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Potential Habitat of Sumatran Elephant (*Elephas maximus sumatranus*) in Rawa Bunder Resort, Section III Kuala Penet, Way Kambas National Park, Lampung

Habitat Potensial Gajah Sumatra (Elephas maximus sumatranus) di Resort Rawa Bunder, Seksi III Kuala Penet, Taman Nasional Way Kambas, Lampung

Subeno^{1*}, Awang Hariyanto², & Ryan Adi Satria³

¹Wildlife Ecology and Management Laboratory, Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro No. 1, Bulaksumur, 55281, Yogyakarta, Indonesia

²Kupang Natural Resources Conservation Center, Jl. SK Lerik, Kelapa Lima, 85228, Kupang, Indonesia

³Forest Ecology Laboratory, Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro No. 1, Bulaksumur, 55281, Yogyakarta, Indonesia

*Email: wishben@yahoo.com

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ABSTRACT

Way Kambas National Park (WKNP) in Lampung serves as a critical habitat for the endangered Sumatran elephant (*Elephas maximus sumatranus*). However, the area has increasingly experienced human-elephant conflicts, particularly at the Rawa Bunder Resort. This research aimed to assess the biophysical characteristics and map the distribution of potential elephant habitats within the resort area. Field data were collected using 70 nested plots distributed along established transects and analyzed through a modified sampling protocol. An Agglomerative Hierarchical Cluster (AHC) analysis was employed to classify the habitats into suitable, moderately suitable, and less suitable categories. The georeferenced plot data were processed using ArcGIS 9.3 to create a habitat suitability map. The findings indicated that 24% of the plots were classified as suitable, 33% as moderately suitable, and 43% as less suitable. The suitable habitats were predominantly located in lowland forest areas, which represent a relatively small proportion of the total area. To expand suitable habitats and mitigate human-elephant conflicts, strategic habitat management measures, such as forest restoration and targeted enrichment, are essential. These results provide a spatial framework for conservation planning for elephant habitats in Way Kambas and other fragmented landscapes.

INTISARI

Taman Nasional Way Kambas (TNWK) di Lampung merupakan habitat utama bagi gajah Sumatra (*Elephas maximus sumatranus*) yang terancam punah. Namun, kini TNWK menghadapi konflik antara manusia dan gajah, terutama di kawasan Resort Rawa Bunder. Penelitian ini bertujuan untuk mengevaluasi karakteristik biofisik dan memetakan sebaran habitat potensial gajah di wilayah resort tersebut. Data lapangan dikumpulkan melalui 70 plot bersarang (nested plots) yang tersebar di sepanjang transek dan dianalisis menggunakan metode modifikasi protokol sampling. Analisis Agglomerative Hierarchical Cluster (AHC) digunakan untuk mengelompokkan habitat ke dalam kategori sesuai, cukup sesuai, dan kurang sesuai. Data plot yang telah diberi georeferensi diproses menggunakan ArcGIS 9.3 untuk menghasilkan peta kesesuaian habitat. Hasil penelitian menunjukkan bahwa 24% plot tergolong sesuai, 33% cukup sesuai, dan 43% kurang sesuai. Habitat yang sesuai umumnya ditemukan di kawasan hutan dataran rendah, meskipun hanya mencakup sebagian kecil dari total luas area resort. Pengelolaan habitat secara strategis, seperti restorasi hutan dan pengayaan vegetasi secara terarah, diperlukan untuk memperluas area yang sesuai dan mengurangi konflik antara manusia dan gajah. Temuan ini memberikan kerangka spasial penting untuk mendukung perencanaan konservasi habitat gajah di Way Kambas dan lanskap lain yang terfragmentasi.

Introduction

The Sumatran elephant (*Elephas maximus sumatranus*), a subspecies native to Sumatra, is classified as endangered on the IUCN Red List (Williams et al. 2020) and is protected under Indonesian Government Regulation No. 7 of 1999. As a keystone species, the Sumatran elephant plays an essential role in maintaining the structure and biodiversity of tropical forest ecosystems. Its natural habitat encompasses lowland tropical forests and open swamp environments. The region that this species relies on for foraging, movement, breeding, and social interactions extends from sea level up to 1,000 m (Sach et al. 2019; Kurniadi et al. 2020; Husain et al. 2022).

Way Kambas National Park (WKNP), the last remaining stronghold for the Sumatran elephant, is situated in Lampung Province and is home to an estimated population of 200–250 individuals (Indraswati et al. 2018; Veriasa & Indraswati 2020). However, ongoing threats such as habitat degradation, fragmentation, and human encroachment are undermining its ecological integrity. The expansion of agricultural land and human settlements along the park's boundaries has exacerbated human-elephant conflict (Das Chatterjee 2016; Kuswanda et al. 2022), particularly in high-risk areas like the Rawa Bunder Resort (Khairani et al. 2022). Located in Section III of Kuala Penet within WKNP, Rawa Bunder Resort serves as a spatial interface between conservation forests and surrounding cultivated landscapes. Its proximity to plantations and residential gardens heightens the risk of elephant incursions and conflict. Additionally, recurring forest fires have diminished habitat quality and resource availability, prompting elephants to migrate into adjacent, human-modified areas (Aryasatya et al. 2022; Winarno et al. 2023). These challenges highlight the urgent need to assess whether the habitat can still sustain elephant populations and to explore strategies for mitigating ongoing conflicts with surrounding communities.

The landscape is crucial for supporting elephant ecology; however, detailed assessments of habitat suitability at the sub-landscape level, such as at the resort scale, remain limited. Most prior research has primarily concentrated on broader landscape

connectivity or general species distribution patterns, leaving a gap in our understanding of localized habitat conditions that can directly inform site-specific management (Moßbrucker et al. 2016; Collins 2018; Brooks et al. 2019; Anggraini 2021; Chaiyarat et al. 2022; Edwin et al. 2024). To effectively guide habitat restoration, mitigate human-elephant conflicts, and develop conservation strategies, it is essential to comprehend the spatial distribution and quality of potential elephant habitats (Moßbrucker et al. 2016; Mandal & Das Chatterjee 2021; Rendana et al. 2023). This research aimed to evaluate the biophysical conditions and map the distribution of potential habitats for the Sumatran elephant in Rawa Bunder Resort, WKNP. A comprehensive evaluation of habitat suitability was achieved by integrating nested sampling, measuring vegetation and physical parameters, applying agglomerative hierarchical cluster analysis, and utilizing GIS-based spatial mapping. The findings support targeted management interventions in WKNP and provide insights applicable to other fragmented elephant landscapes throughout Sumatra and Southeast Asia.

Methods

This research was conducted at Rawa Bunder Resort, located in Section III (SPTN III) of Kuala Penet, WKNP, Lampung, Indonesia. The resort covered approximately 9,824.47 ha and was centrally situated within the national park. The landscape comprised a mosaic of lowland tropical rainforest (4,876.3 ha), shrubland (3,472.9 ha), and swamp forest (1,688.5 ha), representing 48.6%, 34.6%, and 16.8% of the total area, respectively. A significant portion of the shrubland originated from former agricultural land that was once cultivated with cassava. The region is characterized by gently sloping topography (0–8%) and is positioned at an elevation of about 39 m above sea level. Daytime temperatures can reach up to 34.5 °C, with relative humidity averaging around 50.5%. These conditions heighten the risk of wildfires, particularly in the dry, grassy, and shrubland areas (Winarno et al. 2023).

Fieldwork was conducted from May to November 2015, employing a stratified sampling design. The sample plots were proportionally distributed across

three primary land cover types: secondary forest, shrubland, and residential gardens. Data collection aimed to assess both the physical and biological characteristics of elephant habitats. The physical variables recorded at each sampling point included temperature, humidity, slope, and the distance to the nearest water source and road. Measurements were taken using a modified protocol based on the methodologies of Noon (1981) and Morrison (2013), supplemented with spatial data extracted from road and waterway network maps. For biological data on vegetation structure, nested sampling techniques were employed, following the frameworks suggested by O'Connor (2017) and Sampson et al. (2018). Four nested plot sizes were established at each sampling

point to measure various vegetation layers: 2 m × 2 m for seedlings, 5 m × 5 m for saplings, 10 m × 10 m for poles, and 20 m × 20 m for mature trees (as shown in Figure 1). These nested plots were systematically positioned along 14 transect lines, each measuring 1,000 m with 500 m spacing between lines, resulting in a total of 70 sample points distributed at 200 m intervals along the transects (as illustrated in Figure 2). All individuals within each plot were counted and identified according to their respective vegetation layers.

Understorey and canopy cover were estimated using the ocular tube method as described by Noon (1981) and Morrison (2013). A circular plot with a radius of 11.3 m was established within a 20 m × 20 m tree plot.

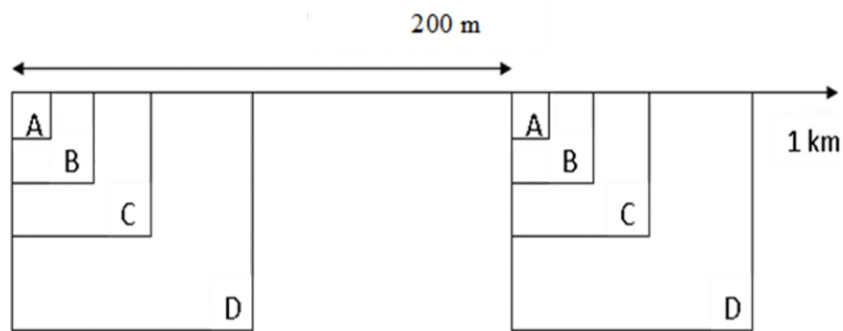


Figure 1. The method of combining line transect and nested sampling

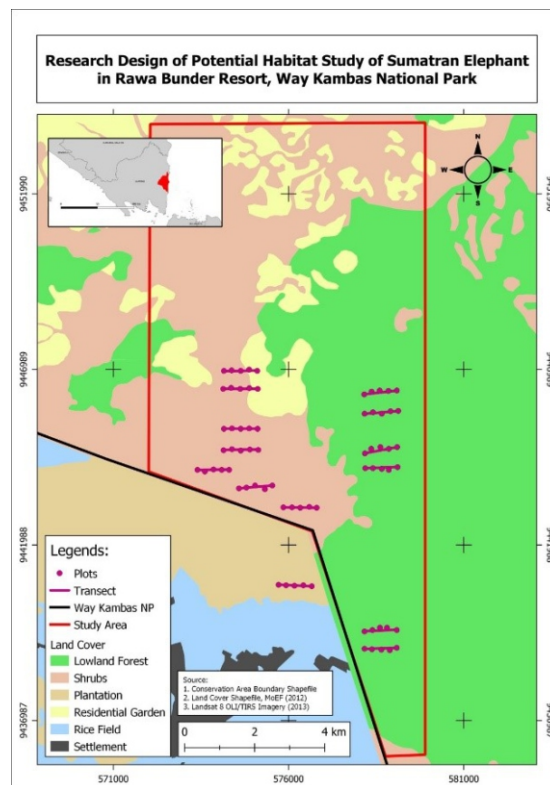


Figure 2. Potential habitat research design

Table 1. Criteria for the biophysical conditions of potential habitat for Sumatran elephants (Akbar et al. 2023)

Variables	Suitable	Moderately	Less Suitable
Temperature (°C)	30–32	33–34	>34
Humidity (%)	60–64	65–75	<60
Slope (%)	<5	5–10	>10
Distance to water source (m)	<500	500–1,000	>1,000
Understorey cover (%)	<50	50–75	76–100
Canopy cover (%)	75–100	50–74	<50
Seedling density (ind./ha)	<50,000	50,000–100,000	>100,000
Sapling density (ind./ha)	<8,000	8,000–10,000	>10,000
Pole density (ind./ha)	<1,000	300–1,000	<300
Tree density (ind./ha)	175–250	50–175	<50

Observers traversed the plot along north-south and east-west transects, recording the presence or absence of vegetation at the ocular cross points, while looking upward (for canopy) and downward (for understorey) at a height of 1 m. This method yielded consistent estimates of vegetation cover percentage. Additionally, several habitat variables were collected and analyzed, including temperature (°C), humidity (%), slope (%), distance to the nearest water source (m), understorey cover (%), canopy cover (%), seedling density (ind./ha), sapling density (ind./ha), pole density (ind./ha), and tree density (ind./ha).

Plots were georeferenced and spatially analyzed utilizing ArcGIS 9.3 (Withanage et al. 2023). Habitat suitability was evaluated using criteria adapted from Akbar et al. (2023) and Abdullah (2022), categorized into three groups: suitable, moderately suitable, and less suitable, as detailed in Table 1. To group plots based on biophysical similarity, Agglomerative Hierarchical Cluster (AHC) analysis was employed, applying Ward's method and Euclidean distance as the measure of dissimilarity.

Results and Discussion

Biophysical Conditions of Sumatran Elephant Habitat

The land cover in the research area consisted of lowland secondary forest, shrubland, residential gardens, and plantations managed by PT Nusantara Tropical Fruit. Each land cover type exhibited unique physical and biological characteristics that affected its suitability as an elephant habitat. A thorough understanding of these conditions was crucial for assessing the landscape's ability to support elephant populations.

Lowland Forest

The lowland forest at Rawa Bunder Resort features gentle to moderate slopes ranging from 0.25% to 12.5%. The temperatures in this area fluctuate between 27.5 °C and 30 °C, accompanied by relatively high humidity levels of 52% to 74%. Water sources are located at distances varying from 20 to 2,027 m from the forest. This diverse ecosystem supports a range of vegetation, including *Microcos paniculata*, *Schima wallichii*, *Dillenia grandifolia*, and *Nephelium costatum*. Seedling densities ranged from 7,500 to 130,000 individuals/ha, while the categorization of trees and saplings indicates moderate to high prevalence. The canopy and understorey cover show significant variation, ranging from 33% to 92%, highlighting the habitat's structural complexity and ecological significance.

Shrubland

Shrubland consisted of areas that had been degraded and previously cultivated by local communities. This land type was primarily characterized by the presence of *Imperata cylindrica* and *Dalbergia latifolia*, featuring flat topography (ranging from 0% to 1.75%), high temperatures (approximately 34 °C), and moderate humidity levels (between 52% and 70%). The biological structure was sparse, exhibiting a high density of seedlings but low canopy and tree density. A total of 35 plots were sampled within this dominant land cover type, revealing limited suitability for elephants. The sparse vegetation and significant distances to water sources—reaching up to 3,310 m—created a challenging environment that could not adequately meet the elephants' needs. These factors significantly reduced the area's value as a viable habitat for elephants.

Residential Gardens

Residential gardens cultivated with cassava and rubber exhibited flat topography, ranging from 0% to 2%. These areas presented variable conditions, with temperatures ranging from 32 °C to 40 °C and humidity levels fluctuating between 56% and 64%. The vegetation structure was characterized by a high seedling density and a sparse canopy, primarily dominated by monoculture crops. While these gardens provided limited cover, they offered foraging opportunities near the forest edge. Additionally, their proximity to suitable habitats facilitated the occasional presence of elephants.

Company Plantations

Company-managed plantations predominantly feature fruit-bearing species, such as guava, which contribute to agricultural output. However, certain regions within these plantations have experienced incursions by elephants, leading to subsequent damage to the cultivated areas. Despite this, the overall structural diversity of these plantations remains minimal, thereby limiting their habitat value. The predominance of monoculture practices, combined with human-induced disturbances, significantly diminishes the ecological functionality

of these environments for elephants.

Habitat Suitability Classification

According to the classification criteria established by Akbar et al. (2023) and the Agglomerative Hierarchical Cluster (AHC) analysis, the 70 sampling plots were categorized into three habitat types. Specifically, 23 plots were classified as suitable, 17 as moderately suitable, and 30 as less suitable, as illustrated in Figure 3. Suitable and moderately suitable plots were primarily found in lowland forests and residential gardens, whereas less suitable plots were predominantly situated in shrubland and plantation areas.

Moderate temperatures, gentle slopes, abundant canopy cover, and proximity to water characterize the habitat of elephants. These conditions fulfill the essential needs of elephants, providing spaces for feeding, resting, and social interaction. Areas deemed moderately suitable still offered some of these features; however, they often lacked consistent water availability or dense vegetation. In contrast, less suitable areas tended to be open and arid, located far from water sources, and provided limited cover or food, making them ineffective for elephants. Detailed criteria for this classification are presented in Table 1.

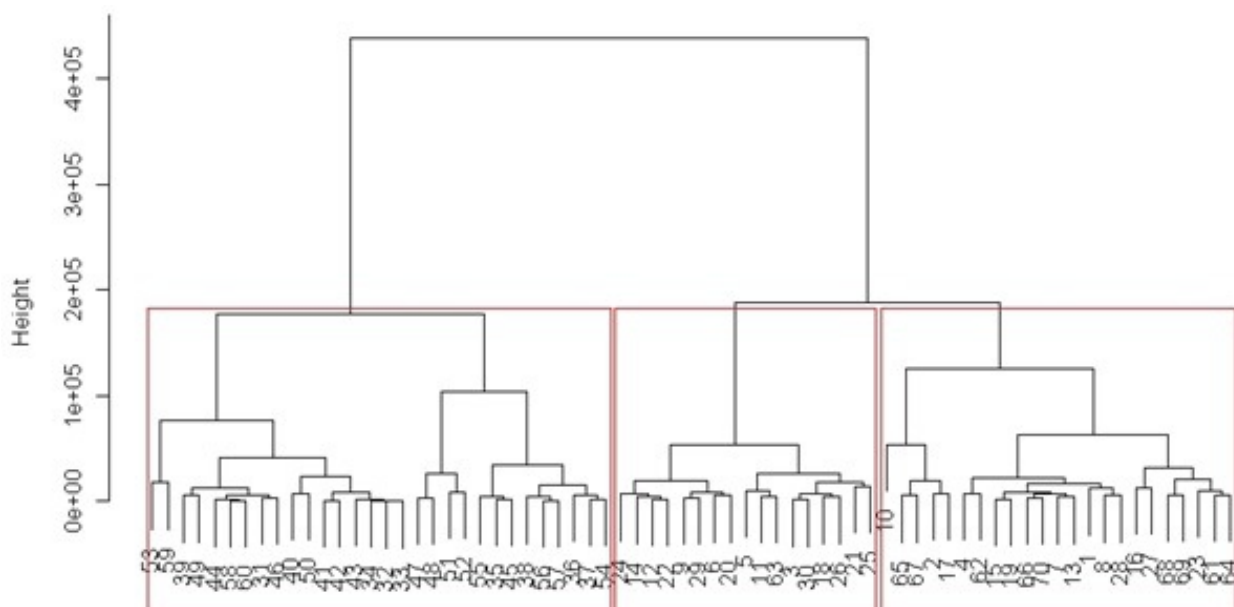


Figure 3. Cluster Analysis Dendrogram for suitability plots of Sumatran elephant habitat

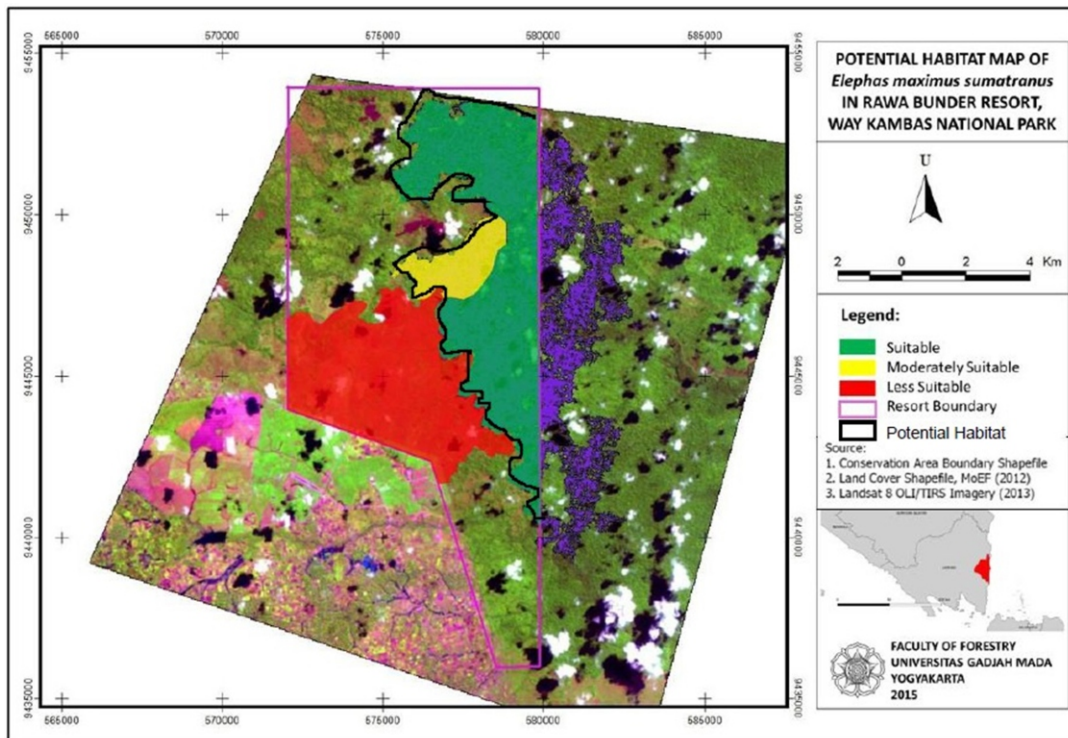


Figure 4. Potential habitat map for Sumatran elephant in Rawa Bunder Resort, WKNP

Potential Habitat Distribution

The spatial analysis indicated that suitable and moderately suitable habitats were predominantly located near lowland forests within core areas and in transitional zones adjacent to buffer areas. The landscape was primarily characterized by less suitable habitats, particularly in degraded shrublands and regions bordering plantations. Field observations corroborated the presence of elephants, as evidenced by tracks and dung explicitly found in lowland forest plots. Additionally, a suspected elephant resting site was identified within a shaded area of the forest.

Seasonal water availability, particularly during the dry season, posed a significant limitation in various parts of the landscape (Mandal & Das Chatterjee 2021). While some rivers within the research area provided water year-round, temporary swamps during the rainy season served as crucial sources of water. The seasonal variation in habitat quality influenced elephant movement patterns and heightened the likelihood of conflict when these animals entered nearby residential or agricultural zones. These findings align with earlier research, which indicated that elephants typically prefer areas characterized by dense vegetation, gentle slopes, and reliable water access (Setiawan et al. 2021; Fikri et al. 2023). Despite shrub-

covered areas comprising a substantial portion of the landscape, their habitat value was limited unless enhanced through the planting of food species or other restoration initiatives. Improving these regions could significantly bolster the landscape's capacity to support elephant populations (Sukmantoro et al. 2019; Chaiyarat et al. 2022). Observations of elephants in residential gardens adjacent to the park further underscored the need for effective habitat management in buffer zones. Rehabilitating canals has contributed to improvements, but achieving further enhancements may require additional strategies. Implementing measures such as physical barriers, planting more elephant-friendly vegetation, and conducting routine maintenance can significantly help mitigate conflict. Figure 4 illustrates the distribution of various habitat types across the resort, providing a clear overview of the most suitable areas for each habitat type. This map serves as a valuable resource for guiding targeted conservation and habitat restoration efforts.

Conclusion

In conclusion, the insufficient habitat at Rawa Bunder Resort underscores the urgent need for

targeted management initiatives. Restoring lowland forests and enhancing the availability of vegetation that elephants rely on in shrub areas can create more space conducive to their habitation and safe movement. Additionally, improving habitat connectivity and ensuring reliable access to water resources will alleviate pressure on core areas, thereby contributing to a reduction in human-elephant conflict. These findings offer a spatially informed foundation for conservation planning and adaptive management within WKNP and other fragmented elephant habitats across Sumatra. Future research should investigate how seasonal fluctuations affect elephants' use of different habitat types, informing long-term conservation strategies. Furthermore, establishing continuous monitoring systems will yield vital data to support informed and adaptive management decisions. A deeper understanding of these temporal dynamics is crucial for ensuring that conservation actions are evidence-based, context-specific, and responsive to ecological changes over time. Lasting ecological outcomes and a shared commitment to conservation efforts also depend on sustained collaboration between conservation authorities and local communities.

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