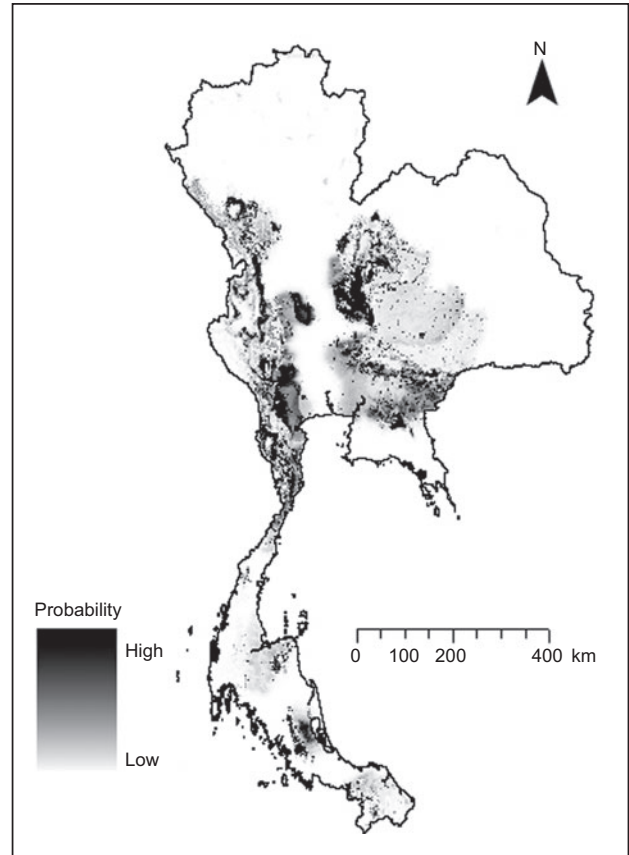
Our results indicate that the strongest correlate with the distribution of dholes, which led to the highest model gain when used in isolation, is the presence of *Sambar*. A strong association with this single prey species was expected considering sambar comprise 30% of the frequency of occurrence of prey items in dhole feces in Thailand (Grassman et al. 2005, Salangsingha and DoungKae 2009) and up to 90% occurrence in feces of dhole in India (Rice 1986).

Besides prey, the other variable shaping dhole distribution is the presence of leopards. Although there are accounts



**Figure 3** Graphical representation of the relationship between Leopard (A), Sambar (B), Stream (C), Red Muntjac (D), and Dhole probability of presence. Each of the curves represents a different MaxEnt model created using only the corresponding variable.

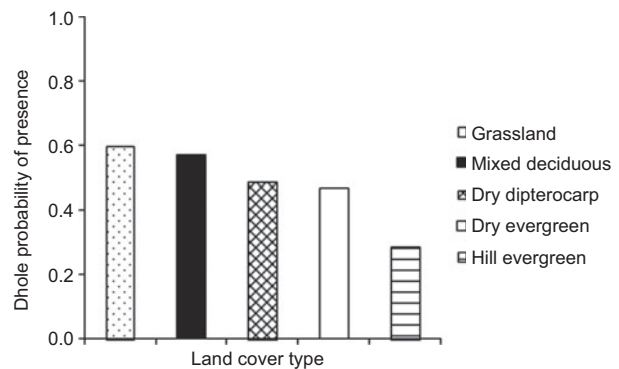
of interspecific competition between leopards and dholes (Johnsingh 1983, Wood 1929, Venkataraman 1995), our modeling indicates that dhole presence increased as leopard presence increased. This probably arises because these



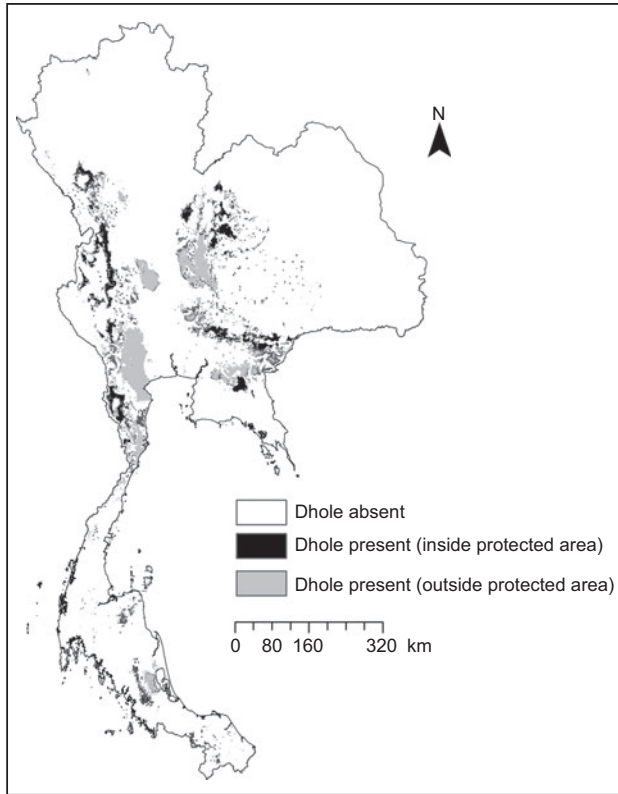
**Figure 4** Predicted distribution for dholes within Thailand estimated by MaxEnt modeling. Potential areas are shown in gray shading, with the darker color indicating higher probabilities of occurrence.

two species share habitats owing to similar prey preference (e.g., Johnsingh and Yoganand 1999, Karanth and Sunquist 2000). *Sambar* (a large prey, on average >180 kg) contributed most in the MaxEnt model for leopards and second most for dholes.

The other possibility is that the positive association of dholes with leopards is related to their predicted negative association with tigers, their potential intra-guild predator.



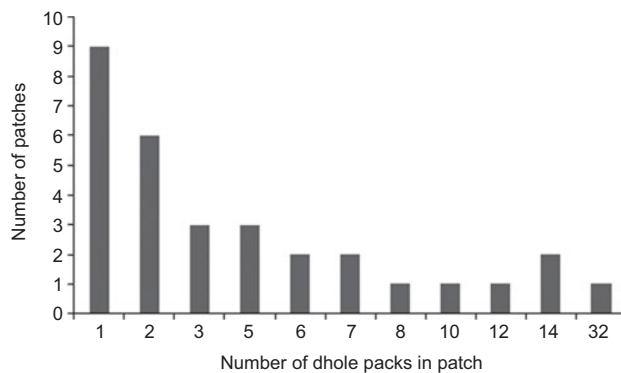
**Figure 5** Land cover categories with the highest probability of predicted dhole presence in Thailand.



**Figure 6** Predicted occurrence of dholes in Thailand on the basis of a 0.08 threshold of prevalence (96 dhole detection locations out of 1174 total sampling locations). Areas in black represent predicted dhole occurrence inside protected areas. Areas in gray represent predicted dhole occurrence outside of protected areas.

However, our *Tiger* variable as modeled contributed very little (neither positively nor negatively) to predicted dhole distribution.

The potential range of dholes covered a wide spectrum of habitats; however, our model predicted that dholes occur primarily in grasslands and mixed deciduous forest at generally 150 m elevation. This is consistent with a previous radio-telemetry study in PK where one dhole pack was found to



**Figure 7** Approximate number of dhole packs in a given patch vs. the number of patches.

base its home range around a grassland area (Grassman et al. 2005). We caution, however, that this may be an artifact of the prey distribution in PK and may not represent the general population. Regardless, overall, the impact of land cover type alone only contributed 2.5% to predicting dhole occurrence; this emphasizes that prey base, not land cover type, is the main limiting factor for the species.

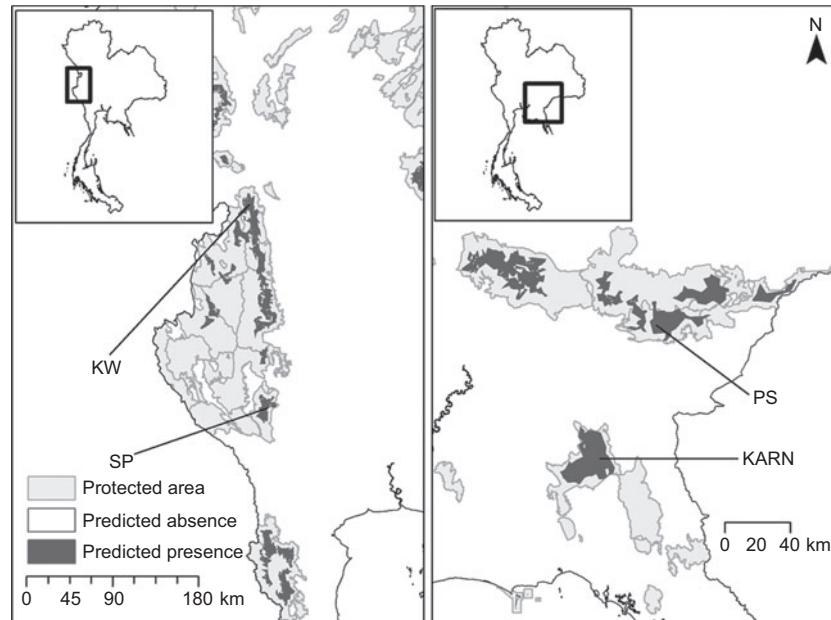
The range of predicted dhole habitat does not expand into the north and the model failed to predict dhole occurrence in Doi Chiang Wildlife Sanctuary and Lum-nam-pai Wildlife Sanctuary in the far north, despite field records of dhole sign from Kanchanasaka (2005). The protected areas in this region may preclude large populations of sambar due to poaching pressure (Pattanaivibool and Dearden 2002). However, the north does have contiguous forest cover; we could be missing key variables or there is the possibility that poor input (e.g., an out-of-date land cover layer) may have resulted in the model being inaccurate for this region.

This study provides a first indication of how much dhole habitat is not protected in Thailand. Our results show that currently only 30% of potential habitat falls within protected areas in Thailand. Additionally, protection measures inside protected areas may not be adequate because there are large areas of potential habitat inside protected areas where dholes are apparently absent. This might be related partly to prey availability, but the edge itself may be a sink for dholes due to the proximity to human settlements and the greater likelihood of getting shot (K. Jenks, pers. obs.) or poisoned (S. Vitnitpornawan, pers. obs.) there relative to the safer core area. The observation that wildlife abundance is higher in central parts of protected areas vs. marginal areas has been specifically documented in KY (Lynam et al. 2003, Jenks et al. 2011). Current protection efforts are most intense in areas close to a park or sanctuary headquarters, with remote areas getting less protection. We recommend that protected area edges be specially managed to support dhole and their prey.

Additionally, there is a low probability that the 70% of potential dhole habitat outside of protected areas actually supports dholes because there are no verifiable records of dholes living outside of protected areas in Thailand. Many areas predicted to have suitable ecological conditions for dholes may actually be devoid of dhole populations because virtually all forests outside of protected areas in Thailand have been converted to agriculture and intersected by roads for human settlement. If forests are still present, they are likely to be largely without prey. For example, even sambar is now listed as vulnerable due to intense poaching pressure (IUCN 2008). Moreover, the lack of formalized protection measures outside of protected areas means that dhole survival chances are much reduced there.

If we exclude all areas outside of protected areas, the total potential habitat for dholes is 10,461 km<sup>2</sup> or only 2% of Thailand. If we restrict these areas further to include only contiguous patches of predicted habitat >50 km<sup>2</sup>, the remaining patches very roughly support 161 dhole home ranges.

Another challenging issue facing individuals involved in dhole conservation is locating suitable sites for basic research



**Figure 8** Individual protected areas in Thailand that are recommended for future field studies based on the large area of dhole presence: Khlong Wangchaow National Park (KW), Salakpra Wildlife Sanctuary (SP), Pang Sida National Park (PS), and Khao Ang Rue Nai Wildlife Sanctuary (KARN). Predicted presence of dholes on the basis of a 0.08 threshold and only includes patches that are  $>50 \text{ km}^2$ .

of this elusive species. Our MaxEnt predictive map is a preliminary step that can guide field research to further clarify the breadth of the dhole's distribution. The model can be tested by surveying for dhole presence in (1) areas predicted to have a high probability of dholes and (2) areas predicted to have no probability of dholes where the model may be wrong. We identified four protected areas (KW, SP, PS, and KARN) where dholes were predicted to range across almost the entire area. These are ideal starting locations for basic dhole ecological research. However, these areas also represent locations where large predators (i.e., potential competitors) are almost absent, especially tiger. To understand more about the fate of dholes in the presence of large predators, research also needs to be conducted in protected areas where dholes were predicted to be present along with tigers and leopards, such as KK, KB, HKK, and TYW. Additionally, we need to determine if dholes are using areas outside of protected areas. The focus for this should stem from areas of predicted presence from our modeling, including the area north of MP and south of SP, and a region southwest of PK. Finally, we also support surveys in the north to test whether the model predictions are correct in this region.

We have now explored the question of where dholes are found; the next step is to shed light on the size and stabilities of their populations. It may be that 7% of the country is potential habitat for dholes; however, this was inferred from a small number of records and may not support stable populations, but only small, isolated packs. Furthermore, we estimated that the majority of contiguous patches may support fewer than three packs. MaxEnt modeling has provided us with a helpful evaluation of the distribution of the dhole in Thailand, which can now be used for conservation planning.

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