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PLANNING THAILAND'S PROTECTED AREAS IN RESPONSE TO FUTURE LAND USE AND CLIMATE CHANGE

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Abstract

Only limited research on conservation planning to mitigate the impacts of synergies between land use and climate change have been conducted in Asia. The objectives of this research were to determine shifts in habitats of 17 mammal species resulting from land-use and climate change scenarios in 2050 in northern Thailand and to assess the proposed expansion of protected areas to mitigate the predicted impacts. Qualitative vulnerability assessment of species was determined by using national conservation status, shifts in distribution and coping capacity of protected areas. The potential expansion areas were identified using gravity model. The results indicated that the existing protected areas cannot guarantee the long-term survival of many species. Most selected species would substantially shift their current distributions and will be upgraded from moderate to high-risk. The proposed expansion areas of 5,200 km^2 or 3% of the region would substantially minimize the risk level and increase the average coping capacity of the protection of suitable habitats from 82% as the current plan to 90%. Such patches adjoining existing protected areas should be included in the current system, while patches that are relatively far should be managed as stepping stones or habitat corridors to facilitate movements of wildlife in the landscape.

***Keywords**: Adaptation; Conservation planning; Mammal species; Species distribution; Species vulnerability; Thailand*

Introduction

Being situated at the biogeographic crossroads and found in a region influenced by seasonal monsoons, and altitude ranges, Thailand is recognized as 1 of the 35 global biodiversity hotspots [1, 2]. It is estimated that the country is inhabited by about 4, 8 and 6% of the world's described plant, vertebrate and invertebrate species, respectively. In addition, biodiversity provides an abundance of valuable ecosystem services to local communities [3]. Southeast Asia (SEA) experiences high rates of deforestation and may lose approximately 70% of its original forest cover by the year 2100 [1, 4]. The annual rate of deforestation during 1990–2010 was approximately 1.3 million ha [5].

In addition to deforestation, climate change is likely to become a significant driver of biodiversity loss in the next century. The Intergovernmental Panel on Climate Change AR5 report predicted that mean annual temperatures in the SEA will increase by 2-4°C by the year 2100, whereas rainfall intensity and long drought periods are expected by all climate models [6]. These conditions potentially cause altered ecosystems and subsequently result in shifts in species distributions. The results of statistically environmental stratification conducted in Yunnan province, China indicated that more than 75% of all bioclimatic zones were predicted to shift to different zones [7]. In addition, a prolonged period of warming and climate disruption

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predicted in the Lower Mekong Sub-basin for the years 2030 and 2060, would expand existing bioclimatic zones towards the extremely hot and mesic zones [8]. Similarly, future climate change would alter approximately 60% of evergreen forest to open woodland [9] and deciduous tree species would invade habitats of evergreen species [10]. This change will have increasingly substantial and direct impacts on ecosystems, biodiversity and available water resources in the dry season, as well as effect human health and livelihoods. Moreover, the combination of land-use and climate change could amplify the extinction risk of tropical species [11-14]. Likewise, the effectiveness of current conservation measures will be affected, as ecological conditions may shift beyond limits conducive for the species currently found within narrow niches or designated protected areas [13, 15, 16].

ASEAN Centre for Biodiversity [17] revealed that 29% of the total forest area in the ASEAN has been protected in different forms and protected areas cover approximately 13% of the region's total land area, which is 4% behind the Aichi Biodiversity target set for terrestrial ecosystems [18]. The existing protected areas in Thailand cover approximately 21% of the country land area [19] similar to Malaysia and the Philippines, which is less than Brunei Darussalam (48%) and Cambodia (26%). However, Thailand is one of the fairly few tropical counties that will pass the Aichi Target 11 of at least 17% of the terrestrial area protected. In addition, the Thai government provides more resources to manage and to effectively protect biodiversity than those countries in neighboring countries [17, 20].

Nevertheless, most protected area systems in Thailand, including other ASEAN countries, were established on an *ad hoc* basis to protect remaining forest cover and head watershed, but not to sufficiently represent ecosystems and species diversity [21]. In addition, most protected areas are located in high altitude and rugged terrains to avoid parks and human conflicts [20, 22, 23]. The current designation criteria may not be able to cope with biological processes and the predicted results from multiple climate and land-use changes in spatial and temporal scales [13, 24-26]. Therefore, current and future efforts to conserve forests, biodiversity and to deal with the multiple anthropogenic pressures require an improved understanding of both species distribution and environmental changes. Furthermore, it remains unclear whether quantitative achievements of Aichi target of 17% for terrestrial ecosystems for some ASEAN countries will adequately protect biodiversity and maintain other ecosystem services generated from protected areas [27, 28].

The goal of this research was to optimize protected areas to adapt to future land-use and climate change. Specific objectives were to determine range shifts of mammal species and to propose an expansion of existing protected areas to mitigate the vulnerability. Northern Thailand was selected for this study because it is situated at a crossroad of tropical rain forest to monsoon forest, and still contains a high percentage of forest cover and protected areas. The region covers a wide range of ecosystems, ranking from rain forests to dry forests [29]. Therefore, its geographical location is suitable to investigate the altered precipitation, seasonality, and temperature on species distributions and find alternative options for conservation planning. In addition, this study advances the recent work on assessing potential effects of land-use and climate change in northern Thailand [14].

Study Area

Northern Thailand is situated between 14°56' and 20°27'N and 97° 21' and 101°47'E. The region covers 17 million ha and accounts for one-third of the country land area (Fig. 1). Mean annual temperature during 1980-2010 was 25.4°C, and the annual rainfall was 1,232mm. According to the HadCM3 B2a climate scenario (http://www.ccafs-climate.org/), mean temperature is expected to rise to 27.1°C in 2050, while the annual rainfall will be 1,302mm.

Dominant vegetation types in the region include mixed deciduous forest, dry dipterocarp forest, dry evergreen forest and hill evergreen forests. Forest cover in 1962 was 68% of the region's land area and decreased to 52% in 2015 due to extensive encroachment for rubber plantations and the government policy to promote rubber plantations. Based on the recent land-use trend, forest cover will most likely decline to less than 50% in 2050 [30]. The northern region is recognized as important watersheds that supply water resources to the lower north and central regions. Approximately 31% of the region (54,151km^2) has been designated as wildlife sanctuaries and national parks [19] and most of them are located in high mountains along the borders between Thailand and neighboring countries (Myanmar and Lao PDR).

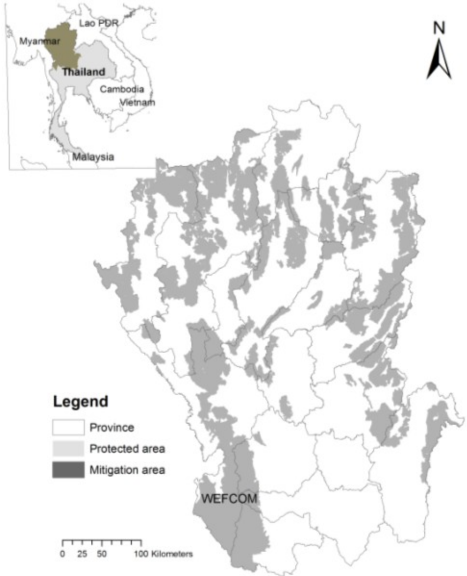

Fig. 1. Location of provinces and protected areas in northern Thailand

Methods

There were three main steps conducted in this research: i) to determine shifts in habitats resulting from land-use and climate change, ii) to identify risk species, and iii) to propose an expansion of protected areas. Detailed procedures are described below.

Shifts in habitats of selected mammal species

The predicted distributions of 17 selected mammal species at current (S) and future conditions were obtained from a previous study [14]. They were generated from the maximum entropy model or Maxent [31]. The distribution maps were superimposed and the analyses were done in terms of total extent, gained suitable habitat (G = a new suitable habitat that a species (taxa) will potentially move into) and lost suitable habitat (L= an area currently predicted as suitable but predicted not to exist in the future). A shift in the species distribution or turnover rate was calculated using gained habitat and lost habitat predicted at present and in the future, $100\times[(G+L)/(S+G)]$. In addition, centroids of current and future projections were determined and compared to estimate of the likely shifts in distribution for each species, both directional shifts, and distance from original centroids using SDMtoolbox1.1 [32].

Species risk assessment

Species risk was determined by using modified qualitative risk assessment matrix [33] and the risk framing concept used in the IPCC AR5 report [6]. The criteria for assessment included hazards, vulnerable level, and coping capacity. In this research, the term *hazard* refers to the conservation status of selected species in the national red list [34]. *Exposure* refers to the level of distribution shifts or turnover from the baseline as the result of the dual change drivers of predicted land-use and climate change in 2050 because these scenarios predict the greatest impact [14]. *Coping capacity* is defined as the effectiveness of protected areas for protecting suitable habitats relative to the total suitable areas. In this research, we considered national parks and wildlife sanctuaries but ignored non-hunting areas, and forest parks although they met

IUCN definitions [18] due to their coverage were not available. The extents of Thailand's protected areas were downloaded from the World Database on Protected Areas (www.protectedplanet.net). Then, each criterion was qualitatively classified into five classes (from very low to very high) as shown in Table 1.

Table 1. Species risk assessment criteria and class

Level	National conservation status[1]	Turnover rate[2]	% suitable habitat predicted in protected areas[3]
Very low	Least concern	<20%	>80%
Low	Near threatened	20-30%	70-80%
Moderate	Vulnerable	30-40%	60-70%
High	Endangered	40-50%	50-60%
Very high	Critically endangered	> 50%	<50%

Notes: 1- hazard; 2 - exposure; 3 - coping capacity

In order to obtain a species risk level, two consecutive steps were undertaken. First, the hazardous level was correlated with exposure level to derive at severity class. For instance, banteng (*Bos javanicus* d'Alton, 1823) is categorized as a very high hazard, because it is listed as critically endangered in Thailand [34]. Its suitable habitat would shift approximately 35% from the current distribution range [14], thus its hazardous level is categorized as extreme. Using the risk assessment matrix (Table 2), banteng would be ranked as high severity to future land-use and climate change. In addition, more than 80% of suitable habitats for banteng in 2050 were predicted inside protected areas meaning with very effective protection, therefore banteng would be categorized as a very high risk species.

Table 2. Qualitative risk assessment matrix to determine species risk

Step 1 (determining severity level)	**Hazard level[1]**				
Exposure level[2]	**Very low**	**Low**	**Moderate**	**High**	**Very high**
Very low	Very low	Very low	Low	Moderate	Moderate
Low	Very low	Low	Low	Moderate	High
Moderate	Very low	Low	Moderate	High	Extreme
High	Low	Moderate	High	Extreme	Extreme
Very high	Low	Moderate	High	Extreme	Extreme
Step2 (determining risk level)	**Severity level[3]**				
Coping capacity[4]	**Very low**	**Low**	**Moderate**	**High**	**Extreme**
Very effective (>80%	Low	Moderate	High	Very high	Very high
Effective (70-80%)	Low	Moderate	High	Very high	Very high
Moderate (60-70%)	Low	Low	Moderate	High	Very high
Poor (50-60%)	Very low	Low	Moderate	High	High
Very poor (<50%)	Very low	Low	Low	Moderate	High

Notes: 1- national conservation status; 2 - turnover rate; 3 - derived from the combined hazard and turnover rate; 4 - % range found in protected areas, Modified from Villagran De Leon (2006) and IPCC (2014)

In this research, the moderate to very high risk were considered for species at risk that would require effective and urgent conservation efforts to mitigate the impacts as otherwise, they may be extinct in the future.

Define priority expansion of protected areas to mitigate impacts

The Gravity Model [35] was applied to identify priority areas of extended protected areas. The original model was usually used to determine trade flows and population migration [36]. The modified model used in this research was to describe the potential wildlife migration in response to future land-use and climate change. The equation is as written below:

$$I_{ij} = (R_i \times A_j)/(D_{ij} \times C_{ij}) \qquad (1)$$

where: I_{ij} is defined as priority areas for expansion of future protected areas; R_i is the assemblages of all 17 species at the baseline. The (new) attraction (A_j) is defined as the location of the assemblages of at-risk species in 2050 located in nature areas (excluding settlements and water bodies). D_{ij} is the effective distance (direct distance) between the existing nearest protected areas boundary (patch i) and new suitable habitats (A_j) larger than 1.0km^2.

Besides, habitat connectivity (C_{ij}) was added in the original Gravity Model to determine the potential route migration. The connectivity classes were adopted from the infrastructure pressure used in the Global Biodiversity Assessment (GLOBIO3) [37] because the construction of roads causes at least four negative effects to animals, including edge effects in natural conditions, a physical barrier for animal migration, road accidents, and accessibility for humans for agriculture and extraction of forest products. The impact zones were determined by the combination of road buffers and nature areas. They were subdivided into five classes i.e. very close (≤ 1km), relatively close (> 1km ≤ 3km), moderate (> 3km ≤ 5km), far (> 5km ≤ 10km), 2) and very far (> 10km).

Each variable was ranked as 1 (very low) -5 (very high). The greater value is the more suitable. All spatial analyses were done using cell-based modeling at a grid resolution of 100 m. Higher species richness (R_i), suitable habitats (A_j) and closer to existing protected areas (D_{ij}) were assigned as potential areas for expansion. In contrast, greater distance and less connection (C_{ij}) were of lower suitability. The accumulated scores derived from the modified Gravity Model were sub-divided into five priority classes (very low, low, moderate, high and very high) using +/-1 standard deviation (SD). Very high and high classes were determined as priority areas for protected area expansion or "*mitigation areas*".

Results

Suitable habitat changes and shifts

The predicted suitable habitats of 17 selected mammal species at the baseline ranged from 2.3% of the study area for gaur (*Bos gaurus* C.H. Smith, 1827), and Chinese goral (*Naemorhedus caudatus* (Milne-Edwards, 1867) to 23.2% for wild boar (*Sus scrofa* Linnaeus, 1758). Future reduction of forest cover from 57% in 2002 to 50% in 2050 [30] would affect the distributions of selected mammal species in different directions. Gaur, bear (*Ursus thibetanus* G. Cuvier, 1823 and *U. malayanus* Raffles, 1821) and civets *(Viverra megaspila* Blyth, 1862, *V. zibetha* Linnaeus, 1758, *Viverricula indica* (Desmarest, 1804)) were predicted to relatively remain unchanged (less than 5% change of either increase or decrease from the baseline). In contrast, barking deer (*Muntiacus muntjak* (Zimmermann, 1780)), and Chinese goral would gain suitable habitats (>5% from the baseline). The remaining 12 species showed a tendency of range decline (<5% from the baseline).

Seven species would gain considerable habitats under future climatic conditions, but banteng, golden jackal (*Canis aureus* Linnaeus, 1758), sambar deer (*Cervus unicolor* (Kerr, 1792)) and tapir (*Tapirus indicus* Desmarest, 1819) were predicted to lose some habitats (Table

3). More species and greater habitat loss were predicted for the combination of land-use and climate change scenario. Major shifts were predicted for leopard (*Panthera pardus* (Linnaeus, 1758)), Chinese goral and civets as they would have turnover rates greater than 50% under the combined drivers. The minimum range shift of 7% was predicted for gaur under land-use change scenario.

Table 3. Selected mammal species, extent and predicted centroid shifts

No.	Common name	Baseline	LU				CC				LUCC			
		Extent[1/] (%)	Extent (%)	Turn[2/] (%)	Dist[3/] (km)	Direct[4/]	Extent (%)	Turn (%)	Dist (km)	Direct	Extent (%)	Turn (%)	Dist (km)	Direct
1	Gaur	2.3	2.3	7	21.6	SW	2.3	32	43.0	S	2.2	32	29.6	SW
2	Banteng	2.4	1.8	33	124.5	S	1.9	27	24.9	NE	1.7	36	33.2	NE
3	Golden jackal	18.3	15.4	38	18.4	SW	17.2	26	17.8	SW	13.9	44	22.7	W
4	Sumatran serow	14.7	11.9	30	22.3	SW	14.1	28	25.2	E	12.0	40	48.6	NE
5	Dhole	14.3	12.7	37	34.6	NE	16.7	26	3.2	N	13.6	38	36.4	S
6	Sambar	4.3	3.7	28	20.7	SW	3.5	35	5.2	W	3.2	41	167.9	SW
7	Asian elephant	4.3	4.0	29	19.77	SW	4.8	36	25.4	E	3.8	40	15.8	SW
8	Gibbons	12.6	9.9	38	49.0	N	13.3	33	19.7	SW	11.4	41	2.5	NE
9	Barking deer	20.1	22.0	27	14.8	E	22.0	27	34.5	NE	21.9	33	45.2	E
10	Chinese goral	2.3	2.5	49	16.7	N	2.2	28	2.5	NE	2.7	54	6.4	NE
11	Leopard	4.9	2.7	37	125.9	SW	5.6	43	30.3	W	2.6	58	118.7	SW
12	Tiger	5.3	3.8	34	185.6	S	5.6	34	28.7	W	4.1	39	104.4	S
13	Small felids	7.6	6.6	37	6.5	W	8.3	41	107.9	S	6.9	50	8.5	N
14	Wild boar	23.2	21.4	27	12.3	W	22.4	24	29.0	W	20.5	34	15.5	SW
15	Tapir	3.0	2.8	18	24.4	SW	2.8	16	2.6	E	2.6	24	17.8	W
16	Bears	14.8	14.6	32	9.5	SW	14.8	36	10.9	N	13.6	34	14.0	E
17	Civets	16.4	16.8	34	75.1	NE	16.6	42	70.1	NE	15.9	52	68.6	NE
Very high class[5/]		3.4	3.3		100.8	SW	3.4		107.5	SW	3.1		116.0	SW

Remarks: LU = land-use change; CC = climate change; LUCC = land-use and climate change; N = north; NE = northeast; E = east; SE = southeast; S = south; SW = southwest; W = west; NW = northwest; [1//]percentage of study area; [2/] percentage of shift from original habitats; [3/] shift in centroid of suitable habitats from baseline; [4/] cardinal direct change of centroid; [3] extent of suitable habitats for ≥ 10 species

The current centroids of the 17 mammal species were situated in the western part of the northern region. Nine species (gaur, banteng, golden jackal, serow (*Capricornis sumatraensis* (Bechstein, 1799)), sambar, Asian elephant (*Elephas maximus* Linnaeus, 1758), leopard, tapir and bear) had a tendency to move further towards the south or southwest in response to the land-use change, while other species would be moving towards different directions but less likely towards the east direction (Table 3). The habitat centroids of banteng, leopard, and tiger *(Panthera tigris* (Linnaeus, 1758) were predicted to move more than 100km from the current locations. Moderate shifts (30-100 km) in centroids were predicted for gibbons *(Hylobates lar* (Linneaus, 1771) and *H. pileatus* (Gray, 1861)), civets and dhole (*Cuon alpinus* (Pallas, 1811)).

Under the climate change scenario that anticipates that annual mean temperature and the mean minimum temperature will increase approximately 2°C in 2050, while the annual rainfall and rainfall in dry months will decrease 80mm most species, except golden jackal, wild boar and civets will have the same movement direction, while other species will change directions (Table 3). In addition, 13 species (excluding gaur, barking deer, small felids *(Prionailurus bengalensis* (Kerr, 1792), and *Pardofelis marmorata* (Martin, 1837)) and wild boar) were predicted to shift their habitat centroids substantially less than the land-use scenario. For instance, the centroid shift for banteng and leopard for climate change impact was approximately 25 and 30km, and would increase to 124 and 126km respectively with deforestation impact.

The patterns of the centroid habitat shifts under the combination of two drivers were likely similar to the land-use change, except for Sumatran serow, dhole, small felids, and bear. Sumatran serow was predicted to shift in opposite direction with a far distance compared to the land-use change. Although sambar deer had similar movement direction as previous scenarios, its centroid would shift more than 7 folds compared to individual impact. In contrast, climate change and deforestation impacts generated similar movement patterns for banteng.

Species at risk

Using the qualitative vulnerability assessment criteria (Table 2), the results showed that the number of very high and high risk to land-use change, climate change, and the combined threats will be 5, 5 and 7 species, respectively. Gibbons, Chinese goral and small felids were predicted to be a high risk either for climate change impact or land-use change impact, while leopard and civets are more sensitive to climate change than land-use change (Table 4). Dhole, bears, golden jackal, tiger, and Asian elephant were categorized as moderate risk species to all scenarios. In contrast, Sumatran serow, gaur, sambar, wild boar, and barking deer were less sensitive to extinction. This is due to the fact that wild boar, sambar, Sumatran serow, and barking deer are listed as not threatened species.

Table 4. Species at risk assessment to climate and land use changes in 2050

Species name	LU		CC		CCLU	
	Current plan	With expansion	Current plan	With expansion	Current plan	With expansion
Gibbons	H	H	VH	H	H	H
Dhole	M	L	M	L	M	L
Leopard	M	M	H	M	M	M
Bears	M	L	M	L	M	L
Chinese goral	H	M	H	M	H	M
Banteng	H	M	M	M	VH	H
Sumatran serow	L	L	L	L	M	L
Tapir	M	L	L	L	L	L
Golden jackal	M	L	M	L	H	M
Tiger	M	M	M	M	M	M
Small felids	H	H	H	H	H	H
Civets	M	M	H	M	H	M
Gaur	L	L	M	L	L	L
Wild boar	VL	VL	L	VL	L	L
Sambar	L	L	L	L	L	L
Barking deer	VL	VL	L	VL	VL	VL
Asian elephant	H	H	M	M	H	H

Notes: LU = land-use change; CC = climate change; LUCC = land-use and climate change;
VH = Very high risk; H = High risk; M = Moderate risk; L = Low risk; VL = very low risk

This research aimed to propose extension areas to mitigate the predicted effects derived from the combination of land-use and climate change scenario as a precaution measure because the cumulative drivers cause more impact than an individual driver. Therefore, 12 species categorized as moderate to high-risk species were selected as target or risk species that require urgent conservation efforts, otherwise, they are sensitive to extinct. The total ranges of risk species cover 50,714km^2 or approximately 29.6% of the northern region. Of this number, 32% or 16,200km^2 was predicted outside existing protected areas and became preliminary targets for expansion.

Priority expansion of protected areas

The total ranges or assemblages of all 17 species *(R_i)* at the baseline covered an area of 67,837km^2 or 40% of the northern region. About 73% of the total ranges were predicted inside existing protected areas. The assemblages areas were sub-divided into five classes: very low (0-2 species), low (3-5 species), moderate (6-8 species), high (9-12 species) and very high (≥13 species). The extents of each class were 52.9, 22.9, 13.5, 7.1 and 3.6% of the total study area, respectively (Fig. 2). The assemblages of 12 at-risk species (A_j) were also subdivided into five classes: very low (0-1 species), low (2-3 species), moderate (4-5 species), high (6-7 species) and very high (≥8 species) (Fig. 3). The extents of each class were 64.9, 19.8, 8.0, 4.2 and 3.1% of the total assemblages, respectively.

Using cell-based modeling and the four criteria defined in the modified Gravity model, the accumulated scores of all patches varied from 0 to 625. There were altogether 2,043 patches ranking from 0.25-644km^2. Small patches less than 1.0km^2 or 100ha were removed. The preliminary areas were shortened to 1,640 patches and the mean patch size was 624ha. Next, they were reclassified into five priority classes using +/-1 SD. The extents of very low, low, moderate, high and very high priorities classes (excluding non-suitable habitats) were 111,796, 14,137, 5,714, 2,981, and 2,215km^2 respectively. The accumulated area of high and very high classes (*expansion areas)* covered 5,196km^2 or 3% of the northern region (Fig. 4). If the expansion areas were included in the existing protected areas, the total area will be 59,347km^2 or 34.4% of the region.

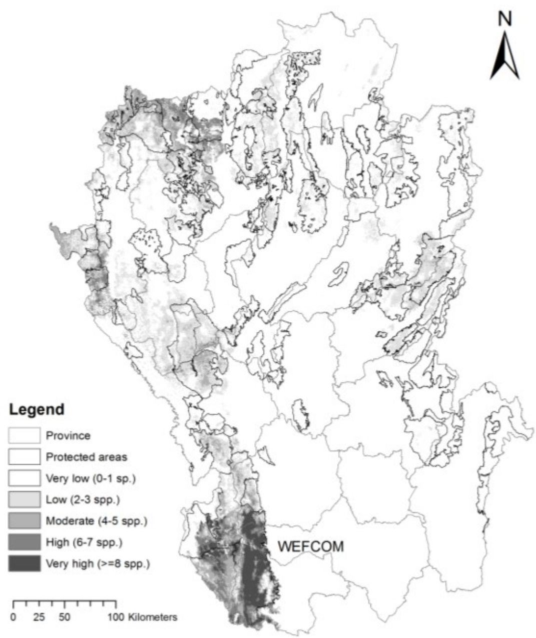

Fig. 2. Species richness of 17 mammal species at the baseline

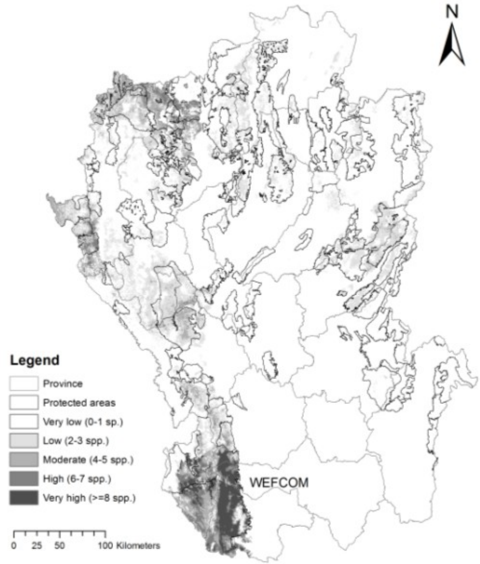

Fig. 3. Species richness of 12 risk species under land-use and climate change scenario in 2050

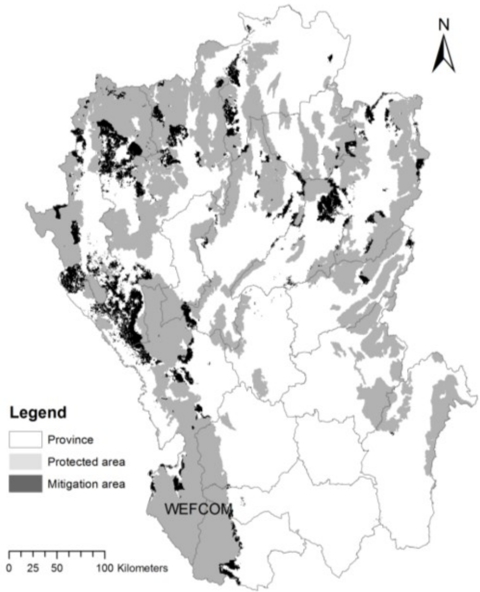

Fig. 4. Proposed expansion areas of protected areas to mitigate land-use and climate change scenario in 2050

The proposed expansion areas were mainly located in the northwest and the west of the study area, and only a few areas were targeted in the northeast. These areas would reconnect and enhance the capacity of protected areas network. Furthermore, they will substantially increase the coping capacity in protecting the 10 moderate and high-risk species to future land-use and climate changes (Fig. 5).

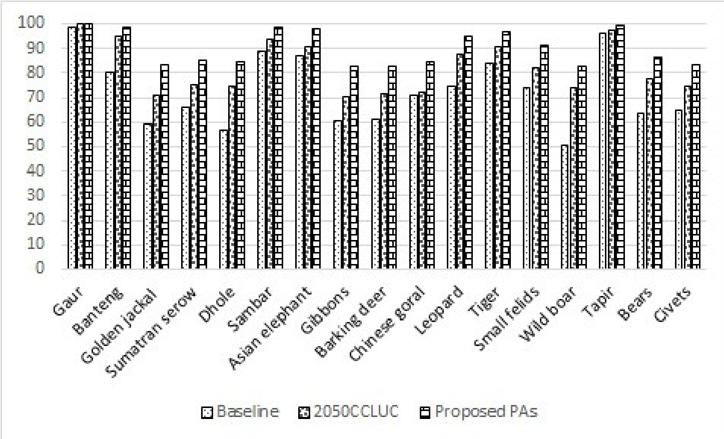

Fig. 5. Contribution of protected areas in protecting 17 selected species

The average coping capacity would increase from 82% as the current plant to 90%. Substantial contributions were predicted for Golden jackal, Sumatran serow, dhole, gibbons, barking deer, Chinese goral and small felids. For example, the percentage of suitable habitat for dhole was 57% at the baseline and will be 74% and 84% in 2050 for the combined land-use and climate change impact, and for the inclusion of expansion areas, respectively. The additional contributions are very low (less than 2%) for gaur and tapir because the entire suitable habitats of these two species already exist inside protected areas. Using the same qualitative risk assessment matrix, the expansion of protected area coverage would downgrade Chinese goral, Golden jackal and civets from high risk to moderate risk under the land-use and climate change scenario. In addition, the risk conditions for dhole, leopard, Sumatran serow and bears will decrease from moderate to low risk (Table 4). Meanwhile, six and ten species would be downgraded to lower risk under land-use and climate change, respectively.

Discussion

Future trends in distributions of key mammal species

The predicted climatic patterns used in this research (HadCM3 B2a climate scenario) showed agreement with previous studies [38]. There is a clear trend of increasing precipitation, except for the western border, where future precipitation may most likely remain unchanged. The future climatic patterns would flavor ecosystems and species associated with hot and mesic bioclimatic zones to expand and replace rain forests and subtropical forests [7-10].

Twelve of all 17 selected medium– and large–mammal species have a tendency of range decline and the predicted effects are more severe under the dual climate and land-use changes, which are consistent with previous studies either for birds [39, 40] or mammals [41]. Most selected species likely move towards the southwest direction toward the western forest complex or WEFCOM (Table 4). The WEFCOM is the largest (nearly 20,000km^2), contiguous, and effectively managed protected areas in Thailand [42]. Future precipitation most likely remains stable in the WEFCOM [38]. The results are consistent with a recent study of predicted montane birds in Thailand [43], but are opposite to results in the temperate zone (e.g., UK) where species distributions are shifting northward to avoid warmer temperature trends in low latitudes [44]. The distance of centroid range shifts for small felids under climate change scenario and for sambar, leopard and tiger under the combined land-use and climate change scenario were predicted to be more than 100km largely due to disappearance of remnant suitable habitats scattered in the north and northeast parts of the region in 2050 [30].

Species vulnerable to land-use and climate change

There are four main approaches used for assessing species vulnerability to climate change: i.e. species distribution models (SDMs), mechanistic, trait-based, and combined (or hybrid) approaches [45]. In this study, we used the hybrid approach, which combined SDMs with adaptive capacity due to available data obtained from previous works [14, 30]. SDMs provide spatially explicit outputs that are used for conservation planning. In addition, adaptive capacity determines the ability of each species to disperse or to migrate to future climatically suitable habitats as the result of land-use change and habitat fragmentation [46].

Based on the three designed criteria (hazard, exposure, and coping capacity), the number of risk species as a result of individual land-use and climate change was similar, while more risk species were expected from the combined threats. Gibbons, Chinese goral, and banteng and small felids were predicted to suffer high negative effects either from land-use or climate change. When both drivers were combined, more vulnerable species (golden jackal, civets, and Asian elephant) would be affected (Table 4). Gibbons are arboreal species and prefer relatively mature forest with a closed canopy (>90%) and mostly occupy old growth forest in either pristine or degraded dry evergreen forests, seasonally dry evergreen forests and rain forests [47, 48]. Future deforestation in northern Thailand [30], expansion of open deciduous forests in evergreen forests [9] will minimize locomotion or branchiation capacity of gibbon [48].

Suitable habitat for Chinese goral is restricted to high altitudes in northern and western Thailand and it is now listed as a critically endangered species [34] largely due to hunting pressure. Although the SDM results indicated that suitable habitats at present and in the future were similar, 30% of its total habitats were predicted to be outside protected areas that and therefore vulnerable to agriculture expansion [42]. Therefore, it was at present ranked as highly vulnerable.

Banteng is one of the endangered species in Thailand. It prefers grassland and open woodland habitats that are usually maintained by forest fire regimes with 2-3 years intervals [49]. Additional annual rainfall of approximately 80-100 mm (http://www.ccafs-climate.org/) and an increase in summer days would alter forest fire patterns and trigger fires, as well as degrade grassland habitats. The current range of banteng (2.4% of the study area) would decline approximately 25-30% in 2050 and would shift more than 30% from current distribution (Table 4). In addition, future agriculture expansion will also lessen and restrict its habitat [30].

Although the small felids are widely distributed and use various habitats, their current populations are under increasing threats from habitat loss, shortage of prey species and anthropogenic impacts [50-52]. Previous studies indicated that mean annual survival for leopard cats was greater in a remote protected area compared to highly visited national parks [53, 54]. In addition, its lower survival was observed during dry conditions due to less prey abundance. Therefore, adult leopard cats had greater ranges for finding enough food during the dry season than in the wet season [55]. Previous results are relevant to our study, which indicated that the predicted range of small felids would increase approximately 9% from the baseline, but turnover rate was 41% under climate change. In addition, land-use change (either individually or combined with climate change) would decrease suitable habitats for small felids approximately 10% from the baseline (Table 3).

Conservation planning adaption to land-use and climate change

Quantitatively, the current percentage of protected areas (e.g., national parks and wildlife sanctuaries) in Thailand (approximately 21% of the country's land area) and in northern Thailand (31% of the region area) is greater than the 17% set for terrestrial ecosystems in Aichi Biodiversity target 11 [18]. However, past and current designation of Thailand's protected areas is not effective in protecting ecosystems and species diversity, especially in the face of rapid environmental changes. They are mainly located in rugged terrain for forest and watershed protection [22, 23]. This also applies to other countries in the region [20]. Thus, accelerating and expanding protected areas to adapt to future trends in land-use and climate change is very essential in order to facilitate species migration to new suitable habitats and to protect remaining habitat ranges [13, 27, 28, 57].

The inclusion of expansion areas of 5,196 km^2 or 3% of the northern region would minimize risk level for 6 and 10 species under future land-use and climate change scenarios, respectively and 7 species will be under the combined threats (Table 4). The percentage of protection or coping capacity would substantially increase for most species under all impact scenarios, especially for Golden jackal, dhole, wild boar, and bears where large portions of currently suitable habitats are located outside protected area boundaries (Fig. 5).

It should be noted that approximately 95% of the total expansion patches (1,640 patches) are smaller than 10km^2, and are thus not suitable to be established as a new protected area [18]. Such patches that adjoin existing protected areas should be included in the current system. Meanwhile, patches that are relatively far from existing protected areas should be managed as different forms of ecological linkages that provide landscape connectivity and facilitate movements of animals such as stepping stones or habitat corridors [18, 42, 56-58]. *Y. Trisurat et* al. [42] indicated that effective protection and habitat improvement in areas between suitable habitats inside the WEFCOM, Thailand would enhance the viabilities of large mammals. In addition, incorporation of *ex-situ* conservation to supplementary *in-situ* conservation for specific species requiring a narrow habitat range such as gibbons is also needed for long-term persistence of these species.

Conclusions

Northern Thailand is facing uncertain climate conditions and high deforestation rate. In this research, we combined spatially explicit species distribution models with dispersal limitations to assess the vulnerability of 17 mammal species under different climate change and land-use scenarios. The results revealed that 70-80% of suitable habitats are found inside protected areas at current, but most of them will substantially shift their distributions and loss suitable habitats, especially when both drivers are combined. Hence, the existing protected areas cannot guarantee the long-term survival of many species. If the proposed expansion areas of approximately 5,200km^2 or 3% of the northern region are added, many of those risk species will be less sensitive to those anthropogenic threats. These areas would be either managed as extension protected areas or as habitat connectivity in a large landscape. In addition, ex-situ conservation is also essential for very high-risk species having narrow habitat ranges and physical tolerance such as gibbons. Our study provides a new framework for adaptive protected areas management that contributes to the protection of mammal species in current and future land-use and climate change scenarios. The approach used in this study contributes to the Aichi biodiversity targets (e.g., 11-protected areas, 12-reducing risk of extinction). In addition, the approach can be applied in accelerating protected areas planning in response to land-use and climate change in Southeast Asia, where deforestation and climate change become significant drivers of biodiversity loss in the next century.

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