

## A GIS Based Multi-Criteria Evaluation Approach to Develop an Asian Elephant Habitat Suitability Model in Peninsular Malaysia

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**Abstract.** This study aims to develop an Asian elephant habitat suitability model using remote sensing and GIS technology with multi-criteria evaluation. The home range of wild Asian elephants was determined using GPS-telemetry. This data was used to identify Asian elephants' habitat preference parameters and their distributions. Fuzzy logic model was then applied in the process to determine the suitability habitat in GIS environment. The results showed the presence of highly suitable habitats outside protected areas, thereby supporting habitat management and landscape connectivity initiatives within the National Elephant Conservation Action Plan in Peninsular Malaysia.

### Introduction

Forest loss and fragmentation are a major threat to the survival of Asian elephants (*Elephas maximus*) throughout Asia, including in Peninsular Malaysia (Santiapillai & Jackson 1990; Sukumar 1990; Leimgruber *et al.* 2003; Hedges *et al.* 2005; Saaban *et al.* 2011). Much of elephant habitat in Peninsular Malaysia has been converted into plantations, dams, housing areas, highways, and other development schemes in recent decades (DWNP 2013). In addition, the isolated clearing of forests in small areas can cause fragmentation, which further reduces the amount and quality of habitat available for elephants. Fragmentation is particularly harmful for wildlife species that, like elephants, have large home ranges and require vast areas to sustain viable populations. In this sense, one of the key goals of conservation planning and protected area design in Malaysia is to consider and enhance habitat connectivity for wide-roaming species such as elephants (NRE 2008).

Due to the apparent rapid decline of their populations, the conservation status of Asian elephants in Peninsular Malaysia was elevated from 'Protected Species' in 1972, to 'Totally Protected Species' in 2010 (Wildlife Conservation

Act of Malaysia). Based on IUCN records, there are only around 40,000 to 50,000 Asian elephants left in the wild. In Peninsular Malaysia, there is an estimated population of about 1223 to 1463 wild Asian elephants, occurring in only seven of the eleven states of Peninsular Malaysia, namely, Kelantan, Perak, Johor, Pahang, Terengganu, Kedah, and Negeri Sembilan (Saaban *et al.* 2011).

With more than 600,000 wild elephants (*Loxodonta* sp.) in Africa, the continued survival of Asian elephants is obviously more highly threatened (Bagheera 2015). The plight of the Asian elephant demands for serious consideration towards conservation measures, such as the protection of their habitats and mitigation of HEC, particularly in Southeast Asia.

Here we analyze elephant habitat suitability in some landscapes of Peninsular Malaysia using a multi-criteria evaluation (MCE) and a fuzzy logic model in a geographic information system (GIS) environment. This MCE approach provides tools for the effective development of a habitat suitability model, with its capability for parameter integration. The GIS model can help to better understand a phenomenon by retaining significant features or relationships, whereas the membership function in the fuzzy model is used

to define the level of confidence of data. This is important because the prediction of animal behavior is imprecise and there is a need to analyze phenomena that do not have clearly set boundaries.

Moreover, the use of real time satellite imagery incorporated with field surveys data is more accurate and cost-efficient to produce habitat parameters, particularly for the preparation of forest type data. Consequently, the spatial information at broad spatial scale (landscape area using remote sensing data) for habitat suitability can be used to assist the local authorities, i.e. the Ministry of Natural Resources and Environment (NRE) and the Department of Wildlife and National Parks (DWNP), in the conservation of Asian elephants. In this study, we are particularly interested in understanding elephant habitat suitability both inside and outside protected areas as well as in identifying connectivity within our study area in Peninsular Malaysia.

## **Methods**

### *Study area*

The study area covers part of Lipis District, including Taman Negara National Park, in Pahang State, Peninsular Malaysia. This area supports four forest types: lowland, hill, upper-hill and mountain forests. The Forest Reserves in the study area are production forests and have been subject to selective logging in the past, resulting in logged forests that have been identified as suitable home range for Asian elephants.

### *Selecting evaluation criteria and generating criterion maps*

Selection of criteria in our approach is based on the theory, empirical research, examination of relevant study, and also analytical study. Prior identification of the criteria was done through consultation with a representative officer from DWNP and supported by the analytical study of satellite-transmitted data on elephant movement in the study area. These sources provided information on elephant distribution, home range, and habitat utilization. The results from

this analysis were used to perform a model of habitat suitability in the main study area.

Through the analysis of the GPS-telemetry data of elephant movements, five factors were identified as relevant environmental and physical landscape layers for elephant habitat preference to develop the suitability habitat map. These factors are (1) land cover (consisting of forest status), (2) slope, (3) presence of saltlicks, (4) elevation, presented in a digital elevation model (DEM), and (5) the availability of water sources. Additionally, we also added information on human disturbance as layers of (6) roads and (7) non-forest area.

At this stage, all the extracted and generated data layers were integrated into a GIS database. The habitat parameters were obtained from digitization of features, digital processing of remote sensing data, and conversion of data from other sources. Satellite imageries were used to generate the land cover and forest status data layers. Furthermore, the DEM, slope, and river buffer layers were generated from topographical maps using analysis tools and simplified using the spatial modeller in GIS software. The DEM map was generated from a contour line, where the spatial resolution was based on the satellite resolution image used. The DEM data layer was also used to derive slope map, while river buffer was generated with certain distance based on the analysis of the elephant distribution.

### *Generating standardized criterion maps and assigning a fuzzy membership*

In the MCE procedure, a crucial step is to ensure a standardization of measurement system across all criteria considered. Standardization is performed by assigning a fuzzy membership values (0 to 1) to each habitat parameters data layers while the Euclidean distance tool was applied when data representing distance from a particular object was needed. This process aims to give the distance from each cell in the raster to the closest source. The Euclidean distance was used to facilitate the process of assigning the fuzzy membership of related data layers, namely saltlick location, river, non-forested area, and road data layers (Fig. 1).

**Table 1.** Summary of used fuzzy membership types (FMT) in the study area.

No.	Habitat	FMT	Justification
1	Forest status	Linear	Based on specific classification of forest status.
2	Non-forested	Large	High membership for value far from built-up/ development area.
3	Road	Large	High membership for value far from road.
4	River	Small	High membership for value closer to river.
5	Saltlick	Small	High membership for value closer to saltlick location.
6	DEM	Small	High membership for smaller input values (elevation - meter).
7	Slope	Small	High membership for smaller input values.

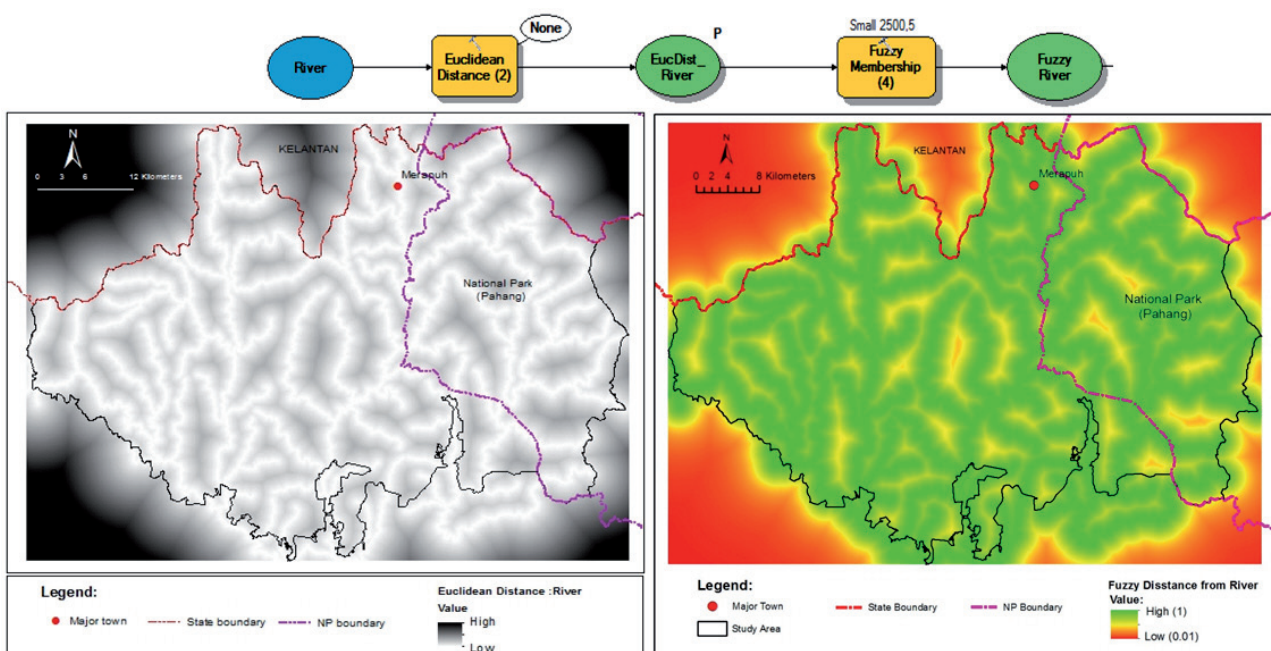
Assigning a fuzzy membership refers to the steps of determining the degree of the members of dataset whether a particular location is either suitable or unsuitable. The value range of fuzzy membership is from 0 to 1 scale, where 1 represents a full membership and 0 represents non-membership as stated in Table 1.

#### *Combining maps and sensitivity analysis*

The fuzzy overlay of ‘AND’, ‘OR’, and ‘PRODUCT’ tools were applied in order to establish an output map of Asian elephant habitat suitability within our study area. The type of overlay fuzzy ‘OR’ was used for environmental habitat parameters on forest status, river, and saltlick; the ‘AND’ function was applied for human disturbance factors (non-forest and road) and physical environmental factors (DEM and

slope); subsequently, the ‘PRODUCT’ fuzzy overlay was performed into intermediate output maps in order to find the most suitable locations of Asian elephant habitat in this study.

Through the model builder capabilities, the elephant habitat suitability was generated using the fuzzy overlay functionality in the GIS software. Furthermore, a sensitivity analysis was performed in order to determine how the output map of habitat suitability is affected by changes in the input (Malczewski 1999), particularly on the habitat parameters weights and their attributes. Finally, the map of Asian elephant habitat suitability in the study area was verified with the ground data of the elephants’ presence from the surveyed points, which included camera trap photos from a study conducted by the DWNP from 27 December 2011 to 29 March 2012.

**Figure 1.** Euclidean distance and fuzzy membership map for river data.



## Results and discussion

Our results (Figs. 2 & 3) show highly suitable habitats for Asian elephants both inside (primary forests in Taman Negara National Park) and outside (logged forests in Ulu Jelai Forest Reserve) the protected area. Our habitat suitability model was largely influenced by food availability, distance to water source (less than 2.5 km), and the presence of saltlicks to obtain minerals and salts from the soil that elephants cannot obtain from plants. Meanwhile, the physical landscape criterion was influenced by slope and elevation of 40° and 1000 meters respectively.

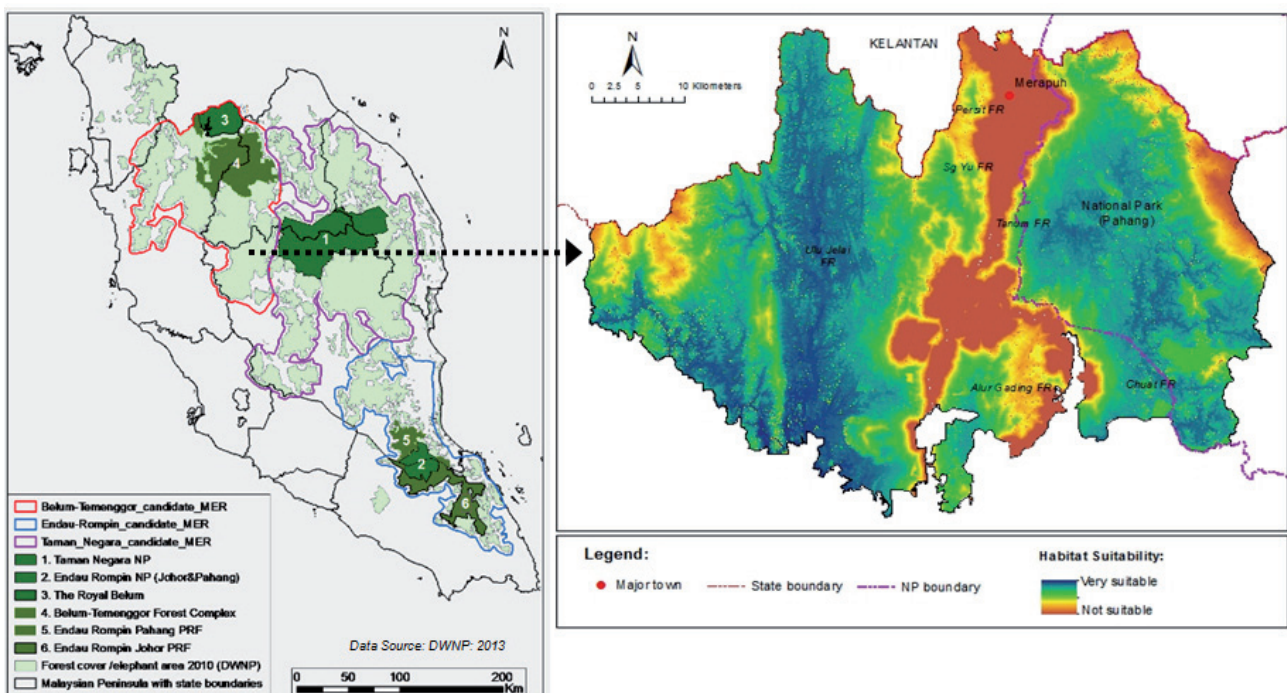
However, the availability of food sources in the logged forest is the main influencing factor, where the optimal habitat for elephants is not undisturbed forest but habitat with an intermediate disturbance regime (Fernando *et al.* 2012). This habitat is often found outside protected areas such as in Malaysia's forest reserves (i.e. production forests where logging is generally allowed), rich in secondary regrown forest edges and elephant plants (Olivier 1978; Salman & Nasharuddin 2003; Pittiglio *et al.* 2012). Logging in Malaysia's forest reserves is implemented following a Selective Management System for forest harvesting practise. According to Khan (1991), there are 60 species of plants



**Figure 3.** Camera trap photo of a elephant herd in the Ulu Jelai Forest Reserve

in Peninsular Malaysia identified to have been utilized by Asian elephants in secondary and logged forests.

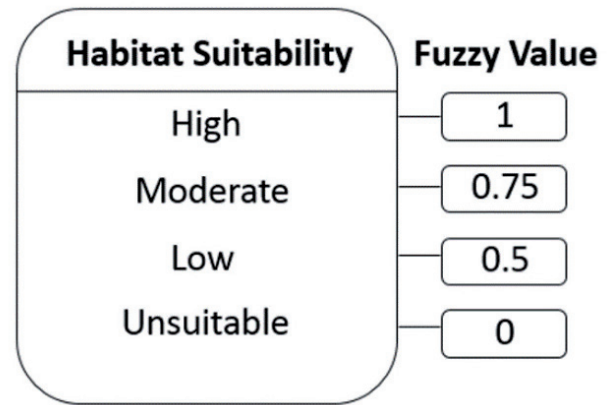
Subsequently, logging generally occurs in association with habitat alterations particularly construction of roads. However, a standard road specification is another good practice that was implemented to minimize the impact of timber harvesting operation for sustainable forest management. In this context, the analytic hierarchy process has the potential for prioritizing and ranking criteria for forest road planning where



a set of data must rely in part on professional judgement (Norizah & Hasmadi 2012). At the same time previously logged roads offer good accessibility for elephant movements from one to another area. As a result of production forest, Ulu Jelai Forest Reserve was identified as a highly suitable habitat for elephant where it continues to provide high quality food source outside the protected areas.

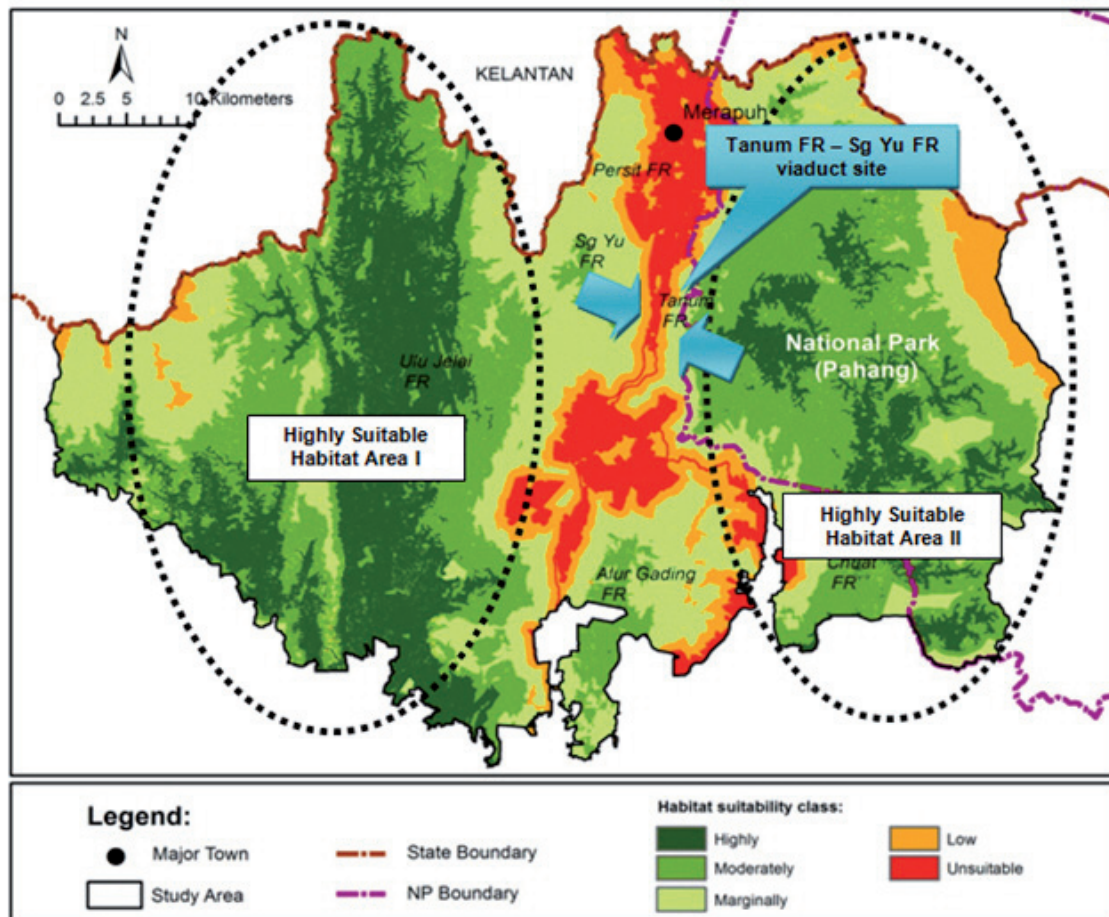
Low habitat suitable values were influenced by topographical factors i.e. elevation (DEM) and slope as well. Additionally, unsuitable areas for elephant habitat are strongly influenced by human disturbance factors that were concentrated along the road and development areas (non-forest) that run from North to South of our study area, bisecting the two large blocks of suitable habitat (Fig. 2).

We were also able to evaluate the output map (fuzzy output) to suit the use requirements of the local conservation authorities, i.e. DWNP.



**Figure 4.** Concept of fuzzy classification used in the study (adapted from Morrison *et al.* 2006 and Reynolds *et al.* 1997).

For example, the reclassification map of Asian elephant habitat suitability (Fig. 4) was generated from the final map (output in fuzzy value), suggested by DWNP which was further classified into five levels of suitability (high, moderate, marginal, low, and unsuitable classes; Fig. 5). Accordingly, the most common category was moderately suitable habitat (87,911 ha or



**Figure 5.** Location of Tanum Forest Reserve – Sg Yu Forest Reserve viaduct in a habitat suitability map for elephants.



34% of the study area), followed by marginally suitable (72,704 ha, or 28% of the study area). The highly suitable area covers around 22% of the study area (55,741 ha; Fig. 5).

### *Ulu Jelai Forest Reserve*

Our results show that Ulu Jelai Forest Reserve is a highly suitable area for elephant habitat, supporting its inclusion in one of the proposed Managed Elephant Ranges (MERs; Fig. 2) in Peninsular Malaysia. The identification and management of MERs is one of the key components of Peninsular Malaysia's National Elephant Conservation Action Plan (NECAP). MERs act as human-elephant co-existence areas, including maintaining connectivity core conservation areas (DWNP, 2013). MERs, therefore, provide essential elephant habitat outside protected areas. The implementation of MERs will significantly increase the amount of habitat area to support elephant conservation in Peninsular Malaysia. The highly suitable habitat that we have identified in Ulu Jelai Forest Reserve has been incorporated under the Belum-Temenggor MER (red polygon in Fig. 2).

### *An eco-viaduct to promote landscape connectivity*

Importantly, our results show that the two main highly suitable habitat areas (Ulu Jelai Forest Reserve and Taman Negara National Park) are bisected by a barrier of unsuitable habitat (Fig. 5), which disrupts connectivity between them. In this context, the construction of a wildlife crossing viaduct seems to be an appropriate measure to promote habitat connectivity for elephants in this

landscape (DWNP 2013). The viaduct can also provide safe crossing points for wildlife, hence locally reducing roadkills.

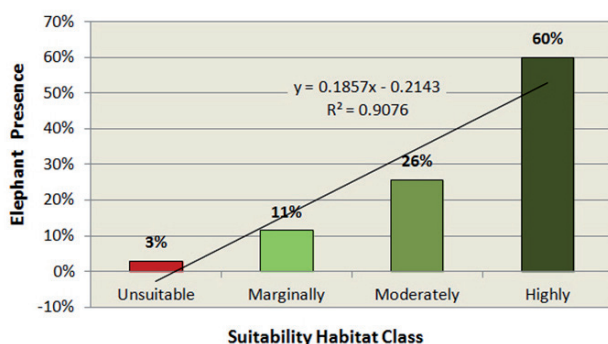
Such an eco-viaduct was built in Sungai Yu, near the town of Merapoh. This eco-viaduct, which was completed in 2014, provides a passageway for animals between Yu River Forest Reserve and Tanum Forest Reserve (adjacent to Taman Negara). Without this linkage, Taman Negara would be isolated from the rest of forested landscape in the west. Therefore, this linkage will give wildlife a wider home range and access to areas with availability of quality food outside the protected areas.

The results of model verification show that, from 35 elephant presence data recorded, 21 presence points occurred mainly in 'highly suitable' category area by more than a 50%. Whilst, less than 10% of the elephant presence occurred in the 'unsuitable' category in the generated elephant habitat suitability map. The result in Figure 6 clearly shows that elephant presence has consistently risen over habitat suitability classes with R-squared value is 0.9076 which indicates strong correlation.

### *Analysis of fuzzy logic for MCE in habitat suitability modelling*

Nowadays, the fuzzy set theory is commonly applied in multi-criteria decision-making in various applications, particularly in site selection and habitat suitability models. In our study we applied a GIS-based MCE through fuzzy logic approach to assess the habitat suitability of Asian elephants in a landscape of Peninsular Malaysia. MCE is primarily concerned with how to combine the information from several criteria to form a single index of evaluation. Meanwhile the fuzzy approach offers a great tool for criterion standardization, weighting, and combining of the habitat parameters in the process of identifying suitable habitat for Asian elephants.

The use of fuzzy logic in MCE plays an important role due to the increase in highly complex GIS applications and the incorporation of wildlife habitat suitability indeed involves uncertainty.



**Figure 6.** Linear regression; relationship between habitat suitability map and elephant presence data.

In this study, the fuzzy logic approach provided a more comfortable method for GIS users, especially the wildlife conservation authorities, compared with traditional crisp techniques (known as a weighted overlay) since it has the tendency to overlook into criterion percentage and their weightage.

As indicated earlier, the most important element in a fuzzy model is the membership function. It is used to define the level of confidence of data or whether an element belongs to the set. In this case the fuzzy modelling with presence data was very helpful in determining the membership function where a relative weight of the input data can be controlled and the importance of each habitat parameters can be assessed.

In this study, the fuzzy logic model in MCE has been proven to be useful in assessing Asian elephant habitat suitability, which aligns with existing national strategic directions such as NECAP, the implementation of MERs, and the construction of eco-viaducts in Peninsular Malaysia. Moreover, we were able to evaluate the parameter criteria used by adding or modifying them to suit the wildlife authorities (DWNP) preferences based on a multi-criteria decision-making approach.

This methodology offers another feasible analysis to stakeholders in order to identify suitable habitat for wildlife conservation and



**Figure 7.** Camera trap photo of elephants in a river in the Ulu Jelai Forest Reserve

to maintain the sustainability of the forests including protected areas. In addition, the fusions of fuzzy logic within GIS-MCE offer greater tools for managing complexity of data analysis and controlling computational cost as well. As the world goes increasingly digital, conservation initiatives should also adopt technological innovation to conserve Malaysia's biodiversity.

## Conclusion

Our results showed that GIS and remote sensing technologies can provide flexibility to identify habitat suitability for Asian elephants. A GIS offers an advanced tool for data analysis and modelling, while remote sensing data provides accurate and timely geospatial information on essential habitat parameters, particularly forest cover and its status. In particular, the home range estimation provided in a GIS environment offers a viable method for quantifying habitat use and assists with a greater understanding of species and habitat relationships.

We adopted the fuzzy logic concept into MCE procedures in order to develop Asian elephant suitability habitat. MCE through the fuzzy logic is an appropriate approach that allows bringing an element of uncertainty combined with expert knowledge concurrent with presence data into habitat suitability analysis.

Based on our findings, Asian elephants need effective management both inside and outside protected areas, supporting the MER approach in Peninsular Malaysia. At the same time, the Central Forest Spine, which is defined as backbone of Peninsular Malaysia's environmentally sensitive area network (FDTCP 2007), provides a holistic template to delineate MERs boundary.

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especially Biodiversity Conservation Division for providing the satellite transmitter data of elephant distributions in the study area and ground data of the elephants' presence in Ulu Jelai Forest Reserve.

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