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RESEARCH ARTICLE

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Spatio-temporal dynamics of human–elephant conflict in a valley of pineapple plantations

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Abstract

Human–elephant conflict (HEC) is a major conservation challenge negatively impacting elephant populations and local agricultural livelihoods. Studies of drivers and spatiotemporal patterns of HEC have potential to indicate where mitigation actions should be prioritized with the goal of achieving long-term coexistence. We examined temporal and spatial patterns of elephant crop raiding adjacent to Kuiburi National Park in southern Thailand by assessing locations of elephant raids in conjunction with multiple environmental variables along with crop characteristics and crop availability. Raiding incidents primarily happened in pineapple plantations, however compositional analysis suggested that fruit orchards were most preferred by elephants probably reflecting the high frequency of raiding in orchards relative to their small spatial area. Logistic regression models predicted that crop type and crop maturity stage, distance to forest and mitigation strategy combined had the strongest support in explaining the probability of crop raiding. Relative probability of raiding appeared to be associated with crop accessibility for elephants and perhaps crop nutrient value, with orchards with ripe fruit being most raided, while oil palm the least. The most frequently used mitigation measure was guarding by local people and could lower the probability when compared with other mitigations, although the relative effectiveness did not show a clear pattern; local guarding, patrolling by park rangers and physical barriers appeared to have some benefit but elephant-preferred crops still had >40% chance of being raided. Other results also indicated that water availability and season were not associated with elephant raiding, but rather crop type/crop stage had the most influence. The surprising lack of seasonality was likely due to the availability of the elephant's preferred crops year-round. Finally, our results indicated that there is no zone in Kuiburi that is free from elephant raiding, leaving the entire community vulnerable. We recommend improvements in the mitigation measures through better coordination among stakeholders in such communities and development of concrete action plans for all stakeholders including an extensive market-based examination of the feasibility of growing crops less preferred by elephants.

KEYWORDS
HEC mitigation strategies, Kuiburi National Park, Thailand

Plain language summary
This is a study of the spatiotemporal patterns of Human-Elephant conflict in a community area adjacent to Kuiburi National Park, southern Thailand. We examined temporal and spatial patterns of elephant crop raiding by assessing the locations of elephant raids in conjunction with environmental factors along with crop characteristics and crop availability. Raiding incidents primarily happened in pineapple plantations; however, compositional analysis suggested that fruit orchards were the most preferred by elephants. Logistic regression models predicted that crop type/crop stage, distance to forest and mitigation strategy combined had the strongest support in explaining the probability of crop raiding. The most frequently used mitigation measure was guarding by local people, although the relative effectiveness did not show a clear pattern. Other results also indicated that water availability and season were not associated with elephant raiding. Our study also indicates that there is no zone in Kuiburi that is free from elephant raiding which cause the current state of this area to be critical and unsustainable. We recommend improvements in the mitigation measures through better coordination and development of action plans including an examination of the feasibility of growing crops less preferred by elephants.

Practitioner points

- We aimed to identify factors influencing elephant crop raiding in Kuiburi, Thailand, a landscape suffering intense human–elephant conflict (HEC). Pineapple and orchards were identified as elephant's prefered crops; elephants were willing to travel more than 2 km from the forest edge to consume them. HEC was prevalent throughout the landscape, with no "safe zone" out of elephant reach.
- There is a need to improve HEC mitigation in Kuiburi and other similar landscapes. We recommend developing an action plan that promotes stakeholder collaboration to implement effective mitigation measures.
- We suggest to conduct a market-based assessment to identify crops that are less preferred by elephants while considering the limited landscape and well-being of locals in the area.

1 | INTRODUCTION

The Endangered Asian elephant (*Elephas maximus*) has been declining due to hunting pressure (Nijman, 2014), habitat loss (Ling et al., 2016), and habitat conversion following agricultural expansion (Rood et al., 2010), with the increased habitat overlap leading to sharp increases in elephant crop raiding, resulting in extensive human–elephant conflict (HEC) (Hoare, 2015; Shaffer et al., 2019). HEC impacts local livelihoods through the depletion of agricultural resources preventing farmers from meeting their basic needs (Naha et al., 2019), causing people to retaliate which, in turn, leads to deaths and injuries to both elephants and people (Gubbi et al., 2014).

To reduce and deter crop raiding, several mitigation strategies have been designed (Shaffer et al., 2019; Wahed et al., 2016). However, the effectiveness of these strategies is affected by site-specific variables such as habitat type, level of habitat degradation and local human cultural practices which can lead to short-term solutions or additional problems (Shaffer et al., 2019). To achieve long-term solutions, the main conflict drivers need to be addressed and conflict hotspots must be identified to support management planning. At a local level, predictive knowledge of HEC incidents has the potential to indicate where mitigation should be prioritized.

Locally in Southeast Asia, including Indonesia (Suba et al., 2017), Myanmar (Sampson et al., 2021), Malaysia (Zafir & Magintan, 2016), and Thailand (WWF, 2015), there has been limited analysis of the patterns of elephant incursion and little planning as to where mitigation infrastructure would likely be most effective. In Thailand, HEC is widespread and can be intense in particular areas, often associated with fruit crops (i.e., pineapple) with physical barriers combined with local guarding as the main mitigation strategies (Panyasuppakan, 2018). Most studies here have investigated the HEC human socioeconomic aspects and the local management options (Jarungrattanapong, 2012; Jenks et al., 2013; van de

Water & Matteson, 2018). The only study investigating HEC spatiotemporal characteristics in this region was in eastern Thailand (Kitratporn & Takeuchi, 2019) at a coarse landscape scale. They found strong seasonal patterns in HEC, and potentially complex nonlinear correlations with drought. Unfortunately, such data are of limited value at the village or farm scale for mitigation planning as the probability and distribution of HEC varies with resource availability in the area, which strongly affects the movements of wild elephants (Shaffer et al., 2019).

HEC in Kuiburi National Park in southern Thailand appears to be relatively typical; HEC is a major problem with 332 incidents in 2005 alone, and 11 elephant deaths from 1997 to 2005 (WWF, 2015). In addition, over the course of more than 20 years, multiple mitigation strategies have been used in the area, including physical barriers, guarding by local people as well as park rangers and the use of firecrackers and other means to drive off elephants and discourage them from returning (Parr et al., 2008). HEC still continues to be a problem, with 3 farmers injured in 2020. Therefore, we aimed to understand HEC spatio-temporal trends using Kuiburi as a case study to identify conflict hotspots and determine the potential spatial drivers of crop-raiding as well as find suitable mitigation strategies to help manage the conflict and promote coexistence.

To do so, we first examined the spatial and temporal patterns of crop raiding. We assess crop availability in the area and determining which crop, and at which stage, was preferred by elephants. Mitigation methods and resource availability (distance to water, saltlicks, and forest edge) were also analyzed to assess how these influence crop raiding. Second, we identified factors driving crop raiding in the study site. We predicted that elephants raided mostly on ripe or nearly ripe pineapple as it is the most abundant food source in the study area. We also predicted that seasonal changes would also affect the probability of raiding and that the dry season may have higher HEC (Campos-Arceiz et al., 2009) due to the lower quality and availability of natural food (Webber et al., 2011). Finally, we expected that guarding by locals could lower the probability of crop raiding, followed by patrolling by rangers, and then physical barriers due to the relative effort involved.

2 | STUDY SITE

The study was conducted in two communities adjacent to Kuiburi National Park (11°40′—12°10′N and 99°20′—99°50′E), Kuiburi district, Prachuap Khiri Khan Province, in southern Thailand (Figure 1a). The study area was approximately 200 km^2 consisting of two communities, Baan Ruam Thai (northern part of study site) and Bann Yan Sue (southern part of study site) (Figure 1a). The national park covered an area of 969 km^2 and lies along the Tenasserim Range at the border between Thailand and Myanmar. The forest consists of dry and wet evergreen forest and was home to several globally threatened species; gaur (*Bos gaurus*), leopard (*Panthera pardus*) and Asian tapir (*Tapirus indicus*). Tiger (*Panthera tigris*) was formally present but has likely been recently extirpated (R. Steinmetz unpublished data). There were also more than 230 wild elephants distributed within the area of the park (WWF, 2015). Because of frequent HEC events, it was also designated as a site for a Monitoring the Illegal Killing of Elephants (MIKE) project under CITES (Parr et al., 2008). As noted above, within the Kuiburi area, multiple crop types, mitigation methods, and levels of community involvement are present. Most of the agriculture in Kuiburi focuses on pineapple (*Ananas comosus*) and para rubber (*Hevea brasiliensis*). Outside the forest, the other land use/land cover types include paddy fields, cattle farms, villages, and reservoirs. Local farmers use a variety of mitigation methods including (a) physical barriers (barriers to prevent elephant from entering an area e.g., trenches, fences [often electric]), (b) guarding (e.g., guarding by local people using firecrackers or shouting to drive elephants away), and (c) patrolling (e.g., patrolling by national park rangers) (see below).

3 | METHODS

3.1 | Data collection

Data collection was conducted for 12 months (August 2020–July 2021). Collection of incident data (see below) was conducted every 3 days in the northern part of the study area followed by 3 days in the southern part, followed by 3 days in the northern section and so on. The data were collected in three-day periods due to logistic limitations, whereby 3 days was required to sample each of the two communities in the study area. Incident locations were collected from the "Early Warning Team" database set up by the national park, typically based on initial elephant detections from closed circuit television cameras established along the forest edge or from information provided by park rangers or local people to the team. Additionally, villagers were contacted to obtain more detailed information such as time and location of elephant raiding at incident sites, mitigation applied, and elephant activity, described as either (a) passing by the site, (b) knocking down crops at the site—in the case oil palm (*Elaeis guineensis)* and para rubber, or (c) consuming crops the site. Data collection was separated into two seasons of wet (May–October) and dry (November–April) to assess if there were any major differences in raiding patterns associated with season. The climate is fairly seasonal in Kuiburi, with a peak monthly rainfall during the wet season of ~246 mm to a low of ~12 mm during the dry season, according to average rainfall data from 1960 to 1990 (Temchai et al., 2017).

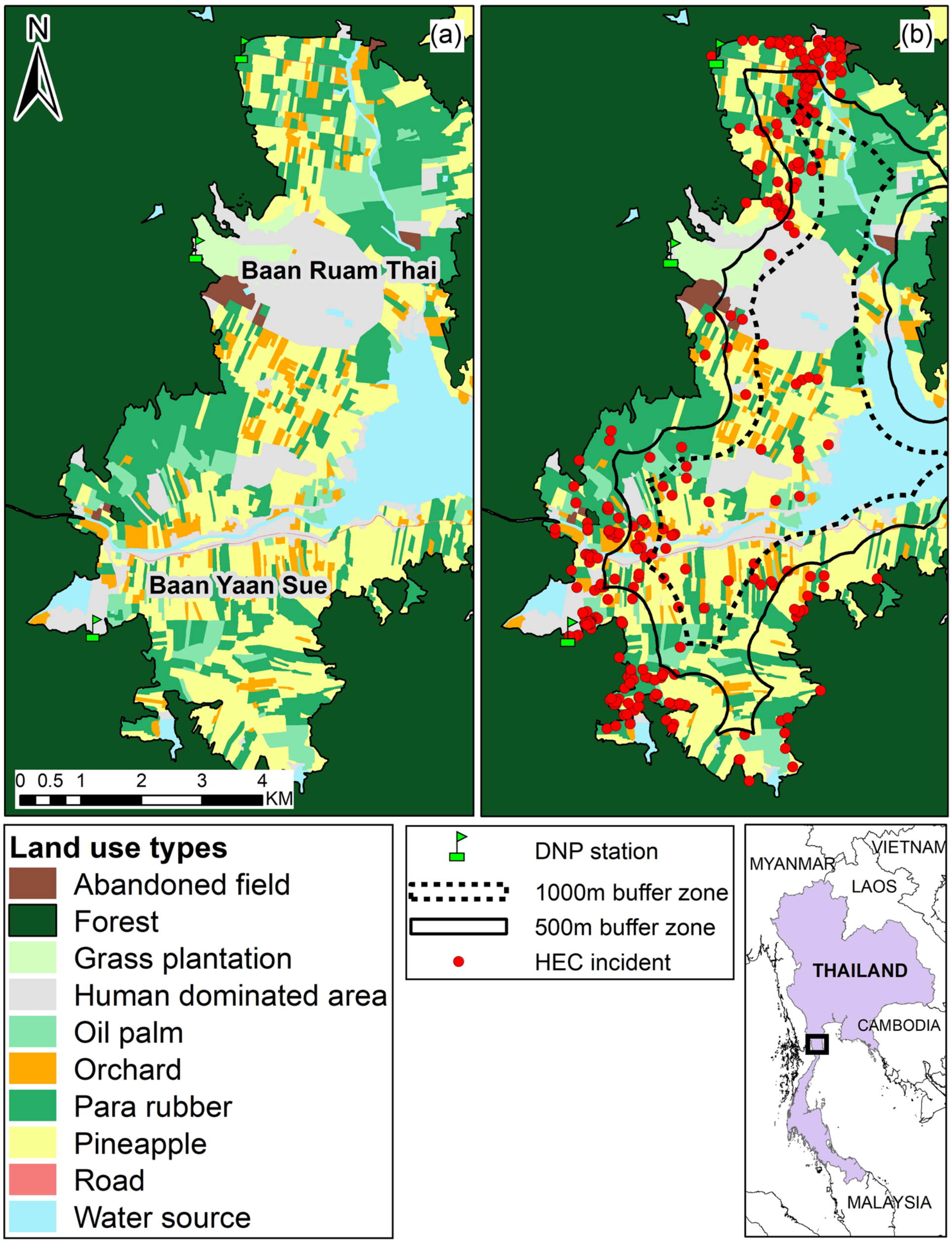

FIGURE 1 (a) Study area around Kuiburi National Park. (b) Map showing incidents and 500 m and 1000 m buffer distances adjacent to the Kuiburi community. The buffer distances are shown to highlight the vulnerability of crops in the study area relative to distance from the forest. This figure suggests that the entire community is vulnerable to be raided by elephants. DNP stands for Department of National Parks, Wildlife and Plant Conservation.

In locations where HEC incidents occurred, we collected the following variables: (1) the time and location of incident, (2) number of elephants, (3) the type and percent cover of crops within a 50 and 100 m radius around the incident site and the size of the area damaged measured by using ArcGIS (ArcGIS 10.3.1), (4) the activity of elephants (eating or passing by), (5) effectiveness of mitigation used (mostly successful (<25% damaged), partially successful (~50% of the crop was damaged), mostly unsuccessful (>75% of the crop was damaged)). Other variables included: (1) crop type, (2) crop stage (land preparation, seedling, immature, or mature [ready for harvest]), (3) mitigation used in the area (physical barriers, guarding by local farmers, patrolling by national park rangers, or no mitigation), and (4) nearest distance to elephant landscape resource (water, saltlick, and forest edge) (see Table 1). The other variables collected through ArcGIS included: mitigation intensity, village intensity, distance to village, household density (100 m, 200 m, and 500 m), NDVI, and elevation. Mitigation intensity was collected to estimate the intensity of mitigation at the incident site by assessing the number of different mitigation methods applied in the area (Table 1). Household density was estimated as the number of households near the incident area and was indicated as hotspots to indicate the density of households. Household density was calculated at 3 scales, 100 m, 200 m, and 500 m as elephants may respond differently to different levels of human density.

TABLE 1 Covariates that were collected and tested in the logistic regression model to assess their influence on elephant raiding patterns.

Predictor variables	Habitat category	Description
Damaged Crop types	Abandoned land	Land use types of abandoned field crops and other abandoned land
	Forest	Old growth and disturbed evergreen forest in the study site
	Crops in human settlements (CHS)	Human dominated, which also contain small areas of crops such as *aloe vera*, coconut, sugarcane, mulberry, along with single family homes, shrubland, cattle farms, grassland, and institutional lands
	Oil palm	Oil palm plantation
	Orchard	Orchard consisting of mango, jackfruit, and banana
	Para rubber	Para rubber plantation
	Pineapple	Pineapple plantation
	Water	Water sources in the area such as from canals, farm ponds, reservoirs, rivers
Area of Para rubber (50 m)		Area (m^2) of para rubber around the incident point in a 50-m radius
Area of Para rubber (100 m)		Area (m^2) of para rubber around the incident point in a 100-m radius
Area of Oil palm (50 m)		Area (m^2) of oil palm around the incident point in a 50-m radius
Area of Oil palm (100 m)		Area (m^2) of oil palm around the incident point in a 100-m radius
Area of Orchard (50 m)		Area (m^2) of orchard around the incident point in a 50-m radius
Area of Orchard (100 m)		Area (m^2) of orchard around the incident point in a 100-m radius
Area of Pineapple (50 m)		Area (m^2) of pineapple around the incident point in a 50-m radius
Area of Pineapple (100 m)		Area (m^2) of pineapple around the incident point in a 100-m radius
Crop stages	Land preparation	A stage where the land is prepared before planting
	Seedling	A stage in which the crops are starting to plant
	Immature	A stage where crops are in Growing stage and fruit not ripening
	Mature	A stage which crops are ready to harvest
Mitigation Type	No mitigation	No mitigation implemented
	Guarding	Human guarding crops, including alarm fence where people are still needed.
	Patrolling	Patrol team of National Park rangers
	Physical barriers	Barriers implemented such as local fence, trenches, electric fences, semi-permanent fences
Mitigation Intensity	0	Low intensity of mitigation; either no mitigation or one mitigation implemented in the area (such as using fences without guarding).
	1	Moderate intensity of mitigation: Using two or three mitigation types to protect the area. Such as guarding together with alarm fences.
	2	High intensity of mitigation. Using multiple mitigation types together to protect the crops. Such as guarding, trenches, alarm fences, and ranger patrolling.
Village Intensity		Number of households close to the incident area. Indicated as hotspot to represent the intensity of households
Distance to Village (m)		Distance to closest household or human settlement from the incident and random points
Household density (100 m)		Density of households in the 100 m radius of the sample point
Household density (200 m)		Density of households in a 200 m radius of the sample point
Household density (500 m)		Density of household in a 500 m radius of the sample point

(Continues)

TABLE 1 (Continued)

Predictor variables	Habitat category	Description
Distance to water (m)		Distance to nearest water source from sample point
Distance to saltlick (m)		Distance to saltlick from sample point
Distance to forest edge (m)		Distance to forest edge from sample point
NDVI		NDVI values of each point within a pixel. NDVI close to zero represent open lands such as bare soil or water sources. Higher values indicate greater tree/vegetation cover.
Elevation (m)		Elevation values of each survey point (m)

A land use map from the Thailand Development Department (2020) combined with our field survey data were used to categorize the study area into 8 major cover types: (1) Abandoned land, (2) Forest, (3) Crops in human settlements (CHS), (4) Oil palm, (5) Orchard, (6) Para rubber, (7) Pineapple, and (8) Water (Table 1). Abandoned land was defined as abandoned field crops and other abandoned land where there was no human activity. Forests were mostly disturbed evergreen forest located at the boundary of the national park. Crops in human settlements were defined as crops found in the human-dominated areas which consisted of small areas of crops such as *aloe vera*, coconut, mulberry, sugarcane, intermixed with single family homes, shrubland, cattle farms, grassland, and institutional lands. Oil palm plantations in the study site were mostly a mix of young and old (>5 years) plants and covered approximately 9% of the study area. Orchards consisted of mango, jackfruit and banana plantations and also covered approximately 9%. Para rubber plantations consisted of a mix of sizes from relatively young (~2 years) to mature (~5 years) trees which covered approximately 37%. Pineapple was the dominant crop type covering about 45% of the study area. Water consisted of water sources in the area including canals, farm ponds, reservoirs, and a river.

The mitigation method used at each incident site was also recorded. If there was no apparent method being implemented at the site, the site was labeled as having "No Mitigation". If people were observed guarding crops, including the use of alarm fencing (fences with trip alarms to alert locals), this was classified as "Guarding." If the incident site was regularly protected by a patrol team of national park rangers, this mitigation was defined as "Patrolling". When there were physical barriers constructed such as locally-made fences, trenches, electric fences, and/or semi-permanent fences, without regular presence of guarding/patrolling these were defined as "Physical Barriers." Because the study area was relatively large, we could not randomly sample farms to assess the overall use of different mitigation methods. However, we were able to sample mitigation used at and nearby incident sites. Overall, the most prevalent mitigation strategy in the study area was guarding by local people (67%) followed by ranger patrolling (17%), physical barriers (9%) and no mitigation (7%) at the incident points. The two villages, Ruam Thai and Yan Sue, had somewhat different proportions of mitigation strategies implemented in the area. In Ruam Thai, guarding was the most implemented (52%) followed by patrolling (29%), physical barriers (12%), and no mitigation (7%). In Yan Sue, guarding was the most used mitigation (79%) followed by no mitigation (9%), physical barriers (7%), and patrolling (5%).

To help understand why elephants chose to raid at a given incident point, five sample plots (each 100 m in radius) were measured in the field to sample both damage at incident points plus randomly selected areas available, but not used by elephants. In each case, one plot was placed at the center of each incident location and four plots in the cardinal directions away from the incident position (one each to the north, east, south, and west). The percentage cover of crop types was measured using ArcGIS and the crop stage was estimated directly in the field. The four plots around the incident were 200 m from the incident center.

3.2 | Data analysis

Compositional analysis was conducted to identify crop preferences of elephants in the study site. The analysis was carried out by comparing the area of used crop types (area of the locations where elephant was present) with the area of available crop types in the study site. A ranking matrix from the analysis was used to indicate which types were significantly used more or less by the elephants. This analysis was performed using the "adehabitatHS" package (Calenge, 2006) in R software.

Logistic regression was used to test which variables influenced the occurrence of crop damage by elephants (Zuur et al., 2009). The regression was used to model binary outcome variables (sites used or not used by elephants). Before analysis, outliers and correlations among variables were assessed. All variables of interest were tested and the variables that were correlated ≥0.5 were not included in the same model. We used the AIC ranking of variables and so we did not have the case where we excluded one variable over another. Outliers were determined via scatter plots. For incidents that occurred at the same location, we analyzed only the first incident. We also removed 25 incidents that were spatially isolated on the far eastern side of the study area as these incidents were spatial outliers, clearly isolated from all other incidents in the study area. Continuous variables were standardized before analysis by subtracting the values of each variable with its mean and divided by two times the standard deviation. In this case the response variable was either no elephant present ("0") or elephant present and crops damaged ("1") (predictor variables are listed in Table 1). This analysis was performed using "sdmTMB" package (Anderson et al., 2022) in R software. The model was fitted with a spatial structure (mesh) in the model to account for spatial autocorrelation of crop damage locations. The spatial random field was created and we inspected the mesh size before fitting the models. We tested model assumptions by using the DHARMa package (Florian, 2022). We compared models using AIC and AIC_c weights to identify the best model explaining the probability of crop raiding (Akaike, 1973).

The predictability of the models was evaluated by calculating the area under the receiver-operating curve (AUC) (Hanley & McNeil, 1982). The AUC approach works by calculating the numbers of correctly and incorrectly identified predictions across all possible classification threshold values of the binomial response. An AUC value equal to or below 0.5 indicates a prediction performance to random expectation and 1 indicates an excellent predictability. (Franklin & Miller, 2010). Model evaluation was performed using *PresenceAbsence* package in R software (Freeman & Moisen, 2008).

4 | RESULTS

4.1 | Crop damage in the Kuiburi community area

343 incidents were recorded during the study period, 197 incidents during the wet season and 146 during the dry season. There was no significant correlation between incidents and season (tetrachoric correlation = –0.016). During the study, incidents mostly happened in pineapple (37%), followed by para rubber (32%), fruit orchards (24%), oil palm plantations (4%) and crops in human settlements (CHS) (3%). Crop damage events mostly (74%) happened during the mature stage of crops (ready to harvest) and followed by 20% incidents with crops in an immature state. Only 1% of incidents occurred at the seedling stage of crops. Elephants ate pineapple in the seedling stage on three occasions, in these cases the seedlings were eaten before planting during field preparation.

TABLE 2 Results from a compositional analysis for raided crop types in the Kuiburi study area. Table indicates the crop types in the row is selected (+), significantly selected (+++), avoided (-), significantly avoided (---) relative to the crop types in the column.

	Para rubber	Oil palm	Orchard	Pineapple
Para rubber	0	+++	---	-
Oil palm	---	0	---	---
Orchard	+++	+++	0	+++
Pineapple	+	+++	---	0

Note: (e.g., orchard is significantly preferred over other crops. Pineapple is slightly preferred over para rubber.

4.2 | Crop preferences of elephants

Fruit orchards appeared to be the most strongly preferred, followed by pineapple, para rubber, and oil palm (Table 2). The data suggested that the orchards were significantly preferred over the three other crop types. Pineapple was positively preferred relative to para rubber and oil palm. Para rubber was strongly preferred over oil palm but less preferred compared to the other crops. Oil palm in the study area was in a mature stage, in which the trees were mostly too large for elephants to access or knock down, were the least preferred relative to the other crop types.

4.3 | Factors affecting elephant occurrence

From the logistic regression models, we found that the model which included crop type, crop stage, distance to forest and mitigation strategy had the strongest support for explaining the probability of incident occurrence with the lowest ΔAIC value and highest AIC_c weight (Table 3). The AUC value was 0.89 which indicates good model prediction performance and an excellent degree of discrimination.

The results indicated that mature pineapple and other mature orchard fruits (i.e., mango, jackfruit, and banana), had a higher (~25%) chance of being raided by elephant compared to mature oil palm, para rubber and immature pineapple at the mean incident distance from the forest edge (approximately 500 m) (Figure 2a). In addition, crops inside human settlements (CHS) had the lowest chance (~6%) of probability of elephant occurrence at 500 m (Figure 2a).

The distance to water, distance to saltlick, mitigation intensity, village intensity, household density, NDVI, and elevation received little support, ranking below the null model and were not shown in Table 3.

Mitigation methods also appeared to influence the probability of incident occurrence (Figure 2b). Based on our top model, guarded areas had a lower probability (about 8% lower) of incident occurrence compared to physical barriers and patrolling at

TABLE 3 Model selection for predictive models of probability of crop raiding by elephant based on logistic regression.

Model	K	AIC_c	ΔAIC_c	w_i
mitigation + distance to forest * crop damaged	17	1295.66	0.00	0.98
crop damaged + distance to forest + mitigation	12	1304.06	8.40	0.02
distance to forest + mitigation * crop damaged	27	1318.34	22.69	0
mitigation * crop damaged	26	1321.15	25.50	0
Orchard50 + distance to forest + crop damaged	10	1340.51	44.86	0
distance to forest + crop damaged	9	1341.03	45.37	0
crop damaged	8	1346.23	50.57	0
mitigation + distance to forest	7	1375.47	79.81	0
mitigation	6	1378.30	82.64	0
Orchard50 + distance to forest	5	1408.57	112.91	0
Oil palm50 + distance to forest	5	1412.79	117.13	0
Orchard50	4	1415.27	119.62	0
Distance to forest	4	1418.17	122.51	0
Orchard100	4	1421.25	125.59	0
Distance to village	4	1421.45	125.79	0
Oil palm100	4	1421.70	126.05	0
Null	3	1423.52	127.86	0

Note: "K" is the numbers of parameters in the model. "AICc" is Akaike's Information Criteria corrected for small sample size, "ΔAICc" is the difference in AICc. "w_i" is a measure of relative support for each model.

500 m from the forest edge. Physical barriers and patrolling had a higher probability (>20%) of incident occurrence at distances less than 500 m from the forest edge. However, no mitigation areas had the lowest probability of incident occurrence, but was likely an artifact of the small number of no mitigation sites which were in the interior of the study area by which elephants had to pass by heavily mitigated areas to reach no mitigation sites.

5 | DISCUSSION

Overall, the current level of HEC at Kuiburi was extremely high while the mitigations used appeared to be of some, but limited effectiveness. As our results indicate, incidents happened throughout the year regardless of season, mitigation applied, and thus overall, the entire area is highly vulnerable to being raided. First, the results from the compositional analysis suggested that orchards were preferred by elephants compared to the three other major crop types in the study area. The relative importance of orchards to elephants from our analysis may be related to their relatively small area versus the relatively high frequency of being raiding versus the considerably larger area of pineapple plantation. In addition, it is possible that the higher nutrient value of orchard crops, particularly jackfruit (Srivastava & Singh, 2020), was more preferred by elephants. It was also unexpected that oil palm appeared to be the least preferred by elephants compared to para rubber, which we expected to provide minimal nutrient resources. However, during our study, oil palms were mostly in a mature stage where the trees were large enough that elephant could not knock them down and it was difficult for elephants to reach the fruits. This pattern of lower HEC in mature oil palm has also been observed in Aceh, Indonesia (Berliani et al., 2018). Elephants did travel through oil palm to gain access to other more favored crops and caused damage mostly to younger palms, as noted earlier by Othman et al. (2019). Our results support our prediction that elephants would mostly raid mature or nearly ripe fruit crops which also coincides with the previous studies about crop raiding (Branco et al., 2019; Chiyo et al., 2005). Unexpectedly, orchards were the most preferable crops and had the highest possibility of being raided by elephants even when the orchards were distant from the forest edge (Figure 2a), for example, the probability of being raided was high (>40%) even for orchards 2 km away from the forest. As we mentioned above, we hypothesize that this was due to the potentially higher nutrient value of orchard fruits. Overall, our data suggest that if there are preferred crops available in a given area, there is a relatively high chance that such crops will be raided.

As expected, pineapple, the main crop in the study area, was also preferred by elephants; although overall, it had a lower chance of being raided during an immature stage and when farther from the forest edge similar to elsewhere (Nair & Jayson, 2021; Thant et al., 2021; Webber et al., 2011). However, when at a mature stage, pineapple crops, like orchard, had a relatively high probability of being raided even at 2 km from the forest edge, although this probability did decline with distance from the edge (Figure 2a) which contrasts with fruit orchards where the probability did not decline with increasing distance from edges. This suggests that the elephants were willing to travel further for the orchard fruit relative to pineapple. On the other hand, para rubber and oil palm plantations showed relatively lower chances of being raided even when close to the forest edge. With these crops, the probability of incident occurrence was near zero at 2 km away from forest edge. In Kuiburi, most of the incidents with para rubber and oil palm crop trees were knocked down, rather than necessarily a target for consumption. This is somewhat like Aceh, Indonesia (Berliani et al., 2018) where elephants chose more preferred crops (rice and banana) over rubber and oil palm. Elephants, however, may use para rubber and oil palm as cover to hide from people and/or for roaming during their search for other higher value crops such as pineapple and orchard fruits, as observed in Sabah, Malaysia (Othman et al., 2019).

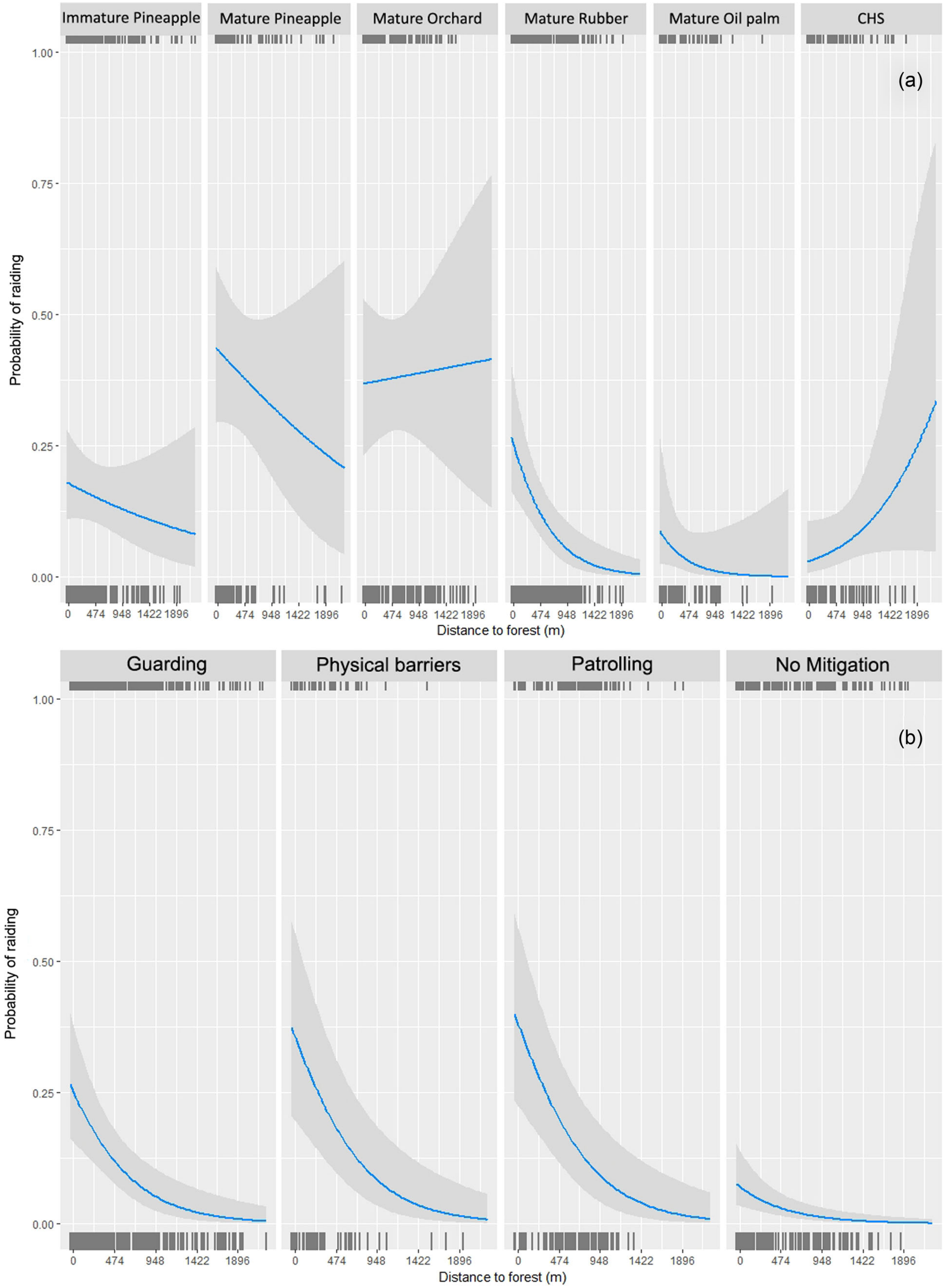

FIGURE 2 Probability of occurrence affected by different variables. (a) Probability of occurrence for each crop type and crop stage related to distance to forest edge. (b) Probability of occurrence for each mitigation method related to distance to forest. Blue lines indicate means and gray shading 95% confidence intervals. CHS indicates crops in human settlements.

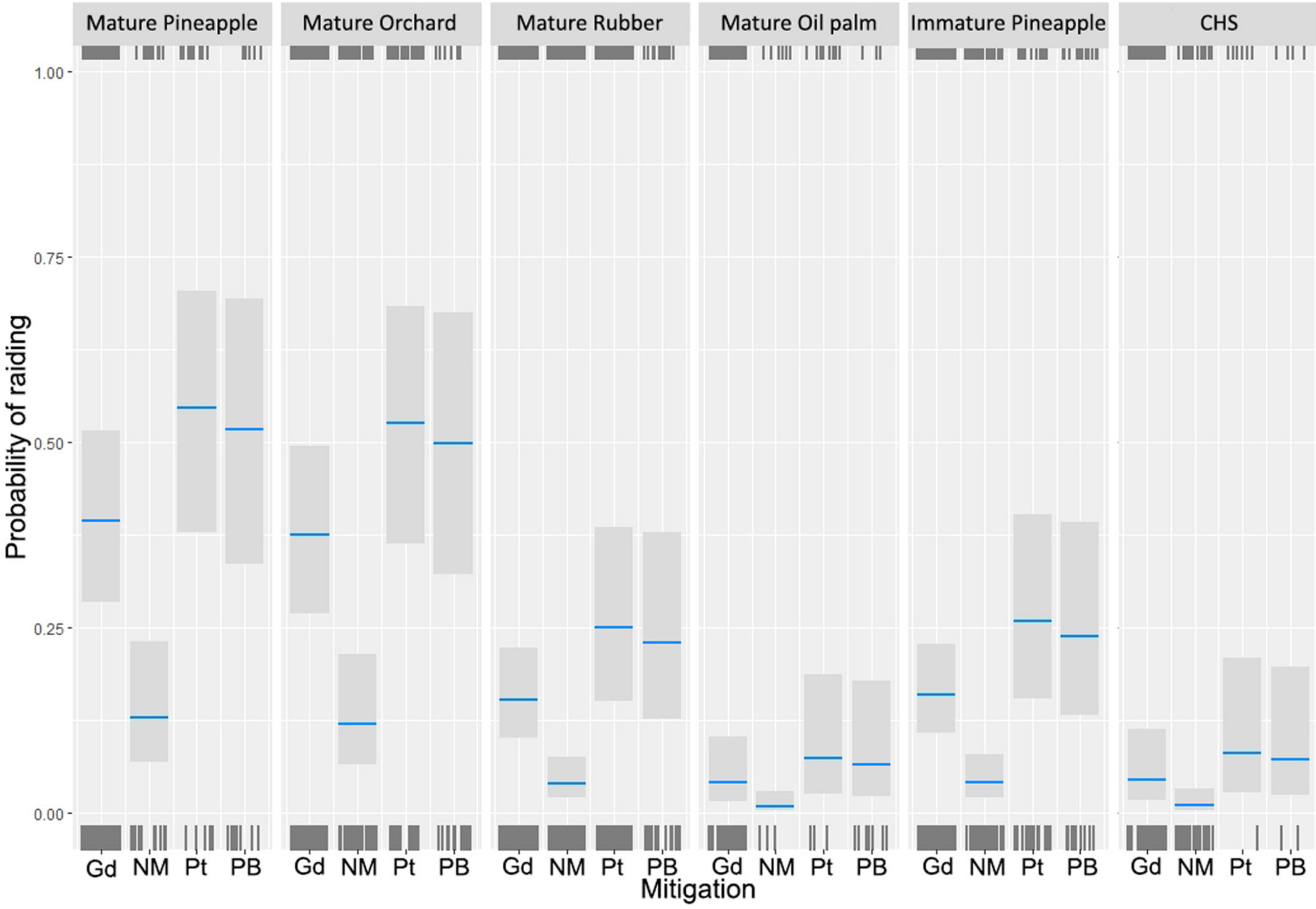

FIGURE 3 Probability of occurrence related to crop type and stage to different mitigation methods. Mitigation methods are (left to right) Guarding (Gd), No mitigation (NM), Patrolling (Pt), and Physical barriers (PB). Blue lines indicate means and gray shading 95% confidence intervals.

In addition, we expected that mitigation methods would affect the distribution and number of incidents. Our results suggested that different mitigation methods used in the area did affect the probability of incident occurrence (Figure 3), although there were some crops that owners could not protect regularly due to a lack of human/financial resources. High quality crops (i.e., orchard and pineapple) guarded by local people appeared to have a lower chance of being raided compared to farms protected by park ranger patrols or physical barriers. Yet, for mature pineapple, there did not appear to be a significant difference among mitigation methods in terms of raiding chances, perhaps due to the high value of pineapple for elephants and the relatively small size of the study area, such that all the mitigation methods were only partly effective against highly "motivated" and highly mobile elephants. It is however important to note here that our study area was mostly (67%) comprised of locally guarded fields. Patrolling on the other hand, was organized and managed by the park's rangers and had a more uneven distribution. With their limited human resources in addition to more difficult accessibility, rangers needed more time to cover the southern areas of the study site which limited their ability to patrol this section. In comparison, the northern part of the study area had more accessible routes for patrols which made the patrols work better.

Physical barriers also need financial support to effectively protect a sufficiently large area. Thus, as previous studies have also shown, a combination of a simple early warning systems together with local guarding could at least reduce crop raiding rates (Gunaryadi & Sugiyo, 2017; Sitati et al., 2003). Furthermore, systematic guarding by patrol teams of protected areas could increase the success of self-guarding by local communities. This further suggests that increasing the amount of effort in guarding the area together with systematic patrols are likely needed to enhance current mitigation measures. Thus, here and shown previously, such mitigation methods are somewhat effective but there is a clear need for improvement (Nguyen et al., 2022; Shaffer et al., 2019; Wahed et al., 2016). Guarding by local people does have the potential to lower the probability of incident occurrence when compared to other mitigations (Figure 2b). Although the existing mitigation (guarding, patrolling, and physical barriers) was sometimes at least partially successful, greater coordination will be required to make it more effective. Also, the mitigation applied in the area was not equally distributed, and therefore a fuller evaluation of the effectiveness of the mitigation methods probably requires a more systematic, balanced study design.

Possibly the biggest challenge to mitigating HEC in the study area is the landscape of Kuiburi itself. Overall, there is no safe zone free from elephant raiding, as the main farmlands are all within 2 km of the forest edge (Figure 1b). These farms are surrounded by forest with elephants having the possibility to emerge from nearly all directions and easily return to the forest relatively quickly. The greatest width of the study area was only about 10 km (from south to north), and when compared to the movements of elephants with incidents frequently occurring 2 km away from the forest edge (which is also similar to other studies, Chen et al., 2016; Gubbi, 2012), suggests that elephants can easily access virtually everywhere in the study site. Due to the cropland being so close to forest edge relative to elephant ranging behavior, even when mitigation methods were applied and could potentially drive elephants away, elephants presumably did not have to travel far to return and reach other extensive areas of productive cropland. As the reward/benefit is high enough to encourage the elephants to frequently emerge from the forest, the current mitigation strategies will likely only have modest success. Our data indicated that the entirety of the Kuiburi agricultural land was within 2 km of the forest (see Figure 1), such that planting further than 2 km is not possible in this landscape, leaving the entire community vulnerable, particularly if they are growing crops that are highly preferred by elephants. Therefore, due to the landscape configuration, it will be extremely difficult to prevent HEC in Kuiburi ("a valley of pineapple") if farmers continue to grow pineapple and other fruits favored by elephants using the current mitigation regime.

Other factors can also influence HEC risk that we only partly touched upon in our study. For example, several previous studies have shown that water availability can influence the movement patterns of elephants (Gubbi et al., 2012; Kroutnoi et al., 2018), for example, Cushman et al. (2005) suggested there is an autocorrelation among elephant movements, rainfall and/or vegetation phenology. However, our study indicated that water availability did not affect elephant raiding incidents around Kuiburi. Our compositional analysis and logistic regression models strongly suggested that elephants followed crop availability and crop stages rather than water resources. Incidents were scattered around Kuiburi throughout the year; pineapple and orchard fruit are available throughout the year which probably explains the lack of seasonal trends in our study.

6 | CONCLUSION

Our study analyzed the spatiotemporal trends of HEC in the Kuiburi community area of southern Thailand, a site that is probably indicative of croplands suffering from elephant crop raiding in Southeast Asia. Our aim was to identify possible factors influencing crop raiding in the study area to promote future mitigation measures that are more sustainable. Our findings show that crop type, crop stage, distance to forest and mitigation all play an important role in affecting the probability of elephant-crop raiding. With the preferred crops such as pineapple, elephants appeared willing to travel more than 2 km from the forest edge. Even using extensive fencing along the forest edge similar to nearby Kaeng Krachan National Park (WCS, 2022), probably would not solve the problem of HEC, rather at best, would shift the problem to other points along the park boundary. Our study thus suggests that there is a clear need to improve mitigation strategies in the Kuiburi community (and presumably other similar communities in forested landscapes), starting by developing an action plan which encourages all stakeholders to work together to develop mitigation strategies that are significantly more unified/coordinated and also to thoroughly explore the economic feasibility of switching to high value crops less favored by elephants. However, the challenge currently is that there is no safe zone in Kuiburi out of reach from raiding elephants.

AUTHOR CONTRIBUTIONS

Poldej Kochprapa: Conceptualization; data curation; formal analysis; funding acquisition; methodology; project administration; visualization; writing—original draft; writing—review and editing. **Chution Savini**: Conceptualization; project administration; supervision; validation; writing—original draft; writing—review and editing. **Dusit Ngoprasert**: Conceptualization; formal analysis; methodology; supervision; writing—review and editing. **Tommaso Savini**: Conceptualization; Supervision; Validation; Writing—review and editing. **George A. Gale**: Conceptualization; project administration; supervision; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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REFERENCES

Akaike, H. (1973) Information theory and an extension of the maximum likelihood principle. In: Petrov, B.N. & Csáki, F. (Eds.) *2nd International Symposium on Information Theory, Tsahkadsor, Armenia, USSR*. Budapest: Akadémiai Kiadó, pp. 267–281.

Anderson, S.C., Ward, E.J., English, P.A. & Barnett, L.A.K. (2022) sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields. *bioRxiv*. https://doi.org/10.1101/2022.03.24.485545

Berliani, K., Alikodra, H.S., Masy'ud, B. & Kusrini, M.D. (2018) Food preference of sumatran elephant *(elephas maximus sumatranus)* to commodity crops in human-elephant conflict area of Aceh, Indonesia. *Journal of Physics: Conference Series*, 1116, 052015. https://doi.org/10.1088/1742-6596/1116/5/052015

Branco, P.S., Merkle, J.A., Pringle, R.M., Pansu, J., Potter, A.B., Reynolds, A. et al. (2019) Determinants of elephant foraging behaviour in a coupled human-natural system: is brown the new green? *Journal of Animal Ecology*, 88(5), 780–792. https://doi.org/10.1111/1365-2656.12971

Calenge, C. (2006) The package "adehabitat" for the R software: a tool for the analysis of space and habitat use by animals. *Ecological Modelling*, 197, 516–519.

Campos-Arceiz, A., Takatsuki, S., Ekanayaka, S. & Hasegawa, T. (2009) The Human-Elephant conflict in southeastern Sri Lanka: type of damage, seasonal patterns, and sexual differences in the raiding behavior of elephants. *Gajah*, 31, 5–14.

Chen, Y., Marino, J., Chen, Y., Tao, Q., Sullivan, C.D., Shi, K. et al. (2016) Predicting hotspots of human-elephant conflict to inform mitigation strategiesin xishuangbanna, southwest China. *PLoS One*, 11(9), e0162035. https://doi.org/10.1371/journal.pone.0162035

Chiyo, P.I., Cochrane, E.P., Naughton, L. & Basuta, G.I. (2005) Temporal patterns of crop raiding by elephants: a response to changes in forage quality or crop availability? *African Journal of Ecology*, 43(1), 48–55. https://doi.org/10.1111/j.1365-2028.2004.00544.x

Cushman, S.A., Chase, M. & Griffin, C. (2005) Elephants in space and time. *Oikos*, 109(2), 331–341. https://doi.org/10.1111/j.0030-1299.2005.13538.x

Florian, H. (2022). DHARMa: residual diagnostics for hierarchical (multi-level/mixed) regression models. *R package version 0.4.5*. https://CRAN.R-project.org/package=DHARMa

Franklin, J. & Miller, J.A. (2010) *Mapping species distributions: Spatial inference and prediction*. Cambridge University Press.

Freeman, E.A. & Moisen, G. (2008) "PresenceAbsence: An R Package for Presence Absence Analysis." *Journal of Statistical Software*, 23(11), 1–31. https://doi.org/10.18637/jss.v023.i11

Gubbi, S. (2012) Patterns and correlates of human–elephant conflict around a south Indian reserve. *Biological Conservation*, 148(1), 88–95. https://doi.org/10.1016/j.biocon.2012.01.046

Gubbi, S., Swaminath, M.H., Poornesha, H.C., Bhat, R. & Raghunath, R. (2014) An elephantine challenge: human–elephant conflict distribution in the largest Asian elephant population, Southern India. *Biodiversity and Conservation*, 23(3), 633–647.

Gunaryadi, D. & Sugiyo, H.S. (2017) Community-based human–elephant conflict mitigation: the value of an evidence-based approach in promoting the uptake of effective methods. *PLoS One*, 12(5), e0173742. https://doi.org/10.1371/journal.pone.0173742

Hanley, J.A. & McNeil, B.J. (1982) The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology*, 143, 29–36.

Hoare, R. (2015) Lessons from 20 years of human–elephant conflict mitigation in Africa. *Human Dimensions of Wildlife*, 20(4), 289–295. https://doi.org/10.1080/10871209.2015.1005855

Jarungrattanapong, R. (2012). Exploring the Concept of Payment for Environmental Services to help Mitigate Human-Elephant Conflict in Thailand (Doctoral dissertation, 立命館アジア太平洋大学).

Jenks, K.E., Songsasen, N., Kanchanasaka, B., Bhumpakphan, N., Wanghongsa, S. & Leimgruber, P. (2013) Community attitudes toward protected areas in Thailand. *Natural History Bulletin of the Siam Society*, 59(2), 65–76.

Kitratporn, N. & Takeuchi, W. (2019) Spatiotemporal distribution of human–elephant conflict in eastern Thailand: A model-based assessment using news reports and remotely sensed data. *Remote Sensing*, 12(1), 90.

Kroutnol, L., Sriburi, T., Wijitkosum, S. & Nuanyai, K. (2018) Determination of stimulating factors of Wild Asian elephant (*Elephas maximus*) dispersal from the Kaeng Krachan National Park to surrounding land use in Thailand. *Walailak Journal of Science and Technology (WJST)*, 17(4), 392–404. https://doi.org/10.48048/wjst.2020.4087

Ling, L.E., Ariffin, M. & Abd Manaf, L. (2016) A qualitative analysis of the main threats to Asian Elephant Conservation. *Gajah*, 44, 16–22.

Naha, D., Sathyakumar, S., Dash, S., Chettri, A. & Rawat, G.S. (2019) Assessment and prediction of spatial patterns of human-elephant conflicts in changing land cover scenarios of a human dominated landscape in North Bengal. *PLoS One*, 14(2), e0210580. https://doi.org/10.1371/journal.pone.0210580

Nair, R.P. & Jayson, E.A. (2021) Estimation of economic loss and identifying the factors affecting the crop raiding behaviour of Asian elephant (*Elephas maximus*) in Nilambur part of the Southern Western Ghats, Kerala, India. *Current Science*, 121(4), 521. https://doi.org/10.18520/cs/v121/i4/521-528

Nguyen, V.V., Phan, T.T.T. & Chun-Hung, L. (2022) Integrating multiple aspects of human–elephant conflict management in Dong Nai Biosphere Reserve, Vietnam. *Global Ecology and Conservation*, 39, e02285. https://doi.org/10.1016/j.gecco.2022.e02285

Nijman, V. (2014) An assessment of the live elephant trade in Thailand. *Traffic International*, 1–38.

Othman, N., Goossens, B., Cheah, C.P.I., Nathan, S., Bumpus, R. & Ancrenaz, M. (2019) Shift of paradigm needed towards improving human–elephant coexistence in monoculture landscapes in Sabah. *International Zoo Yearbook*, 53, 161–173. https://doi.org/10.1111/izy.12226

Panyasuppakan, K. (2018). Nation Thailand. Retrieved May 23, 2022, from https://www.nationthailand.com/in-focus/30357289.

Parr, J.W.K., Jitvijak, S., Saranet, S. & Buathong, S. (2008) 'Exploratory co-management interventions in kuiburi national park, central Thailand, including human-elephant conflict mitigation'. *International Journal of Environment and Sustainable Development*, 7(No. 3), 293–310.

Rood, E., Ganie, A.A. & Nijman, V. (2010) Using presence-only modelling to predict Asian elephant habitat use in a tropical forest landscape: implications for conservation. *Diversity and Distributions*, 16(6), 975–984. https://doi.org/10.1111/j.1472-4642.2010.00704.x

Sampson, C., Rodriguez, S.L., Leimgruber, P., Huang, Q. & Tonkyn, D. (2021) A quantitative assessment of the indirect impacts of human-elephant conflict. *PLoS One*, 16(7), e0253784.

Shaffer, L.J., Khadka, K.K., Van Den Hoek, J. & Naithani, K.J. (2019) Human-elephant conflict: a review of current management strategies and future directions. *Frontiers in Ecology and Evolution*, 6, 235. https://doi.org/10.3389/fevo.2018.00235

Sitati, N.W., Walpole, M.J., Smith, R.J. & Leader-Williams, N. (2003) Predicting spatial aspects of human–elephant conflict. *Journal of Applied Ecology*, 40, 667–677. https://doi.org/10.1046/j.1365-2664.2003.00828.x

Srivastava, R. & Singh, A. (2020) Jackfruit (*Artocarpus heterophyllus* lam) biggest fruit with high nutritional and pharmacological values: a review. *International Journal of Current Microbiology and Applied Sciences*, 9(8), 764–774. https://doi.org/10.20546/ijcmas.2020.908.082

Suba, R.B., Ploeg, J., Zelfde, M., Lau, Y.W., Wissingh, T.F., Kustiawan, W. et al. (2017) Rapid expansion of oil palm is leading to human–elephant conflicts in north kalimantan province of Indonesia. *Tropical Conservation Science*, 10, 194008291770350.

Temchai, T., Suksawang, S. & Jaikaew, P. (2017) Kuiburi national park, Thailand. *Journal of Thailand National Park Research*, 1–15

Thai Land Development Department (2020). Land use map 2018–2019. Bangkok.

Thant, Z.M., May, R. & Røskaft, E. (2021) Pattern and distribution of human-elephant conflicts in three conflict-prone landscapes in Myanmar. *Global Ecology and Conservation*, 25, e01411. https://doi.org/10.1016/j.gecco.2020.e01411

Wahed, M.A., Ullah, M.R. & Irfanullah, H.M.d (2016) *Human-Elephant Conflict Mitigation Measures: Lessons from Bangladesh*. Dhaka, Bangladesh: IUCN, International Union for Conservation of Nature, Bangladesh Country Office, p. 30.

van de Water, A. & Matteson, K. (2018) Human-elephant conflict in Western Thailand: socio-economic drivers and potential mitigation strategies. *PLoS One*, 13(6), e0194736. https://doi.org/10.1371/journal.pone.0194736

WCS. (2022, January 13) *Passive fencing keeps Thailand's elephants out of harm's way*. Passive Fencing Keeps Thailand's Elephants Out of Harm's Way > Newsroom. Retrieved from https://programs.wcs.org/newsroom/News-Releases/articleType/ArticleView/articleId/17113/Passive-Fencing-Keeps-Thailands-Elephants-Out-of-Harms-Way.aspx

Webber, C.E., Sereivathana, T., Maltby, M.P. & Lee, P.C. (2011) Elephant crop-raiding and human–elephant conflict in Cambodia: crop selection and seasonal timings of raids. *Oryx*, 45(2), 243–251. https://doi.org/10.1017/S0030605310000335

WWF. (2015, December 4) *2015 to be a zero poaching year for elephants in Kuiburi National Park*. WWF. Retrieved May 23, 2022, from https://www.wwf.or.th/?257690%2F2015-to-be-a-zero-poaching-year-for-elephants-in-KuiBuri-National-Park

Zafir, A.W.A. & Magintan, D. (2016) Historical review of human-elephant conflict in peninsular Malaysia. *Journal of Wildlife and Parks*, 31, 1–19.

Zuur, A.F., Ieno, E.N., Walker, N.J., Saveliev, A.A. & Smith, G.M. (2009) *Mixed effects models and extensions in ecology with R*. Springer

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