Ranging behaviour, habitat use and predicting the potential distribution of Asian elephant (Elephas maximus) in Gua Musang, Kelantan, Malaysia

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Ranging behaviour, habitat use and predicting the potential distribution of Asian elephant (*Elephas maximus*) in Gua Musang, Kelantan, Malaysia

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Abstract : Land conversion has influenced the distribution and movement of Asian elephants. This study was conducted to understand the ranging behaviour and habitat use of Asian elephants in Sungai Betis Forest Reserve (SBFR) in Gua Musang, Kelantan, Malaysia. ArcGIS and MaxEnt softwares were used to estimate the home range and potential distribution based on the occurrence data points and environmental variables, such as distance to water and road, elevation, slope and vegetation cover. The results obtained showed that home ranges of the elephants were concentrated in the fragmented forest. There was a strong correlation between the environmental variables, which play significant roles in influencing the ranging behaviour and habitat use of Asian elephants.

Keywords: Ranging behaviour, habitat use, potential distribution, Asian elephants, MaxEnt, ArcGIS

INTRODUCTION

Tropical rainforests provide essential services to humans and biodiversity (Ambe & Onnoghen, 2019). In Malaysia, Protected Areas (PAs) have been established to help conserve and protect its inhabitants (Bakar, 2018). However, research has shown that forest fragmentation, deforestation, and changes in land use and forest cover have significantly diminished the global biodiversity (Woodley *et al*., 2015). A fragmented forest habitat creates an imbalance in the biodiversity and ecosystem (Farina, 2008; Forman, 1995). Such threats have become a great concern for the species living within and surrounding the PAs. This is especially true for wide-ranging terrestrial mammals (Shevade *et al*., 2017, Bahar *et al.,* 2018), like the Malayan tiger (*Panthera tigris*) and Asian elephant (*Elephas maximus*) throughout their range in Asia (Santiapillai & Jackson, 1990; Leimgruber *et al*., 2003; Hedges *et al*., 2005), including Peninsular Malaysia (Saaban *et al*., 2011).

The study area, Sungai Betis Forest Reserve (SBFR) in Gua Musang, Kelantan is recognised as one of the PAs in Peninsular Malaysia. Agricultural development, mainly for oil palm plantations, surrounding the area has degraded the conditions of this protected habitat. These major landscape disturbances have caused habitat loss, affected the availability of food and water sources, and jeopardised the overall health of the forest ecosytem as well as causing landslides during heavy rain, particularly during the Northeast Monsoon from October to March (Syafril *et al*., 2020).

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There is a growing concern about the safety of the Asian elephants in Gua Musang due to the changes in their natural habitats. Anthropogenic infiltration into the wildlife reserve has also become a common occurrence (Newton *et al.*, 2020). Frequent disturbance by human activities has forced the elephants to leave their habitat and approach human settlements in search for space and food resources, increasing the risk of human-wildlife conflicts. This includes invasion of crops, which sometimes results in loss of life (Leimgruber *et al.*, 2003; Newmark, 2008; Mcdonald *et al.*, 2009; Western *et al.*, 2009; White & Ward, 2011; Liu *et al.*, 2017). Human-elephant conflict is a serious social problem across the species' range (Shaffer *et al.*, 2019; Denninger Snyder & Rentsch, 2020). The costly destruction and retaliatory cycle of human-elephant conflict is largely due to the similarities in diet. Elephants are attracted to the same plants that humans often cultivate on their landscapes (Lim & Campos-Arceiz, 2022).

There are several factors that affect the ranging behaviour and habitat use of the elephants. These include biotic and abiotic factors, as well as physical and anthropogenic factors associated with spatial or geographic information (Aini *et al.*, 2015), such as availability of food, water and shelter (Sukumar, 1989; Schaller, 1967). It is known that Asian elephants prefer to forage in dry and moist deciduous forests where there is abundance of grass and bamboo (Sukumar, 2003; Koirala *et al.,* 2016) and has cooler temperature to rest during the day (Mandal & Chatterjee, 2018; 2019). Whereas elephants in the tropical evergreen rainforest prefer openings within rainforest fragments due to the availability to forage (Sukumar, 2003; Barnes *et al*., 1991). The movement of the Asian elephants is influenced by seasonal factors – dry or wet season, particularly in search for shelter and water (Kumar *et al*., 2002; Sukumar, 2003; Kumar *et al*., 2010). Besides this, temporal factors such as day and night, could also influence elephants' movement and habitat use (Graham *et al*., 2009; Kumar *et al*., 2010).

According to Evans *et al.* (2020), the understanding of home range of the wildlife is important to estimate the area required to be protected for the animal populations. In this study, the ranging behaviour and habitat use of Asian elephants were examined in an area undergoing deforestation in Gua Musang, Peninsular Malaysia. The drastic change in landscape occurring throughout the natural habitats of Asian elephants is limiting their distribution and threatening their extinction in Gua Musang. Hence, this research aimed to investigate: (1) the extend that elephants use their disturbed habitat and whether this usage varies depending on the time of the year; (2) the potential distribution of elephants that are found in Gua Musang and; (3) the environmental variables affecting their ranging behaviour and habitat use. The results of this study will contribute to the existing knowledge of the ranging patterns, habitat use and potential distribution of the Asian elephants. This information will be used to identify critical areas for the conservation of Asian elephants and to develop management strategies of remaining habitat.

MATERIALS AND METHODS

Study area

This study was conducted at Sungai Betis Forest Reserve (SBFR) which is located within the Gua Musang region in the state of Kelantan, Peninsular Malaysia (Figure 1). The study area is predominantly covered with forest plantations, especially oil palm plantations, which poses a major challenge in conserving this majestic wildlife species (Mudappa & Raman, 2007; Graham *et al*., 2009).

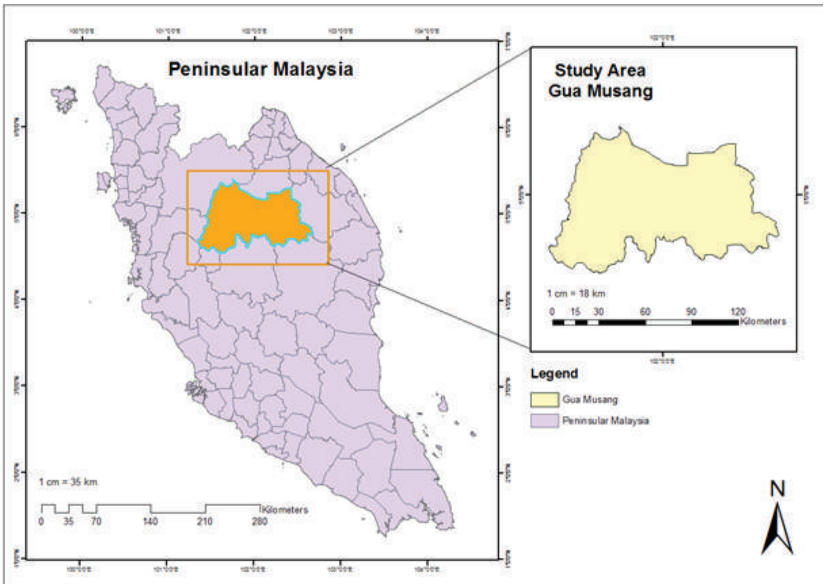


Figure 1. Location of the study area.

Occurrence data collection

The Asian elephant occurrence data for this study were obtained from the Department of Wildlife and National Park (DWNP) in XML file format. This file contains the Global Positioning System (GPS) location of Asian elephants in Gua Musang. The GPS location was tracked through a satellite telemetry placed on a female elephant (approximately 30 years old), as part of the Central Forest Spine (CFS) project. This female elephant lived in a herd of 30 individuals of various ages and sexes. However, the age and sex of other elephants among this herd were not recorded.

On December 31, 2018, the female elephant was sedated with 10ml of Xylazil-100 by a DWNP staff. The sedative was inserted in a dart before released from a dart gun. The amount of sedative was prescribed by a veterinary officer, depending on the size of the elephant. After the female elephant was sedated, a satellite telemetry unit was fitted to monitor its vitals. Other elephants from the herd were monitored from a distance to prevent them from approaching the sedated female. The female elephant was then injected with 10ml of Xylazine reversal agent to arouse it before re-joining the herd. The GPS locations of the Asian elephant herd were recorded at every three-hour intervals over a six-month period from January 1, 2019 to June 31, 2019. The herd of elephants were observed to remain closely together throughout the study period and without seperating into other groups.

Environmental variables

The environmental variables used to model the elephant distribution and habitat use includes both topographical and vegetation-related variables. The environmental variables assessed were elevation, slope, distance to waterbody, distance to the nearest road, and vegetation cover.

Elevation and slope were estimated using a 30-meter resolution Digital Elevation Model (DEM) obtained from the United States Geological Survey (USGS) website (https://earthexplorer.usgs. gov/). ArcGIS software was also used to estimate the slope from DEM. A waterbody shapefile was obtained from the Department of Survey and Mapping Malaysia (JUPEM) and converted to a distance raster using the Euclidean distance spatial tool in ArcGIS. The distances to waterbody and nearest road was measured from the map in metres.

$$NDVI_{L8} = \frac{Band_5 - Band_4}{Band_5 + Band_4}$$

Where;
$Band_4$ = red light (RED)
$Band_5$ = near infra-red light (NIR)

Data analysis

i. Home range modelling

In order to understand the ranging behaviour of Asian elephants in the study area, it is necessary to model their home range. A standard method of estimating home range for wildlife is by mapping the size of the area using Minimum Convex Polygon (MCP) where a set of available point location would geometrically define the home range in the form of a convex hull (Wartmann *et al*., 2010). In this study, the MCP was computed from species occurence data using the minimum bounding geometry tool available in ArcGIS software. The measurement tool was used to measure the area of the home range in kilometers squared (km^2).

ii. Predictive modelling of distribution and habitat use using maximum entropy (MaxEnt)

MaxEnt software version 3.3.3k was used to produce a functional predictive model of the elephants' distribution in the study area, as described by Young *et al.* (2011). The species occurrence data and the environmental variables were used to extract background locations (Merow *et al*., 2013). Since present data would cluster around the predicted area, a regularisation multiplier value of one was used to avoid over-fitting of the model (Elith *et al*., 2011). Jackknife approach was used to validate the model. When the models were generated in MaxEnt, the most likely combination of variables that best explained the observed data was identified.

The MaxEnt model output provided necessary informations about influence of each variable on the model, as well as the performance and importance of each variable (Baldwin, 2009; Hosseini *et al*., 2013). The Receiver Operating Characteristic (ROC) or Area Under the Curve (AUC) metrics determined whether the model is performing well. An AUC reading of < 0.7 indicates a low-performance model, while a reading of 0.7 - 0.9 indicate a medium-performance model, and > 0.9 reading indicate an excellent-performance model (Pearce & Ferrier, 2000).

Default settings were used for MaxEnt, except for a few changes made according to the manual described by Young *et al.* (2011). The data were then divided into training data (75%) and test data (25%). The accuracy of the model was evaluated using the test data, while training data was used to create the predictive model (Briscoe *et al*., 2014). A cross validation was performed using replication method, where the samples were divided into replicates folds. Each fold was then used as test data. The replications were set to a value of 15, and the final output was the average result obtained.

RESULTS AND DISCUSSION

Size of home range

A total of 1306 GPS location data points were obtained from monitoring the movements of the female Asian elephant through the satellite telemetry. However, only 1294 points were used for analyses after removing duplicates. The 100% MCP calculation showed that the elephants' home range was about 112.76 km², which encompassed both fragmented and non-fragmented forest. A study by Alfred *et al.* (2012) reported that the home range size of Bornean elephants was 250 – 400 km² in non-fragmented forest, and approximately 600 km² in disturbed and fragmented landscapes. Their study provided the first indication that forest connectivity and quality are important factors in landscape use by the elephants. In this study, the elephant monthly ranges were between 24 to 42 km² (Figure 2). The smallest area covered by the elephants was in June (24.05 km²), and largest in February (42.28 km²; Table 1).

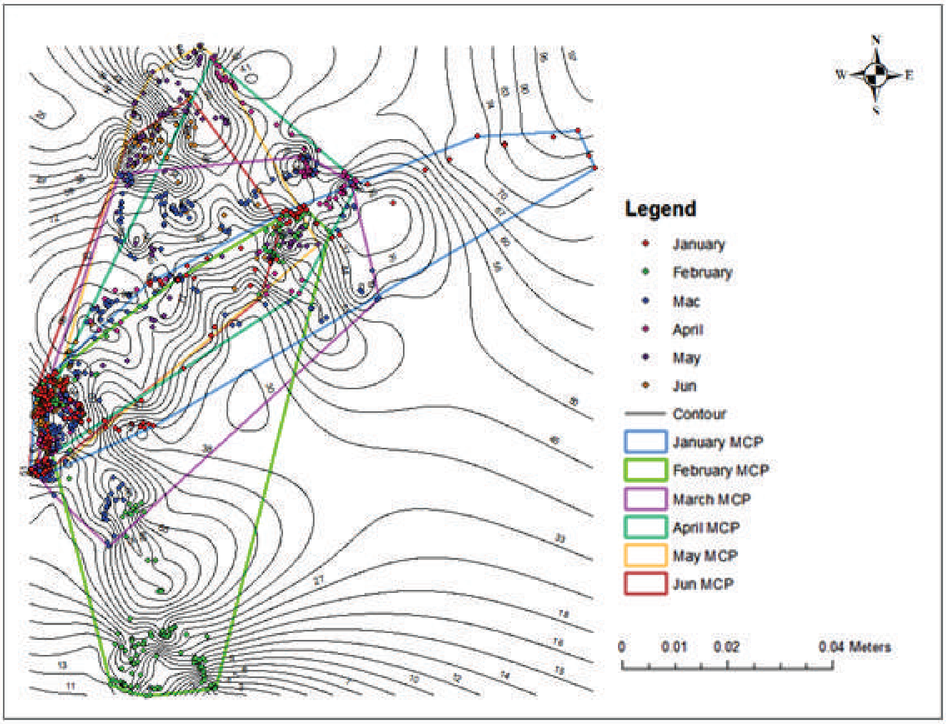


Figure 2. Monthly range [Minimum Convex Polygon (MCP) method] of Asian elephants in SBFR, Gua Musang, Kelantan.

Table 1. Area covered by Asian elephants in SBFR, Gua Musang, Kelantan.

Month	Area covered (km^2)
January	31.67
February	42.48
March	42.18
April	28.02
May	28.58
June	24.05

NDVI value of vegetation cover

The map in Figure 3 shows that the presence of elephants is likely to occur in an area with mixed vegetation classes. The area in red with NDVI values ranging from -0.19 to 0.27 indicated a non-vegetation area (Table 2) due to the fragmented forest and a road network. Low-vegetation area (represented in yellow) has NDVI values ranging from 0.27 to 0.42, indicating the presence of shrubs and grasslands. On the other hand, high-vegetation area (represented in green) with dense vegetation and covered in evergreen forest, has NDVI values ranging from 0.42 to 0.63.

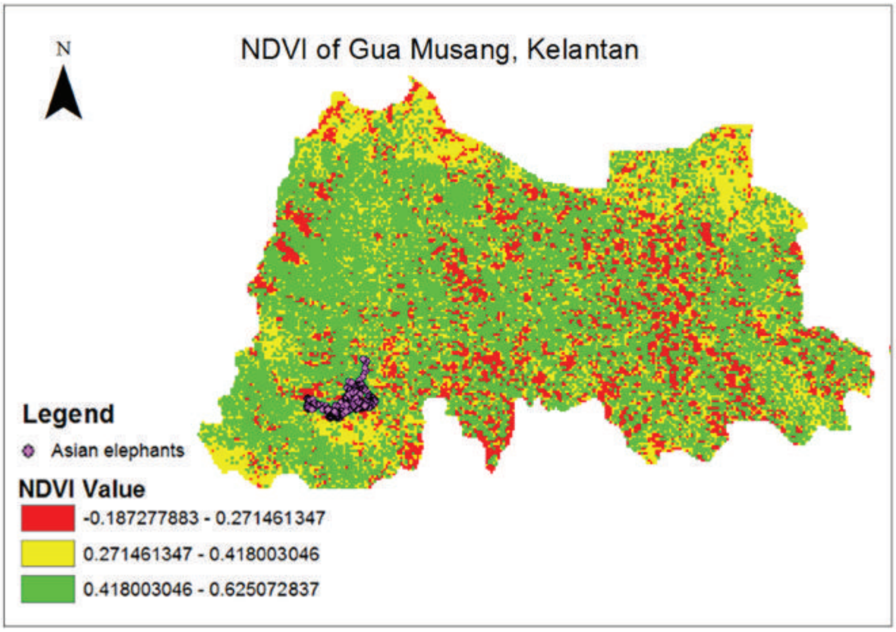


Figure 3. Normalised Difference Vegetation Index (NDVI) analysis of Gua Musang, Kelantan.

Table 2. Vegetation classification according to NDVI values.

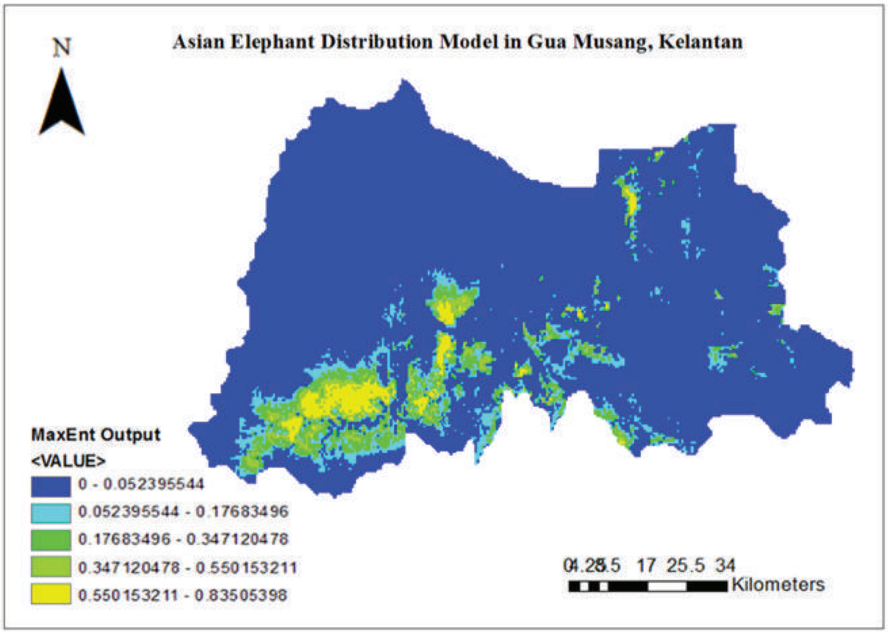
No.	Vegetation Classes	Description	NDVI Value
1	Non-vegetation	Barren area and road network	-0.19 to 0.27
2	Low-vegetation	Shrub and grassland	0.27 to 0.42
3	High-vegetation	Dense evergreen forest	0.42 to 0.63

Asian elephant distribution and habitat use

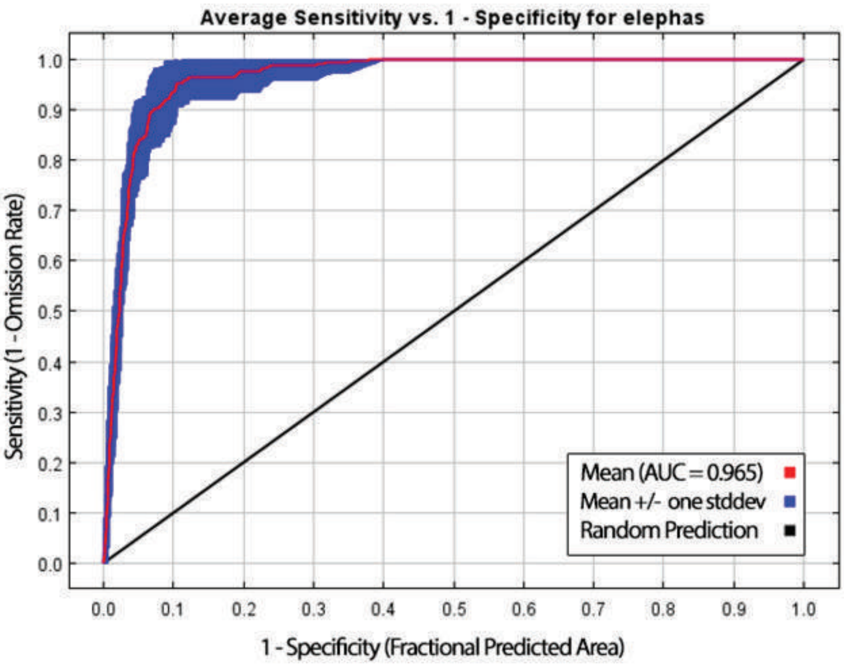
The MaxEnt output suggested that the distribution of Asian elephants extended far beyond the home range that was calculated using MCP method (Figure 4A). The MaxEnt software can predict the likelihood of elephants occurring in different locations according to the environmental variables, which can help determine the suitability of an area. The area in yellow of the map in Figure 4A indicated that the habitat was most suitable for the elephants, while the blue area indicated that the area was less or not ideal for the elephants.

The model's performance was evaluated using a Receiver Operating Characteristic (ROC) curve, as shown in Figure 4B. The red line of the graph indicated the mean of ROC, which compared the performance of two different models. The Area Under the Curve (AUC) value of 0.5 or below indicates that the model performance is no better than the random ones, whereas a value ranging up to 1.0 suggests that the model performs better than other models (Young *et al.*, 2011). The mean value of the AUC was 0.965, which indicated an excellent performance. Jackknife analysis in Figure 4C showed which variables are the most predictive of elephant distribution. The AUC value was highest for the elevation at 0.856. Nevertheless, all of these environmental variables do not strongly influence the distribution of elephants. Even without these variables, the AUC values would still be high, as indicated with the lighter coloured bars in the graph (Matawa *et al.*, 2012).

A)



B)



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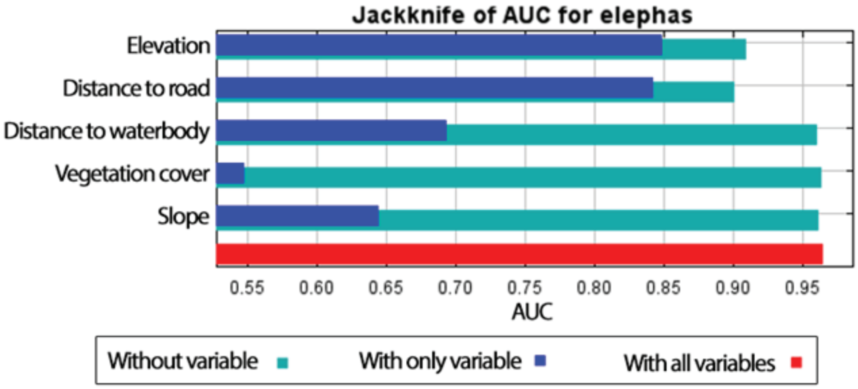

Figure 4. The MAXENT model results showing
(A) the possible distribution of elephants in Gua Musang;
(B) AUC of training data (red) and test data (blue) for model performance; and
(C) Jackknife test for the variables used in the elephant distribution model.

Factors influencing the ranging behaviour and habitat use of Asian elephants

The study area was being heavily developed for oil palm plantations. The elephants were often observed to be moving around the fragmented forest. Such behaviour could be influenced by human activities, including cultivation of oil palm plantations. According to Evans *et al.* (2020), there are zones in the oil palm plantation where elephants move quickly and with a definite direction. This could be driven by the presence of forest corridors, electric fences and availability of food or could be a stress response to the threats posed to elephants in low-quality habitats.

Although the study area landscape was degraded and fragmented, the abundance of various grass species can provide large-scale feeding opportunities for the elephants (English *et al.*) 2014a, 2014b; Yamamoto-Ebina *et al.*, 2016). Apart from that, oil palms provide food resources for elephants (Oliver, 1978) where oil palm kernels and newly planted oil palm shoots were sometimes eaten (Susanto & Ardiansyah, 2003; Suba *et al.*, 2018).

The preference of the Asian elephant herd for non-fragmented forest, as seen in February (Figure 2), could occur due to human harassment, when plantation workers were working over the area (Alfred *et al.*, 2012). Forests not only provide safety and resting place for the large-sized animals, especially herbivores, but also provides food resources (Talukdar & Choudhury, 2017). According to Calabrese *et al*. (2017) and Neupane *et al.* (2019), Asian elephant prefers to rest or hide in the forest core, although they also partially use fragmented forests next to agricultural landscapes as a temporary abode. These forest patches also offers food sources for the elephants (Mandal & Chatterjee, 2021).

Based on the MaxEnt distribution model, primary factors that influenced the habitat use of Asian elephants were distance to road and elevation (Table 3). According to Sharma *et al.* (2020), Asian elephants are more likely to be found in fragmented forests compared to African elephants. The elephants' habitat use in fragmented forest and areas closer to roads suggested that the areas where they frequently occur can be governed as wildlife corridors. This idea could help facilitate the movement of Asian elephants across forest patches.

Table 3. Contribution and importance of environmental variables.

Variable	Contribution (%)	Permutation Importance (%)
Distance to nearest road	49	54.1
Elevation (DEM)	43	41.9
Distance to waterbody	4.7	1.6
Slope	2.3	1.4
Vegetation cover (NDVI)	1	1

In this study, the presence of Asian elephants were more numerous within 2000 m from the road. The frequency of occurrence of the elephants decreased with distance from the road (Figure 5). Roads and highways can affect the habitat preference of wildlife due to changes in their natural environment (Fortin *et al.*, 2013) and subsequently, influence their ranging behaviour (Dussault *et al.*, 2007; Blake *et al.*, 2008). Higher concentration of elephants occupying the roadside may suggest changes in vegetation structure and food availability (Wadey *et al*., 2018). Elephants prefer to forage near the road due to their diet, which consists of early-succession plants and grasses (Yamamoto-Ebina *et al.*, 2016; Terborgh *et al.*, 2017) or agricultural products like paddy, rather than naturally occurring foods (Yamamoto-Ebina *et al.*, 2016). In contrast, elephants that occur further away from the road (>5 km) consume less preferred type of woody plant (Yamamoto-Ebina *et al.*, 2016).

The results of this study suggested that the elephants prefer to utilise open-habitats, such as that of the roadside compared to the undisturbed forest of SBFR. Contrarily, a study in Sabah has shown that Asian elephants do not tend to like urban areas, including villages and roads (Evans *et al.*, 2020), possibly due to the risk of being hunted by poachers. There has been numerous high-profile cases of elephant poaching in Sabah in recent years, primarily for their tusks (Goh, 2019; Kee, 2019; Miwil & Rahman, 2019). This illegal activity has become increasingly common as elephant tusks are highly sought after as wedding dowry (Goh, 2019; Miwil & Rahman, 2019).

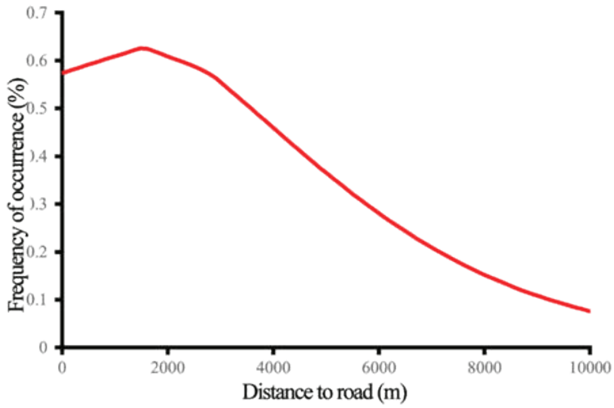

Figure 5. Density curve showing the frequency of Asian elephant occurrence relative to distance from the road in SBFR, Gua Musang, Kelantan.

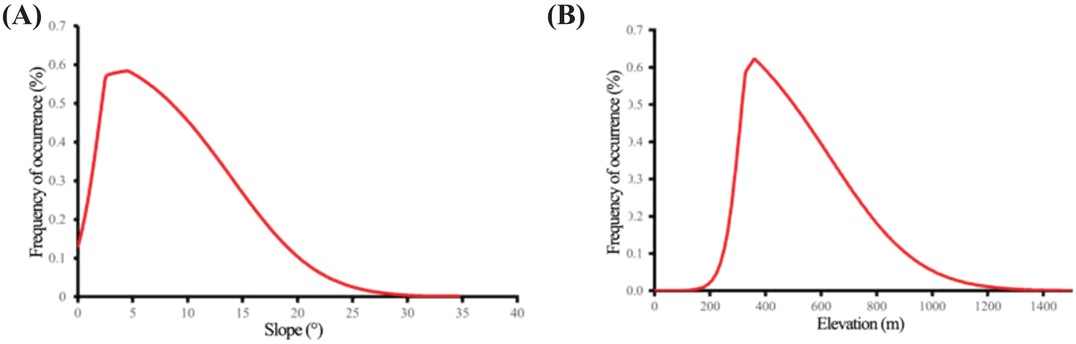

Figure 6. Density curves showing the frequencies of Asian elephants occurrence relative to **(A)** slope and **(B)** elevation in SBFR, Gua Musang, Kelantan.

The density curve showed high frequency of occurrence of elephants at 5º slope and decreased as the slope increases (Figure 6A), while the occurrence of elephants were higher at elevations between 200 m to 400 m. From previous studies, environmental variables such as elevation and slope play an essential role in the ranging behaviour and habitat use of Asian elephants (Rood *et al.*, 2010). Mohd Taher *et al.* (2021) found that elephants choose their habitat based on elevation and slopes, with a preference for areas with low to moderate elevations (< 133 m) and flat to gently undulating slopes (< 20°).

In this study, the elephants were shown to have a higher affinity for areas with lower elevation and gentler slope, indicating that they prefer lowland area compared to mountainous areas. These results were analogous to numerous studies where elephant occurred more frequently at lower elevations and gently undulating slopes (Wall *et al*., 2006; Lin *et al.,* 2008; Pan *et al*., 2009; Alfred *et al*., 2012; Mohd Taher *et al*., 2021). This can be attributed to the fact that a steeper slope would only limit the elephants' movement (Sharma *et al*., 2020). Due to their enormous size, the elephants would need to expend more energy to move along mountainous areas. Lowland areas are also often closer to water sources (Alfred *et al*., 2012). Contrarily, Wu *et al*. (1997) found that Asian elephants prefer to range along elevation between 900 – 1200 m to avoid proximity to humans.

Availability of water sources is a significant indicator for the ranging behaviour and habitat use of Asian elephants (Viljoen, 1989), as water is a vital component for all wildlife species (Mandal & Chatterjee, 2021). Elephants need to consume water frequently because of their high respiratory water loss (Owen-Smith, 1988). An adult male elephant requires between 68.4 and 98.8 L (18 to 26 gallons) of water per day, but can consume up to 152 L (40 gallons) per day and 212 L (55 gallons) in under five minutes (Sukumar, 2003). In addition, elephants like to submerge in the water to regulate their body temperature and prevent overheating. Therefore, the availability of the water source is a key indicator of the habitat quality for the elephants (Viljoen, 1989; Mandal & Chatterjee, 2021).

From Figure 7, the elephants were mostly found around 0 to 6000 m away from a waterbody. This result was supported by Kumar *et al.* (2010), which stated that the elephants often use riparian landscape as it provides easy access to water and vegetation. According to Mohd Taher *et al.* (2021), the distance below 100 m from the river is the most suitable range for elephant habitat. The frequency of elephant occurence decreased at a distance further than 6000 m. Although Gara (2014) found that elephants can travel long distances between habitats in order to locate water sources, Owen-Smith (1988) stated that the distance threshold for elephants to travel to a source of water is within 24 km.

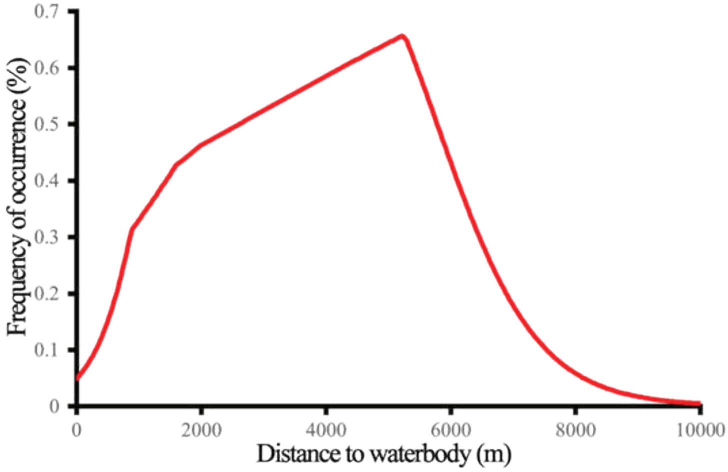

Figure 7. Density curve showing the frequency of Asian elephant occurrence relative to the distance to waterbody in SBFR, Gua Musang, Kelantan.

The vegetation cover, represented in NDVI value has contributed the least to the species distribution model. From the graph in Figure 8 and Table 2, the elephants were mostly located in areas with NDVI of 0.13 and remained constant up to the NDVI value of 0.44. Subsequently, the value fluctuated between 0.45 to 0.49 and increased to 0.52 before fluctuating back to approximately 0.6 and remaining constant within 0.6 to 0.7. The results indicated that Asian elephants in SBFR preferred to inhabit areas near the roads with less vegetation.

The home range shows that they had moved along fragmented forest instead of the non-fragmented forest. Within the dense evergreen tropical forest in SBFR, it is observed that the frequency of Asian elephant occurence were higher at areas with NDVI values between 0.13 to 0.42, but fluctuates within the range of 0.42 to 0.63. This could mean that high vegetation areas were not preferred habitats for the Asian elephants. According to Evans *et al.* (2018) and Wadey *et al.* (2018), elephants tend to live in areas with some disturbed vegetation, such as forest gaps, logged and secondary forests, as well as regrowth or new plantations.

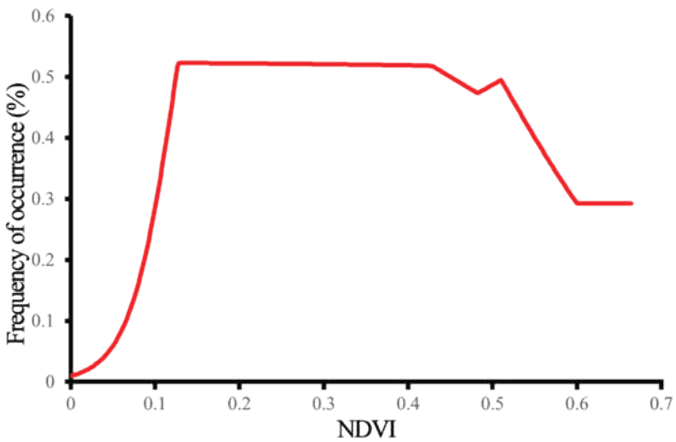

Figure 8. Density curve showing the frequency of Asian elephant occurrence relative to vegetation cover (NDVI) for Asian elephants in SBFR, Gua Musang, Kelantan.

Overall, this study found that Asian elephants in SBFR, Gua Musang were found to range in fragmented forests, and closer towards road areas compared to non-fragemented areas with high vegetation cover. One of the attributing factors could be that the elephants were territorial over the area that was once their natural habitat. As Wadey *et al*. (2018) suggested, it is possible that forest fragmentation and construction of roads in the area has disrupted the ancestral elephant paths prior. The elephants also preferred to range in areas with low elevation and gentle slope, due to ease of movement, food preferences towards undergrowth vegetation and access to waterbodies such as saltlick and streams. Saltlicks are important nutrient sources for wild elephants and should be protected (Ning *et al*., 2016). This study contradicts the findings from previous study by Magintan *et al.* (2017), which stated that the distance from the rivers and roads have less influence on the home range of elephants in Gua Musang. Their close proximity to human presence is worrying as it increases the risk of human-wildlife conflicts.

Recommendations

It is therefore recommended that the existing disturbed habitats of Gua Musang to be totally protected and that rehabilitation efforts be undertaken to restore the area. Authorities should be mindful to not disturb the elephants' movement paths in future road projects. Other recommendations include the construction of a wildlife corridors to facilitate the movement of elephants between areas without having to cross roads, and reducing the risk of injury or death (Sharma *et al*., 2020). According to de la Torre *et al.* (2019), wildlife corridors represent a key element of landscape conservation planning and are one of the most popular solutions for dealing with the deleterious effects of isolation and small population sizes. Other wildlife species may also benefit from the forest corridor. It is also essential for any activities that could potentially impact the watershed to strictly comply to the laws and regulations in order to safeguard these crucial natural resources. This includes ensuring that there is no pollution of the water source and proper management of discharge or storage facilities. In addition, land management should take into account the dire survival of this endangered (IUCN, 2022). Lastly, further research on the distribution patterns and habitat use of the Asian elephants are highly required. The MaxEnt software, which uses presence-only data, is recommended for this purpose (Matawa *et al.*, 2012).

CONCLUSION

The ranging behaviour and habitat use of Asian elephants in SBFR, Gua Musang, Kelantan were influenced by the distance to road, elevation, distance to a waterbody, slope and vegetation cover. In this study, the elephants were mostly recorded in fragmented forest and closer to the road and human-dominated landscapes. The elephants were also found to prefer ranging in areas at lower elevations and gentler slope. Other than that, the presence of water bodies were one of the factors contributing to the elephants' ranging behaviour and habitat utilisation. Although the results have shown that the suitable area for this species extends beyond the study site, these areas would not be sufficient to sustain the elephant populations as land conversion, deforestation, and other related factors are constantly reshaping the natural landscape of their habitats. The data and results of this study could be used by relevant authorities to address the conservation needs of this species.

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REFERENCES

Aini, S., Sood, A. M. and Saaban, S. 2015. Analysing elephant habitat parameters using GIS, remote sensing and analytic hierarchy process in Peninsular Malaysia. *Pertanika Journal of Science & Technology* 23(1) : 37–50.

Alfred, R., Ahmad, A. H., Payne, J., Williams, C., Ambu, L. N., How, P. M. and Goossens, B. 2012. Home range and ranging behaviour of Bornean Elephant (*Elephas maximus borneensis*) females. *PLoS ONE* 7(2) : e31400.

Ambe, B. and Onnoghen, U. 2019. Ecosystems services of the tropical rain forest environment: Lessons from the Cross River National Park, Nigeria. *Journal of Geoscience and Environment Protection* 7 : 1–10.

Bahar, A. R. H. A. M., Nur, H. A. K. and Kamarul, H. 2018. Home range and movement patterns of Asian elephant (*Elephas maximus*) in Gua Musang, Kelantan, Malaysia. *Malayan Nature Journal* 70(2) : 221–232.

Bakar, A. N. 2018. Policy and related issues pertainaing community participation in the management of Protected Area (PA): A case of Pahang National Park, Malaysia. In *National Parks – Management and Conservation*, ed. Suratman, M. N. Vienna: IntechOpen.

Baldwin, R. A. 2009. Use of maximum entropy modeling in wildlife research. *Entropy* 11(4) : 854–866.

Barnes, R. F. W., Barnes, K. L., Alers, M. P. T. and Blom, A. 1991. Man determines the distribution of elephants in the rain forests of northeastern Gabon. *African Journal of Ecology* 20 : 54–63.

Blake, S., Deem, S. L., Strindberg, S., Maisels, F., Momont, L., Isia, I. B., Douglas-Hamilton, I., Karesh, W. B. and Kock, M. D. 2008. Roadless wilderness area determines forest elephant movements in the Congo Basin. *PloS ONE* 3(10): e3546.

Briscoe, D. K., Hiatt, S., Lewison, R. and Hines, E. 2014. Modeling habitat and bycatch risk for dugongs in Sabah, Malaysia. *Endangered Species Research* 24(3) : 237–247.

Calabrese, A., Calabrese, J. M., Songer, M., Wegmann, M., Hedges, S., Rose, R. and Leimgruber, P. 2017. Conservation status of Asian elephants: *The influence of habitat and governance. Biodiversity and Conservation* 26(9) : 2067–2081.

de la Torre, J. A., Lechner, A. M., Wong, E. P., Magintan, D., Saaban, S. and Campos-Arceiz, A. 2019. Using elephant movements to assess landscape connectivity under Peninsular Malaysia's central forest spine land use policy. *Conservation Science and Practice* 1(12) : 1–14.

Denninger Snyder, K. and Rentsch, D. 2020. Rethinking assessment of success of mitigation strategies for elephant-induced crop damage. *Conservation Biology* 34(4) : 829–842.

Dussault, C., Ouellet, J. -P., Laurian, C., Courtois, R., Poulin, M. and Breton, L. 2007. Moose movement rates along highways and crossing probability models. *Journal of Wildlife Management* 71(7) : 2338–2345.

Elith, J., Phillips, S. J., Hastie, T., Dudík, M., Chee, Y. E. and Yates, C. J. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* 17(1) : 43–57.

English, M., Gillespie, G., Ancrenaz, M., Ismail, S., Goossens, B., Nathan, S. and Linklater, W. 2014a. Plant selection and avoidance by the Bornean elephant (*Elephas maximus borneensis*) in tropical forest: Does plant recovery rate after herbivory influence food choices? *Journal Tropical Ecology* 30(4) : 371e379.

English, M., Ancrenaz, M., Gillespie, G., Goossens, B., Nathan, S. and Linklater, W. 2014b. Foraging site recursion by forest elephants Elephas maximus borneensis. *Current Zoology* 60(4) : 551e559.

Evans, L. J., Asner, G. P. and Goossens, B. 2018. Protected area management priorities crucial for the future of Bornean elephants. *Biological Conservation* 221 : 365–373.

Evans, L. J., Goossens, B., Davies, A. B., Reynolds, G. and Asner, G. P. 2020. Natural and anthropogenic drives of Bornean elephant movement strategies. *Global Ecology and Conservation* 22 : e00906.

Farina, A. 2008. *Principles and methods in landscape ecology: Towards a science of the landscape.* Berlin: Springer Science + Business Media.

Fernando, P. and Pastorini, J. 2011. Range-wide status of Asian elephants. *Gajah* 35 : 15–20.

Fortin, D., Buono, P. L., Fortin, A., Courbin, N., Tye Gingras, C., Moorcroft, P. R., Courtois, R. and Dussault, C. 2013. Movement responses of caribou to human-induced habitat edges lead to their aggregation near anthropogenic features. *The American Naturalist* 181(6) 827-836.

Forman, R. T. T. 1995. *Land mosaic: The ecology of landscape and regions.* Cambridge: Cambridge University Press.

Gara, T. W. 2014. Effect of water availability, landscape fragmentation and forage abundance on the movement and habitat utilization of elephants. Master's thesis, University of Twente.

Goh, R. 2019. Dowry needs fuel Sabah's ivory trade. New Strait Times (Kuala Lumpur), October 16. https://www.nst.com.my/news/nation/2019/10/530444/dowry -needs-fuel-sabahs-ivory -trade (accessed on July 12, 2022).

Graham, M. D., Douglas-Hamilton, I., Adams, W. M. and Lee, P. C. 2009. The movement of African elephants in a human-dominated land-use mosaic. *Animal Conservation 1*2 : 445–455.

Hedges, S., Tyson, M. J., Sitompul, A. F., Kinnaird, M. F., Gunaryadi, D. and Aslan. 2005. Distribution, status, and conservation needs of Asian elephants (*Elephas maximus*) In Lampung Province, Sumatra, Indonesia. *Biological Conservation* 124 : 35–48.

Hosseini, S. Z., Kappas, M., Zare Chahouki, M. A., Gerold, G., Erasmi, S. and Rafiei Emam, A. 2013. Modelling potential habitats for Artemisia sieberi and Artemisia aucheri in Poshtkouh area, central Iran using the maximum entropy model and geostatistics. *Ecological Informatics* 18: 61–68.

IUCN. 2022. Asian Elephant *Elephas maximus*. The IUCN Red List of Threatened Species. https://www.iucnredlist.org/species/7140/45818198 (accessed on July 12, 2022).

Kee, A. 2019. Police arrest six in connection with elephant slaying in Sabah, recover tusks. The Borneo Post (Kuching), October 2. https://www.theborneopost.com/2019/10/02/police-arrest-six-in-connection-with-elephant-slaying-in-sabah (accessed on July 12, 2022).

Koirala, R. K., Raubenheimer, D., Aryal, A., Pathak, M. L. and Ji, W. 2016. Feeding preferences of the Asian elephant (*Elephas maximus*) in Nepal. *BMC Ecology* 16(1) : 54–63.

Kumar, M. A., Singh, M., Srivastava, S. K., Udhayan, A., Kumara, H. N. and Sharma, A. K. 2002. Distribution patterns, relative abundance and management of mammals in Indira Gandhi Wildlife Sanctuary, Tamil Nadu, India. *Journal of Bombay Natural History Society* 99 : 184–210.

Kumar, M. A., Mudappa, D. and Raman, T. S. 2010. Asian elephant Elephas maximus habitat use and ranging in fragmented rainforest and plantations in the Anamalai Hills, India. *Tropical Conservation Science* 3(2) : 143–158.

Leimgruber, P., Gagnon, J. B., Wemmer, C., Kelly, D. S., Songer, M. A. and Selig, E. R. 2003. Fragmentation of Asia's remaining wildlands: Implications for Asian elephant conservation. *Animal Conservation* 6(4) : 347–359.

Lim, T. and Campos-Arceiz, A. A. 2022. Review of human-elephant ecological relations in the Malay Peninsula: Adaptations for coexistence. *Diversity* 14 : 36–59.

Lin, L., Feng, L., Pan, W., Guo, X., Zhao, J., Luo, A. and Zhang, L. 2008. Habitat selection and the change in distribution of Asian elephants in Mengyang Protected Area, Yunnan, China. *Acta Theriologic*a 53 : 365–374.

Liu, P., Wen, H., Harich, F. K., He, C., Wang, L., Guo, X., Zhao, J., Luo, A., Yang, H., Sun, X., Yu, Y., Zheng, S., Guo, J., Li, L. and Zhang, L. 2017. Conflict between conservation and development: Cash forest encroachment in Asian elephant distributions. *Scientific Reports* 7 : 6404–6414.

Magintan, D., Lihan, T., Mohamed, K. A., Campos-Arceiz, A., Saaban, S., Husin, S. M. O. D. and Nor, S. M. D. 2017. The impact of hydroelectric development on elephant habitats in Hulu Terengganu. *Malaysian Applied Biology* 46 : 23–33.

Mandal, M. and Chatterjee, N. D. 2018. Quantification of habitat (forest) shape complexity through geo-spatial analysis: An ecological approach in Panchet forest division in Bankura, West Bengal. *Asian Journal of Environment & Ecology* 6: 1–8.

Mandal, M. and Chatterjee, N. D. 2019. Forest Core Demarcation Using Geo-Spatial Techniques: A Habitat Management Approach in Panchet Forest Division, Bankura, West Bengal, India. *Asian Journal of Geographical Research* 2(2): 1–8.

Mandal, M. and Chatterjee, N. D. 2021. Geospatial approach-based delineation of elephant habitat suitability zones and its consequence in Mayurjharna Elephant Reserve, India. *Environment, Development and Sustainability* 23: 17788–17809.

Matawa, F., Murwira, A. and Schmidt, K. S. 2012. Explaining elephant (*Loxodonta africana*) and buffalo (*Syncerus caffer)* spatial distribution in the Zambezi Valley using maximum entropy modelling. *Ecological Modelling* 242 : 189–197.

Mcdonald, R. I., Forman, R. T. T., Kareiva, P., Neugarten, R., Salzer, D. and Fisher, J. 2009. Urban effects, distance, and protected areas in an urbanizing world. *Landscape and Urban Planning* 93(1) : 63–75.

Merow, C., Smith, M. J. and Silander, J. A. 2013. A practical guide to MaxEnt for modeling species' distributions: What it does, and why inputs and settings matter. *Ecography* 36(10) : 1058–1069.
Miwil, O. and Rahman, H. A. 2019. Another pygmy elephant found dead in Sabah, tusks removed. New Strait Times (Kuala Lumpur), October 20. https://www.nst.com.my/news/ nation/2019/10/531790/another-pygmy-elephant-found-dead-sabah-tusks- removed (accessed on July 12, 2022).
Mohd Taher, T., Lihan, T., Tajul Arifin, N. A., Khodri, N. F., Ahmad Mustapha, M., Abdul Patah, P., Razali, S. H. A. and Mohd Nor, S. 2021. Characteristic of habitat suitability for the Asian elephant in the fragmented Ulu Jelai Forest Reserve, Peninsular Malaysia. *Tropical Ecology* 62 : 347–358.
Mudappa, D. and Raman, T. R. S. 2007. Rainforest restoration and wildlife conservation on private lands in the Valparai plateau, Western Ghats, India. In Making Conservation Work, eds. Shahabuddin, G. and Rangarajan, M, pp. 210-240. *Ranikhet: Permanent Black.*
Neupane, D., Kwon, Y., Risch, T. S., Williams, A. C. and Johnson, R. L. 2019. Habitat use by Asian elephants: Context matters. *Global Ecology and Conservation* 17 : e00570.
Newmark, W. D. 2008. Isolation of African protected areas. *Frontiers in Ecology and the Environment* 6(6) : 321–328.
Newton, A., Icely, J., Cristina, S., Perillo, G. M., Turner, R. E., Ashan, D. and Zhang, H. 2020. Anthropogenic, direct pressures on coastal wetlands. *Frontiers in Ecology and Evolution* 8 : 144.
Ning, H., Phin, W. E., Chackrapani, P., Solana-Mena, A., Ling, A. T. S., Nagulendran, K., Wadey, J., Wyn, L. T., Ong, L., Osman, N. A., Kromann-Clausen, A., Yamamoto-Ebina, S., Ponnusamy, V., Saaban, S., Othman, N. B. and Campos-Arceiz, A. 2016. MEME – moving towards a science-based conservation of Malaysian elephants. *Malayan Nature Journal* 68(4) : 191–197.
Oliver, R. C. D. 1978. On the ecology of the Asian Elephant *Elephas maximus* Linn. with particular reference to Malaya and Sri Lanka. PhD thesis, University of Cambridge.
Owen-Smith, R. N. 1988. Megaherbivores: The influence of very large body size on ecology. Cambridge: Cambridge University Press.
Pan, W., Lin, L., Luo, A. and Zhang, L. 2009. Corridor use by Asian elephants. *Integrative Zoology* 4(2) : 220–231.
Pearce, J. and Ferrier, S. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. *Ecological Modelling* 133(3) : 225–245.
Phillips, S. J., Anderson, R. P. and Schapire, R. E. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190(3–4) : 231–259.
Puyravaud, J. P., Cushman, S. A., Davidar, P. and Madappa, D. 2017. Predicting landscape connectivity for the Asian elephant in its largest remaining subpopulation. *Animal Conservation* 20(3) : 225–234.
Rood, E., Ganie, A. A. and 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.
Saaban, S., Othman, N., Yasak, M.N., Nor, B.M., Zafir, A. and Campos-Arceiz, A. 2011. Current status of Asian Elephants in Peninsular Malaysia. *Gajah* 35 : 67–75.
Santiapillai, C. and Jackson, P. 1990. The Asian elephant: An action plan for its conservation. *Gland: International Union for Conservation of Nature and Natural Resources.*
Schaller, G. B. 1967. *The deer and the tiger.* Chicago: The University of Chicago Press.
Shaffer, L. J., Khadka, K. K., Van Den Hoek, J. and Naithani, K. J. 2019. Human-elephant conflict: A review of current management strategies and future directions. *Frontiers in Ecology and Evolution* 6 : 235.
Sharma, P., Panthi, S., Yadav, S. K., Bhatta, M., Karki, A., Duncan, T., Poudel, M. and Acharya, K. P. 2020. Suitable habitat of wild Asian elephant in Western Terai of Nepal. *Ecology and Evolution* 10(12) : 6112–6119.
Shevade, V. S., Potapov, P. V., Harris, N. L. and Loboda, T. V. 2017. expansion of industrial plantations continues to threaten Malayan Tiger habitat. *Remote Sensing* 9(7) : 747.
Suba, R. B., Beveridge, N. G., Kustiawan, W., De Snoo, G. R. and De Iongh, H. H. 2018. Foraging ecology and diet of Bornean elephants (*Elephas maximus borneensis)* in the Sebuku forest area, North Kalimantan Province of Indonesia: Do the choices matter? *Integrative Zoology* 13(2) : 219e223.
Sukumar, R. 1989. *The Asian elephant: Ecology and management.* Cambridge: Cambridge University Press.

Sukumar, R. 2003. *The living elephants: Evolutionary ecology, behaviour, and conservation.* New York: Oxford University Press.
Susanto, P. and Ardiansyah, F. 2003. The palm oil industry in Riau: Dari Hutan Sampai Ke Wajan, Laporan Yayasan. Jakarta: WWF Indonesia.
Syafril, N. S., Udin, W. S. and Achmad Bahar, A. M. 2020. GIS-based landslide hazard evaluation and zonation of Kg. Chas, Kuala Betis, Gua Musang, Kelantan. *IOP Conference Series: Earth and Environmental Science* 549 : 012013.
Talukdar, N. R. and Choudhury, P. 2017. Conserving wildlife wealth of Patharia Hills reserve forest, Assam, India: A critical analysis. *Global Ecology and Conservation* 10 : 126–138.
Terborgh, J., Davenport, L. C., Ong, L. and Campos-Arceiz, A. 2017. Foraging impacts of Asian megafauna on tropical rain forest structure and biodiversity. *Biotropica* 50 : 84–89.
Viljoen, P. J. 1989. Spatial distribution and movements of elephants (*Loxodonta africana*) in the northern Namib Desert region of the Kaokoveld, South West Africa, Namibia. *Journal of Zoology* 219(1) : 1–19.
Wadey, J., Beyer, H. L., Saaban, S., Othman, N., Leimgruber, P. and Campos-Arceiz, A. 2018. Why did the elephant cross the road? The complex response of wild elephants to a major road in Peninsular Malaysia. *Biological Conservation* 218 : 91–98.
Wall J., Douglas-Hamilton, I. and Vollrath, F. 2006. Elephants avoid costly mountaineering. *Current Biology* 16(14) : 527-529.
Wartmann, F. M., Purves, R. S. and van Schaik, C. P. 2010. Modelling ranging behaviour of female orang-utans: A case study in Tuanan, Central Kalimantan, Indonesia. *Primates* 51(2) : 119–130.
Western, D., Russell, S. and Cuthill, I. 2009. The status of wildlife in protected areas compared to non-protected areas of Kenya. *PLoS ONE* 4 : e6140.
White, P. C. L. and Ward, A. I. 2011. Interdisciplinary approaches for the management of existing and emerging human-wildlife conflicts. *Wildlife Research* 37(8) : 623–629.
Woodley, S., MacKinnon, K., McCanny, S., Pither, R., Prior, K., Salafsky, N., Lindenmayer, D., Worboys, G. L., Lockwood, M., Kothari, A., Feary, S. and Pulsford, I. 2015. Managing protected areas for biological diversity and ecosystem functions. In Protected Area Governance and Management, eds. Worboys, G. L., Lockwood, M., Kothari, A., Feary, S. and Ian Pulsford, I, pp. 651–684. Canberra: ANU Press.
Wu, Z. L., Peng, M. C., Liu, L. Y. and Dong, Y. H. 1997. Settlement patterns in Mengyang Nature Reserve of Xishuangbanna. II: Causes and effects. *Chinese Journal of Applied Ecology* 8 : 25–31. [In Chinese with English summary]
Yamamoto-Ebina, S., Saaban, S., Campos-Arceiz, A. and Takatsuki, S. 2016. Food habits of Asian Elephants *Elephas maximus* in a rainforest of Northern Peninsular Malaysia. *Mammal Study* 41(3) : 155–161.
Young, N., Carter, L. and Evangelista, P. 2011. *A MaxEnt Model v3.3.3e Tutorial* (ArcGIS v10). Colorado: Colorado State University.