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Movement Patterns and Habitat Suitability of Translocated Sumatran Tigers (*Panthera tigris sumatrae*)

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ABSTRACT

Sumatran tigers (*Panthera tigris sumatrae*), critically endangered mammals native to Indonesia, play a vital role in maintaining ecosystem balance by regulating prey populations. However, habitat loss and human-wildlife conflict necessitate translocation as a conservation strategy. Translocation becomes an option when the conflict site is no longer possible as a tiger habitat, and the landscape changes from homogeneous to heterogeneous, causing changes in biodiversity that impact resource changes. Ecological studies on the aspects of space use and suitability characteristics of habitats by translocated tigers need to be conducted to improve survival. This study analyzed the home range and habitat suitability of translocated Sumatran tigers in Kerinci Seblat National Park (KSNP) using GPS collar data collected between June and September 2022. This research was conducted by developing a species distribution model using the Minimum Convex Polygon (MCP), fixed kernel (FK), and maximum entropy (Maxent) programs. The most active time used in moving by Sumatran tigers was in the morning of 06.00–08.59, MCP 492 km^2, and FK 98.9 km^2. The results of Maxent modelling obtained an average AUC value of 0.88, and the performance of this model was very good. The response shows how the prediction of the Sumatran Tiger's presence changes with each varying landscape value. The total edge contribution is dominant, with a proportion in this model of 35.5% and a Class area proportion of 27.5%.

Introduction

The Sumatran tiger (*Panthera tigris sumatrae*) is the last surviving subspecies in Indonesia and has been categorized as Critically Endangered by the International Organization for Conservation of Nature (IUCN) since 2006. In Sumatera, tigers generally live only in natural forest areas in a variety of habitat types but are able to adapt to a wide range of diverse environmental conditions. Widespread habitat loss is a major threat to the Sumatran tigers. Another threat to the survival and existence of Sumatran tigers is illegal poaching. The impact of changes in forest function has caused habitat loss and fragmentation in various wildlife species in the Sumatra Island area, which has pushed certain species to extinction, especially mammal species with large body sizes [1].

Sipurak Hook area in Kerinci Seblat National Park (KSNP) has a relatively low abundance of Sumatran tigers. The low abundance of mammalian species in a single area can be caused by unsupportive food, high predators, and unsuitable environmental conditions [2]. The expansion of human-managed land from the original forest habitat that has been massively transformed into plantations has affected habitat quality, such as a decrease in the habitat capacity to support wildlife [3].

Translocation is a conservation effort that involves moving wildlife from one location to another. In human tiger conflict mitigation efforts, translocation becomes an option when conflict location is no longer viable

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for the tigers involved. In general, carnivores translocated for conflict mitigation exhibit strong return abilities, poor survival and reproduction, and a tendency to continue predation on livestock within their new range [4].

Apex predators, such as Sumatran tigers, play an important regulatory role in maintaining healthy ecosystems by exerting top-down pressure on prey communities, and their extinction could lead to negative impacts, ranging from loss of biodiversity. This could be caused by the human suppression of habitats, resulting in the degradation of both quality and quantity. Resource selection functions and other species distribution models have been applied to transform the ecology of niche relationships in environmental spaces into a predictive gradient of habitat suitability across geographic spaces [5]. In addition, the change in landscape from homogeneous to heterogeneous results in changes in habitat biodiversity, affecting natural resources [6].

Landscape metrics are essentially dependent on the remote sensing data used to generate them, and their informative behavior and value are affected by the grain size, coverage, and resolution of the land cover data [7]. Landscape connectivity can be defined as the extent to which a landscape inhibits or facilitates movement among resource patches [8]. Habitat connectivity is critical for conserving species restricted to fragmented populations in human-dominated landscapes. However, identifying habitat connectivity for apex predators is challenging because trophic interactions between primary productivity and prey species influence habitat distribution and predator movements. Predator movement patterns are also influenced by competition, resulting in territoriality in some species [9].

Several studies related to assessed 33 forest patches in Sumatra to better comprehend tiger distribution and found that tigers were present in 27 forest patches. The patches were mostly located in the western part of the island, where the terrain is mountainous. Only a few patches extended to the east, extending to the eastern side of Sumatra Island in Riau and Jambi Provinces. These forests cover an area of 140,226 km^2, of which only 29% are protected [10]. To simulate landscape links within the landscape complex that are expected to act as tiger corridors from source habitat patches to destination habitat patches, landscape factors were identified that, by their nature, may encourage or hinder tiger travel through the landscape at various levels and hence are key determinants in the structural connections that serve as corridors. The landscape features considered were the presence or absence of forest cover across connecting structures [11].

The fragmented matrix results in many edges. Fragmentation is the process of transforming a homogeneous and compact matrix into a heterogeneous and fragmented matrix. This difference causes differences in composition and biodiversity. A narrow edge indicates a relatively low level of biodiversity. Landscapes often feature structural (patterns) and functional (process) characteristics and are dynamic. Two distinct categories of components, pattern, and process, define corridors as crucial landscape components [12]. Habitat suitability studies using regression methods on translocated Sumatran tigers on the island of Sumatra have been carried out [13]. However, the Maxent machine learning method has never been applied using landscape index variables. To increase the life chances of translocated Sumatran tigers, studies on behavioral ecology and space utilization patterns by translocated tigers and the characteristics of release sites and environmental preferences at translocation sites must be conducted. Therefore, the objectives of this study were to (1) analyze the home range of Sumatran tigers after translocation and (2) predict habitat suitability for environmental variables that affect the presence of Sumatran tigers using Maximum Entropy modeling.

Material and Methods

Study Area

This study was conducted in Region 1 of Kerinci Seblat National Park (KSNP), Kerinci Regency, Jambi Province, Indonesia (Figure 1). The majority vegetation type is deciduous broadleaf forest, interspersed with mixed coniferous and broadleaf forest. This area has a geographical condition that is bounded by mountains and hills, unspoilt forests are scattered around this place.

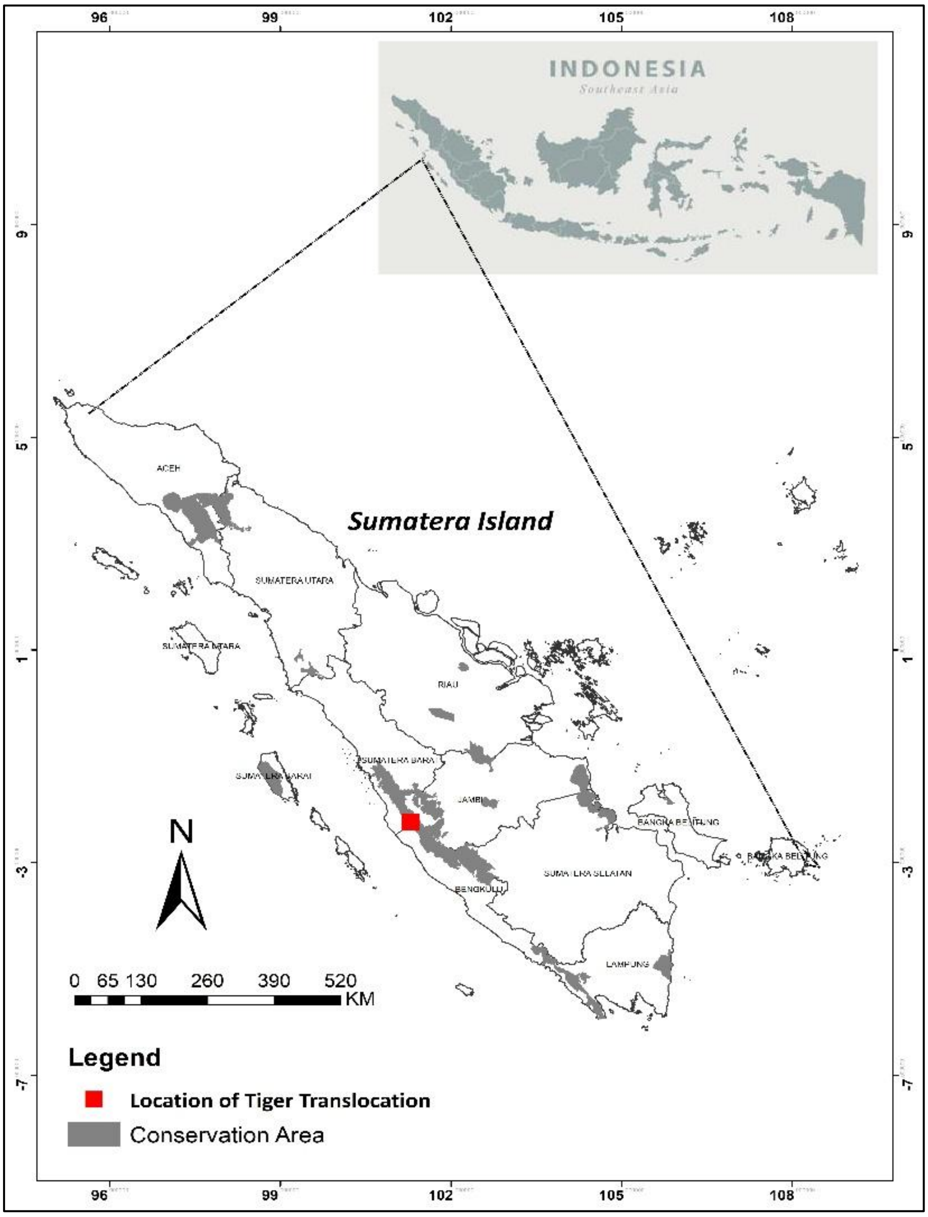

Figure 1. Research site map.

Data Collection

Data on the presence of Sumatran tigers were collected from GPS collars in Sanctuary Barumun Nagari. Their mothers treated Sumatran tigers naturally and were regularly given live food, such as wild boars, rabbits, chickens, etc. In addition, their natural behavior is regularly observed using CCTV. The position data taken every day were set every hour to read movements; only data with high accuracy were used. Sumatran tiger counts from June 14, 2022, to November 16, 2022, for 161 days obtained 3,168 coordinate point data.

The suitability map was modeled using an algorithm-based Maxent application to calculate the degree of habitat preference using information on factors and the presence of species. The environmental variables used were five landscape indices (Total Edge, Edge Density, Mean Shape Index, Mean Patch Fractal Dimension, and Class Area) [14] and two topographies (slope and elevation) (Table 1). The dependent variable was the point of tiger presence.

The landscape index was calculated using the Patch Analyst interface installed in ArcGIS 10.8. The landscape index was calculated based on land cover forest developed using Landsat 8 OLI satellite images, whereas the study area was divided into grid areas of 2.5 x 2.5 km. This size was determined based on the daily movements of the translocated tigers. The supervised classification of Landsat 8/OLI was performed and tested for accuracy by examining the overall accuracy and kappa coefficient.

Table 1. Ecological components used as environmental variables for habitat suitability of translocated Sumatran tigers.

Characteristics of size		Description	Formula
Landscape index	Edge Density (ED)	The entire length of all edge segments comprising the appropriate plot type multiplied by 10,000 (to translate to hectares), divided by the total land area (in square meters).	$ED = \frac{\sum_{k=1}^{n} eik}{A}(10.000)$
	Total Edge (TE)	Equals the sum of the lengths (m) as the total number of edge segments involving the relevant patch type. TE contains landscape boundary segments involving the associated patch type and indicating true edge only (i.e., contrast weight > 0) if a landscape border is present.	$\mathrm{TE} = \sum_{k=1}^{m\prime} eik$
	Mean Shape Index (MSI)	Quality is calculated by calculating the sum of the patch perimeter (m) divided by the square root of the patch area for each corresponding patch type, adjusted by a constant to match the circle standard (vectors) or square standard (rasters).	$\mathrm{MSI} = \frac{\sum_{j=1}^{n}\left(\frac{pij}{\sqrt[2]{\pi.aij}}\right)}{ni}$
	Mean Patch Fractal Dimension (MPFD)	Equals the sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2) for each patch of the corresponding patch type, divided by the number of patches of the same type.	$\mathrm{PFD} = \frac{\sum_{j=1}^{n}\left(\frac{2LnPij}{Lnaij}\right)}{ni}$
	Class Area (CA)	Equals the sum of the areas (m^2) of all patches of the corresponding patch type, divided by 10,000 (to convert to hectares); that is, total class area.	$\mathrm{CA} = \sum_{J=1}^{n} aij\left(\frac{1}{10.000}\right)$
Topography	Slope	https://opentopography.org/ (m).	
	Elevation	https://opentopography.org/ (mdpl).	

(A) = total landscape area (m^2). m' = number of patch types (classes) including any landscape boundaries that exist in the area. aij = area (m^2) of patch ij. pij = perimeter (m) of patch ij. eik = total length (m) of edges in the landscape between patch types (classes) i and k = number of patches in the landscape of patch type (class) i. (Source: MacGarigal et al. [14])

Data Analysis

For the GPS collar, the X signal showed movement in the vertical forward and backward directions, while the Y signal indicated a horizontal left and right movement. Eight-time intervals were used to separate the tiger's 24-hour activity pattern: morning (06.00–08.59), afternoon (09.00–11.59), (12.00–14.59), evening (15.00–17.59), midnight (18.00–20.59), mid-night (21.00–23.59), early morning (00.00–02.59), and dawn (03.00–05.59). The tiger home range area was performed using Minimum Convex Polygon (MCP) 100%, Fixed Kernel (FK) 95%, and FK 50%. The MCP is a habitat delineation method that connects the furthest points in wildlife encounter data and forms the smallest polygon or convex polygon with the condition that the smallest polygon has no internal angle exceeding 180° and contains all locations of animal-finding points [15]. The FK method was used to determine the home range of animals. This method includes all coordinate points that are frequently visited to form a pattern of home ranges and core areas [16].

Habitat suitability was predicted by calculating the probability of tiger presence in a landscape and modeling the species distribution based on machine learning algorithms. Spatial analysis was conducted using maximum entropy. The higher the probability of tiger presence, the more suitable the area is as a tiger habitat. The habitat suitability model was created using ArcGIS 10.8. The model was assessed using the area Under the Curve (AUC). The Maxent output contains important information, such as the number of predictions or the region AUC, each variable's performance, and the influencers' input into the prediction model [17]. The AUC intervals for model performance were <0.7 (poor model performance), 0.7–0.9 (fair/useful), and >0.9 (excellent). The habitat suitability map was divided into three classes: low, medium, high, and unsuitable. division based on [18]. The highest probability value minus the lowest probability value is then divided based on the number of suitability classes. The 10-percentile threshold for training presence logistics in the MaxentResults.csv file shows the basic class division value.

Results

Time Activity

Size patch of 2.5 x 2.5 km^2 was used as a reference for the relative evaluation of landscape structure and tiger movement behaviour as the daily mobility of tigers is 2.5 km per day (Table 2). Tiger activity patterns over 24 hours were divided into eight-time intervals. The most active time used for moving by Sumatran tigers was in the morning from 06.00 to 09.00, with an average movement length of 51 km (Figure 2). Active tiger time can affect various responses such as the ability of tigers to forage and follow the activities of prey animals.

Table 2. Home range sizes.

Tiger	Year of age	Fate after translocation	Time required to set up a home range	100% MCP home range (km^2)	95% FK home range (km^2)	50% FK home range (km^2)	Average of straight line distances (km)
KSNP	4 (adult-male)	Survived 9 months and then the GPS collar stopped working	17 (weeks)	492.60	98.90	12.48	2.55

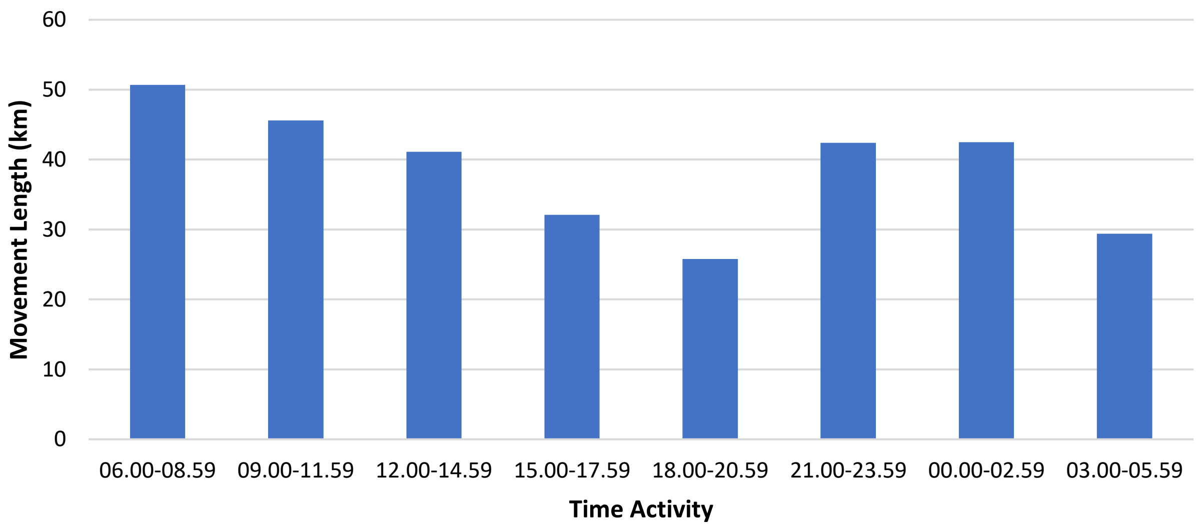

Figure 2. Accumulated movement of translocated tigers based on time of day.

Home Range

Tiger movements occur more frequently outside conservation areas and favor forest edges; therefore, translocated tigers are more likely to be disturbed in their habitat and conflict with humans. However, translocated tigers can effectively adapt to human presence by using forests as cover and agricultural areas to capture prey. The results showed that translocated tigers did not make the release area part of their home range, and were more likely to stay at the edge of the forest. It took 17 weeks to establish a home range at the release site. The results obtained using the 95% FK method estimated a male home range size of 98.90 km^2. A 50% FK (territory) home range of 12.48 km^2.

Figure 3 shows that tigers exhibited different movements in habitat selection during the exploration and settling periods. Sumatran tigers resulting from translocations are often found in secondary forests and dry land agriculture. This can occur because there are more prey animals in transitional forest areas. Another factor could be the presence of tigers that had previously existed in the area, resulting in the marginalized translocation of tigers.

Habitat Suitability

The classified land cover map study area of KSNP was 83.57% overall, resulting in a kappa coefficient value of 81.04%. Primary and secondary forests were predominant in this habitat. To provide a patch size for the relative comparison of landscape structure and movement behavior. The threshold used in the Sumatran Tiger presence prediction model is the result of a threshold of 10 percentile training intensity of 0.1609. The habitat is not suitable for 0–0.1609 and a suitable habitat probability value above 0.1609–0.9967.

Red modelling results indicate high suitability with a higher probability of animal presence in the landscape, yellow medium suitability, and green low suitability (Figure 4). Landscape structure refers to the extent of a landscape in terms of its spatial heterogeneity. Two aspects of spatial heterogeneity can be investigated by landscape structure analysis: composition and configuration.

Although they are distributed inland, three charismatic mammals use and utilize habitats that are a good distance from the forest border (Table 3). This illustrates how the tiger's habitat, along with other habitat components such as forest cover and prey, is accessible to humans and at risk of overexploitation, emphasizing the importance of protection within protected areas.

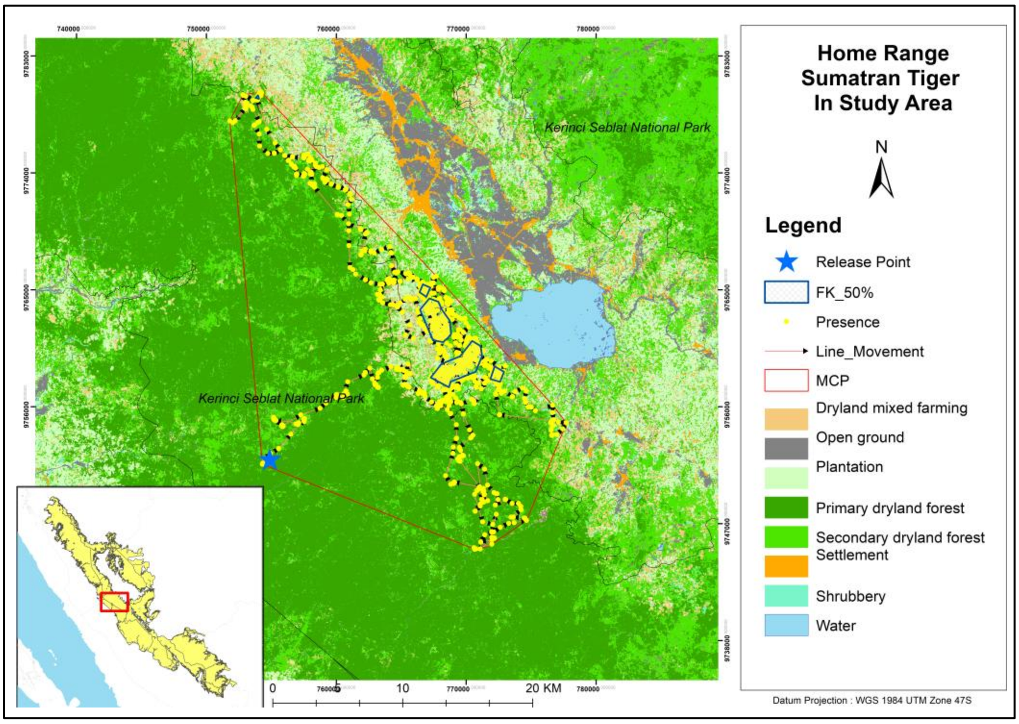

Figure 3. Home range tiger in the study area.

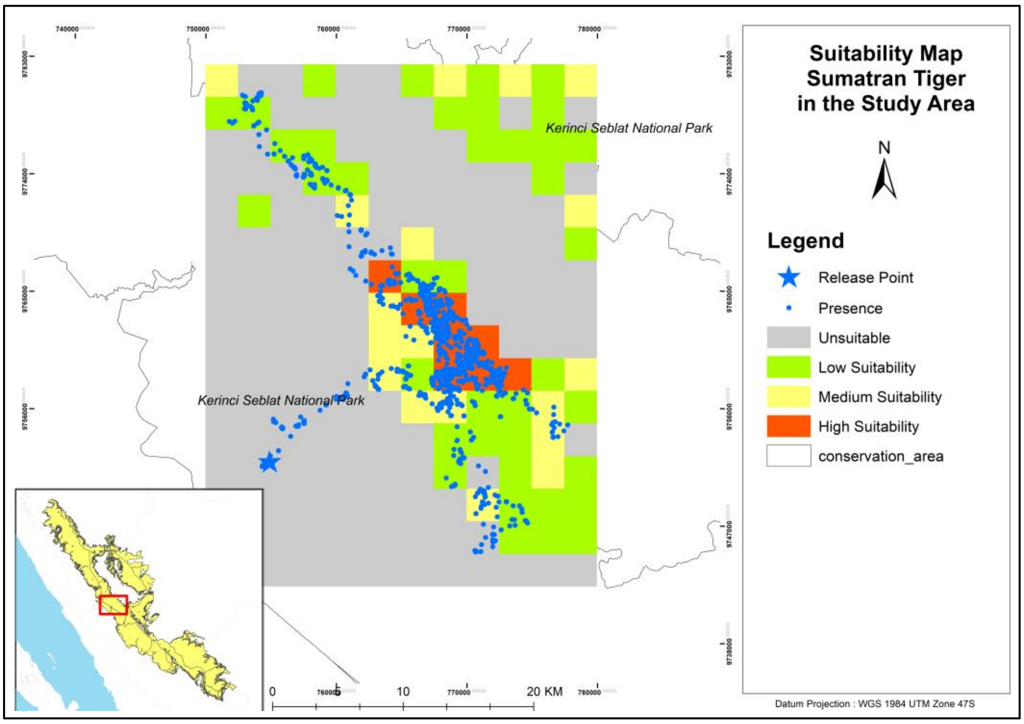

Figure 4. Map of the KSNP forest area suitability for translocation of Sumatran tigers based on these variables.

Table 3. Range of each habitat suitability class.

No	Class	Suitability class interval	Area (ha)	Percentage (%)
1	Unsuitable	0.0000–0.1609	79,355.16	66
2	Low suitability	0.1609–0.4372	24,382.35	20
3	Medium suitability	0.4372–0.7136	11,234.97	9
4	High suitability	0.7136–0.9967	4,997.52	5

Curve Response

Forest edge areas were important environmental factors within the Sumatran tiger range. The transition area of the Ecotone zone between forest vegetation and open space is a place for ungulate species to select their food. The Sumatran tiger movement behaviour revealed interactions between the structures. As landscape structure changes with resource size, tigers modify their prey and shelter strategies. These modifications occur as a result of the behavioural mechanisms used in response to pre-existing tigers (Figure 5).

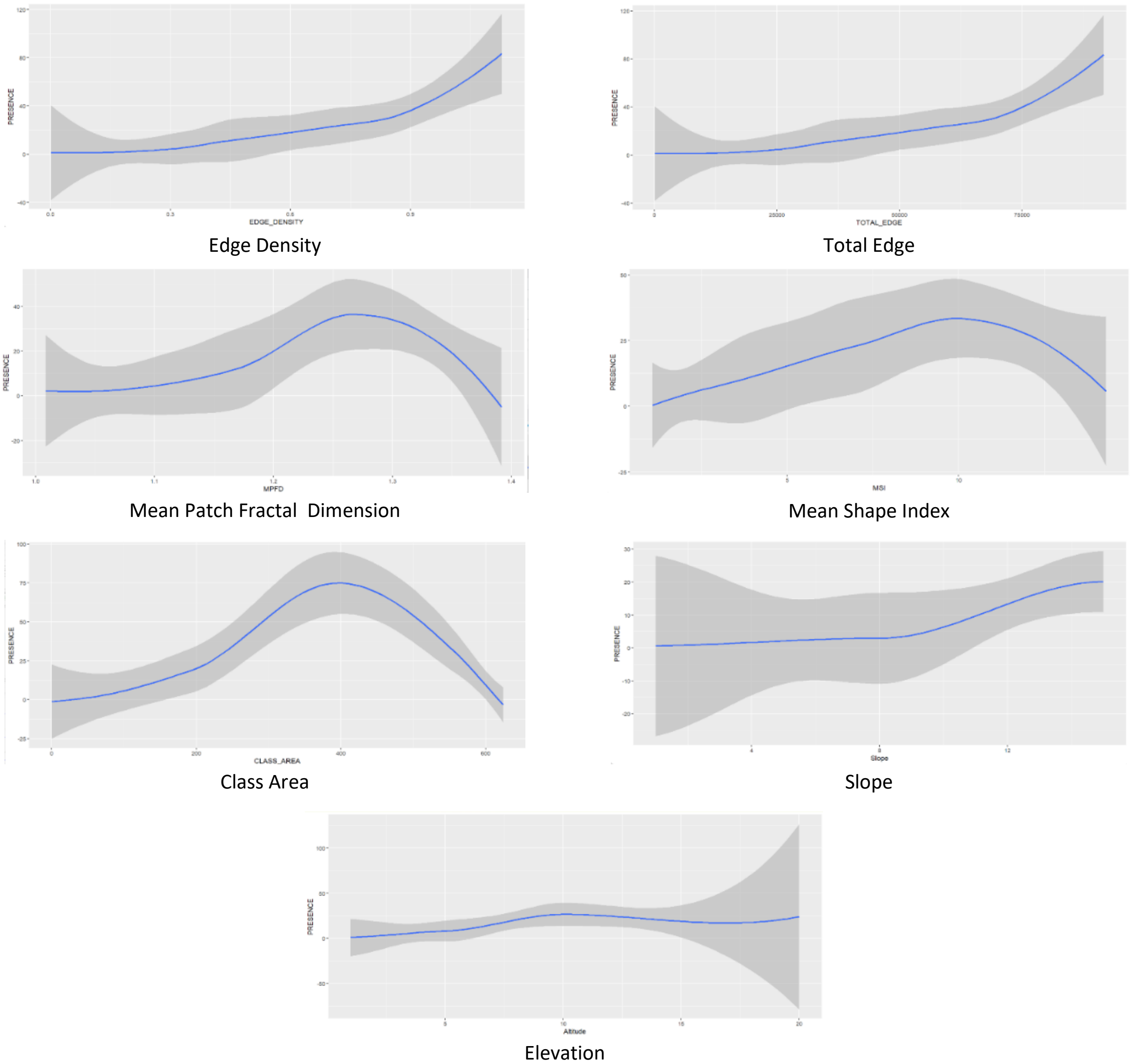

Figure 5. Scaling sensitive response curve.

Model Performance

The results of Maxent modelling showed an average AUC value of 0.88, and the performance of this model was very good. In this model, variables with high contributions can be observed (Table 4). The table shows the percentage of significant contributions of each variable in the model. Overall, each ecosystem landscape variable that shows spatial interactions affects the potential habitat suitability. Forest edge contributed the most to this model. Initially, forest as a habitat supported the model, with the total edge contributing the most, with a proportion of 35.5% in the model and a class area proportion of 27.5%.

Tigers accessed the habitat in similar proportions, but small-scale responses showed that tigers searched these landscapes differently, depending on their patch and gap structure. Several factors contribute to the suitability of landscape metrics, including the large number of areas converted for other uses, competition for forage with similar and dissimilar animals, and poaching by communities for agricultural pests.

Table 4. Variable contributions to the model.

Class	Variable	Percentage (%)
Landscape index	Total edge	35.50
	Class area	21.07
	Mean shape index	12.50
	Edge density	09.03
	Mean patch fractal dimension	07.01
Topography	Slope	08.03
	Elevation	05.05

The fragment area indicator was the land cover that experienced a significant increase in the Edge Density (ED) value. Fragments are homogeneous areas that can be distinguished from the surrounding areas. The ED indicates that land cover has a fairly high edge density when viewed from an edge aspect. A high ED value indicates that the edge area is very wide, indicating a fragment or change in structure from homogeneous to heterogeneous. The mean shape index an indicator of fragment shape. Landforms become more regular if the value is close to one with a square or circular shape. MSI values, in general, have decreased due to changes in land structure to become more regular due to the presence of

Discussion

Monitoring Sumatran tiger movement activity during the day was low because tigers spent more time resting. This is in line with research that male tigers translocated to Bukit Barisan Selatan National Park (BBSNP), KSNP, and Mount Leuser National Park; their active time is in the afternoon/evening (18.00–21.59) and morning (06.00–11.59) [19]. Result study used camera traps to measure the daily activity patterns of Sumatran tigers and human presence in the Intensive Protection Zone of BBNSP, tigers were found to be active in the morning [20].

Male tiger home range size can be influenced by a variety of ecological factors, such as larger home ranges of radio collared responses to the high spatial and temporal uncertainty of available resources. the extent of a male tiger's home range is influenced not only by the variety of its prey but also by the population density and social organization of the area. However, there may be insufficient information for comparison [21]. However, most observed patterns suggest that tigers favour dense vegetation transitions [22]. Tigers prefer forests with sharper slopes and heavier subterranean cover and steer clear forests with more anthropogenic influence from logging and human settlements [23].

landscape metrics can be used to quantify the spatial information of landscape pattern composition, configuration, and land use/land cover change at single or multiple scales [24]. Landscape metrics are used for many application areas (e.g. evaluation of land use/cover change, landscape function, regulatory function, ecosystem services, etc.); in the field of ecological research, they are frequently employed to explore structural influences on animal communities on a variety of scales [25].

Figure 5 shows the probability of tiger use for seven environmental variables. Each figure shows the effect of a particular control variable when all the other control variables are set at their mean values. The dark blue line indicates the mean value, and the light gray polygon represents the 95% standard deviation interval. All continuous control variables were standardized, so the effect shown was the difference in the probability of landscape use.

The mean patch fractal dimension (MPFD) indicates area fragments. Fragments are homogeneous areas that can be distinguished from the surrounding areas. A fragmented matrix can result in edges or edge areas with large sizes. This implies that the scaling has an optimal range of values. Beyond the tipping point threshold, the scaling sensitivity decreased as the curve decreased, and some landscape metrics became blurred because of the loss of spatial information and heterogeneity of the landscape. The scaling-sensitive scalogram quantitatively explained the response relationship of scaling sensitivity, and predicting the optimal sensitivity of various metrics indicated that tigers responded differently to various grids.

The mean patch fractal dimension value indicates the degree of isolation of land cover and is an indicator of landscape connectivity. landscape connectivity. The higher the MPFD value, the higher the level of spatial isolation between patches, which indicates spatial isolation due to a significant decrease in land area and fragmentation. The class area indicates land fragmentation, which expresses the degree of remoteness of land cover based on the grid. This indicates that spatial mixing between the patches decreases [26].

Model approach assumes a higher risk of mortality in areas with less suitable habitats and high resistance, with a higher risk outside protected areas. In addition, it is evident from the calculation results that land cover with a relatively high patch density tends to have a high level of interference and vice versa [27]. In general, there is a link between the values of the Class Area, MPFD, and MSI and the values of TE and ED. The same is true for land use change; if the TE and ED values increase, the CLASS AREA, MPFD, and MSI values decrease.

Based on the results of habitat suitability modeling in the KSNP, the low level of suitability of suitable habitats compared to unsuitable habitats illustrates that the threat of translocated tigers remains relatively high. The threat posed by the presence of translocated tigers remains relatively high. The model evaluation is a general technical tool. It evaluates model performance to assess the accuracy of the model in describing the ecological situation of a species [28].

Conservation Implications

These findings can be used to assist in the development of tiger population management and conservation strategies as well as spatial population models for other endangered species. Adjustment of the maximum population density did not substantially affect the population growth rates [29]. However, the predictions are highly sensitive to mortality risk patterns, and the high variation in the simulated population rates generated in the model indicates the vulnerability of this small and isolated tiger population. Habitat type, quality, spatial layout, and connectivity affect biodiversity and ecosystem functions. Patches have also been described from the perspective of the presence of edge areas in landscapes.

The release site must undergo comprehensive analysis before being selected as a tiger-translocation site. Further studies should consider environmental factors, such as the edge of lowland forests with young secondary forest land cover, the presence and demographics of local tigers at the release site, and the adequacy of availability of key prey animals. It is critical to ensure that potential translocation sites are free from human disturbances that could harm tigers because several translocated Sumatran tigers have been killed by snares (either set by communities to protect fields from wild boar pests or deliberately set by poachers). A social assessment of the area close to the translocation site should be conducted before tiger translocation begins.

Habitat fragmentation negatively affects population viability, especially in small and geographically isolated populations. Ensuring tiger survival requires a well-connected network of conservation areas and reserves through animal movement corridors that maintain existing high-quality habitats. Therefore, it is important to make joint efforts in animal conservation at the parties, including the government, area managers, farmers, locals who live nearby, and individuals who benefit from direct access to KSNP. This can be achieved by promoting the coexistence between humans and wildlife. Conservation strategies such as creating corridors for animals to move through can act as barriers or filters for gene flow. Habitat connectivity is necessary for stepping stones, which require one or more ecologically isolated habitat patches that provide resources and refuges for animals to move across a landscape and enhance landscape-scale restoration, thus contributing to the conservation of the landscape. Stated in their modelling that tigers in Sumatra were mostly found in areas adjacent to forest patches. The boundary areas between open areas and forests are areas favoured by many ungulates as a place to find food [30].

Conclusion

The most preferred time for the tiger to move and hunt prey animals was in the morning (between 06.00 am and 09.00 am). The home range area translocated Sumatran tigers for 4 months (MCP) of 492 km^2. A total of 95% core home range is 50 %, with an area of 98.90 km^2 and an area of 12.48 km^2. The environmental variables that affected the presence of translocated Sumatran tigers were the total edge, class area, mean shape index, edge density, mean patch fractal dimension, slope, and altitude. The total forest edge contributed dominantly, with a proportion of 35.5% in this model. Unsuitable habitat covers a large area of 79,355.16 ha (66%), and suitable habitat can be classified into three classes. The low-suitability class is 24,382.35 ha (20%), the medium-suitability class is 11,234.97 ha (9%), and the high-suitability class is 4,997.52 ha (5%).

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