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# Predictive distribution modelling for rufous-necked hornbill *Aceros nipalensis* (Hodgson, 1829) in the core area of the Western Forest Complex, Thailand

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**Abstract.** The rufous-necked hornbill, *Aceros nipalensis* (Hodgson, 1829), is listed as vulnerable and is found only in the Western Forest Complex. The objectives of this research were: 1) to estimate the geographical distribution for the rufous-necked hornbill at the Thung Yai-Huai Kha Khaeng World Heritage Site in both the breeding and non-breeding seasons; and 2) to determine seasonal changes in its habitat use. We collated the occurrence records of the rufous-necked hornbill from long-term monitoring data and conducted additional surveys during 2004–2008. In addition, spatial layers for potential environmental variables that might affect hornbill distribution were developed and Maximum Entropy (MaxEnt) modelling technique was used to generate potential distributions. The results indicated that MaxEnt models performed very well and the overall accuracies of the predicted maps in breeding and non-breeding seasons derived from the contingency matrix were 81% and 85% respectively. In addition, altitude and land cover were considered significant variables in the species distribution model. Suitable habitats for the rufous-necked hornbill were predicted in the high altitude evergreen forest and were clustered into three patches in the center of Thung Yai Naresuan West, Huai Kha Khaeng, and along the western boundary of Huai Kha Khaeng adjoining Thung Yai Naresuan East. Suitable habitats covered 11.7% of the world heritage site, of which 6.6% and 9.2% were in the breeding and non-breeding seasons respectively, owing to the fact that the home range during breeding season is smaller compared to non-breeding season. Future conservation efforts should focus on enhancing the connectivity between suitable large and small patches within the distribution range, the installation of artificial nests, and patrolling to minimise poaching.

**Key words.** MaxEnt, maximum entropy modelling, species distribution modelling, Thung Yai–Huai Kha Khaeng World Heritage Site

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## INTRODUCTION

Hornbills are recognised as the largest bird species in the tropical forests of Asia and are classified in the family Bucerotidae of the order Bucerotiformes (Sibley & Monroe, 1990). Thirty species of hornbills are found in tropical Asia, with a further 22 species in Africa. Besides being a flagship species for conservation because of their striking appearance and intriguing nesting behaviour, with the female imprisoning herself inside a cavity in a tree (Poonswad et al., 1987), hornbills are among the primary frugivores of the many forests they inhabit, where they have a significant role in seed dispersal (Kemp, 1995). Large hornbills are also good indicators of forest condition and human disturbance because they require large tracts of contiguous primary forest with large trees for nesting sites and food resources, and they are targeted for hunting (Poonswad & Kemp, 1993). Meanwhile, hornbills also control populations of small seed predators such as insects and mice, thus helping to maintain forest structure and the productivity of forest ecosystems (Poonswad & Kemp, 1993).

However, due to severe deterioration of tropical forests, eight out of 31 Asian hornbill species are threatened species (BirdLife International, 2001; Kinnaird & O' Brien, 2007). The rufous-necked hornbill (RNH, *Aceros nipalensis* [Hodgson, 1829]) was originally distributed in the mountainous regions in Bhutan, north-eastern India, Myanmar, Thailand, Laos, Vietnam, southern Yunnan, and south-eastern Tibet in China. Its range has declined dramatically and it is now very rare across much of its historical range (BirdLife International, 2001). The RNH is classified as a vulnerable species at the global level and an endangered species in Thailand (Vidhidharm et al., 1995; Round, 2000; Sanguansombat, 2005) because its original habitat has disappeared from many areas, and it is now

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found mainly in the Western Forest Complex (WEFCOM), particularly in the hill evergreen forest of the Huai Kha Khaeng Wildlife Sanctuary at elevations above 1,000 m (Chimchome et al., 1998; Ouithavon et al., 2005). Previous studies of the RNH in Thailand were confined to describing its general habitat, breeding biology, and ecology (Lekagul & Round, 1991; Poonswad, 1993; Poonswad & Kemp, 1993; Kemp, 1995; Chimchome et al., 1998; Poonswad et al., 1999; Ouithavon et al., 2005). Recently, Tifong (2007) studied the home range, feeding, and roosting sites of one female and two male RNHs using radio-telemetry during the breeding and non-breeding seasons. The results indicated that aspects of fruit availability, vegetation type, slope and altitude within the area, and distance from water source affected their daily movements, feeding, and roosting sites.

Much research has attempted to predict species distributions in the landscape. In addition, several approaches have been applied to species-distribution modelling using presence-absence data and a geographic information system (GIS; Agresti, 1996; Corsi et al., 2000), with popular and frequently used methods being Generalised Linear Model (GLM) or Generalised Additive Model (GAM; Guisan & Zimmermann, 2000; Pearce & Ferrier, 2000; Guisan et al., 2002; Beck et al., 2005; Trisurat et al., 2010). A problem found when using logistic regression is that true absence data were often not available and in many cases, pseudo-absence data were created. However, the determined pseudo-absence may appear in the presence localities (Brotons et al., 2004; Phillips et al., 2006) because species that are listed as near extinction (endangered or critically endangered species) are often difficult to detect (Engler et al., 2004), or the survey may not have covered the habitat(s) of the species (Trisurat et al., 2010).

Recently, there has been progress in the development of models to predict species distribution using only presence data. Most research indicated that Maximum Entropy (MaxEnt) model was superior in performance (Phillips et al., 2006; Sérgio et al., 2007) to other models (e.g., Artificial Neural Networks [ANN; Pearson et al., 2002], Ecological Niche Factor Analysis [ENFA; Chefaoui et al., 2005; Peterson, 2006; Santos et al., 2006], Genetic Algorithm for Rule-set Production [GARP; Stockwell & Peters, 1999]). Phillips et al. (2006) reported that MaxEnt model performed well even for small sample sizes.

The Thailand Hornbill Project conducted long-term studies of hornbills over 30 years, where only occurrence data was recorded and the MaxEnt model was adopted. The objectives of this research were: 1) to estimate the geographical distribution of the RNH in the Thung Yai–Huai Kha Khaeng World Heritage Site in both the breeding and non-breeding seasons; and 2) to determine the seasonal habitat use of the RNH.

## MATERIAL AND METHODS

**Study areas.** The research was conducted in the Thung Yai Naresuan and Huai Kha Khaeng wildlife sanctuaries (Fig. 1), which cover approximately 6,488 km$^2$ and designated as a UNESCO Natural World Heritage Site in 1991. Thung Yai Naresuan has been divided into East and West parts for effective administration. Thung Yai Naresuan and Huai Kha Khaeng formed the core area of the 18,727 km$^2$ WEFCOM, which comprise of six wildlife sanctuaries and 11 national parks. The WEFCOM is the largest forest complex in Thailand and more importantly, the largest conservation area in mainland Southeast Asia. It is especially important for its high capacity to support large and endangered mammal species (Trisurat et al., 2010) and birds. At least six hornbill species have been observed in the World Heritage Site, including the great hornbill *Buceros bicornis* (Linnaeus, 1758), RNH, wreathed hornbill *Rhyticeros undulatus* (Shaw, 1811), plain-pouched hornbill *Rhyticeros subruficollis* (Blyth, 1843), Tickell's brown hornbill *Ptilolaemus tickelli* (Blyth, 1855), and Oriental pied hornbill *Anthracoceros albirostris* (Shaw & Nodder, 1807).

**Species occurrence data.** Occurrence records of the RNH were gathered along 14 transects, each 9 km in length (Fig. 1). Transects 1–4 were located in Huai Kha Khaeng, 5–9 in Thung Yai Naresuan West, and 10–14 in Thung Yai Naresuan East. Forty-five point-count sampling spots at 200-m intervals were designated at each transect and trained personnel spent 10 minutes at each spot to record hornbill presence based on sightings and calls (Fig. 1). Field surveys along each transect were conducted twice in each breeding and non-breeding season between January 2004 to December 2008. The breeding season commences in January and lasts until May while the non-breeding season is between June and December (Chimchome et al., 1998; Ouithavon et al., 2005; Tifong, 2007). Additional records of hornbill occurrence were obtained from long-term monitoring studies of hornbills jointly conducted by the Thailand Hornbill Project in association with the Wildlife Conservation Society–Thailand Program.

**Dataset.** Environmental variables that may influence hornbill distribution at landscape levels were identified from

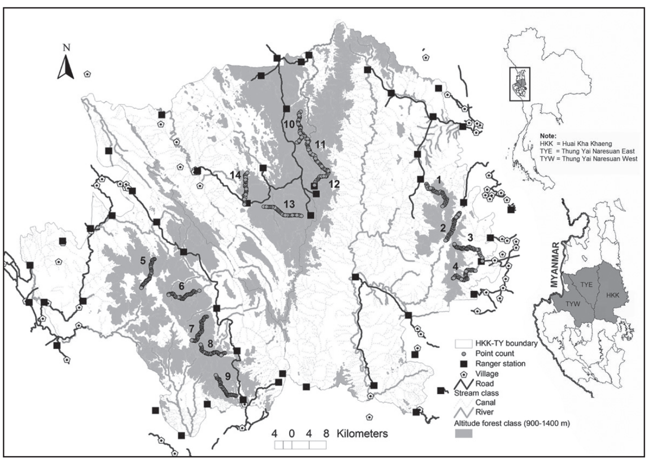


Fig. 1. Map of research locations showing the study areas where the point counts were conducted along14 line-transects, using a hand-held GPS to accurately measure the count locations or extent and position of evergreen forest where the RNH lives, in order to predict RNH distribution.

previous research (Kinnaird & O' Brien, 2007; Tifong, 2007; Trisurat et al., 2013). These variables consisted of climate (minimum and maximum temperature, precipitation), land cover, topography (digital elevation model (DEM), slope), proximity to roads, proximity to streams, and proximity to ranger stations. A land cover map in 2008 and the locations of ranger stations were obtained from the Department of National Parks, Wildlife and Plant Conservation. Climatic variables were downloaded from the WORLDCLIM database (see http://www.worldclim.org/), while topographic feature layers were obtained from the WEFCOM GIS database at a scale of 1:50,000 (WEFCOM, 2004). All environmental variables were converted to a raster (grid) with a spatial resolution of 100 × 100 m and ArcGIS 9.2 software was used for all spatial analyses.

**Species distribution model.** We selected the MaxEnt model because it was developed specifically to model species distributions with presence-only data (Phillips et al., 2006), which is the only hornbill data available for Thailand. We ran the MaxEnt model using the following parameters: random test percentage = 25%, regularisation multiplier = 0.2, maximum iteration = 1,000, convergence threshold = 0.001, maximum number of background points = 10,000.

The output of the MaxEnt model was the continuous probability of occurrence of the species' distribution model output (0.00–1.00). In this study, the more conservative cut-off value of "equal training sensitivity and specificity" was used to classify the continuous probability into a binary prediction (0–1) of presence-absence. If the probability value was equal to or greater than this threshold value, it was classified as present, if less, it was classified as absent. Presence-absence data were separated between the breeding and non-breeding seasons.

Previous studies normally used the area under the curve (AUC) of a receiver operating characteristic (ROC; Zweig & Campbell, 1993; Trisurat et al., 2011) to determine the accuracy of the predicted distribution models. However, the AUC has several shortcomings that were pointed out by Lobo et al. (2008) and Allouche et al. (2006). In the current research, the presence data were randomly partitioned into two datasets. Seventy percent of the data were used as training data to generate the distribution model and the remaining 25% were used as independent points to validate the model. In addition, the same amount of absence data from all transects was randomly selected and used as an independent test. Then, the contingency matrix was developed to calculate omission and commission errors and the kappa coefficient for assessing the accuracy of predicted distribution maps rather than the AUC (Sim & Wright, 2005; Allouche et al., 2006).

The predicted distribution maps for the RNH were generated for both the breeding and non-breeding seasons. In addition, the extents of predicted presence-absence in both seasons and estimated seasonal shifts in distribution were compared and discussed (Fig. 2). It was noted that preliminary predicted distribution maps were generalised using the average home range size for a RNH male in the breeding season (6.19 km$^2$) and non-breeding season (11.16 km$^2$) determined in Huai Kha Khaeng by Tifong (2007) as a minimum habitat size to eliminate smaller habitat areas (noise) for preparation of the final distribution maps.

## RESULTS

**Species occurrence sampling points.** In total, 330 presence data were obtained for the study areas, of which 169 were for breeding and 161 for non-breeding seasons (Table 1). In the breeding season, 127 presence records were used to generate distribution model, 42 for testing and, in the non-breeding season, 121 and 40 records were used, respectively. In addition, 40 absence points were randomly chosen from all transects in the breeding season and 39 points were chosen for the non-breeding season. These data were used as independent absence data to validate the species distribution model accuracy.

From the surveys, we found the occurrence of the RNH in Huai Kha Khaeng over all four trails used for point counts (trails 1–4), but only along trail 4 in the non-breeding season. In Thung Yai Naresuan West, we observed RNH in both seasons over all five trails (trails 5–9). In Thung Yai Naresuan East, the RNH was detected on trails 10–12 in both seasons but was absent along trails 13 and 14 (Fig. 1).

**Model performance and favorable habitat factors.** Among the 10 possible environmental factors contributing to RNH presence in the breeding season, the MaxEnt model indicated that DEM was the highest contributor (33%), followed by land cover (29%), and minimum temperature (13%; see Table 2 for details). The contributions of proximity to ranger stations, villages, and roads were moderate (6%), while proximity to streams, annual precipitation, and maximum temperature contributed the least (<5%). However, in the non-breeding season, while the contributions of elevation and minimum temperature were still significant, the contribution of land use had dropped from 29% in the breeding season to 9%. In both seasons, the vegetation type used by the RNH was evergreen forest, which includes hill evergreen

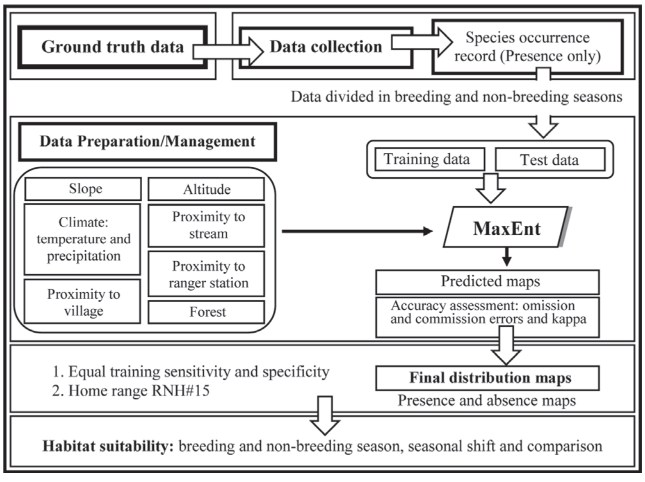


Fig. 2. Diagram showing the conceptual framework used to model the distribution of the rufous-necked hornbill in the Western Forest Complex (WEFCOM), Thailand.

Table 1. Rufous-necked hornbill occurrence data in the breeding and non-breeding seasons in the core areas of the Western Forest Complex.

| Protected Area Name | Trail No. | Number of Occurrences | |
|---|---|---|---|
| | | Breeding Season | Non-Breeding Season |
| Huai Kha Khaeng | 1 | 31 | 28 |
| | 2 | 7 | 8 |
| | 3 | 6 | 2 |
| | 4 | 0 | 10 |
| Thung Yai Naresuan West | 5 | 18 | 15 |
| | 6 | 20 | 19 |
| | 7 | 16 | 27 |
| | 8 | 23 | 5 |
| | 9 | 2 | 18 |
| Thung Yai Naresuan East | 10 | 18 | 13 |
| | 11 | 28 | 16 |
| | 12 | 0 | 0 |
| | 13 | 0 | 0 |
| **Total** | | **169** | **161** |

Table 2. Contributions of environmental factors to rufous-necked hornbill distribution in the breeding and non-breeding seasons, in descending order of importance.

| Breeding Season | | Non-breeding Season | |
|---|---|---|---|
| **Variables** | **% Contribution** | **Variables** | **% Contribution** |
| Altitude (m) | 33.4 | Altitude (m) | 47.6 |
| Land use | 28.8 | Minimum temperature (°C) | 17.5 |
| Minimum temperature (°C) | 12.9 | Land use | 8.5 |
| Proximity to ranger station (m) | 9.0 | Proximity to road (m) | 6.9 |
| Proximity to village (m) | 6.7 | Proximity to ranger station (m) | 5.3 |
| Proximity to road (m) | 6.0 | Maximum temperature (°C) | 4.3 |
| Proximity to stream (m) | 1.2 | Annual precipitation (mm) | 4.2 |
| Annual precipitation | 1.0 | Proximity to village | 2.6 |
| Slope (%) | 0.8 | Proximity to stream (m) | 2.1 |
| Maximum temperature (°C) | 0.3 | Slope (%) | 1.0 |
| **Total** | **100.0** | **Total** | **100.0** |
| **AUC values** | **0.98** | | **0.96** |

forests (montane), degraded hill forests, and dry evergreen forests. Hill evergreen forest occurs from about 1,000–1,700 m above mean sea level (asl). No single tree species or family is dominant, but the families of Fagaceae, Myrtaceae, Lauraceae, Theceae, and Magnoliaceae are well represented in the mountainous WEFCOM. Dry evergreen forest generally occurs from 600–1,000 m asl and is sometimes found along streams at altitudes as low as 400 m asl. Common species at canopy level include *Dipterocarpus* spp. (e.g., *D. costatus* and *D. turbinatus*; WEFCOM, 2003, 2004).

The accuracies of the predictive models were tested by the confusion matrix and the kappa coefficient. The contingency matrix shown in Table 3 indicates that the overall accuracy of prediction in the breeding season was 83.53% and in non-breeding season was 87.34%. It was noted that the kappa coefficient value in the breeding season was approximately 67% while it was 74% in the non-breeding season. The higher kappa coefficient in the non-breeding season was due to the lower omission and commission errors for both presence and absence classes.

**Species distribution maps.** The presence-absence maps for the RNH in the breeding and non-breeding seasons were derived from equal training sensitivity, and specificity threshold values of 0.245 in the breeding season and 0.247 in the non-breeding season. The preliminary predicted distribution areas for the RNH in the breeding and non-breeding seasons covered 476 and 675 $km^2$ respectively; the areas of suitable habitat gain and habitat loss were 86 and 285 $km^2$ respectively; and the seasonal shifts were 371 $km^2$ (5.7%; Table 4). If the suitable habitats in both seasons were combined, their total area was approximately 13% of the study area. In addition, the overlapped suitable habitats of the RNH in both breeding and non-breeding seasons covered 390 $km^2$ or 6.0% of the study area. After the preliminary habitat remnants that were smaller than a home range size (Tifong, 2007) were eliminated, the final distribution areas

Table 3. Contingency matrix of predicted distributions in breeding and non-breeding seasons for rufous-necked hornbill.

| Breeding Season | | Predicted Class | | | |
|---|---|---|---|---|---|
| | | Presence | Absence | Total | Omission errors |
| Observation | Presence | 34 | 8 | 42 | 19.05 |
| | Absence | 6 | 37 | 43 | 13.95 |
| | Total | 40 | 45 | 85 | |
| | Commission errors | 15.00 | 17.78 | | 83.53 |
| | KHAT | | | | 0.67 |
| **Non-breeding Season** | | **Predicted Class** | | | |
| | | Presence | Absence | Total | Omission errors |
| Observation | Presence | 34 | 6 | 40 | 15.00 |
| | Absence | 4 | 35 | 39 | 10.26 |
| | Total | 38 | 41 | 79 | |
| | Commission errors | 15.53 | 14.63 | | 87.34 |
| | KHAT | | | | 0.74 |

for the RNH in the breeding and non-breeding seasons were 421 and 595 $km^2$ respectively. In addition, the habitat use for both seasons and the shifting habitats were 351 and 313 $km^2$ respectively (Table 4).

The distribution patterns appeared to be similar in both seasons, predicting the RNH's absence from the southeastern corner of the study area with the main distribution being in the center of Thung Yai Naresuan West and along the western boundary of Huai Kha Khaeng adjoining Thung Yai Naresuan East (Fig. 3A, 3B). The largest patch was predicted in Thung Yai West, followed by Thung Yai Naresuan East and Huai Kha Khaeng. The predicted habitat sizes and patterns of distribution for RNH in Huai Kha Khaeng between the breeding and non-breeding seasons were quite stable, while in the other two sanctuaries these were quite different. For example, the predicted habitat sizes in the non-breeding season were greater than in the breeding season (30% for Thung Yai East and 35% for Thung Yai West) due to the fact that they are connected with the remaining evergreen forest, while suitable habitat patches in Huai Kha Khaeng are isolated and surrounded by deciduous forest (WEFCOM, 2004).

## DISCUSSION

**Species occurrence data for RNH.** The species occurrence data recorded for RNH in the breeding season were more restricted to certain areas and/or less frequent than in the non-breeding season. We detected RNH on three trails in the breeding and four in the non-breeding season in Huai Kha Khaeng. Although we sighted the species over all five trails in both seasons in Thung Yai Naresuan West, its detection in the breeding season was lesser than the non-breeding season (e.g., two versus 18 records on trail nine, respectively). This phenomenon may be explained by the ecological niche concept, which is defined as a species only being able to establish populations in areas that match the ecological conditions that limit its native distribution (Peterson, 2003), which, in this case, produce seasonal movements in response to variations in availability of fruits and hence, home range size. Tifong (2007) found that the average home range size for RNH male #15 in the non-breeding season was 1.8 times greater than in the breeding season (11.16 $km^2$ versus 6.19 $km^2$). The fact that the male hornbill can feed the female up to 73 times a day during the breeding season (Chimchome et al., 1998) limits the male's range distance from nest tree.

Several previous studies (Poonswad & Kemp, 1993; Pattanavibool & Dearden, 2002; Sitompul et al., 2004; Kinnaird & O'Brien, 2007; Trisurat et al., 2013) indicated that landscape patterns and human disturbance are significant factors affecting hornbill distribution. Rufous-necked hornbill was formerly recorded in northern Thailand, such as in Doi Inthanon and Doi Suthep-Pui national parks, Chiang Mai Province (Poonswad & Kemp, 1993). Unfortunately, it is now locally extinct at these two parks owing to hunting and deforestation by the Hmong and Karen tribes, with a 2005–2007 survey led by the Thailand Hornbill Project finding only Oriental pied hornbills in some protected areas. These patterns support the finding from this research where, even though the study area is large, the distribution of the RNH was limited to specific areas of evergreen forest, particularly large patches of hill evergreen forest, and is also dependent on particular combinations of altitude, temperature, and available foods. In this research, hornbills were found on trails 10–12 in both seasons but not on trails 13 and 14 (Fig. 1) because the topography of trails 13 and 14 is generally flat and easily accessible by people living nearby (WEFCOM, 2004).

**Species distribution model.** We selected the MaxEnt model to predict the RNH distribution because its distribution prediction provides a powerful new tool that uses only presence data. MaxEnt estimates the most uniform distribution (maximum entropy) of the occurrence points of the RNH across the study areas, given the assumption that an expected value for each environmental predictive variable within this estimated distribution matches its empirical average (average values for a set of RNH occurrence data). In addition, it takes into consideration the interactions between environmental variables and seems to perform relatively well with small sample sizes of occurrence data (Phillips et al., 2006). Our research demonstrated that this approach can be applied to

Table 4. Comparison of data from presence-absence maps in the breeding and non-breeding seasons.

| Site | Total Area ($km^2$) | Distribution Threshold (cut off value) | Habitat Suitability Area in $km^2$ (percent per study area) Breeding Season | Non-Breeding Season | Uses in Both Seasons | Habitat Gain | Habitat Loss | Seasonal Shifts |
|---|---|---|---|---|---|---|---|---|
| Study areas Huai Kha Khaeng, Thung Yai Naresuan East and West Wildlife Sanctuary | 6,487.52 | equal training sensitivity and specificity* | 476.63 (7.35%)(1) | 675.37 (10.41%)(1) | 390.17 (6.01%) | 86.46 (1.33%) | 285.20 (4.40%) | 371.66 (5.73%) |
| | | equal training sensitivity and specificity, and generalised using home range** | 421.17 (6.49%)(2) | 595.16 (9.17%)(2) | 351.57 (5.42%) | 69.60 (1.07%) | 243.59 (3.75%) | 313.19 (4.83%) |

Note: * Predicted presence derived from the MaxEnt model,
** Predicted presence greater than the home range of RNH#15 (breeding season = 6.19 km2; non-breeding season = 11.16 km2),
(1) Number of patches in the breeding season = 990 and in the non-breeding season = 1,092.
(2) Number of patches in the breeding season = 9 and in the non-breeding season = 6.

many taxa in Thailand that have only presence data, such as plant specimens (Trisurat et al., 2011).

Species distributions for hornbills were conducted previously at either regional (Kinnaird & O' Brien, 2007) or national levels (Trisurat et al., 2013), and analyses were undertaken at a resolution of 1 km. However, previous studies did not consider seasonal movement. This research used a pixel resolution of 100 m for the estimation of the distribution of the RNH—a scale appropriate to study the species' distribution at the microhabitat level in response to variations in the habitat factors used in the model.

In this study, altitude (m), slope, land use, temperature, precipitation, and the proximity to ranger stations, to villages and to roads were used to generate the distribution models for the RNH because they had been defined previously as potential environmental factors (Kinnaird & O' Brien, 2007; Tifong, 2007; Trisurat et al., 2013). However, the results derived from the MaxEnt model indicated that altitude, land use, and minimum temperature were preferable habitat factors in the breeding season, and altitude and land use were identified as habitat preferences in the non-breeding season (Table 2). The contribution of altitude was very high for both seasons (48% in the non-breeding season and 33% in the breeding season). The current findings indicated that the elevation range of the RNH in the breeding season was 748–1,640 m and 493–1,640 m asl in the non-breeding and breeding seasons, respectively, and was concentrated in an altitudinal range between 1,000–1,400 m asl for both seasons. These findings were quite different from previous research (Chimchome et al., 1998; Ouithavon et al., 2005; Tifong, 2007), except the concentration areas, which indicated that the RNH normally occurs above 1,000 m. In addition, the response curves derived from MaxEnt indicated that evergreen forest was a preferable habitat for the RNH in both seasons. Chimchome et al. (1998) and Ouithavon et al. (2005) revealed that there were 13 and 15 plant species (mainly figs) in the dry evergreen and hill evergreen forests of the Huai Kha Khaeng Wildlife Sanctuary identified as fruit-foods for the RNH in the breeding season and these contributed approximately 80% of the total fruit in the RNH diet. Sitompul et al. (2004) and Kinnaird & Brien (2007) reported that figs have been recognised as "keystone species" for tropical frugivorous vertebrates, especially birds (hornbills) and primates. However, after the RNH female and chick emerge from the nest, they need more food, especially proteins for the growth of the fledged chicks (Poonswad, 1998; Ouithavon et al., 2005; Tifong, 2007), and they range much farther afield. Therefore, the contribution of land use factor on a particular hill evergreen forest was substantially reduced from 29% in the breeding season to 8% in the non-breeding seasons (Table 4).

**Habitat suitability and seasonal shifts.** The results of the MaxEnt models indicated that suitable habitats for the RNH after generalisation were located in three forest patches (Fig. 3). The first patch was consistent with Tifong (2007), who depicted that suitable habitats were located in intact and degraded evergreen forests, at altitudes 800–1,400 m asl, mostly near streams. The second patch was situated along the junction west of Huai Kha Khaeng and east of Thung Yai Naresuan East. Even though it was located in a large patch of evergreen forest (238 km$^2$), not all of this area was defined as suitable RNH habitat (Figure 3B), though other hornbill species that are less threatened than the RNH were found, such as the great hornbills, Tickell's brown hornbills, and Oriental pied hornbills (BirdLife International, 2001). The third patch in the central zone of Thung Yai Naresuan West was the largest extent of suitable RNH habitat found in this study and thus vital in maintaining local RNH populations in this area (Bailey, 2007).

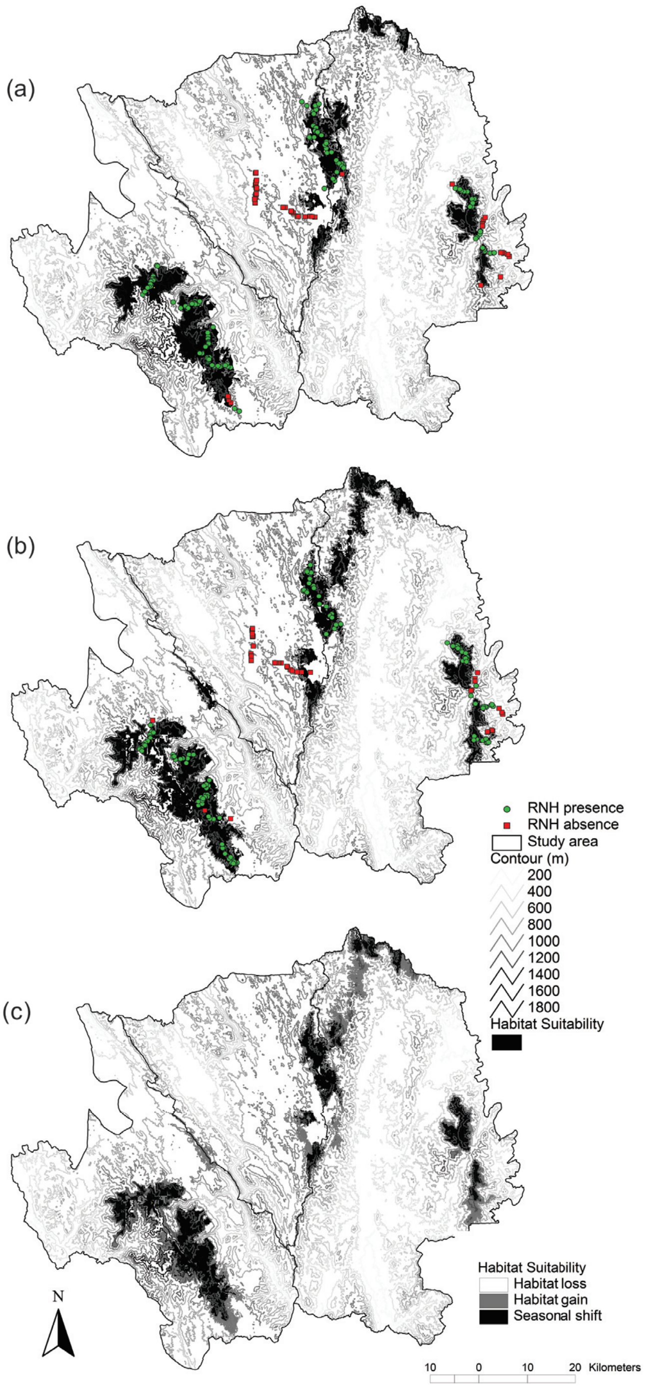


Fig. 3. Presence-absence binary models for RNH distributions after introducing equal sensitivity-specific threshold values to the continuous MaxEnt model based on the smallest home range size of the male RNH #15, as derived from Tifong (2007), during: a, the breeding season; b, the non-breeding season; and c, showing the combined habitat classification.

These preliminary suitable habitats consisted of 990 sub-patches in the breeding season and 1,092 in the non-breeding season. Nevertheless, the predicted areas may be overestimated since the RNH did not appear in many of the small patches of suitable habitats estimated as used from the MaxEnt model. This was especially so on mountain tops where patch sizes were smaller than the home range and distance to other suitable patches was greater than the average daily movement. In addition, Akçakaya (2005) suggested that the estimation of metapopulations for endangered species with a small population size and limited distribution should employ the smallest home-range size in the analyses. Therefore, this study used the average home range size for RNH male #15 in Huai Kha Khaeng to generalise the preliminary map. Hence, the number of sub-patches was substantially reduced in both seasons (Table 4).

When suitable habitats in the breeding season were subtracted from habitats in the non-breeding season, the predicted suitable habitats for RNH before and after generalisation differed by 29%. This estimate conforms to the studies by Chimchome et al. (1998) and Tifong (2007), which found that during the breeding season a male RNH utilised a habitat that is 45% smaller than that in non-breeding season because of sufficient availability of fruits around the nest tree. In addition, this finding is consistent with Poonswad et al. (1987), who noticed that differences in habitats used by different hornbill species potentially correlated with differences and variations in the availability of fruit foods and the stages of the reproductive period.

**Conservation and protection measures.** Poonswad et al. (1999) indicated that nest trees, home range, food source, and roosting sites during flocking are limiting factors for hornbills. The results of this research clearly indicated that in the non-breeding season, RNH used extended contiguous patches in the study area. On the other hand, in the breeding season, patches were clearly segregated, which resulted in three sub-populations (Fig. 3A) that can be best explained by the concept of "habitat fragmentation" (Akcakaya, 2005). The predicted habitat patches situated along the junction west of Huai Kha Khaeng and east of Thung Yai Naresuan East can be used by RNH as stepping stones for dispersion to adjacent and larger suitable habitats (Sitompul et al. 2004) located in Mae Wong National Park and Umphang Wildlife Sanctuary even though these patches are small.

Poonswad (1993) indicated that the availability of nesting cavities of appropriate size may be the most important population-limiting factor for hornbills as hornbills are large birds and require large nesting cavities that exist naturally only in large trees. Most hornbills' nesting holes occur in trees of the genus *Dipterocarpus.* Before Thung Yai Naresuan was declared as a wildlife sanctuary in 1957, indigenous hill tribes had settled in the area and converted the forest into agricultural lands. The GIS database (WEFCOM, 2004) and vegetation assessment (WEFCOM, 2003) reported that 30% of Thung Yai East and 19% of Thung Yai West are classified as degraded evergreen forest. Hence, big trees that are both potential nest trees and sites with suitable cavities were removed (Duengkae & Chimchome, 2007) and this became a critical factor for the RNH. Recent attempts to install artificial nests to assist hornbill conservation at the Budo-Su-Ngai Padi National Park, Southern Thailand showed that the number of nests visited by hornbills steadily increased after installation (Pasuwan et al., 2011). This conservation effort and a proper artificial nesting design can be applied to the study area in order to increase the carrying capacity and enhance degraded habitats.

In addition to enhancing the habitat connectivity between three suitable large patches and degraded habitats located within ranging distance, and the installation of artificial nests, protection measures are also essential to maintain RNH and other hornbill populations in the WEFCOM. Pattanavibool & Dearden (2002) and Poonswad & Kemp (1993) revealed that hornbill species were extinct from most protected areas in northern Thailand owing to hunting pressures and habitat destruction. Currently, seven and nine villages are located inside Thung Yai Naresuan East and Thung Yai Naresuan West respectively, with populations of 2,900 and 1,200 individuals (WFCOM, 2004). Field surveys also showed the evidence of poaching near these communities. The Department of National Parks, Wildlife and Plant Conservation, with the technical and financial support from the Wildlife Conservation Society-Thailand Program, has implemented a smart patrol system in the Thung Yai-Huai Kha Khaeng World Heritage Site since 2005. It aims to equip park rangers and managers with information technology to better protect the areas. It is expected that the conservation and protection measures will increase the carrying capacity of suitable habitats, enhance the connectivity between suitable habitats outside the current distribution ranges, and subsequently help to maintain the population viability of the RNH population in the WEFCOM.

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