RESEARCH AND REPORTS

Importance of protected areas in conservation and recovery of gaur (*Bos gaurus*) in Thailand

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Abstract

Gaur (*Bos gaurus*) listed as vulnerable on the IUCN Red List and is an endangered species in Thailand, one of the wild cattle that play a crucial role in forest habitats. This research is aimed at predicting gaur's suitable habitat within Thailand. Gaur occurrence data were obtained in 2020 by field surveys and recorded gaur signs on wildlife trails, patrol routes, and buffer zones in protected areas. The maximum entropy was used to generate a habitat suitability model. The results of the gaur distribution range showed that gaur occurred in 11 of 17 terrestrial forest complexes which mostly connected in large patch distribution range. Despite its wide distribution range, the result of the suitable area indicated that potential habitat remains in seven forest complexes, with an area of only 8.8% of the mainland found to be suitable habitat for gaur. 80.2% of this suitable area is located inside protected areas, while one of five suitable habitats fell outside protected areas, especially in small forest patches and agricultural areas. The results of this study are important data to provide guidelines for the management and maintenance of gaur habitat in Thailand.

Introduction

Gaur (*Bos gaurus*), the herbivorous wild cattle species, plays an important roles in the quantity control of plants in the ecosystem and as the main prey of large carnivores (Karanth & Sunquist, 1995; Roininen et al., 2007). According to the IUCN Red List, the gaur is a Vulnerable species and its population is decreasing in scattered areas along the 10 range states: Bhutan, Cambodia, China, India, Lao PDR, Malaysia, Myanmar, Nepal, Thailand, and Viet Nam (Duckworth et al., 2016). Meanwhile, the species is listed as endangered in Thailand (Office of Natural Resources and Environment Policy and Planning, 2017) and are protected as listed in the Wild Animal Reservation and Protection Act (2019). The gaur consists of two subspecies (*B. g. readei* and *B. g. hubbacki*) which can be found in the north and south of the Isthmus of Kra, respectively (Lekagul & McNeely, 1977). They were widespread in the 13 forest complexes (46 protected areas) with high abundance in the Eastern, Dong Phayayen-Khao Yai, Khlong Sang-Khao Sok, and Western For-

est Complex, respectively (Kanchanasaka et al., 2010).The forest area in Thailand has decreased from 43% in 1973 to 32% in 2019 (Royal Forest Department, 2018), and with the degradation, fragmentation and transformation of suitable habitat, the populations of gaur are low in abundance or are currently extirpated in many protected areas (Kanchanasaka et al., 2010; Prayurasiddhi et al., 2013). On the other hand, the gaur population is increasing in some places, such as in Khao Pang Ma Non-hunting Area, a part of Dong Phayayen-Khao Yai Forest Complex, where they have increased from 30 individuals in 2001 to 271 individuals in 2017 (Bidayabha, 2001; Laichanthuek et al., 2017).

In Thailand, holistic data for the suitable habitat of gaur have been lacking. This data is necessary to inform an action plan for guidelines for gaur conservation. Therefore, the understanding of gaur habitat, especially suitable areas, is very important to maintain and manipulate that habitat. The objective of this research was to assess the habitat suitability for gaur in Thailand. The results will provide guidelines on habitat management and effective conservation planning for gaur and their habitat.

Materials and methods

Study area

This study was conducted in protected areas (PAs) in Thailand, located between 5°37′–20°27′ N and 97°22′–105°37′E. The total 402 PAs covered 116,860 km^2. These are established to protect and buffer of wildlife habitat, covering 22.8% of the country. These PAs are comprised of 60 wildlife sanctuaries (37,377 km^2), 155 national parks (70,651 km^2), 96 non-hunting areas (7,704 km^2), and 91 forest parks (1,128 km^2) which are grouped into 19 forest complexes (17 terrestrial and two marine forest complexes). The survey areas covered 211 protected areas (105,173 km^2) consisting of 60 wildlife sanctuaries (37,377 km^2), 133 national parks (63,616 km^2) and 18 non-hunting areas (4,180 km^2).

Species occurrence data

Gaur occurrence data were obtained from the Department of National Parks, Wildlife and Plant Conservation. The presence data were recorded from the signs survey and also included direct sightings by the Smart Patrol Monitoring Center in 2020. The survey team recorded the presence of gaur along wildlife trails, patrol routes, and buffer zones in PAs across Thailand. Gaur signs in one 30-minute survey time period corresponded to one presence record. There were 4,629 records of presence. The presence records and trails were standardized by creating 1km^2 grid cells to analyze the study area, which covered all forest types and elevations. The survey covered 72,428 grid cells, or 68.8% of the survey area.

Environment variables

The habitat suitability was generated based on 14 variables including the ecological variables (forest type, forest canopy height, distances to the nearest intact forest landscape [IFL], and distances to the nearest stream), topographic variables (elevation and slope), and climatic variables (annual mean temperature (BIO1), mean diurnal range (BIO2), isothermality (BIO3), temperature

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seasonality (BIO4), maximum temperature of the warmest month (BIO5), annual precipitation (BIO12), precipitation seasonality (BIO15), and precipitation of warmest quarter (BIO18)).

Four ecological variables were included. Firstly, the forest type in 2018 was used to generate the model. The forest areas covered 31.7% of Thailand (Royal Forest Department, 2018). It was classified from satellite imagery into 15 categories namely tropical rain forest, dry evergreen forest, hill evergreen forest, coniferous forest, peat swamp forest, mangrove forest, fresh-water swamp forest, beach forest, mixed deciduous forest, dry dipterocarp forest, bamboo forest, secondary forest, grassland, vegetation on a rock platform, and non-forest area (agricultural area and abandoned agricultural land). This data was obtained from Royal Forest Department (2018). Secondly, the forest canopy height in 2019 (Potapov et al., 2020) was used to generate the habitat suitability model. Thirdly, the IFL around 17,333 km2 (16% of PAs) in 2016 was used to predict the suitable habitat which extracted from www.intactforest.org. Lastly, the stream was created from the topographic map at 1:50,000 scale in 2018 which obtained from Royal Thai Survey Department.

The topographic variables consist of the elevation and slope which extracted from www.worldclim.org (version 2.1). For the climatic variables, the climatic data period 1970-2000 was predicted the modeling which extracted from www.worldclim.org (version 2.1). The band collection statistics tool in ArcGIS was used to select 8 variables (BIO1, BIO2, BIO3, BIO4, BIO5, BIO12, BIO15, BIO18) that correlated less than 0.8 ($r < 0.8$) for predicting habitat suitability (Trisurat et al. 2015; Ebrahimi et al. 2017).

Habitat suitability model

The Maximum Entropy Species Distribution Modeling (Maxent) version 3.3.3 was used to analyze habitat suitability (Phillips et al., 2006; Phillips & Dudik, 2008; Ebrahimi et al., 2017). Maxent was chosen because the data set was presence-only data. The maxent generated pseudo-absence data which covered the whole area in Thailand. A randomly selected sample of 75% of occurrence data was used as train data and 25% as test data (Cianfrani et al., 2010; Trisurat et al., 2015). All environmental layers were resampled to the same cell size as 1 km2 covering 511,000 km2 of the mainland. For identification of the area of habitat suitability, the probability of presence value (0-1) was cut off by using the logistic threshold of maximum training sensitivity plus specificity to identify the suitable area and equal

Table 1 Distribution of gaurs in Thailand

Forest complex	Area (km^2)	Number of grid (1 km^2/grid)	
		Survey grid	Gaur presence grid
Srilanna-Khun Tan	9,879	5,619	13
Phu Miang-Phu Thong	5,167	3,686	26
Phu Khieo-Nam Nao	8,347	5,904	199
Phanom Dongrak-Pha Tam	3,146	2,669	9
Dong Phayayen-Khao Yai	6,587	2,049	427
Eastern	3,695	1,861	100
Western	19,816	14,669	678
Kaeng Krachan	5,056	2,763	96
Chumphon	2,630	1,866	55
Khlong Saeng-Khao Sok	5,563	3,879	520
Hala-Bala	2,474	861	2

training sensitivity and specificity to identify the core area (Trisurat et al., 2015; Planisong et al., 2018; Silva et al., 2020).

Results

Distribution

Gaur occurred in 11 terrestrial forest complexes (Fig. 1 and Table 1). The distribution range of gaur covered 41,198 km^2 over 59 PAs. The distribution area mostly connected to the large patch habitat except the Srilanna-Khun (1), Tan and Hala-Bala (11) Forest Complexes. The largest distribution range was located in the Western Forest Complex (7).

The gaur occurrence data was distributed in eight forest types including dry evergreen forest, mixed deciduous forest, moist evergreen forest, hill evergreen forest, dry dipterocarp forest, secondary forest, grassland, and non-forest area (agricultural area and abandoned agricultural land). The gaur distributed in different forest canopy height, elevation, and slope (Fig. 2). The results showed gaur mostly positively associated in the habitat less than 28m of forest canopy

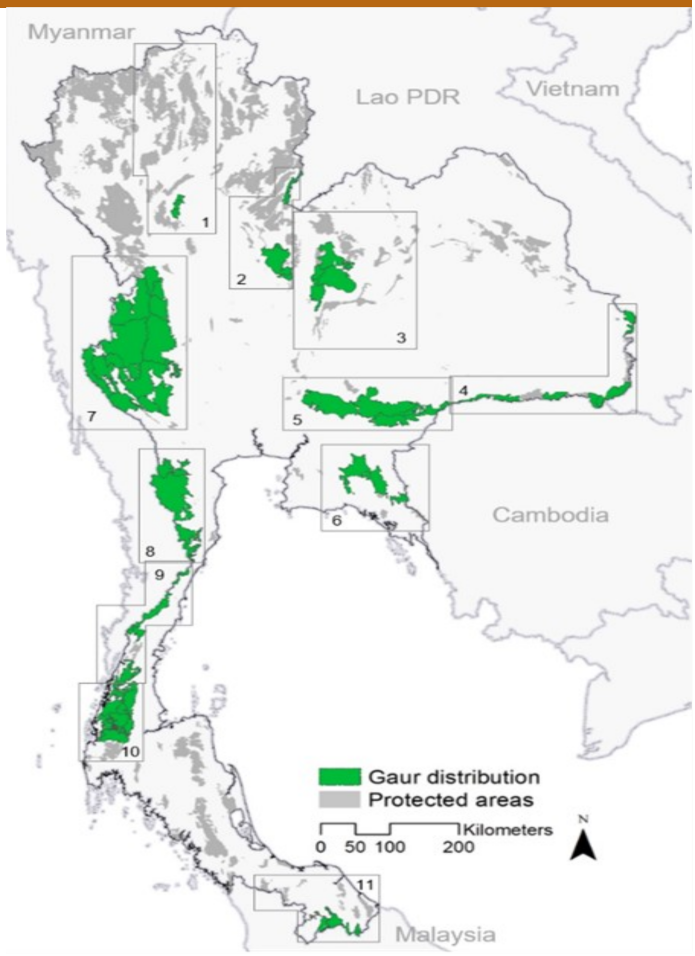

Figure 1 Gaur distribution in Thailand, where outlines of boxes indicate forest complex management units: (1) Srilanna-Khun Tan, (2) Phu Miang-Phu Thong, (3) Phu Khieo-Nam Nao, (4) Phanom Dongrak-Pha Tam, (5) Dong Phayayen-Khao Yai, (6) Eastern, (7) Western, (8) Kaeng Krachan, (9) Chumphon, (10) Khlong Saeng-Khao Sok, and (11) Hala-Bala Forest Complex

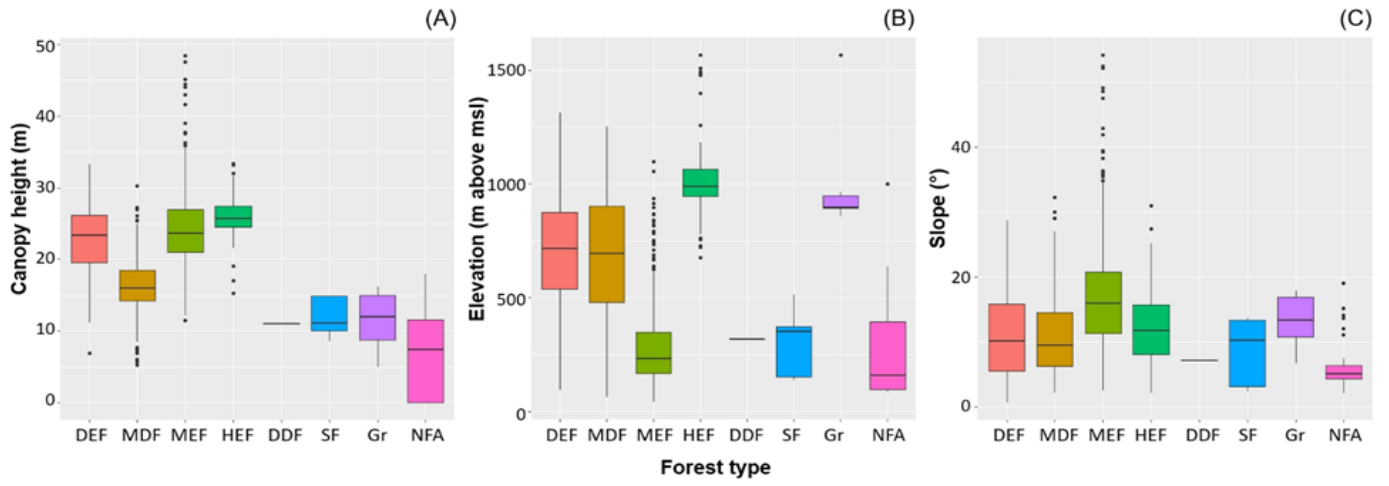

Figure 2 Gaur distribution between different forest type and (A) forest canopy height, (B) elevation, and (C) slope (DEF = dry evergreen forest, MDF = mixed deciduous forest, MEF = moist evergreen forest, HEF= hill evergreen forest, DDF = dry dipterocarp forest, SF = secondary forest, Gr = grassland, NFA = non-forest area i.e. agricultural area and abandoned agricultural land)

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height, 1,100m above mean sea level (msl), and 20 degree of slope .

Habitat suitability

The habitat suitability model showed a high degree of accuracy (AUC = 0.9). The intact forest landscape had the highest relative percentage contribution for gaur suitable habitat, followed by forest type, precipitation seasonality, and forest canopy height, respectively (Table 2). The gaur probability of presence increased when nearest the IFL. The mixed deciduous, dry evergreen, and moist evergreen forest had the highest probability of presence, respectively. The jackknife test of variable importance for the gaur habitat suitable model indicated that the IFL was the highest gain when used in isolation, followed by forest type, forest canopy height, and max temperature of warmest month, respectively (Fig. 3).

Table 2 The relative percentage contributions and permutation importance for environmental variables used in modeling of gaur habitat suitability

Environmental variable	Relative percentage contributions	Permutation importance
Ecological variable		
Distance to intact forest landscape	73.0	15.6
Forest type	12.9	1.9
Forest canopy height	2.6	2.2
Distance to stream	0.1	0.1
Topographic variable		
Elevation	0.5	1.5
Slope	0.2	0.5
Climatic variable		
BIO1: Annual mean temperature	2.2	16.4
BIO2: Mean diurnal range	0.2	1.0
BIO3: Isothermality	2.0	6.2
BIO4: Temperature seasonality	1.0	28.8
BIO5: Max temperature of warmest month	1.3	2.3
BIO12: Annual precipitation	0.2	2.3
BIO15: Precipitation seasonality	3.4	18.6
BIO18: Precipitation of warmest quarter	0.5	2.6

The gaur habitat suitability showed the high probability of suitable habitat located with the large patch area (Fig. 4A). The potential habitat for gaur covered 45,008 km^2 or only 8.8% of the mainland, while the core areas located in suitable area remained 21,415 km^2 (4.2% of the mainland). 36,089 km^2 (80.2% of gaur suitable area) was located inside the PAs, while the around 8,929 km^2 (19.8% of suitable area) was located outside PAs, especially in small forest patches, agricultural area, and abandoned agricultural land (Fig. 4B and Table 3). The results indicated the potential habitat remained in seven forest complexes consists of the Western, Dong Phayayen-Khao Yai, Khlong Saeng-Khao Sok, Kaeng Krachan, Phu Khieo-Nam Nao, Eastern, and Phu Miang-Phu Thong Forest Complex, respectively.

Although the gaur occurred in 11 forest complexes, only seven forest complexes were suitable. Moreover, 20% of the suitable habitat area fell outside PAs and bordered PAs (Fig. 5). Most of these areas were connected to become large patches of area which were probably large enough for gaur to inhabit, although some of these patches were fragmented and small, nearly destroyed areas.

Table 3 Suitable habitat and core area of gaur in Thailand

Gaur habitat	Logistic thresholds	Area (km^2)	Percentage of Thailand[b]	Percentage of PAs[c]	Area located inside PAs	
					Area (km^2)	% of Area
Suitable area	0.2054	45,008	8.8	41.9	36,089	80.2
Core area	0.4415	21,415	4.2	20.0	20,239	94.5

[a]Logistic threshold cut-off value; [b]Mainland area 511,000 km^2; [c]Total PAs area in the mainland 107,458 km^2 (excluding forest parks

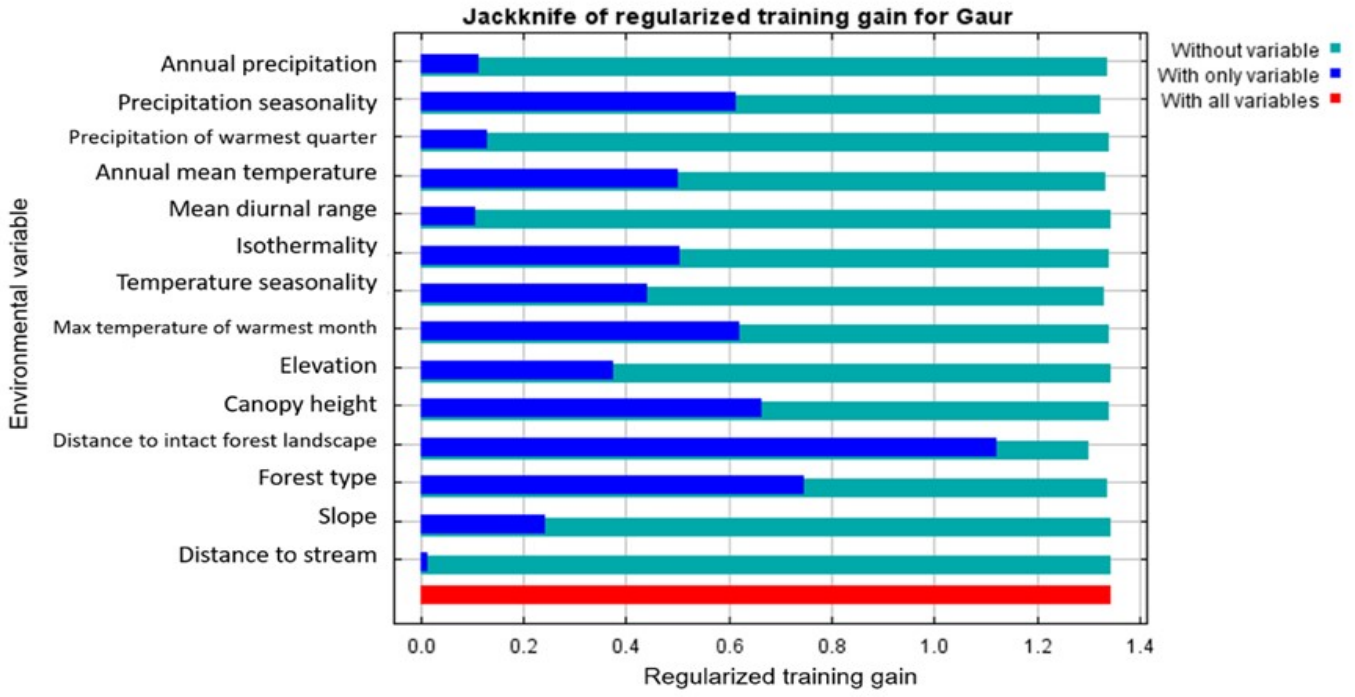

Figure 3 Jackknife analyzed individual predictor variables important in the development of the model to the overall model quality (regularized training gain). The dark-blue bars indicate the gain achieved when including only that variable and excluding the remaining variables; light-blue bars indicate the gain is diminished without the given predictor variable.

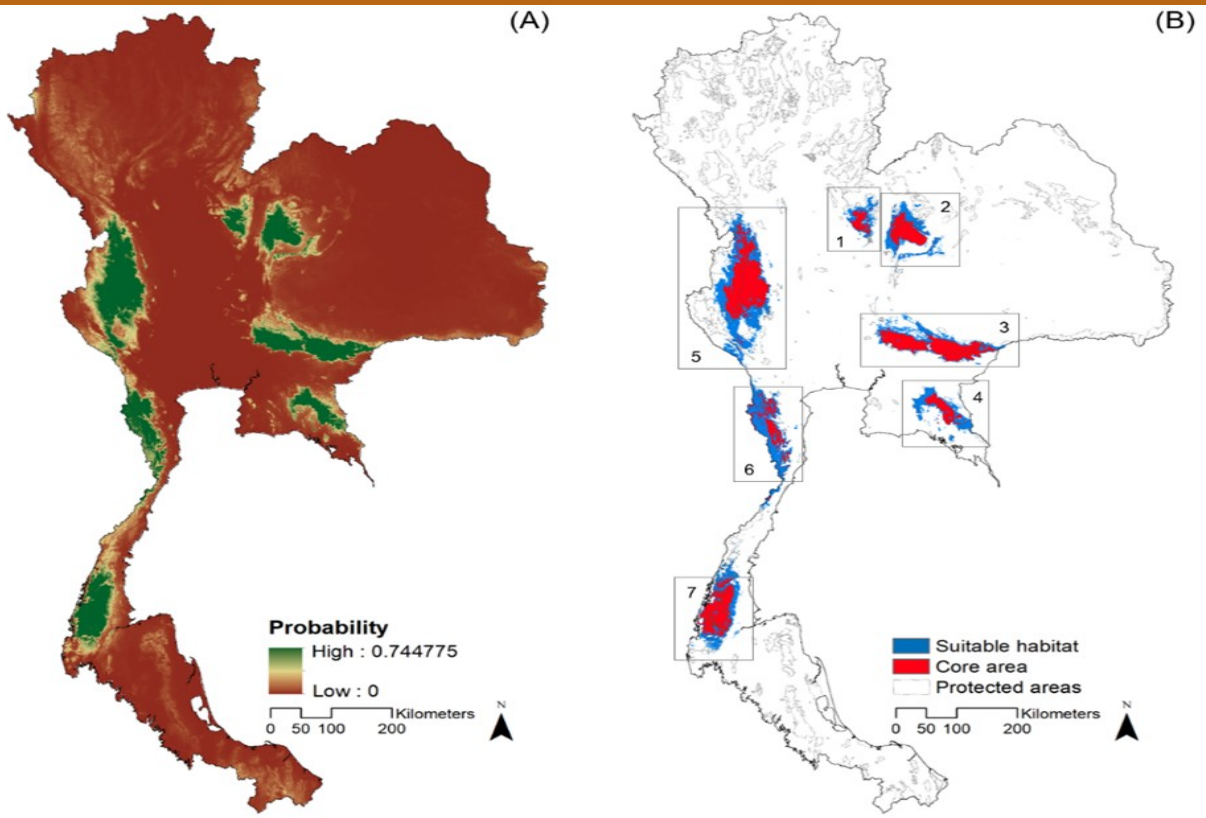

Figure 4 Habitat suitability for gaur (A) Habitat suitability (B) Habitat is classified as suitable habitat and core areas: (1) Phu Miang-Phu Thong, (2) Phu Khieo-Nam Nao, (3) Dong Phayayen-Khao Yai, (4) Eastern, (5) Western, (6) Kaeng Krachan, and (7) Khlong Saeng-Khao Sok Forest Complex

Discussion

Distribution

Currently, gaur occur in 11 forest complexes, which is a decrease from 13 forest complexes in 2010. However, the number of PAs occupied by gaur has increased from 45 in 2010 to 59 in 2020 (Kanchanasaka et al., 2010). This new occurrence could be from the dispersal of gaur population from the adjacent PAs. Another possible reason for the additional areas is the increased protection and patrolling of PAs (National Parks, Wildlife and Plant Conservation Department, personal communication). Presently, gaur are distributed more widely than in the past, but are extirpated from some northern and southern PAs where they were found in 2010. Additionally, Kanchanasaka et al. (2010) reported that gaur increased in abundance in large PAs connected to large habitat patches. The highest abundance within forest complexes were Eastern, Dong Phayayen-KhaoYai, Khlong Saeng-Khao

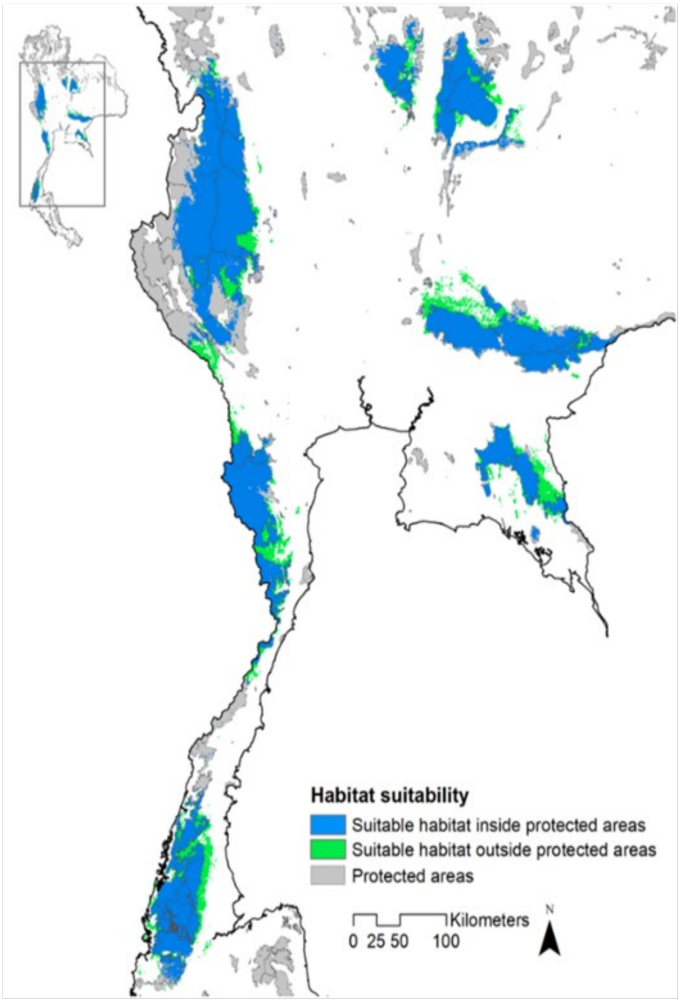

Figure 5 Gaur suitable habitat inside and outside protected areas

Sok, Western, Phu Khieo-Nam Nao, and Kaeng Krachan Forest Complex, respectively. Additionally, a small group of Gaur inhabited areas outside of PAs.

Habitat suitability

Gaur inhabited several forest types and elevations. According to these results, gaur used many elevation levels from 100 m up to 1,100 m above sea level (asl), while the habitat suitability model predicted the highest probability of presence appeared in 900–1,000 m asl. In addition, this research showed the land cover variables (IFL and forest type) are more important than bioclimatic variables for gaur habitat. Meanwhile, Trisurat et al. (2015) discovered the strongest variables associated with gaur presence in northern Thailand were composed of the temperature variables (mean, maximum, and minimum temperate), precipitation of coldest quarter, and distance to road, respectively. However, according to the results of suitable habitat in the Western Forest Complex, gaur are likely to inhabit areas of the shallow slope, closer to the ranger stations and streams, and further from villages (Trisurat et al., 2010). Kanchanasaka et al. (2010) showed that environmental factors were significant to the habitat selection of gaur in Thailand. The suitable area consists of less sloped areas (0–27 degrees), near salt licks, and close to the water sources (less than 6 km distance). The data indicated the gaur's probability of presence was increased when nearest to streams and gaur avoided human disturbed areas. Moreover, the effects of loss of suitable habitat showed that deforestation had a stronger impact than climate change (Trisurat et al., 2015).

Habitat management concern

According to the results of suitable area analysis, huge suitable areas were located outside PAs in agricultural areas and small forest patches in the potential forest complexes for gaur habitat (i.e. Dong Phayayen-Khao Yai, Eastern, Western, Khang Krachan, and Khlong Saeng-Khao Sok Forest Complex). Around 19.8% of the suitable habitat for gaur is at risk because it is located outside PAs which did not proceed to protect the areas. Moreover, the local communities used these areas and natural products in border forest lands and the buffer zones between PAs and villages. Therefore, suitable gaur habitats located outside of PAs were nearly destroyed. Nowadays, agricultural areas have surrounded the edges of PAs and in some places have disturbed the forest areas at the edges of PAs. Additionally, the expansion of agricultural areas, settlements, and roads in Thailand has caused many wildlife habitats to become fragmented, degraded and transformed, especially in the lowland forest (Prayurasiddhi et al., 2013, Namkhan et al., 2020). These landscape changes cause suitable gaur habitat to decrease and as such threaten the gaur populations. The suitable area outside PAs can be an important part of and add great value for gaur conservation. Future gaur habitat management planning should therefore include these areas to manage and maintain the habitat for effective gaur conservation in Thailand.

Acknowledgements

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