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Factors influencing appearance and suitable habitat for wild elephants in the Khao Yai National Park, Thailand

YAMEERA NANLA[1,3], DOKRAK MAROD[1], PRATEEP DUENGKAE[1], PAANWARIS PAANSRI[2], JEDSADA NOOWONG[1], CHIRANAN MANITOEM[3], RONGLARP SUKMASUANG[1,♥]

[1]Department of Forest Biology, Faculty of Forestry, Kasetsart University. 50 Phahonyothin Road, Chatuchak District, Bangkok 10900, Thailand. Tel./fax.: +66-257-90176, ♥email: mronglarp@gmail.com

[2]Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University. Blacksburg, Virginia 24061, United States of America

[3]Khao Yai National Park. PO Box 9, Pak Chong Post, Moosi Subdistrict, Pak Chong District, Nakhon Ratchasima Province 30130, Thailand

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Abstract. *Nanla Y, Marod D, Duengkae P, Paansri P, Noowong J, Manitoem C, Sukmasuang R. 2024. Factors influencing appearance and suitable habitat for wild elephants in the Khao Yai National Park, Thailand. Biodiversitas 25: 3061-3072.* Protected areas are designated to conserve biodiversity and provide a safe habitat for wildlife. This study aims to investigate the factors affecting elephant appearance and changes in habitat. The maxEnt program was used to analyze data derived from the patrolling system with constant quality monitoring. Four categories of environmental factors, climatic, physiological, biological, and anthropological factors were used to analyze the wild elephant data yearly from 2017 to 2022. The aim was to understand the effect of environmental factors on the wild elephants' appearance and their habitat suitability. The results showed an average area under the receiver-operating-characteristic curve (AUC) was 0.81±0.004 SD. The results indicated that climatic (42.97%), physiological (32.62%), and anthropological (21.23%) factors affected the appearance of wild elephants significantly. Temperature factors showed the highest percentage contribution (39.04%), while water sources and salt licks, considered physiological factors, contributed 22.13% and 5.06%, respectively. Habitat suitability analysis revealed that the majority of the park area (64.91%) was categorized as unsuited and poorly suited habitat areas, while 35.07% was categorized as moderated and well-suited habitat areas for wild elephants. Implementing strategies to improve water sources and salt lick sites within the park and managing the area to minimize human disturbance both on the surrounding boundaries and the tourist destination sites are recommended to manage the wild elephant.

Keywords: Human-elephant conflict, MaxEnt, species distribution model, variance inflation factor, world heritage site

INTRODUCTION

Protected areas are designated to conserve biodiversity and provide a safe habitat for wildlife (Pulido-Chadid et al. 2023). However, human activities around these areas increased the likelihood of human-wildlife conflicts (Zhou et al. 2023), particularly due to habitat encroachment (Thant et al. 2023), agricultural expansion (Anuradha et al. 2019; Al-Razi et al. 2023), land cover and land use changes (Billah et al. 2021; de Silva et al. 2023), community establishment, urban development (van de Water and Matteson 2018), infrastructure development, and transportation passing near elephant habitats (Chen et al. 2022), as well as tourism, all of which could disrupt wild elephant habitats and behaviors (Bateman and Fleming 2017), leading to increased interactions between humans and wild elephants (Narayan and Rana 2023), and habitat disturbance and degradation (Ram et al. 2022). Meanwhile, crops planted around forest attract wildlife, such as elephants (Wettasin et al. 2023), leading to damage of property or destruction of crops (Shaffer et al. 2019), and retaliation by residents contributing to human-elephant conflict (Acharya et al. 2016; Shaffer et al. 2019; Gunawansa et al. 2023).

The conflict between humans and elephants not only fosters negative sentiments but also instills fear and resentment among local communities, who faced life-threatening encounters as they shared resources and came into close contact with these animals (Hossen and Røskaft 2023). These issues were cited as the primary contributors to severe conflicts and the decline in the global elephant population (Gunawansa et al. 2023; Thant et al. 2023). Some studies have found that wild elephants tend to prefer habitats on the periphery of protected areas (de la Torre et al. 2022). Moreover, environmental crises, particularly climate change, were significant factors impacting the interaction and confrontation between humans and wild elephants (Kitratporn and Takeuchi 2022; Newsom et al. 2023; Shiweda et al. 2023). Shiweda et al. (2023) studied habitat changes, home range shifts, and their linkage to emerging human-elephant conflict hot spots and found that human farming activities, poor rainfall, and frequent droughts were responsible for habitat loss leading to conflicts. Khao Yai National Park (KYNP), the primary habitat for wild elephants in the Dong Phaya Yen Khao Yai Forest Complex was crucial for long-term elephant conservation efforts (Pla-ard et al. 2019; 2021b; UNESCO 2024).

The elephants venturing outside conservation areas for foraging have intensified the human-elephant conflict over the last few decades (Department of Wildlife and National Parks: DNP 2023). Although the factors mentioned above were related, especially changes in land use (de Silva et al. 2023) that affected conflicts between people and wild elephants. This study investigated wild elephant appearance concerning environmental factors, including climatic, physiological, anthropological, and biotic factors, conducted through continuous data collection over six years. MaxEnt software was utilized to analyze data (Kramer-Schadt et al. 2013). While this study aimed to raise awareness and contribute to mitigating the human-wild elephant conflict problem, there had been limited studies conducted in Thailand. Additionally, the abundant water and food sources available around the park's boundary, coupled with human activities, significantly influenced the propensity of wild elephants to seek sustenance outside their natural habitats, thereby exacerbating conflicts between humans and wild elephants (Su et al. 2020; Wettasin et al. 2023).

This study aimed to investigate the factors affecting the appearance and habitat suitability of wild elephants, focusing on two primary hypotheses. Firstly, it investigated whether the appearance of wild elephants was influenced by environmental factors, encompassing anthropological, climatic, physical, and biological factors. Secondly, it examined whether the then-current sizes and conditions of various wild elephant habitats were adequate to sustain the then-present population. The findings of this study hold paramount importance for devising strategies to address the pressing issue of wild elephants encroaching into human settlements.

MATERIALS AND METHODS

Study site

The Khao Yai National Park (KYNP) spans an area of 2,166.55 km^2, situated within the eastern Pranom Dongrak mountain range on the Korat Plateau in northeastern Thailand, between 14°5'-14°15' north latitudes and 101°5'-101°50' east longitudes, constituting a part of the Dong Phaya-Yen Khao Yai Forest Complex, which covers approximately 6,152 km² area (UNESCO 2024). Elevation within the park ranges from 50 to 1,351 m above mean sea level, with the majority of the terrain between 400 and 800 m. The park serves as a crucial watershed in the region, regulating water resources to surrounding provinces. Meteorological data collected around the park's headquarters from 2009 to 2017 indicate an annual rainfall of 1,897 mm and an average temperature of 21°C. The northeastern region of the park falls within a rain shadow area, receiving less than 1,300 mm of annual rainfall (National Parks Research and Innovation Development Center 2017).

The park's vegetation predominantly consists of evergreen dry forests but also encompasses a variety of other habitats such as mixed deciduous forests, grasslands, and agricultural areas. It boasts a high diversity of wildlife species, including at least 71 mammal species, 447 bird species, 86 reptile species, and 18 amphibian species (Pla-ard et al. 2021a; Bangthong et al. 2023).

Declared Thailand's first national park in 1962, the KYNP covering an area of 2,166.55 km^2 (Figure 1) was later declared as a part of the Natural World Heritage Site by UNESCO in 2003 (UNESCO 2024). Due to the diverse flora and fauna, the world natural heritage site comprises five almost contiguous protected areas: Khao Yai, Thap Lan, Pang Sida, and Ta Phraya National Parks, and Dong Yai Wildlife Sanctuary, covering a total area of approximately 6,155 km^2 (Figure 1). The area harbors one of the largest and healthiest wild elephant populations under protection, with the estimated population numbering between 100-150 individuals in 1985 (Dobias 1985) and reaching approximately 300 individuals in 2019 (Pla-ard et al. 2019). The park reported an average of 685 human-wild elephant conflicts per year during 2018-2023 within the four provinces surrounding the park (KYNP 2023).

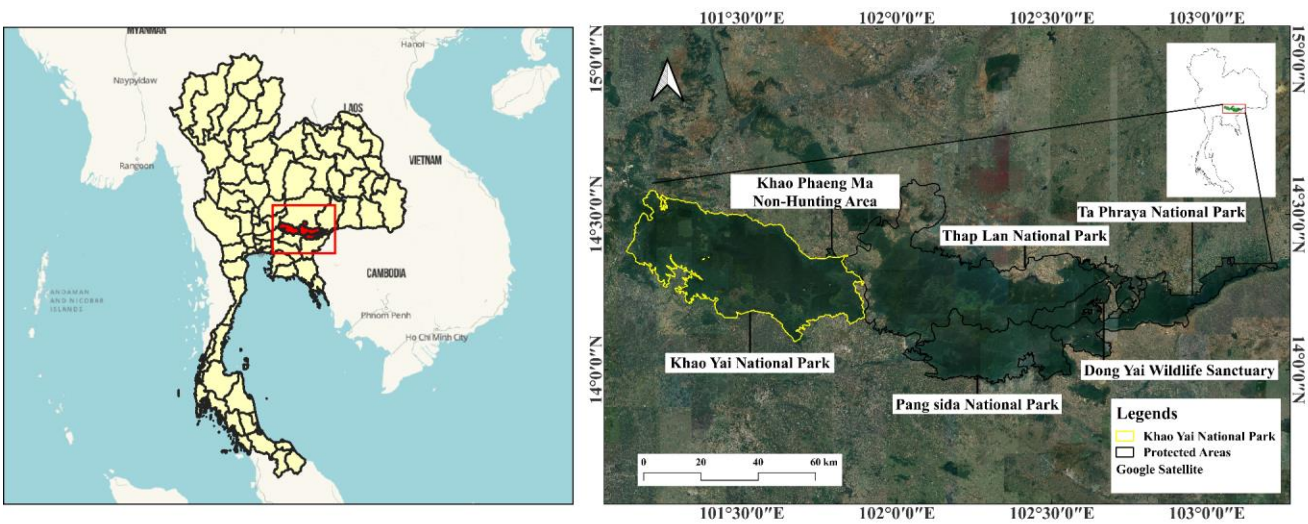

Figure 1. Boundary map of the Khao Yai National Park (KYNP) and the Dong Phaya-Yen Khao Yai Forest Complex, Thailand

Data collection

Data collection was facilitated by the Smart Patrol System, which utilizes SMART (Spatial Monitoring and Reporting Tool) database system to provide officers with information and technology for efficient resource management (WCS Thailand 2023). Crucial information documented includes the geographic locations where wild elephants were sighted or their traces and signs were found, as well as the locations of salt licks, water ponds, villages, and grasslands. The date of discovery, characteristics of the area such as climatic conditions, forest type, and the size of traces found, along with other relevant environmental details, were also recorded.

Patrol units regularly covered all sections of the national park, excluding inaccessible wilderness areas like cliffs and canyons. The study area encompasses over 90% of the park, with more than 30 patrol units responsible for monitoring their respective areas from the Ranger Station located within. The operation extended to approximately 3 kilometers beyond the park’s boundary into the national forest reserves, which are still inhabited by wildlife. This proactive approach addressed conflicts between humans and wild elephants by maintaining a presence around the national park perimeter, resulting in the study area encompassing regions beyond the park's boundaries.

The data collection involved recording the presence of wild elephants within and outside the jurisdiction of each patrol unit responsible for monitoring in the national park. There were a total of 30 patrol units, each comprising 5-6 park rangers per team. These ranger units conducted patrols four times a month, with each patrol lasting from 3 to 5 days (WCS Thailand 2023). Whenever they encountered signs, tracks, or direct sightings of elephants, the information was documented using a data recording form. The data were collected from patrol unit reports starting from January 2017 until December 2022, aiming to compile high-quality qualitative records of wild elephant sightings within the boundaries of the KYNP.

Predictor variables

Environmental variables in this study comprised a total of 28 variables, categorized into five physical factors, two biological factors, two anthropological factors, and 19 climatic factors. The physical factors included elevation, slope, distance to water sources and streams, distance to saltlick sites, and distance to roads. Biological factors comprised forest types and grassland, while the anthropological factors consisted of distance to villages and distance to tourist destination areas. The sources of the predictor variables data can be accessed via the network as detailed were shown in Table 1.

Table 1. Explanation and sources of the predictor predictors used in the MaxEnt model

Variable	Resolution	Explanation	Sources
Topographic variables Elevation	30 m	Digital Elevation Model (DEM) derived from SRTM (Shuttle Radar Topography Mission) was used	https://portal.opentopography.org/ (NASA Shuttle Radar Topography Mission, 2013)
Distance to river/stream (River)	Vector	The river/stream shape file was extracted from the OpenStreetMap and The distance calculated in kilometers using the Euclidean Distance tool in ArcGIS 10.8.1	http://download.geofabrik.de/asia.html (Planet OpenStreetMap)
Climatic variables	~1 km	All of the 19 climate variables used for modeling climatic niches	https://www.worldclim.org/data/worldclim21.html (Fick and Hijmans 2017)
Distance to road (Road)	Vector	Distance to roads were calculated in kilometers from the road shape file of OpenStreetMap using the Euclidean Distance tool in ArcGIS 10.8.1.	http://download.geofabrik.de/asia.html (Planet OpenStreetMap)
Distance to water sources (Water)	Vector	Distance to water or dam/reservoirs were calculated in kilometers from water points’ shape file of OpenStreetMap using the Euclidean Distance tool in ArcGIS 10.8.1	http://download.geofabrik.de/asia.html (Planet OpenStreetMap)
Distance to tourist destination sites (camping ground, visitor center, cabin house areas and the area around the head quarter of the KYNP)	Vector	Distance to tourist destination sites were calculated in kilometers from recreation points’ shape file of OpenStreetMap using the Euclidean Distance tool in ArcGIS	http://download.geofabrik.de/asia.html (Planet OpenStreetMap)
Distance to villages	Vector	Distance to villages were calculated in kilometers from recreation points’ shape file of OpenStreetMap using the Euclidean Distance tool in ArcGIS	http://download.geofabrik.de/asia.html (Planet OpenStreetMap)
Forest type	Raster	Forest type	https://www.forest.go.th/land/
Grassland area	Raster	Grass land area	Data from the smart patrol system
Saltlicks	Raster	Saltlicks	Data from the smart patrol system

Table 2. Climate variables used for modeling climatic niches

Variable	Code	Unit
Annual mean temperature	bio1	°C
Mean diurnal range (mean of monthly (max temp - min temp))	bio2	°C
Isothermality (bio2/bio7) (×100)	bio3	-
Temperature seasonality (standard deviation × 100)	bio4	C of V
Max temperature of warmest month	bio5	°C
Min temperature of coldest month	bio6	°C
Temperature annual range (bio5-bio6)	bio7	°C
Mean temperature of wettest quarter	bio8	°C
Mean temperature of driest quarter	bio9	°C
Mean temperature of warmest quarter	bio10	°C
Mean temperature of coldest quarter	bio11	°C
Annual precipitation	bio12	mm
Precipitation of wettest month	bio13	mm
Precipitation of driest month	bio14	mm
Precipitation seasonality (coefficient of variation)	bio15	mm
Precipitation of wettest quarter	bio16	mm
Precipitation of driest quarter	bio17	mm
Precipitation of warmest quarter	bio18	mm
Precipitation of coldest quarter	bio19	mm

All 19 climatic variables, as outlined in Table 2, were obtained from the WorldClim database (www.worldclim.org) at a resolution of 30 sec (~1 km^2) for the period of 1970-2000 (Hijmans et al. 2005). These climate layers were then clipped to the area of the KYNP using QGIS (QGIS Development Team 2020). Subsequently, all layers were converted into ASCII files (Promnun et al. 2020; 2021). The modeling of wild elephant distribution, appearance opportunities, and habitat use was conducted based on the predictor variables. Additionally, the percentage contribution values for each environmental covariate, obtained from model testing each year, were utilized to illustrate the results of the analysis examining the relationship between the wild elephant presence and the predictor variables.

Variable selection aimed to improve model performance by mitigating multicollinearity and reducing the number of required variables (Dormann et al. 2013; Yi et al. 2016). The Variance Inflation Factors (VIFs) of 28 environmental variables were assessed using the “usdm” package in R studio (Naimi et al. 2014; Pradhan 2016; Pradhan and Setyawan 2021). Variables with VIFs >5 were excluded, except for elevation, recognized as pivotal for predicting habitat suitability (Brickle 2002; Chatterjee and Hadi 2012). Ultimately, 13 variables were chosen for inclusion in the model: distance to tourist destinations, distance to grasslands, distance to saltlicks, and distance to villages, distance to waterbodies, elevation, slope, and forest types, BIO2, BIO3, BIO17, BIO18, and BIO19.

Waterbody presence was depicted by calculating the distance from the grid centroid to the nearest stream (MST). The anthropogenic influence was characterized by the distance from the grid centroid to the nearest villages (VLG), roads, and tourist destinations (Suksavate et al. 2019; Jornburom et al. 2020; Suksavate et al. 2022). The data were transformed into raster format and analyzed using Geographic Information System (GIS) software, particularly QGIS, with a grid size of 1×1 km^2. A habitat suitability model was developed using the Maximum Entropy (MaxEnt) software version 3.4.4, a widely adopted tool for species distribution modeling (Merow et al. 2013; Renner et al. 2015; Phillips et al. 2017).

Data analysis

Data in this study were represented at 1 km^2 grid resolution, following the referenced scale for protected area management (Royal Forest Department 2019). Grid cells covering the 5 km buffered study area were generated to include the transboundary connection, totaling an area of 2,692 km^2. Direct observations and recent signs, primarily tracks and dung within the grid cells were considered as quarterly observing occasions within annual occupancy. Raster data of ecological and anthropogenic covariates were obtained from the SMART database and GIS public domain.

All environmental variables used in the model development were resampled using the bilinear re-sampling technique, except for forest type, which the nearest-neighbor re-sampling technique (Renner et al. 2015). They were subsequently clipped to the same dimensions at 30-arcsecond resolution (~1-km spatial resolution) in ASCII format using R program (R Core Team 2018). The models were reprojected to Universal Transverse Mercator at a 1-km spatial resolution.

To conduct the analysis, the data needed to be converted into a raster format for utilization in the MaxEnt program. The data comprised two types: continuous and categorical. Continuous data, such as slope, numerical forest canopy cover, mean temperature in the coldest quarter, and dry season precipitation, were directly utilized. However, for categorical data like plant community types, conversion into numerical categories was necessary, with each category assigned a unique numerical value for representation in the analysis. The equal training sensitivity and specificity criterion were applied, and a clog-log threshold was selected to distinguish the presence and absence of elephants. To evaluate the importance of each environmental factor, metrics such as percentage contribution and percentage permutation were employed, derived from model testing, following the methodology outlined by Phillips et al. (2017).

Subsequently, testing the accuracy of models derived from the data categorized at different clog-log thresholds was performed. The maximum number of modeling iterations was set to 500, the number of repetitions to 10, and the repetition category selected as cross-validation. The relative contribution of the environmental variables to the prediction of the suitable distribution area of the wild elephant was calculated using the jackknife analysis (Mohd Taher et al. 2021; Li et al. 2023).

The percentage contribution and percentage permutation values provide insights into the significance of each predictor variable in predicting species presence. These values quantify the influence of each variable on the model's performance and predictions, with percentage contribution reflecting the improvement in the model performance when a specific variable is included, while percentage permutation indicates the variable's predictive strength (Li et al. 2023).

Accuracy of the model

This study assessed model accuracy by evaluating the Area Under receiver-operating-characteristic Curve (AUC) values and transforming each average model into suitable and unsuitable habitats using the clog-log threshold for the maximum test sensitivity plus specificity (TSS) (Li et al. 2023). The AUC values, which range from 0.00 and 1.00, serve as indicators of model performance. An AUC value below 0.5 suggests random prediction, while values between 0.5 and 1 indicate varying degrees of predictive capability (Shabani et al. 2018). Specifically, AUC values below 0.7, are indicative of poor model performance, 0.7-0.9 indicates moderate performance and 0.9-1.0 indicate good model performance (Ewanation et al. 2023). The True Skill Statistic (TSS) values, ranging from 0.2-0.5 for poor performance, 0.6-0.8 for useful performance, and greater than 0.8 for excellent performance, further elucidate the model's efficacy (Li et al. 2023).

Habitat suitability model

The habitat suitability models were constructed using the MaxEnt ver. 3.4.4 (Phillips et al. 2017; 2021). Using the subsample method, 10 replicate runs with a maximum of 500 iterations were conducted for building the model with the default of 10,000 background points. Data partitioning allocated 75% for training and the remaining 25% for testing purposes. Model outputs were generated in clog-log format (Trisurat et al. 2016; Ab Lah et al. 2021; Mcgarvey et al. 2021; Khan et al. 2022).

Response curves were generated to explore the relationship between the individual environmental predictors and the suitability predictions (Zhao et al. 2021), aiming to identify the model that best fits the data and its patterns. The mentioned values were utilized assess accuracy and predictive capacity, following the methodology outlined by Trisurat et al. (2016). Model accuracy was further assessed using the AUC, with significance levels set at both $P<0.05$ and $P<0.01$ (Lavazza and Farina 2023). Additionally, the duration of appearance was calculated as a percentage, and probability maps of elephant presence were generated for each year from 2017 to 2022. The continuous probability map obtained from the MaxEnt model was classified into four habitat class categories as per Habitat Suitability Index (HSI): highly suitable or well suited ($0.75 \leq HSI < 1$), moderately suitable ($0.5 \leq HSI < 0.75$), poorly or generally suitable ($0.25 \leq HSI < 0.5$), and unsuitable habitat ($0 \leq HSI < 0.25$) (Zhu et al. 2021). The size of the areas with a probability of elephant presence in each level was determined using raster files with a grid size of 1×1 km^2.

RESULTS AND DISCUSSION

Wild elephant locations

The data was collected from the SMART system through the patrol staff, comprising 30 sets of patrolling units, involving a total of 7,776 patrols, covering a cumulative distance of 91,997.74 kilometers. The analysis primarily focused on the presence of wild elephants, resulting in a total of 14,859 events. These instances were classified based on data obtained from dung piles (3,751 events.), direct sightings (184 events), and trace evidence such as footprints and trails (10,924 events). Annual occurrences ranged between 1,175 and 2,515 events. The patrols effectively covered over 80% of the total area (Table 3 and Figure 2).

Factors affecting wild elephant appearance

Considering the AUC values obtained from the analysis, it was found that the average training AUC value was 0.81±0.004 and the average test AUC value was 0.75±0.012, as detailed in Table 4.

Table 3. Number of wild Asian elephant locations identified based on the animals' dung, tracks and signs, and direct sightings from 2017 to 2022 by the SMART patrol system in the KYNP, Thailand

Year	2017	2018	2019	2020	2021	2022	Total
Dung	570	591	677	830	726	357	3,751
Direct sighting	30	22	22	57	33	20	184
Tracks and signs	1,175	1,607	1,914	2,515	2,050	1,663	10,924
Total	1,775	2,220	2,613	3,402	2,809	2,040	14,859

Table 4. The training AUC and the average test AUC values gained from the analysis yearly between 2017 and 2022

	2017	2018	2019	2020	2021	2022	Average
Training AUC	0.83	0.85	0.80	0.82	0.77	0.79	0.81
SD	0.005	0.003	0.005	0.002	0.004	0.003	0.004
Test AUC	0.77	0.79	0.74	0.78	0.71	0.73	0.75
SD	0.02	0.01	0.01	0.01	0.01	0.009	0.012

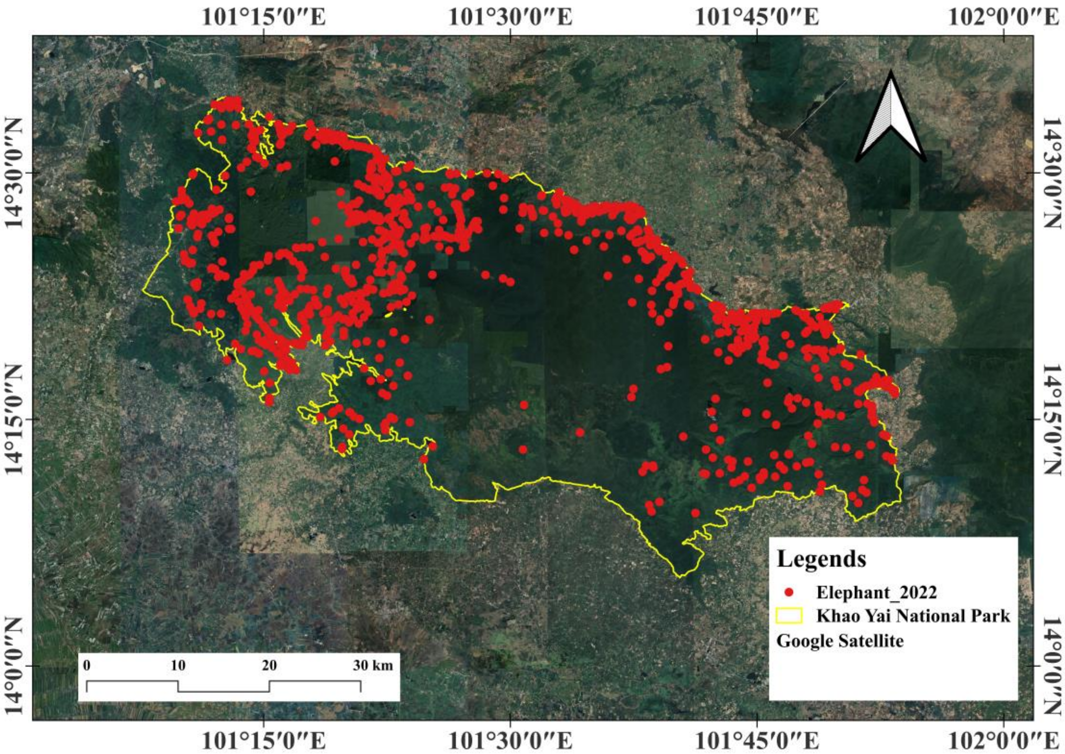

Figure 2. Map showing the distribution of wild elephants in the KYNP based on data collected by the SMART patrol system during 2017-2022

The analysis of the variables related to the appearance of wild elephants, considering the average percentage contribution over the six years, revealed that climatic factors exerted the highest influence, with a percentage contribution of 42.97%. Specifically, temperature factors significantly impacted the appearance of wild elephants, with an overall percentage contribution of 39.04%. Within temperature factors, isothermality (bio3) ranked highest in influence with a contribution value of 21.65%, followed by the mean annual temperature range of 17.39%.

Precipitation factors also had an impact on the appearance of wild elephants, contributing 3.93% overall. Among precipitation factors, the precipitation of the warmest quarter had a 2.29% contribution; followed by precipitation of the driest quarter (1.04%), and precipitation of the coldest quarter (0.60%).

When considering the combined influence of both precipitation and temperature factors over the six years, their percent contribution was found to be 42.97%, the highest compared to other analyzed factors. Physical factors, including slope, elevation (DEM), distance to the river, and distance to saltlicks, collectively contributed 32.62%, with individual contributions of 1.00%, 4.42%, 22.13% and 5.06%, respectively. Anthropological factors, such as distance to villages and the distance to tourist destinations inside the park, impacted the appearance of wild elephants with contributions of 16.59% and 4.64%, respectively. Overall, anthropological factors collectively contributed 21.23%. Biological factors, including the forest type and distance to grassland, had an average total contribution of 3.23%, with forest type contributing 0.54% and distance to grassland contributing 2.70% (see Table 8).

Response analysis

The study identified the mean and the optimum ranges of various climatic and environmental factors, including mean diurnal range (mean 9.62 hours, range 9.13-10.50 hours), isothermally (mean 58.79, range 56.41-62.20), Precipitation of driest quarter (mean 28.33, range 25.00 - 33.00 mm), precipitation of warmest quarter (mean 357.69, range 285.00-423.00 mm) and precipitation of coldest quarter (mean 44.37, range 39.00-52.00 mm). Altitude exhibited a mean of 542.02 m, with a range of 27.83-1,254.02 m), while slope had a mean of 4.60, ranging from 0.22-17. 4 degrees. The distance to the river showed a mean of 1,553.78 m, ranging from 219.09-6,366.12 m, and the mean distance from saltlicks was 2,171.47 m, with a range of 225.85-9,361.54 m. In terms of biotic factors, the mean distance to grassland was 6,692.01 m, ranging from 238.55 to 25,483.83 m, and the forest type ranged between the secondary forest and the dry evergreen forest. Additionally, the mean distance to tourist destination areas in the park was 8,505.54 m, with a range of 238.55-20,831.82 m, while the mean distance to villages around the park was 6,530.44 m, ranging from 415.34-16,146.43 m (Table 5).

Habitat suitability

The results of the 10-fold cross-validation indicated an average Test AUC of 0.75 and average Training AUC of 0.81. Additionally, the maximum test sensitivity plus specificity was found to be 0.41±0.02, with a logistic threshold of 0.61±0.02, which served as the classification threshold for different levels of suitable habitat, as illustrated in Table 6.

Further, analysis revealed that well-suited habitat area comprised an average percentage of 9.75±1.58 (211.18 km^2) of the total area for wild elephants. Moderately suited habitat area covered an average percentage of 25.32 ± 5.58 (548.43 km^2) of the total area, while areas classified as poorly suited habitat comprised an average percentage of 25.26 ± 2.23 (547.13 km^2). Moreover, unsuited habitat areas constituted an average percentage of 39.65 ± 8.54 (858.81 km^2) of the total area (Figures 3-4 and Tables 6-7).

Discussion

Based on the yearly analysis, the average training AUC was found to stand at 0.81±0.004, while the average test AUC was recorded at 0.75±0.01, indicating a moderate model performance (Ewanation et al. 2023). The lower standard deviation observed across years suggests a suitable number of wild elephant locations used in this analysis. Despite variations in the number of elephant locations analyzed annually, it was observed that this did not significantly impact the results, as indicated by the AUC values used to measure model accuracy. The average training AUC value, for instance, hovered around 0.81±0.004 SD, reflecting reasonably fair analysis outcomes. However, there were decreases in values, dropping below 0.80 between 2021 (0.77) to 2022 (0.79), despite analyzing more elephant locations compared to 2017-2020. This discrepancy might be attributed to the broader distribution of elephant sightings in these years with relatively fewer data, potentially introducing sampling bias during data collection, thereby affecting the accuracy measured by AUC. This highlights the importance of addressing sampling bias to mitigate omission and commission errors in studies reliant on sighting data from area surveys (Kramer-Schadt et al. 2013). Nevertheless, the study found that the average AUC value over the six-year analysis period exceeded 80%, indicative of fair analysis outcomes.

The study also revealed that the 10-percentile training presence clog-log threshold (threshold) was 0.41±0.02, while the clog-log threshold for maximum test sensitivity plus specificity (TSS) had average values of 0.61±0.02, indicating usefulness (Li et al. 2023). The model accuracies were relatively moderate. The threshold optimized to maximize the sum of sensitivity and specificity was determined as 0.41±0.02, which was subsequently utilized to convert the habitat suitability map.

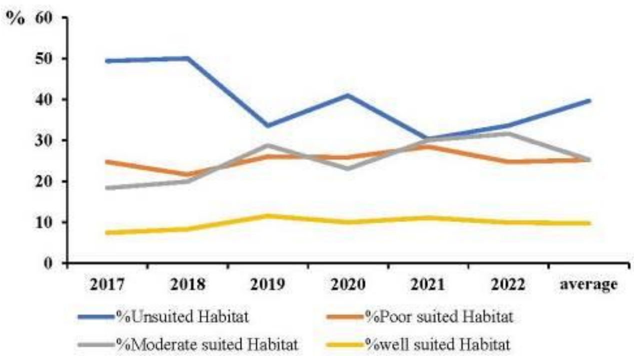

Figure 4. Alterations in habitat suitability for wild elephants within the KYNP according to the predictor variables revealed four categories: well-suited habitat, moderately suited habitat, poorly suited habitat, and unsuited habitat areas

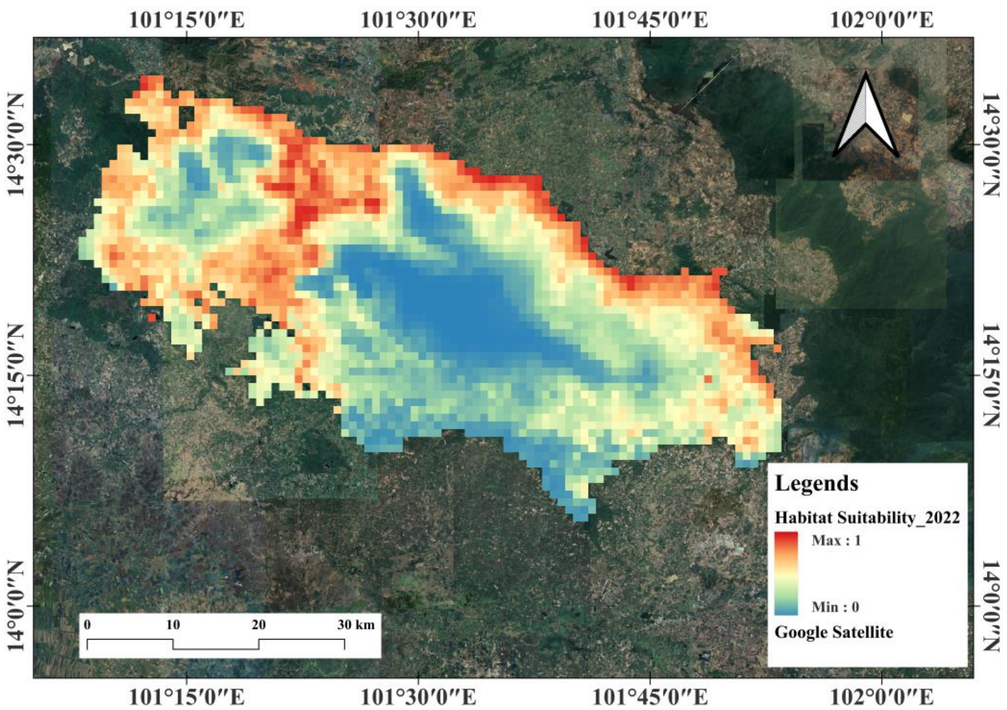

Figure 3. Map showing changes in suitable habitat for the wild elephant in the KYNP between 2017 and 2022

Upon ranking factors influencing the appearance of wild elephants in the area based on average percentage contribution, climatic factors were found to be most influential, accounting for 42.97% contribution. Specifically, temperature factors were found to exert the greatest influence, contributing to 39.04% of the appearance of wild elephants, surpassing the impact of precipitation factors, which stood at 3.93%.

Climate, particularly rising temperatures linked to global climate change (Amnuaylojaroen et al. 2023), exerted the strongest influence. Amnuaylojaroen et al. (2023) projected global temperature rise of 0.62°C per decade, which may exacerbate heat stress by 0.1 to 4°C between 2020 and 2029. This aligns with our findings of increased elephant presence under such conditions. Additionally, Sentian et al. (2022) forecasted temperature increases between 0.93 and 2.50°C in Southeast Asia, further supporting our observations.

Table 5. The profile which includes the minimum, maximum, mean, and SD of the selected variables

Variable	Code	Unit	Min	Max	Mean	SD
Climatic factors						
Mean diurnal range	bio2	°C	9.13	10.50	9.62	0.20
Isothermality	bio3	-	56.41	62.20	58.79	1.25
Precipitation of Driest Quarter	bio17	mm	25.00	33	28.33	1.30
Precipitation of Warmest Quarter	bio18	mm	285.00	423.00	357.69	26.41
Precipitation of Coldest Quarter	bio19	mm	39.00	52.00	44.37	2.05
Physical factors						
Elevation	-	m asl.	27.83	1,254.02	542.02	258.97
Slope	-	degree	0.22	17.04	4.60	2.98
Distance to the river	-	m	216.09	6,366.12	1,553.78	1,121.25
Distance to the saltlick	-	m	225.85	9,361.54	2,171.47	1,324.16
Biotic factors						
Forest type	-	-	Secondary forest	Dry evergreen forest	-	-
Distance to the grassland	-	m	17.16	25,483.83	6,692.01	5,109.94
Anthropological factors						
Distance to the tourist destination site	-	m	238.55	20,831.82	8,505.54	4,943.80
Distance to village	-	m	415.34	16,146.43	6,530.44	3,644.68

Table 6. The evaluation of habitat suitability, expressed as the percentage, was conducted through 10-fold cross-validation, the Area Under the Curve (AUC), Training AUC, 10-percentile training presence clog-log threshold (Threshold), and the maximum test sensitivity plus specificity (TSS) encompassed the number of parameters and the area covered by each habitat suitability category

Year	2017	2018	2019	2020	2021	2022	Average	SD
Test AUC	0.77	0.79	0.74	0.78	0.71	0.73	0.75	0.01
Training AUC	0.83	0.85	0.80	0.82	0.77	0.79	0.81	0.004
Threshold	0.40	0.40	0.42	0.40	0.44	0.43	0.41	0.02
TSS	0.58	0.57	0.61	0.61	0.60	0.61	0.61	0.02
Number of parameters	all	all	all	all	all	all	all	all
%Unsuited Habitat	49.41	50.04	33.58	40.97	30.31	33.64	39.65	8.54
%Poor suited Habitat	24.74	21.66	26.05	25.89	28.49	24.77	25.26	2.23
%Moderate suited Habitat	18.39	19.95	28.79	23.1	30.05	31.64	25.32	5.58
% well-suited Habitat	7.47	8.36	11.59	10.03	11.14	9.95	9.75	1.58

Table 7. The areas of each category of habitat suitability of the wild elephant during 2017 and 2022 in the KYNP, Thailand

	Level of habitat suitability (km^2)				Total area (km^2)
	Unsuitable habitat	Poor suitability habitat	Moderately suitable habitat	Good suitability habitat	
The habitat area of the KYNP	858.81	547.13	548.43	211.18	2,166.55
SD	184.97	48.30	120.86	34.22	
Coefficient of correlation	0.21	0.08	0.22	0.16	

Table 8. Percentage contribution according to environmental factors affecting the chances of the appearance of wild elephants in the KYNP, Thailand

Environmental factors	Variable	Percentage contribution							
		2017	2018	2019	2020	2021	2022	average	SD
Climatic factors									
Temperature									
Isothermality (bio2/bio7) (×100)	bio 3	23.66	16.76	20.80	24.31	25.85	18.52	21.65	3.55
Mean diurnal range (mean of monthly (max temp - min temp))	bio2	14.64	29.22	13.75	14.02	19.31	13.37	17.39	6.20
Subtotal temperature	-	38.30	45.98	34.55	38.33	45.16	31.89	39.04	5.62
Precipitation									
Precipitation of the driest quarter	bio17	0.50	1.75	0.81	1.29	1.69	0.18	1.04	0.64
Precipitation of the warmest quarter	bio18	2.54	4.02	2.15	1.56	2.46	1.03	2.29	1.02
Precipitation of the coldest quarter	bio 19	0.49	0.50	0.44	0.45	1.15	0.58	0.60	0.27
Subtotal precipitation	-	3.53	6.27	3.40	3.30	5.30	1.79	3.93	0.38
Total climatic factors	-	**41.83**	**52.25**	**37.95**	**41.66**	**50.46**	**33.68**	**42.97**	**0.34**
Biological factors									
Forest type	-	1.03	0.12	0.84	0.16	0.51	0.55	0.54	0.36
Distance to grassland	-	5.46	2.05	1.87	2.22	2.71	1.88	2.70	1.39
Total biological factors	-	**6.49**	**2.17**	**2.71**	**2.38**	**3.22**	**2.43**	**3.23**	**0.73**
Physiological factors									
Slope	-	1.06	0.69	1.18	1.05	1.38	0.66	1.00	0.28
Elevation	-	2.28	4.40	1.70	2.80	4.08	11.23	4.42	3.50
Distance to river	-	27.78	16.22	24.14	31.81	16.30	16.54	22.13	2.27
Distance to saltlick	-	4.53	4.89	8.39	2.12	6.08	4.37	5.06	1.62
Total physical factors	**-**	**35.65**	**26.20**	**35.41**	**37.78**	**27.84**	**32.80**	**32.62**	**1.34**
Anthropological factors									
Distance to village	-	11.96	10.88	21.61	16.10	16.94	22.03	16.59	4.67
Tourist destination area	-	4.05	8.48	2.31	2.10	1.54	9.37	4.64	3.44
Total anthropological factors		**16.01**	**19.36**	**23.92**	**18.20**	**18.48**	**31.40**	**21.23**	**0.88**
	Total	**99.98**	**99.98**	**99.99**	**100.02**	**100.00**	**100.31**	**100.05**	**0.82**

The crucial components of wild elephant habitats are areas with cool air, shade (such as in dry or moist evergreen forests or deciduous forests at higher elevations), and access to water sources, and on hot days, elephants spend more time seeking shelter in shaded areas (Thaker et al. 2019). Hence, various studies have attributed rising temperatures to increased sightings of elephants (Kanagaraj et al. 2019; Beirne et al. 2020; Kitratporn and Takeuchi 2022). Accordingly, it was indicated that an increase in the annual mean temperature raises the likelihood of encountering elephants. Moreover, an increase in precipitation of the driest quarter, the warmest quarter, and the coldest quarter also significantly increases the chances of elephant sightings. These findings are consistent with the observed trend of elephants venturing beyond their typical habitats during the night (Department of Wildlife National Parks and Plant Conservation 2023). Conversely, factors related to temperature, such as isothermality and mean diurnal range hurt the presence of wild elephants. As elephants lack sweat glands (Rozen-Rechels et al. 2020) and do not have a clear evaporative heat loss mechanism like panting, which is crucial for maintaining heat homeostasis, struggle to regulate their body temperature when environmental temperatures exceed their core body temperature (Mole et al. 2016). Although passive water diffusion through their skin contributes minimally to heat dissipation (Tan and Knight 2018). Therefore, climate change driven droughts incidences in the forests of Thailand (Trisurat et al. 2023; Yang et al. 2023), may have significant impacts on wild elephants (Domínguez-Oliva et al. 2022). Physical characteristics also influenced elephant presence. Slope and elevation significantly influenced the presence of elephants, aligned with the habitat of wild elephants, which was found to increase significantly in areas with natural forests. Forest type significantly impacted suitability, with dry evergreen forests, bamboo forests, and mixed deciduous forests, more so than the other forest types analyzed.

Studies have suggested that wild elephants are drawn to surrounding agricultural areas (Wettasin et al. 2023), areas of human activities, including those within tourism zones (Narayan and Rana 2023; Withanage et al. 2023), especially where secondary forests and open habitats were more abundant, providing more food resources for the elephants (Wadey et al. 2018). In this study, anthropological factors like distance to villages and distance to tourist destination areas were found to be correlated with the appearance of wild elephants, contributing to 21.23% of the overall influence, showing that anthropological factors had accelerated the confrontation between human and wild elephants (Köpke et al. 2021).

Analysis of the suitable habitat revealed a concerning trend. Unsuitable habitat areas for wild elephants had a decreasing trend, whereas, areas with low suitability, moderate suitability and well suitability exhibited significant increasing trend. Notably, most suitable areas overlapped with the tourist destinations, including the central part of the KYNP, the villages located along the boundary of the KYNP, and along the road surrounding the

KYNP, especially along the northern boundary. Conversely, unsuitable areas were primarily located in the central-eastern sector. This highlights a potential conflict between human activity and elephant habitat suitability.

The average elephant density in KYNP was estimated at 0.15 individuals/km^2 (with a range of 0.12-0.18 individuals km^2) (Pla-ard et al. 2019), translating to a population of approximately 300 individuals of wild elephants in KYNP. Habitat loss due to the shrinkage of KYNP, compared to historical boundaries is a significant concern. de Silva et al. (2023) estimated a 67% reduction in suitable elephant habitat between 1700 and 2015, leading to fragments of elephant population across discontinuous conservation areas. Furthermore, de Silva et al. (2023) reported that over half of the area within a 100-kilometer radius of the current elephant range, once considered suitable habitat in the year 1700, had been converted to agricultural land and urbanized areas by 2015, leading to potential human-elephant conflicts.

In conclusion, the study found that climatic factors, particularly rising temperatures associated with global climate change, emerged as the most significant factor influencing wild elephant presence in KYNP. Physical factors including slope, elevation, distance to river, and distance to saltlicks collectively contributed 32.62% to model building. Anthropological factors such as distance to villages (16.59%) and the distance to tourist destinations in the park (4.64%), are also significant contributors, to the model, thus impacting the appearance of wild elephants. The biological factors like forest type and distance to grassland had the least impact on elephant presence compared to the aforementioned factors. Analysis of suitable elephant habitat areas revealed low usage of over 60% of the land, being either unsuitable or poorly suitable. Meanwhile, the most suitable habitat areas covered an average of 9.75% or 211.18 km^2, which also covered areas with anthropogenic footprint such as villages around the park boundary, tourist destination areas, camping grounds, and traveling using transportation routes through the center of the KYNP. Based on the findings, the current study recommends prioritizing habitat improvement and protection, particularly for the secondary forests, bamboo forests, mixed deciduous forests, and dry evergreen forests. Additionally, the creation or improvement of water sources, grasslands, and saltlick sites in areas distant from human activities are suggested to increase suitable habitat areas for accommodating the existing elephant population. Furthermore, the ecological impact of developing forest areas for human activities needs careful consideration. Strict regulations are essential for those residing near the border of the national park.

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