Dynamic Occupancy of Wild Asian Elephant: A Case Study Based On the SMART Database from the Western Forest Complex in Thailand

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ABSTRACT

Understanding distribution patterns is essential for the long-term conservation of megafauna, particularly the Asian elephant (*Elephas maximus*). We investigated the dynamic occupancy of Asian elephants in the Thung Yai Naresuan West Wildlife Sanctuary in Thailand. Asian elephant occurrences were recorded during patrol activities from 2012 to 2019. We applied a single-species dynamic occupancy model to examine the environmental factors influencing habitat occupancy of Asian elephant across multiple seasons. The best-supported model, based on the Akaike information criterion (AIC), indicated that the normalized difference vegetation index and elevation positively influenced the probability of colonization. In contrast, the distance to the nearest population source sites showed a negative association. The probability of local extinction was positively correlated with the distance to the nearest villages and population source sites. The predictive map indicated a higher probability of colonization in a remote mountainous region of the center of the protected area. Higher extinction probability was associated with areas of dense human activity and far from population source sites connecting the Asian elephant population to the east. This is the first study to utilize a patrol database for assessing the dynamic occupancy of Asian elephants across multiple years. Our model provides insight into the dynamic distribution patterns of Asian elephants within the wildlife sanctuary and the factors that most influence these patterns. Long-term ecological data provide crucial information for assessing biodiversity, population status, and the ecological processes of focal wildlife species and are valuable for both protected area management and conservation efforts.

1. INTRODUCTION

A global conservation crisis has resulted from biodiversity declines and associated threats to various megafauna species (Davis et al., 2018). The Asian elephant (*Elephas maximus*), a terrestrial megafauna species, is a keystone and umbrella species with varied ecological functions (Suksavate et al., 2019). The global population of Asian elephant is in decline, with approximately 40,000-52,000 individuals surviving in the wild, and the species is listed as Endangered in the IUCN Red List (IUCN, 2020). However, Asian elephant have low reproductive output and require large home ranges, making them highly vulnerable to population declines (Cardillo et al., 2005). Increases in human disturbances (Allbrook and Quinn, 2020) threaten wildlife via habitat loss and fragmentation (Leimgruber et al., 2003; Nekaris et al., 2015). Poaching is also a threat to remnant Asian elephant populations due to the high value of body parts in the wildlife trade (McClenachan et al., 2016). The conflict between humans and Asian elephant has increased substantially due to human impacts (Krishnan et al., 2019; Sukumar, 2006).

The wild Asian elephant population in Thailand was estimated to be approximately 3,124 individuals, with 642 individuals inhabiting the Western Forest Complex (WEFCOM) (IUCN, 2017). WEFCOM is the most significant conservation landscape consisting

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of 17 contiguous and strongly protected areas in Thailand (Duangchatrasiri et al., 2019; Simcharoen et al., 2007), particularly in the Huai Kha Kheng Wildlife Sanctuary (HKK). The distribution range of these Asian elephant extends into adjacent protected areas (Sukmasuang, 2009). Large-scale surveys conducted throughout the WEFCOM in 2010 indicate that the Asian elephant populations in these peripheral protected areas are smaller than those in source sites, particularly in the Thung Yai Naresuan West Wildlife Sanctuary (TYW), where the distribution of Asian elephant was clearly limited (DNP, 2013). The Spatial Monitoring and Reporting Tool (SMART) is used for evaluating and improving law enforcement systems in protected areas (Stokes, 2010). SMART has been used to record the on-site patrols, then compile the observations into a systematic database to identify illegal activities and other conservation management issues (Hötte et al., 2015). In TYW, the SMART patrol system has been implemented since 2008 and expanded to 70% (DNP, 2013). SMART can be used in ecological studies of the major wildlife species to gain insight into ecology, threats, and management of the species. Such understanding could facilitate the maintenance of biodiversity and the achievement of conservation objectives (Marescot et al., 2019).

Occupancy models have been employed to investigate areas occupied by target species within a specific region using appropriately scaled predictors to facilitate occurrence predictions (Scott et al., 2002). Factors at the local scale can provide insight into habitat occupancy based on environmental factors. Such implementations are critical for wildlife management and the conservation of endangered species in particular (Duangchatrasiri et al., 2019; Vinitpornsawan, 2013). Using a standard occupancy model for the Asian elephant could elucidate patterns of seasonal dynamic occupancy over a large and diverse landscape that are mainly determined by key anthropogenic and ecological factors (Jathanna et al., 2015), The occupancy modeling framework has been expanded to account for species interactions, imperfect detection, and changes in species distributions (MacKenzie et al., 2003).

The Asian elephant is a megafauna known once to occupy TYW but historically diminished and nearly absent from the area. The re-occupation of the Asian elephant population was recorded in TYW during the last decade due to improved protected area management with the SMART system, wildly applied in protected areas in many African and Asian nations. However, the re-occupation pattern is poorly understood during the transition period in the dynamic landscape context. We used a single-species, dynamic occupancy model to examine the factors influencing Asian elephant occupancy across multiple seasons (Broms et al., 2016). In this study, we hypothesize that socio-ecological factors affected the dynamic of habitat occupancy of the Asian elephant. The dynamic occupancy model was used to quantify associations between covariates and colonization-extinction processes at the landscape scale. Then, we used the optimal model to develop a spatial representation of the colonization-extinction probability. This predictive map could support the conservation of Asian elephant populations in the study area by providing spatial and temporal information on habitat occupancy and evidence of the transboundary re- population process across protected areas in WEFCOM.

2. METHODOLOGY

2.1 Study area

Thung Yai Naresuan West Wildlife Sanctuary (TYW) is located within WEFCOM in the western region of Thailand, connected to the border of Myanmar. The study area was between the latitudes of 14°8’N and 15°49’N; and between the longitudes of 98°33’E and 99°8’E. TYW is connected to HKK and Thung Yai Naresuan East Wildlife Sanctuary (TYE) to the east. The study area was composed of a portion of WEFCOM landscape declared as a world natural heritage site since 1991, encompassing an area of 2,129 km^2 (Kanchanasaka, 1997; Trisurat, 2004) (Figure 1). The study area is mainly hilly terrain with the elevation ranging from 800 to 1,813 m with 10-40% slopes. The climate is characterized by three main seasons composed of rainy season (May-October), winter (November-January) and summer (February-April) (Kanchanasaka, 1997). The majority of landcover is forest ecosystem which varies across elevation, classified as dry evergreen forest, hill evergreen forest, dry dipterocarp forest, and savannah grassland (Duangchatrasiri et al., 2019). TYW is rich in biodiversity, including several endemic and internationally threatened species such as Indochinese tiger (*Panthera tigris*), Gaur (*Bos gaurus*), Banteng (*Bos javanicus*), and Rufous-necked Hornbill (*Aceros nipalensis*). Furthermore, this area has been identified as one of the potential landscapes for the long-term conservation of Asian elephants (Leimgruber et al., 2003; Sukumar, 2006).

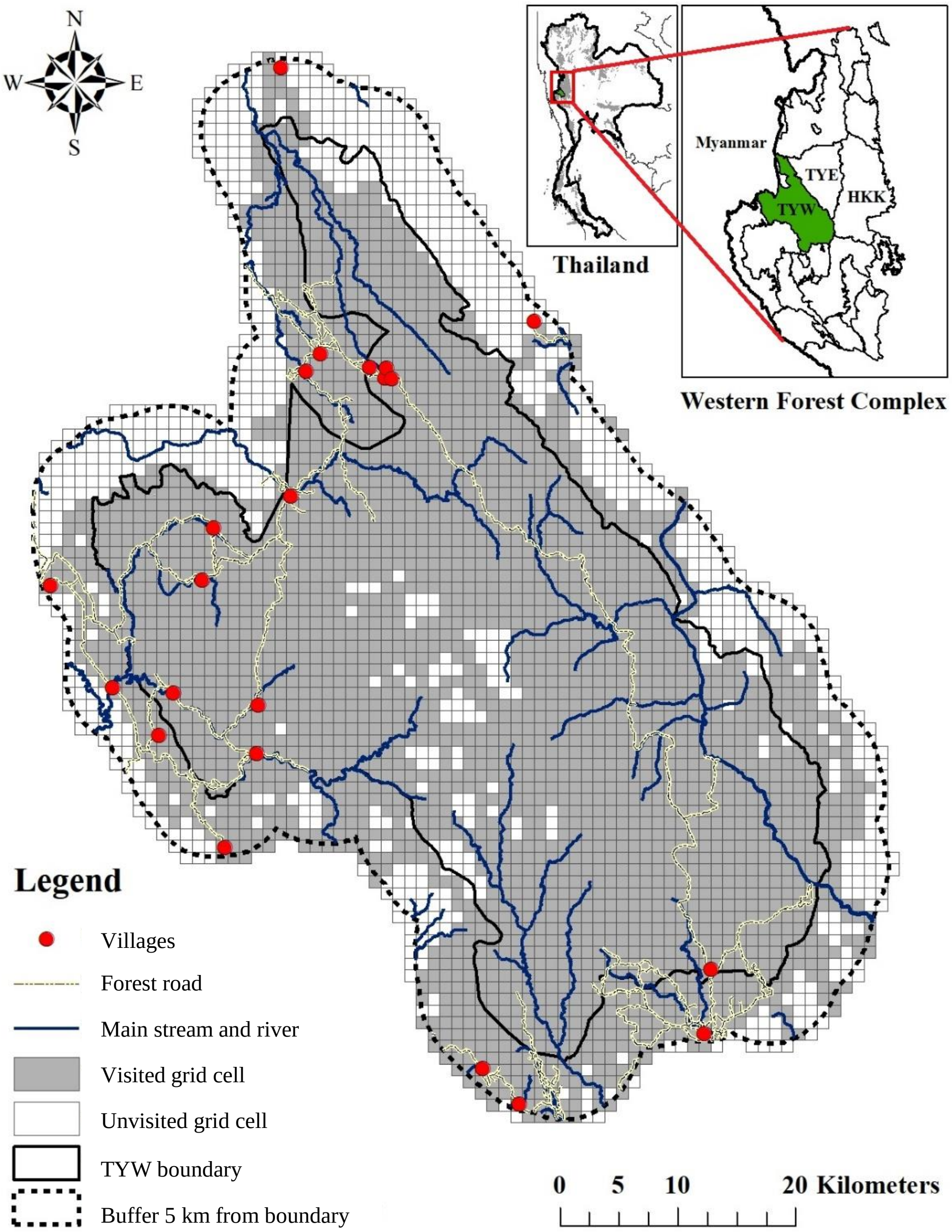

Figure 1. Study area and 1 km^2 spatial grid cell of Asian elephant dynamic occupancy model in Thung Yai Naresuan Wildlife Sanctuary (TYW) from SMART database during 2012-2019

2.2 Data collection and analysis

Occurrence data of Asian elephants was acquired from the SMART database recorded during patrolling routines from 2012 to 2019. The patrol data showed stability of coverage over 90% since 2012 and increase of Asian elephant presence (Figure 2). Data in this study was represented at 1 km^2 grid resolution, following the referenced scale for protected area management (DNP, 2013). Grid cells for the study area were generated to cover the 5 km buffered study area to include the transboundary connection, making the total area of 3,722 km^2 (Figure 1). Direct observation and recent signs, primarily tracks and dungs situated in the grid cell were included as quarterly observing occasions within annual occupancy. Raster of ecological and anthropogenic covariates were obtained from the SMART database and GIS public domain (Figure 1). Eight static covariates were used as the input of the occupancy state model. Geographical covariates comprise the average value of elevation (ELV) and slope (SLP) within a spatial grid (Leimgruber et al., 2003;

Suksavate et al., 2019). The distance from the boundary of HKK and Khuean Srinagarindra National Park (KSR) to the centroid of each grid was used to represent the dispersal fatigue of Asian elephant from the nearest initial population source (PPS) (Vasudev et al., 2021). Average normalized difference vegetation index (NDVI), extracted from Landsat-8 imagery, was used as a critical tool for representing habitat condition, vegetation phenology, and primary production; which many previous studies have shown to correlate with Asian elephant distribution (Jathanna et al., 2015; Pettorelli et al., 2011; Thapa et al., 2019). The presence of the water body was represented by the distance from the grid centroid to the nearest main stream (MST) and secondary stream (SST). The anthropogenic influencing factor was defined by the distance from the grid centroid to the nearest villages (VLG) (Jornburom et al., 2020; Suksavate et al., 2019) (see in Table 1 and Figure 3). Threat intensity (THTyear) was a dynamic covariate to represent the annual kernel density of poaching incidents such as poacher camp, poached animal carcasses, and other belongings (Hötte et al., 2015) (see in Figure 3 and Figure 4). To model the detectability, quarterly patrol frequency (P_{freq}) and distance from the nearest ranger to grid centroid (RGS) was included to represent the effect of sampling intensity and fatigue, respectively. The seasonal and terrain difficulties were also included in modeling detection probability by terrain ruggedness index (TRI) and annual rainfall (R_{avr}) (Table 1).

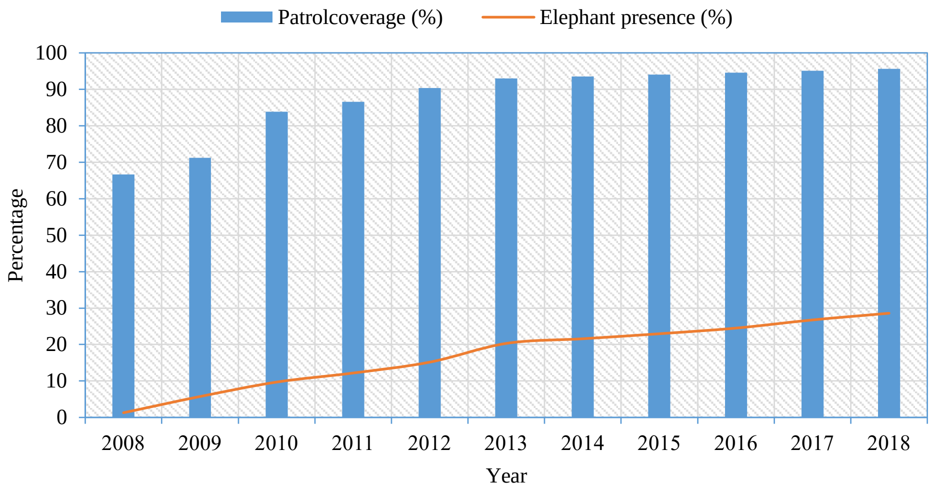

Figure 2. Percentage of patrol coverage compared to Asian elephant sign (orange line) in 1 km^2 grid cell in TYW during 2008-2019

Table 1. Covariates hypothesized to influence patterns of habitat use in spatial (grid cell 1 km^2) and detection probability of Asian elephant in Thung Yai Naresuan wildlife sanctuary

Covariate	Description	Min	Max	Av.	SD
Site level covariates					
PPS	Distance to nearest Asian elephant population source site (km)	0.00	68.35	31.41	17.92
VLG	Distance to nearest villages (km)	0.00	43.86	13.68	9.57
MST	Distance to nearest main stream (km)	0.00	17.46	2.79	2.70
SST	Distance to nearest secondary stream (km)	0.00	12.04	0.50	1.32
ELV	Elevation (m)	118.91	1,633.03	663.66	322.41
NDVI	Normalized difference vegetation index	-0.06	0.46	0.37	0.06
SLP	Slope	0.00	37.16	15.16	5.99
THT12	Threat intensive in 2012, using data from SMART	0.00	0.50	0.01	0.02
Yearly site covariates					
THTyear	Annual threat intensive during 2012-2019, using data from SMART	0.00	0.67	0.005	0.01

Table 1. Covariates hypothesized to influence patterns of habitat use in spatial (grid cell 1 km^2) and detection probability of Asian elephant in Thung Yai Naresuan wildlife sanctuary (cont.)

Covariate	Description	Min	Max	Av.	SD
Observation covariates					
P_{freq}	Patrol frequency (2012-2019), using data from SMART	0.70	39.00	0.00	1.52
R_{avr}	Rainfall average (mm)	14.31	30.67	4.85	4.95
TRI	Terrain ruggedness index	0.00	0.52	0.49	0.03
RGS	Distance to nearest forest ranger station (km)	0.00	19.31	6.62	3.78

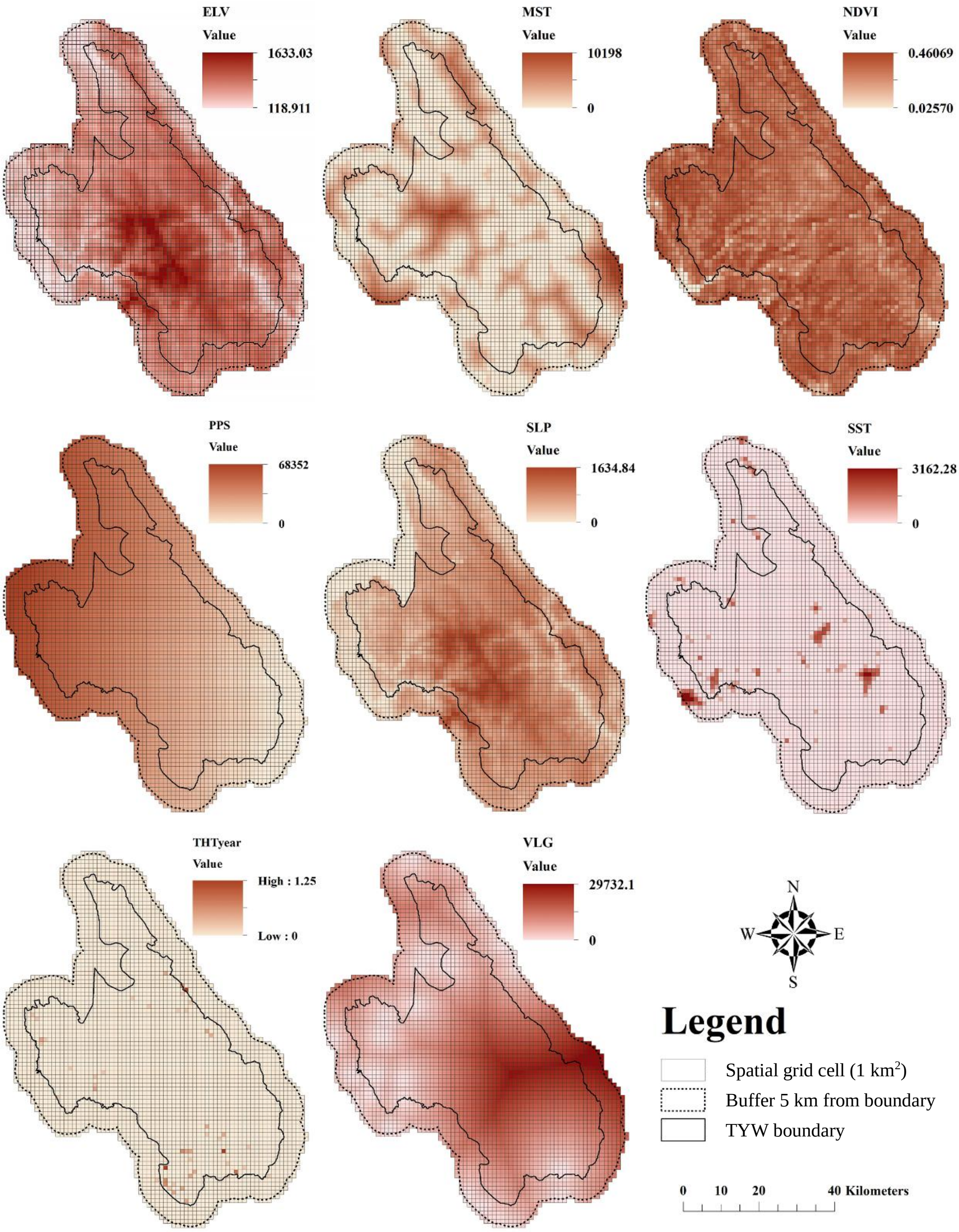

Figure 3. Static covariates (1 km^2 grid cells) of Asian elephant dynamic occupancy model in Thung Yai Naresuan West Wildlife Sanctuary

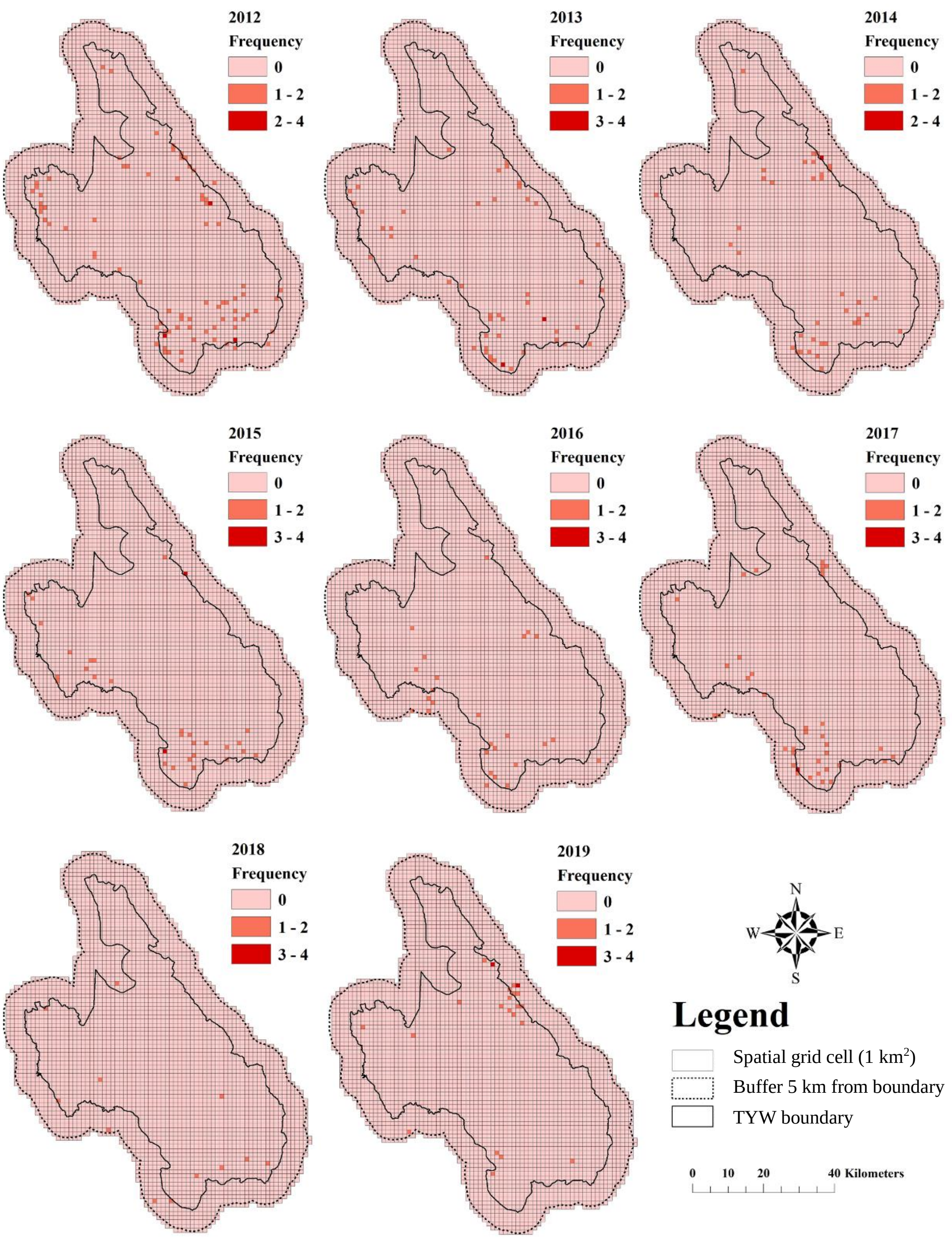

Figure 4. Threat annual intensity (1 km^2 grid cells) during 2012-2019 used for Asian elephant dynamic occupancy model in Thung Yai Naresuan West Wildlife Sanctuary

2.3 Model training and selection

A single species, multi-season, dynamic occupancy modeling framework was used to model the dynamic occupancy of Asian elephants (Broms et al., 2016) in TYW. The model inferred the association between the occupancy states and ecological-anthropogenic covariates. The model was done by introducing probability parameters that justify the changing between states of using of unoccupied habitat, so-called colonization, and the unused of occupied habitat, so-called extinction. The model training was done in R program using unmarked package (Fiske and Chandler, 2011). All exploratory variables were standardized prior to training to improve convergence and interpretability. We firstly identified the most appropriate structure for detection probability parameters (ρ) on the top of full model using Akaike’s information criterion (AIC) following Goswami et al. (2014) and Vasudev et al. (2021). Next, the optimal detection probability structure was fixed to find the optimal initial occupancy (Ψ) based on the full model. Detection and initial state of occupancy were fixed at the optimal form and then selected for the best model combination for colonization probability (γ) and extinction probability (ε). All of the model comparisons were made based on AIC (Thapa et al., 2019). The predictive map of the whole study area was then created from the most optimal model combination to represent the spatial and temporal pattern of occupancy state.

3. RESULTS AND DISCUSSION

Asian elephant occurrence was recorded within 608 grid cells (16.34% of the total sanctuary area) during 2012-2019. The majority of these occupied cells were located in the southern portion of TYW. The parameters of the selected model determined the three components: the probability of initial occupancy (Ψ), colonization (γ), extinction (ε), and detection probability (ρ). The best-supported models were those with the lowest AIC values. Final model candidates were identified with eight site covariates (Table 1). The coefficients of the best-supported model for ρ were composed of patrol frequency (P_{freq}), annual total rainfall (R_{avr}), terrain ruggedness index (TRI), and distance to nearest the ranger station (RGS); with AIC weight of 0.65 (Table 2). For the initial occupancy Ψ, the model included four coefficients consist of elevation (ELV), distance to the nearest secondary stream (SST), normalized difference vegetation index (NDVI), and distance to the neatest population source (PPS) (Figure 5 and Table 3). For colonization-extinction processes, according to the best-supported model, the average probability of colonization across the study area was -4.83. The positive coefficients in the colonization model were composed of NDVI and ELV. In contrast, PPS showed a negative effect on γ (Figure 6 and Table 3). The best-supported model for extinction probability, ε, estimated an average of -7.095 across the study area. The PPS and VLG coefficients were positively associated with ε while THTyear and NDVI were negatively associated with ε. However, the effect of SLP on ε was negative but not significant (Figure 7 and Table 3). The predictive maps of initial occupancy, colonization probability, and extinction probability across the study landscape are shown in Figure 8.

Table 2. Results of top-five dynamic occupancy model selected based on AIC. The model composed of 4 submodels includes detection probability (ρ), occupancy probability of initial stage (Ψ), colonization probability (γ), and extinction probability (ε).

Dynamic occupancy model	Model AIC	ΔAIC	AIC weight	Model likelihood	#Par
Detection probability (ρ)					
ρ (P_{freq}, R_{avr}, TRI, RGS)	10,340.59	0.00	0.65	0.65	8
ρ (P_{freq}, R_{avr}, RGS)	10,342.45	0.68	0.26	0.91	7
ρ (R_{avr}, RGS)	10,345.58	4.99	0.05	0.96	6
ρ (R_{avr}, TRI, RGS)	10,347.40	6.81	0.02	0.99	7
ρ (P_{freq}, R_{avr})	10,350.04	9.45	0.01	0.99	6
Occupancy probability of initial stage (Ψ)					
Ψ (SST, NDVI, ELV, PPS)	9,676.45	0.00	0.14	0.14	12
Ψ (NDVI, ELV, PPS)	9,677.39	0.94	0.09	0.24	11
Ψ (SST, NDVI, ELV, PPS, THT12)	9,677.82	1.37	0.07	0.31	13
Ψ (VLG, SST, NDVI, ELV, PPS)	9,677.98	1.53	0.06	0.38	13
Ψ (MST, SST, NDVI, ELV, PPS)	9,678.31	1.86	0.05	0.43	13
Colonization probability (γ)					
γ (NDVI, ELV, PPS)	9,638.19	0.00	0.61	0.61	15
γ (VLG, SST, NDVI, ELV)	9,640.51	2.31	0.19	0.80	16
γ (VLG, SST, NDVI, ELV, THTyear)	9,642.43	4.24	0.07	0.87	17
γ (MST, NDVI, ELV, THTyear)	9,642.91	4.72	0.06	0.93	16
γ (VLG, MST, NDVI, ELV, SLP)	9,644.25	6.06	0.03	0.96	17
Extinction probability (ε)					
ε (VLG, SST, NDVI, SLP, PPS, THTyear)	9,639.91	0.00	0.58	0.58	18
ε (VLG, MST, SST, NDVI, SLP, PPS, THTyear)	9,642.36	2.45	0.17	0.75	19
ε (VLG, SST, NDVI, PPS, THTyear)	9,644.60	4.69	0.06	0.81	17
ε (VLG, MST, SST, NDVI, PPS, THTyear)	9,646.02	6.11	0.03	0.84	18
ε (VLG, MST, NDVI, ELV, PPS, THTyear)	9,647.11	7.20	0.02	0.85	18

Table 3. Summaries of estimated coefficients based on the best-supported model of dynamic occupancy parameters composed of Initial (Ψ), Colonization (γ), and Extinction (ε)

Model	β_{PPS} (SE)	β_{ELV} (SE)	B_{NDVI} (SE)	B_{SST} (SE)	B_{VLG} (SE)	β_{SLP} (SE)	$\beta_{THTyear}$ (SE)
Occupancy of initial state (Ψ)	-0.52(0.09)*	0.32(0.09)*	-0.26(0.08)*	0.16(0.09)			
Colonization (γ)	-1.3(0.51)*	1.37(0.39)*	1.13(0.31)*				
Extinction (ε)	1.88(0.54)*		-0.80(0.30)*	-8.03(19.85)	0.80(0.38)*	-0.33(0.26)	-5.17(1.89)*

*Significant associate with β coefficients for each covariates.

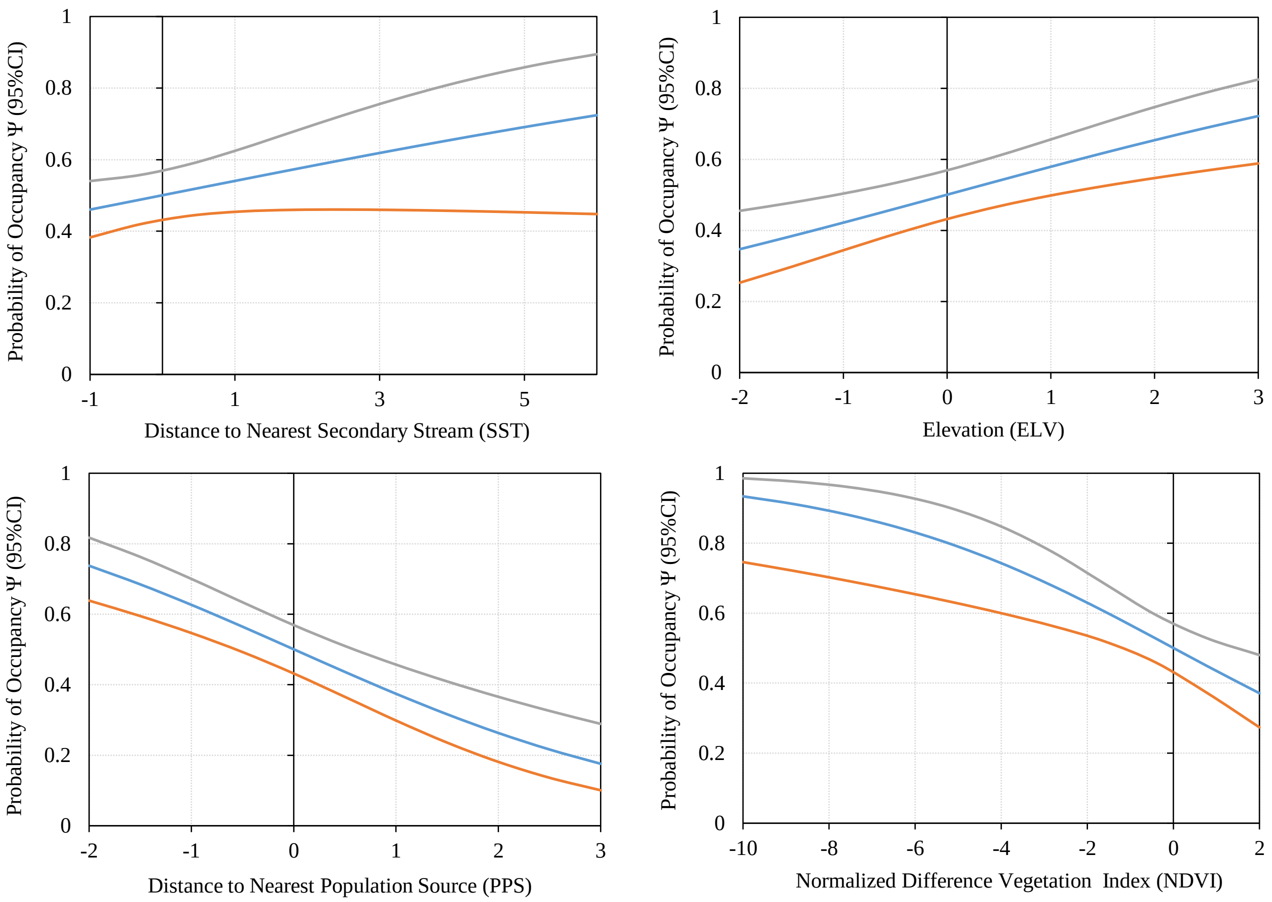

Figure 5. Relationship between influential covariates and estimated Ψ (95% CI) based on best-supported model

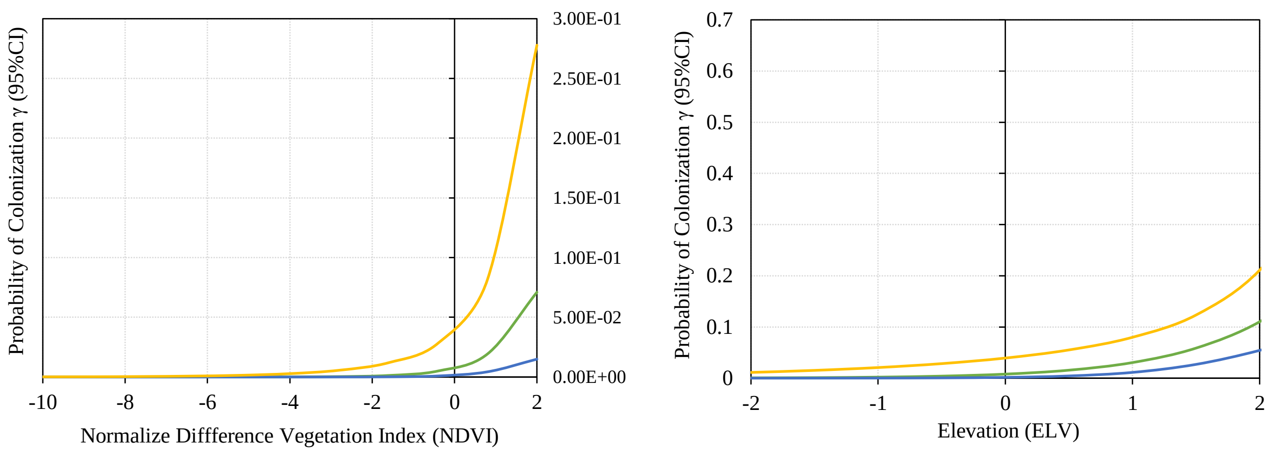

Figure 6. Relationship between influential covariates and estimated γ (95% CI) based on best-supported model

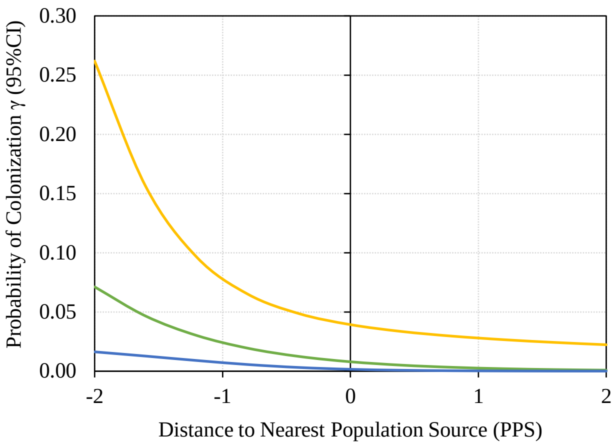

Figure 6. Relationship between influential covariates and estimated γ (95% CI) based on best-supported model (cont.)

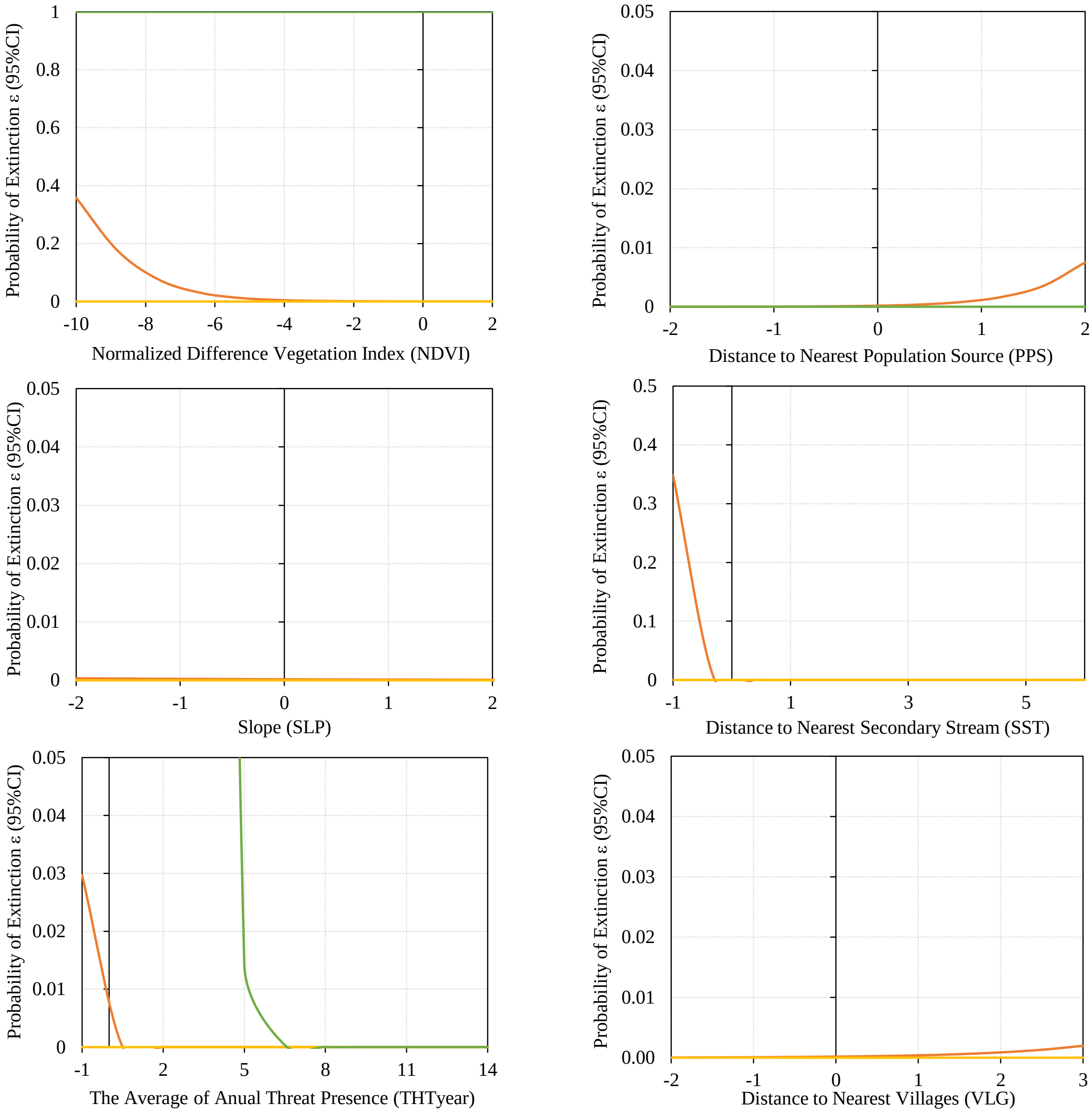

Figure 7. Relationship between influential covariates and estimated ϵ (95% CI) based on best-supported model

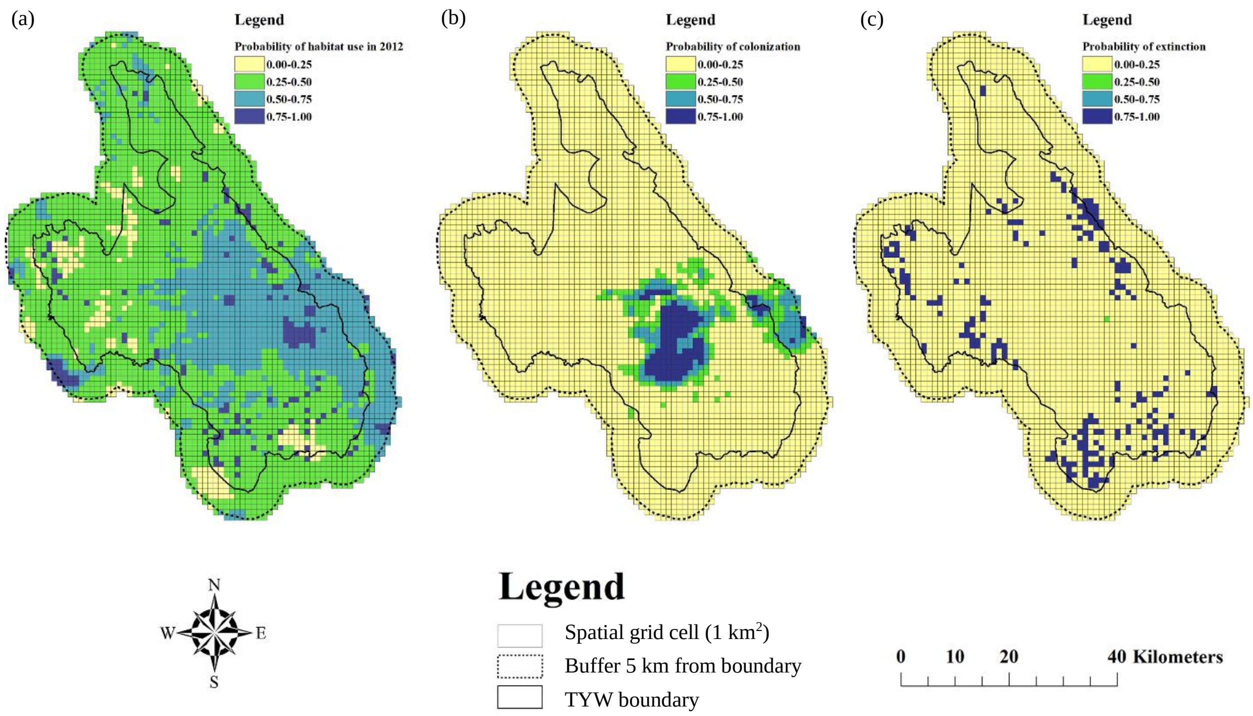

Figure 8. Map of spatially estimated dynamic occupancy parameters across the study area. (a) initial occupancy probability (Ψ), (b) colonization probability (γ), and (c) local extinction probability (ε)

Conservation and management of Asian elephant require robust assessments of populations and patterns of occupancy at the landscape scale. Analyzing occupancy across both spatial and temporal scales may provide helpful information about the influence of environmental conditions, human activity, and management on habitat use and dispersal across the landscape (DNP, 2013; Vinitpornsawan, 2013). Anthropogenic factors may significantly influence many wildlife species, especially keystone species like Asian elephant, and could subsequently affect others (Simberloff, 1998). Intensive human activities historically occurred in the TYW, especially exploration and site preparation for Nam Joan Dam between 1981 and 1988 and mineral extraction suspended in 1990. However, human activity in TYW still exists from nearby settlements in the easily accessible northern part of the conservation area that may affect wildlife habitat, behavior, and population (Duengkae, 2009; Steinmetz et al., 2006). The SMART patrol system has been in use in TYW since 2008, and has provided long-term data on natural resources and threats (Trisurat, 2004). A long-term database of patrol records has further revealed the restricted recolonization of Asian elephants in TYW between 2008 and 2018 (ca. 28.6%). The expansion of the Asian elephant population was thought to be attributable to effective law enforcement.

Dynamic prediction of Asian elephant occupancy patterns has indicated a high probability in TYW southern areas connected to the Huai Kha Kaeng Wildlife Sanctuary and Khuean Srinagarindra National Park, which is the source of the Asian elephant population in WEFCOM (DNP, 2017; IUCN, 2017; Sukmasuang, 2009). Habitat use of Asian elephant could have depended on the availability of resources and impeding factors in and to the destination site (Suksavate et al., 2019). The transboundary distribution extends across the Mae Klong River to the mountain range with ELV of 800-1,800 m and high canopy cover. Higher ELV and NDVI values impact the habitat occupancy of Asian elephants; however, Asian elephants are capable of moving to a wide variety of elevations, and Asian elephants were recorded from sea level to montane (Rood et al., 2010). The NDVI is related to plant community structure and land use that negatively affects primary productivity and reflects the availability of food sources in habitat patches (IUCN, 2020; Jathanna et al., 2015). Natural water sources also play an essential role in the seasonal distribution of elephants (Thouless, 1995). The temporal availability and spatial distribution of food and water are critical to elucidating the local habitat occupancy of the Asian elephant (Kumar et al., 2010; Thapa et al., 2019). According to the SMART database, nearly all signs of Asia elephants have been found in dry evergreen forests compared to tropical rain forests, while Sukumar (2003) suggested that Asian elephants use a variety of habitats, ranging from dry to wet evergreen forests and attain high densities in deciduous forests with substantial grass and bamboo forage. We found weak evidence that the TRI affects occupancy, as nearly all Asian elephant tracks and other signs observed by rangers in mountainous areas were in the vicinity of ridges and flats. Goswami et al. (2014) reported that Asian elephant intensively used sites with high ruggedness. Thapa et al. (2019) reported that a higher TRI, along with forage and water resources, may drive occupancy patterns in areas of high ruggedness.

Our results indicate that human activity in the vicinity of villages within protected areas is a crucial variable impacting occupancy of Asian elephant. Buji et al. (2007) reported that human activity appears to drive Asian elephant distribution in areas where human impacts were thought to be a limiting factor, while Vinitpornsawan (2013) suggested that while the impacts of activities by local people are complex, poaching appears to be the critical factor influencing wildlife abundance and habitat use. Our model indicated dissociation between occupancy and proximity to human settlement and activities, overcoming threat occurrence that had a relatively negative effect on extinction probability. The SMART database indicated that the range of Asian elephants overlaps with the distribution of threats in the southern part of the TYW, which are associated with human settlements connected to other protected areas. The increasing patrol intensity in risky areas such as settlements (Duangchantrasiri et al., 2016; Jornburom et al., 2020) by controlling edge effects (Balme et al., 2010) could reduce the threat to the local wildlife population. Sampson et al. (2018) reported that poachers killed more than 40 Asian elephants in south-central Myanmar for their skin and ivory. However, we have not detected Asian elephant poaching in the TYW, the tiny Asian elephant population in the Myanmar transboundary area, which still lacks information of threat and status on Asian elephants, was found to be dispersed to the area with dense human population in the northern part of TYW.

In our study, the SMART database is highly biased information compared to the research survey, but it had a much larger capacity with continuous collection due to the extensive data recording across space and time. The data could be enhanced to increase the usefulness of studying and monitoring natural resources in the protected areas across the country by implementing bias alleviating methods, for example, dealing with auto-correlation sampling biases in developing occupancy models (Jornburom et al., 2020). Moreover, more detail in temporally ecological covariates could be necessary to accurately determine the occupancy dynamics by including the effect of season, resource availability, and microclimate (Thapa et al., 2019).

4. CONCLUSION

We evaluated and predicted the dynamic occupancy patterns of Asian elephants in the TYW using SMART data collected during 2012-2019 using the monitoring database collected during patrol. The most optimal dynamic occupancy model clarified the re-occupation pattern of the Asian elephant population within TYW and transboundary areas connecting to adjacent protected areas. The results showed that the distance to the initial population sources and vegetation pattern was influential to both the colonization and extinction processes. In contrast, the anthropogenic factors, distance to the nearest village, and poaching were essential to the local extinction process. The spatial prediction from a long-term sustained database could help managers gain insight into the dynamics of the Asian elephant occupation processes across the conservation landscape. The predicted map could provide valuable information in management approaches such as threat prevention to allow dispersal and availability of Asian elephant population and alleviate human-elephant conflict across the protected area and agricultural interface.

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