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# Characteristics and habitat suitability of elephant forage plants in Datuk Gedang Wildlife Corridor, Jambi province, Indonesia

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## Abstract

**Importance of the work**: Conservation of elephant habitats is important for the remaining number of Sumatran elephants of which status is critically endangered. One conservation option is through the development of elephant corridors.
**Objectives**: To obtain information of elephant habitat characteristics and to predict habitat suitability of elephant forage plant growth in the Bukit Tigapuluh landscape.
**Materials & Methods**: Plots were determined based on the marks of elephant activity using a strip transect method. The vegetation characteristics of the elephant forage plants were analyzed by calculating an importance value index (IVI) and by predicting the habitat suitability using maximum entropy (MaxEnt) modeling.
**Results**: Six types of land cover were determined to represent the different land cover types as the habitats of elephants, specifically in the Datuk Gedang Wildlife Corridor (DGWC), with 125 species identified as food for elephants. The three families with the highest numbers of elephant forage were the *Moraceae*, *Euphorbiaceae* and *Aracaceae*. Parts of plants mostly consumed by elephants were the leaves (around 41.6%) and all parts (about 14.4%). The highest number of plants identified as food for elephants were in the secondary forests. Around 94.5% of the DGWC area was suitable for the growth of elephant forage plants.
**Main finding**: The various types of land cover in the DGWC had high levels of diversity, density and dominance and large areas, with much of the corridor being highly suitable for growing plant species suitable as forage for elephants. Enrichment planting needed to focus on the rubber plantations, industrial forest areas and open spaces.

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## Introduction

The elephant is the largest surviving land mammal that has existed since ancient times, with two species recognized: the African elephant (*Loxodonta africana*) and the Asian elephant (*Elephas maximus*) (Shoshani and Eisenberg, 1982; Roca et al., 2015). The Sumatran elephant (*Elephas maximus sumatranus*) is one of the sub-species of the existing Asian elephants living on Sumatra Island (Gerhardt et al., 2014; Nofinska et al., 2019). It is a key species whose status is critically endangered and recorded on the *IUCN Red List of Threatened Species* 2020 due to population decline (Williams et al., 2020). In 1985, the population of Sumatran elephants was about 4,800 individuals (Blouch and Simbolon, 1985), which had sharply decreased to 2,400–2,800 individuals by 2007 (Azmi and Gunaryadi, 2011). By 2017 the population had continued to decrease to 1,694–2,038 individuals (Ministry of Environment and Forestry, 2020; Ardiantiono et al., 2021).

Changing forest cover suitable as habitat for elephants is the main factor of the declining of elephant population in Sumatra Island, with the changes mostly caused by human migration, the expansion of industrial plantations and the development of residential areas and infrastructure; furthermore, changes in forest areas to other functions decreases the availability of forage in elephant habitat and causes habitat fragmentation (Naha et al., 2019; Poor et al., 2019). Consequently, the remaining herds are forced to move to smaller habitats with less food supply. Some scholars have reported that Sumatran elephants consume at least 273 species of plants and require 50–95 species of food plants/d (Joshi and Singh, 2008; Sitompul et al., 2011; Meytasari et al., 2014). An adult elephant needs to consume 200–300 kg/day (Sitompul et al., 2011). Therefore, insufficient food availability in their natural habitat will trigger crop raiding and exacerbate human-elephant conflicts (HECs) that are usually resolved by killing or trapping the elephants involved (Anand and Radhakrishna, 2017; Kuswanda et al., 2021).

Conservation of elephant habitats is important for the remaining number of Sumatran elephants, with one option being through the development of elephant corridors. Corridor development connects the fragmented habitats and consists of many types of land use designated to improve elephant home range, particularly during their migration period (Kuswanda et al., 2022).

Bukit Tigapuluh Landscape (BTL) in Tebo regency, Jambi province is one of the habitats of Sumatran elephants in Sumatra. The population of elephants in BTL is estimated at 90–120 individuals distributed over 61,591 ha of forest. The massive expansion of plantations in Tebo has caused the loss and fragmentation of elephant habitat and has threatened the remaining population. Therefore, in 2022, the Jambi Governor declared some areas of BTL in Jambi named the Datuk Gedang Wildlife Corridor (DGWC) for the protection of elephants by connecting fragmented habitats, as well as conserving the remaining elephants. “Datuk Gedang” is the name for elephants in the local language, which means “the big lord”. DGWC consists of many types of land use, including primary and secondary forests, plantations, shrubs and open areas.

A study on the vegetation characteristics of the DGWC is important in the evaluation of the availability of elephant forage plants in DGWC. Other studies of the vegetation characteristics of elephant habitat in Sumatra have been mainly conducted in conservation forest, such as in the Way Kambas National Park and the Gunung Leuser National Park (Nyhus et al., 2000; Hedges et al., 2005; Sugiyo et al., 2016; Collins, 2018), whereas studies of elephant habitat are still limited in different land use types, such as in BTL. To fill the research gap, the current study aimed to obtain information on the characteristics of and habitat suitability for elephant forage plants in BTL, Jambi province. This study is important as it could provide recommendations on the plants that are suitable to be developed in the habitat enrichment program to mitigate HECs.

## Materials and Methods

### *Study sites*

BTL is located in several areas and provinces on Sumatra Island, including in Tebo regency, Jambi province. Geographically, BTL is located between 0°52’32”S and 1°54’50”S and between 101°48’57”E and 102°49’17”E, with an area of 646,100 ha. The remaining elephant habitat covers 61,591ha (Natural Resource Conservation Institute of Jambi or BKSDA of Jambi, 2020). The research was conducted from June to November 2022. The location is presented in Fig. 1.

### *Data collection*

The determination of research plots in the different land cover types of the DGWC followed a purposive sampling method, based on the marks of elephant activity, such as footprints, food residue, dung and track marks. The plots for obtaining the importance value index (IVI) of vegetation, including the plants consumed by elephants, were installed based on a strip transect method (Alatar *et al.,* 2012; Kuswanda and Sunandar, 2019), where the number and size of plots were determined based on different proportionate levels of plant growth. The plot size for the understorey level (grass, shrubs and herbs) was 1 m × 1 m, at the seedling level was 2 m × 2 m and at the sapling level was 5 m × 5 m (Mandal and Joshi, 2014; Kuswanda and Sunandar, 2019). Sample plots were created to represent the various land cover types in the DGWC, as shown in Fig.1. Determination of the number of sample plots for each land cover type was based on the minimum species-area curve (McGuinness, 1984). In total there were 145 plots on six types of land cover, which consisted of 65 plots for saplings, 65 for seedlings and 15 for understorey. The number of sample plots in each class differed because of species variety differences and the minimum species-area curve of the land cover types.

Data collection started with the identification of the plants and parts of plants consumed by elephants. This was conducted by observing tame elephants foraging in the research site (DGWC). The tame elephants belonged to the BKSDA of Jambi and were from the nearby Elephant Conservation and Training Center. In addition, elephant forage plants were identified by observing the marks from wild elephant activity in the DCWC, interviewing the elephant shepherds (mahouts) and local people and by collecting data from reports and the literature. After drawing up the list of plants consumed by elephants, the next step was identification of the plants in the research plots and recording their local and botanical names. The identification process in the field involved the mahouts and indigenous people who used the forests and recognized the plants. Then, samples of these forage plants were collected and sent to the Bogor Botanical Garden Herbarium and the Bogoriense Herbarium for botanical identification. There, botanists used World Flora Online to verify the botanical names of the forage plants.

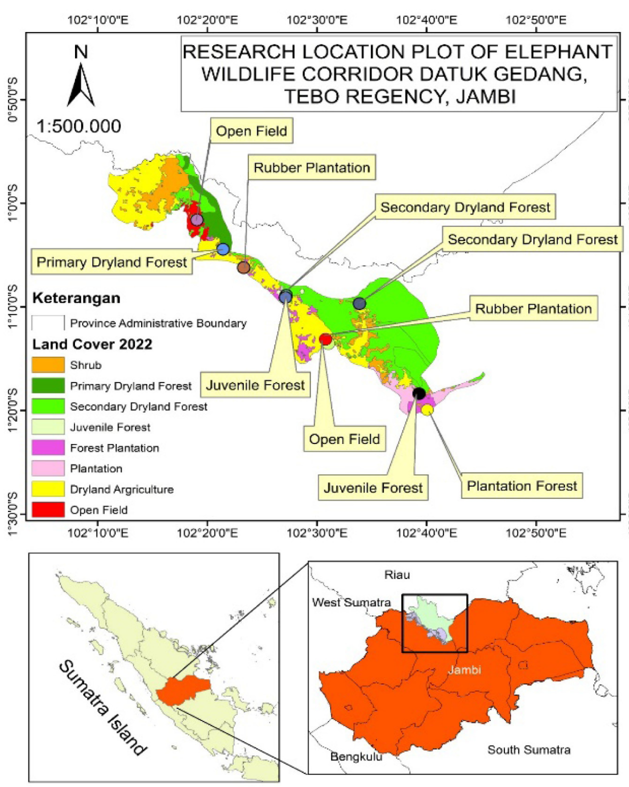


**Fig. 1** Research plot distribution with different land cover types

The database of the locations of individual species utilized geospatial data, such as the coordinates (longitude and latitude) of the samples (Phillips et al., 2006). Each sample was recorded to an accuracy level of 1 km$^2$ for consistency with the resolution of other environmental data used in the analysis. The environmental layer and biophysical information were used to predict suitable areas for the growth of each species of elephant forage plants and to predict their distribution (Saputra and Lee, 2021). Environmental data were obtained from the www.worldclim.com website which provides a climate package consisting of 19 environmental variables: annual mean temperature, mean diurnal range, isothermality, temperature seasonality, max temperature of warmest month, min temperature of coldest month, temperature annual range, mean temperature of wettest quarter, mean temperature of driest quarter, mean temperature of warmest quarter, mean temperature of coldest quarter, annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation seasonality, precipitation of wettest quarter, precipitation of driest quarter, precipitation of warmest quarter and precipitation of coldest quarter (WorldClim, 2020). The biophysical information consisted of elevation and land cover types. However, due to the large number of plant species consumed by the elephants, modelling only considered the suitability of plant growth and the distribution of the dominant species for each growth level.

## *Data analysis*

The vegetation characteristics analyzed were: the vegetation density, frequency, IVI, diversity index (H') and abundance index (N) of each vegetation growth stage (understorey, seeding and sapling). The IVI analysis was obtained from the sum of the relative densities of plants and their relative frequency (Mandal and Joshi, 2014; Alikodra, 2019). The diversity index of the vegetation covering forage plants was calculated using the formula for the the Shannon and Weiner index promoted since 1963 (Alatar *et al.,* 2012). The criteria to confirm the levels of vegetation figures referred to Barbour *et al.* (1987), where H' <1 was categorized as very low, H' >1–2 was low, H' >2–3 was moderate, H' >3–4 was high and H' >4 was very high. The abundance index was obtained by following the formula of Hill (1973). From these criteria, the IVI result was used to represent the dominance of species in the DGWC for further analysis, which involved prediction of the growth suitability of plants and their distribution.

The suitability growth and the distribution of elephant forage plants in the different types of land cover were analyzed using the maximum entropy (MaxEnt) model based on the occurrence data of a species and the environmental variables suitable for the species to exist (Phillips and Dudik, 2008). Maxent is based on a machine learning program that utilizes several layers to calculate the probability of suitability for each species across the research area (Phillips et al., 2004; Elith et al., 2011). Model validation uses the receiver operating characteristic (ROC) graph that produces an area under the curve (AUC) value, where an AUC value greater than 0.5 indicates a reliable high precision that is sufficient for modelling analysis (Saputra and Lee, 2021). The MaxEnt system displays the omission rate in the statistics as an indication of model performance. The Omission and Predicted Area plot consists of three lines. The first line is omission based on training samples showing the fractions of the presence points located outside the potential area as modelled by Maxent from low to high threshold values limiting the predicted area of occurrence (the cumulative threshold). Training samples are synonymous with presence points. The second line is fraction of background predicted, showing the fractions of background points from the study area included in the modelled distribution area under varying cumulative thresholds. The third line is predicted omission which is a reference line (Scheldeman and van Zonneveld, 2010). Based on the observations, as the sample line gets closer to the predicted omission line, this indicates that the model is likely to be overfitting or overly focused on the data used to train the model, resulting in errors when the model is used on unseen data. This is supported by Merow et al. (2013) who stated that when the sample line deviates further from the predicted omission line, it can be interpreted as a lack of sample findings, whereas if the other lines approach the predicted omission line, it can be said that the data source is improving.

MaxEnt applies a jackknife test to assess the importance of the predictor variables used in the model, which assesses the performance and importance of each variable in explaining the distribution of species. A jackknife test is also used to determine the unique information contributed by each variable. The jackknife test runs through removing one variable at a time while running the model. The least influential variable among the remaining ones is subsequently eliminated from further models. This process is repeated until only a single variable remains (Baldwin, 2009).

Then, the Maxent result was projected using the ArcMap 10.4 software to describe the distribution and the suitability of plant growth based on the plant classes. Suitability growth was classified based on the land typology and environmental factors, with a score of 0.0–0.4 classified as not suitable, while greater than 0.4 was classified as a suitable area (Saputra and Lee, 2021).

## Results and Discussion

### *Description of different types of land cover in Datuk Gedang Wildlife Corridor*

Six types of land cover were described to represent the DGWC as habitats of elephants in Tebo regency. The primary, secondary, juvenile and industrial forests were grouped as forest and two others (rubber plantation and open land) were grouped as non-forest. Primary forest in the DGWC was located in the restoration area of the Alam Bukit Tigapuluh (ABT) Company with an area of 3,198.74 ha, containing several large tree species that are economically valuable to humans. The secondary forest was in the concession area of ABT that had been logged around 20 yr ago, having an area of 25,476.98 ha with natural regeneration that had been protected from illegal occupation and illegal logging. The juvenile or young forest (144.27 ha) contained newly regenerated plants, dominated by seedlings and saplings, with the dominant plants being *Macaranga* sp. and other pioneer plants. Juvenile forests are usually found in logged-over forests and clearing areas.

The industrial forest plantation was in the concession of the Wira Karya Sakti (WKS) Company planted with *Eucalyptus* sp. and *Acacia* sp. This type covered 3,140.47 ha in the DGWC area which was not managed intensively by the company. The rubber plantations delineated in the DGWC area was concession area of the Lestari Asri Jaya (LAJ) Company that had been abandoned for elephant habitat (2,812.00 ha). The open land areas (1,717.47 ha) legally belonged to plantation and industrial forest companies in Tebo. However, they had been cleared by local people for plantation and agriculture that was later abandoned due to illegal occupation and tenure conflicts. The open areas were dominated by grass and shrubs.

### *Characteristics of elephant forage plants*

Vegetation analysis from the measurement plots on the six land cover types successfully identified 189 species of plants in elephant habitat in the DGWC. The plants were grouped into 55 families. From the 189 plant species, 125 were identified as suitable for elephant food. There were 98 species in the seedling and understorey classes, with 64 species in the sapling class. Most of the plants were in the families *Moraceae* (12 species), *Euphorbiaceae* (10 species) and *Aracaceae* (9 species).

Elephants consume a large number of different plant species (around 273 plant species in total with around 50–95 species/d). Elephants can consume all the parts plants, such as the leaves, fruit, bark, trunk and roots. However, they are selective in their choice to fulfill their daily diet and the requirements in different growth periods. Therefore, the different types of habitat and vegetation cover can influence their feeding behavior. However, due to the large number of available edible plants, it was difficult to formulate the favorable species to enrich their habitats, including in the DGWC (Sitompul et al., 2011). Fig. 2 provides the number of species and parts of plants that are consumed by elephants.

The parts of plants most commonly consumed by elephants were leaves (preferably young leaves) amounting to 41.6%, a combination of leaves and bark (15.2%) and all parts of the plant (usually herbs and shrubs) amounting to 14.4%. In general, elephants consume more leaves and bark, while other parts are eaten in medium amounts include the roots, fruits and the "Umbut", which is the soft, white part of the base of leaves or stems which is commonly found in pandanus and rattan species (Kuswanda et al., 2021). The different parts of the plants consumed by elephants depend on the season that influences the availability of food in their natural habitat (Eltringham, 1982). In the rainy season, elephants mostly consume grasses and shrubs, while in the dry season, they consume young leaves and browse along river areas (Sukumar, 1989).

The characteristics of the forage plants in the different land cover types were evaluated to help understand the habitat of elephants in the DGWC based on the availability of elephant forage plants. The habitat characteristics in the different land cover types in the DGWC are presented in Table 1.

Based on the total number of species, the highest number of plants used as food by elephants was in secondary forest (36 species at seedling and understorey levels and 31 species at sapling level). Based on the density value, the open areas had the highest density (167,333 individuals/ha). Secondary forest had the highest diversity of forage plants at all growth levels compared to the other cover types, such as primary forest, young forest and plantations because the secondary forest had a variety of canopy cover that possibly provided different layers of plants that could adapt and grow. Modest sun exposure could still support the growth of forage plants in the seedling and understorey classes, whereas in the primary forest the high canopy cover limited the growth of seedling plants (Dupuy and Chazdon, 2008). The previously cleared plantation area before it was allocated to the elephant corridor had a decreased species number. The open areas had the highest score based on the density index of all the land cover types. The high value for the density index in open areas may have been influenced by the high sunlight exposure compared to the other land cover types. Increasing sun exposure can support the fast growth of plants, particularly small plants, which would also increase the density index.

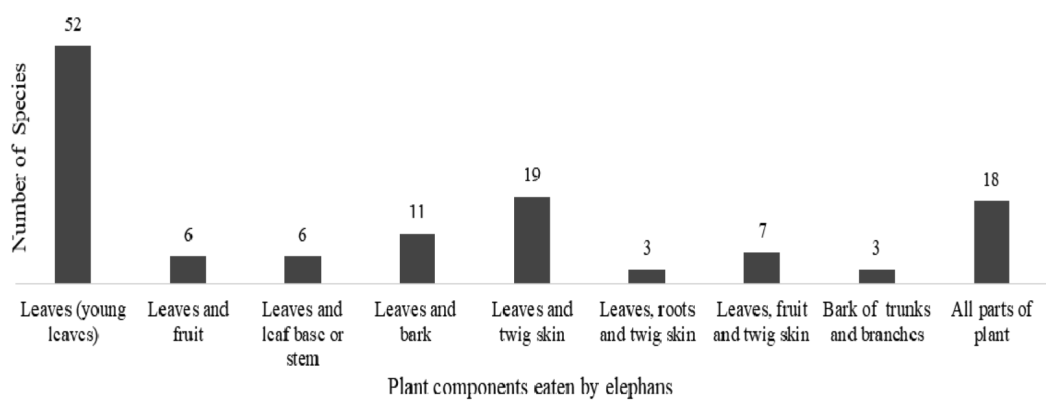


**Fig. 2** Number of plant species of which each plant part was consumed by elephants.

**Table 1** Characteristics of elephant forage plants for different growth levels and land cover types

| Land cover | Growth level | Total species | Density (individuals/ ha) | Frequency | Diversity index | Abundance index |
|---|---|---|---|---|---|---|
| Primary forest | Seedling and understorey | 29 | 23,250 | 4.8 | 2.71 | 31.87 |
| | Sapling | 20 | 2,160 | 3.3 | 2.54 | 22.74 |
| Secondary forest | Seedling and understorey | 36 | 31,667 | 5.0 | 2.68 | 38.82 |
| | Sapling | 31 | 2,587 | 3.4 | 2.42 | 33.53 |
| Young forest | Seedling and understorey | 25 | 34,000 | 4.3 | 2.58 | 27.79 |
| | Sapling | 20 | 2,453 | 2.7 | 2.21 | 22.40 |
| Rubber plantation | Seedling and understorey | 17 | 36,000 | 3.9 | 2.08 | 19.27 |
| | Sapling | 11 | 2,240 | 2.1 | 2.11 | 13.38 |
| Industrial plantation forest | Seedling and understorey | 20 | 51,750 | 6.4 | 2.54 | 22.77 |
| | Sapling | 9 | 2,040 | 2.7 | 1.66 | 10.88 |
| Open land (shrubs) | Seedling and understorey | 34 | 167,333 | 5.5 | 2.91 | 37.09 |

### *Importance value index of elephant forage plants*

The results of the vegetation analysis of the different land cover types were used to determine the IVI to evaluate the dominance of elephant forage plants in a particular area in their habitat. The IVI results for each land cover are discussed below.

### *Importance value index in primary and secondary forest*

The IVI values of the dominant elephant food plants in primary and secondary forests are provided in Table 2.

At the seedling and understorey levels, *P. pubinerve* was dominant in the secondary and primary forests, followed by *C. manan* in the primary forest and *N. cordifolia* in the secondary forest. Diana et al. (2021) reported that *P. pubinerve* is dominant because it is a type of vine that can grow quickly and climb trees access more light for growth. At the sapling level, *Cinnamomum sintoc* and *Sterculia longifolia* Vent were the most common in the research area, with *C. sintoc having* the highest IVI. Kuswanda and Barus (2019) reported that in the Bukit Tigapuluh National Park (BTNP) that was close to the current research area *C. sintoc* and *P. pubinerve* were the dominant plants.

Primary and secondary forests usually have a role as buffer zones to national parks to protect and conserve many species of wildlife, such as orangutan, bear, Sumatran tiger and elephants living in the national parks (Kuswanda and Barus, 2019). However, in BTNP, which is a part of the Sumatran elephant habitat in Tebo, few elephants are found in this national park because of it is hilly with steep contours, making it difficult for elephants to access (Sukumar, 2003). In this region, elephants mostly browse the flatters areas of the buffer zones which now have been mostly utilized by humans for plantation, both legally and illegally. This situation has driven HECs (Kuswanda et al., 2022), and the conflicts in and near the buffer zones of Bukit Tigapuluh National Park, such as in the Pemayungan, Semambu, Muara Sekalo, and Muara Kilis villages, have increased in the last 3 yr (BKSDA of Jambi, 2020). Hence, determination of the DGWC that includes many types of land cover aims to reduce HECs in Tebo.

**Table 2** Importance value index (IVI) of three species of elephant forage with highest number of plants in primary and secondary forests

| Land cover | Growth level | Scientific name | D (individuals/ha) | F | RD (%) | RF (%) | IVI (%) |
|---|---|---|---|---|---|---|---|
| Primary Forest | Seedling and understory | *Phrynium pubinerve* Blume | 2,750 | 0.4 | 9.48 | 6.67 | 16.15 |
| | | *Calamus manan* Miq. | 2,000 | 0.5 | 6.90 | 8.33 | 15.23 |
| | | *Clidemia hirta* (L.) D.Don | 2,000 | 0.4 | 6.90 | 6.67 | 13.56 |
| | Sapling | *Ochanostachys amentacea* Mast. | 280 | 0.4 | 11.11 | 10.26 | 21.37 |
| | | *Cinnamomum sintoc* Blume | 240 | 0.3 | 9.52 | 7.69 | 17.22 |
| | | *Eugenia fastigiata* (Blume) Koord. & Valeton | 200 | 0.3 | 7.94 | 7.69 | 15.63 |
| Secondary forest | Seedling and understory | *Phrynium pubinerve* Blume | 5,000 | 0.5 | 12.10 | 6.99 | 19.09 |
| | | *Nephrolepis cordifolia* (L.) C.Presl | 2,833 | 0.5 | 6.85 | 6.99 | 13.84 |
| | | *Etlingera megalocheilos* (Griff.) A.D.Poulsen | 2,833 | 0.4 | 6.85 | 5.99 | 12.85 |
| | Sapling | *Cinnamomum sintoc* Blume | 373 | 0.3 | 9.46 | 6.33 | 15.78 |
| | | *Sterculia longifolia* Vent. | 187 | 0.2 | 4.73 | 3.80 | 8.52 |
| | | *Streblus elongatus* (Miq.) Corner | 133 | 0.2 | 3.38 | 3.80 | 7.17 |

D = Density; F = Frequency; RD = Relative density; RF = Relative frequency

*Importance value index in young or juvenile forest and open areas*

In young forest and open area, the three dominant species of elephant forage plants in different growth levels are presented in Table 3.

In young forest, *Clidemia hirta* and *Etlingera megalocheilos* were dominant at the seedling and understorey levels, while at sapling level, the dominant plants were *Macaranga lowii* and *Mallotus mollissimus*. *M. lowii* dominated the young forest area possibly because it is a pioneer plant on the newly covered areas (Sancayaningsih and Bait, 2015; Jotan et al., 2020). In the open areas of the study site, vegetation analysis was conducted in the areas that have been abandoned for 1 yr or more. The plants in the open areas were only at the seedling and understorey stages, with many areas growing grasses and shrubs. Based on the IVI analysis, the dominant elephant forage plants were *Scleria sumatrensis, Austroeupatorium inulifolium* and *Mikania micrantha*. These three species are highly tolerant to full sun exposure. *S. sumatrensis* is also commonly found in oil palm plantations near the research area, with the farmers considering this plant as a weed that needs to be cleared. *M. micrantha* is a vine that is easily found in agriculture and plantation areas in Tebo. In the open areas, the newly established plants that grow quickly can produce new leaves and soft stems, which contain more water and fibre that are favourable to elephants.

*Importance value index in rubber plantation and industrial forest plantation areas*

The IVI analysis in the rubber plantation and industrial forest plantation areas is presented in Table 4. *M. lowii* dominated the rubber plantation areas because these areas had been abandoned for years. Many of the rubber trees had died in the plantation, resulting in a rapid increase in the growth of undergrowth plants and vines. Furthermore, in the industrial forest areas, the dominant forage plants at the seedling and understorey levels were *C. hirta,* and *Melastoma malabathricum*, while at the sapling stage, *Eucalyptus pellita* and *Acacia mangium* Willd were dominant. The leaves and bark of *A. mangium* are favorable to elephants (Fadillah et al., 2014).

**Table 3** Importance value index (IVI) of three species of elephant forage with highest number of plants in young forest and opened land

| Land cover | Growth level | Scientific name | D (individuals/ha) | F | RD (%) | RF (%) | IVI (%) |
|---|---|---|---|---|---|---|---|
| Young forest | Seedling and understorey | *Clidemia hirta* (L.) D.Don) | 5,833 | 0.7 | 15.56 | 13.52 | 29.08 |
| | | *Etlingera megalocheilos* (Griff.) A.D.Poulsen | 7,333 | 0.4 | 19.56 | 8.11 | 27.67 |
| | | *Mallotus mollissimus* (Geiseler) Airy Shaw | 3,500 | 0.4 | 9.33 | 8.11 | 17.45 |
| | Sapling | *Macaranga lowii* King ex Hook.f. | 1,067 | 0.6 | 38.46 | 18.02 | 56.48 |
| | | *Mallotus mollissimus* (Geiseler) Airy Shaw | 341 | 0.3 | 12.50 | 8.01 | 20.51 |
| | | *Cratoxylum sumatranum* (Jack) Blume | 160 | 0.3 | 5.77 | 10.01 | 15.78 |
| Opened Land | Seedling and understorey | *Scleria sumatrensis* Retz. | 24,000 | 0.5 | 12.41 | 7.29 | 19.71 |
| | | *Austroeupatorium inulifolium* (Kunth) | 15,333 | 0.5 | 7.93 | 8.33 | 16.26 |
| | | *Mikania micrantha* Kunth | 12,000 | 0.3 | 6.21 | 5.21 | 11.42 |

D = Density; F = Frequency; RD = Relative density; RF = Relative frequency

**Table 4** Importance value index (IVI) of three species of elephant forage with highest number of plants in rubber plantation and industrial forest plantation

| Land cover | Growth level | Scientific name | D (individuals/ha) | F | RD (%) | RF (%) | IVI (%) |
|---|---|---|---|---|---|---|---|
| Rubber plantation | Seedling and understorey | *Scleria sumatrensis* Retz. | 7,167 | 0.7 | 15.21 | 14.29 | 29.50 |
| | | *Clidemia hirta* (L.) D.Don | 7,500. | 0.6 | 15.92 | 11.69 | 27.61 |
| | | *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. | 4,167 | 0.3 | 8.84 | 6.49 | 15.34 |
| | Sapling | *Macaranga lowii* King ex Hook.f. | 600 | 0.5 | 26.79 | 23.81 | 50.60 |
| | | *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg. | 520 | 0.4 | 23.21 | 19.05 | 42.26 |
| | | *Mallotus paniculatus* (Lam.) Müll.Arg. | 320 | 0.3 | 14.29 | 14.29 | 28.57 |
| Industrial Forest | Seedling and understorey | *Clidemia hirta* (L.) D.Don | 10,750 | 0.9 | 19.46 | 12.86 | 32.31 |
| | | *Melastoma malabathricum* L. | 5,750 | 0.8 | 10.41 | 11.43 | 21.84 |
| | | *Etlingera megalocheilos* (Griff.) A.D.Poulsen | 5,500 | 0.7 | 9.95 | 10.00 | 19.95 |
| | Sapling | *Eucalyptus pellita* F.Muell. | 920 | 1.0 | 45.10 | 37.04 | 82.14 |
| | | *Acacia mangium* Willd | 560 | 0.8 | 27.45 | 29.63 | 57.08 |
| | | *Mallotus paniculatus* (Lam.) Müll.Arg. | 120 | 0.2 | 5.88 | 7.41 | 13.29 |

D = Density; F = Frequency; RD = Relative density; RF = Relative frequency

*Habitat suitability and distribution of elephant forage plants in Datuk Gedang Wildlife Corridor*

Prediction of the distribution and habitat suitability of elephant forage plants was first prepared by recording the number of species found in the plots that were used for vegetation characteristic analysis. All the variables were used as input to the MaxEnt software and a further process was used to validate the model based on the ROC graph in the software and on the AUC values. Eight species of dominant plants based on the IVI test from all the land cover types were selected to be inserted in the model. The results of the AUC for the ROC graph is presented in Table 5.

The results showed that the AUC values were the range 0.8–1.0. Based on the minimum AUC cut off value of 0.5, these results indicated that the distribution prediction using all variables (coordinate, land cover and climate factors) was reliable, with high precision in the modelling analysis. Furthermore, the estimation result for the suitable areas for overall elephant forage plants using MaxEnt are presented in Fig. 3.

The suitable areas are had a probability range of 0.4–1.0, with a probability value below 0.4 indicating that the area was not suitable for the growth of elephant forage plants. Fig. 3 shows that 94.5% of the DGWC area was suitable for the growth of forage plants. This result indicated that the geographical and climate factors of each land type were suitable for the growth of elephant feed in the DGWC.

The distribution was investigated of the growth area of the dominant forage plants of eight selected species. A jackknife test was applied to select the most important variable to run the model, which identified land cover was the most important variable for all tested species. The land cover is related to canopy cover, with the forest area having grater canopy cover compared to the opened and agriculture areas. The result of the MaxEnt analysis of the four species at the undergrowth level (*M. crenata, S. sumatrensis, A. inulifolium* and *P. pubenerve*) are presented in Fig. 4. The numbers of samples run in the model for those four species were 732, 721, 722 and 723, respectively.

The maps in Fig. 4 reveal that *M. crenata* and *P. pubenerve* were the most suitable undergrowth plants growing in the DGWC based on their suitability percentages of 54.46% for *M. crenata* and 56.19% for *P. pubenerve. S. sumatrensis* and *A. inulifolium* were less suitable, with values of only 29.15% and 12.00%, respectively. The low percentage of suitable areas for the growth of *S. sumatrensis* and *A. inulifolium* might have been influenced by canopy cover, since *S. sumatrensis* and

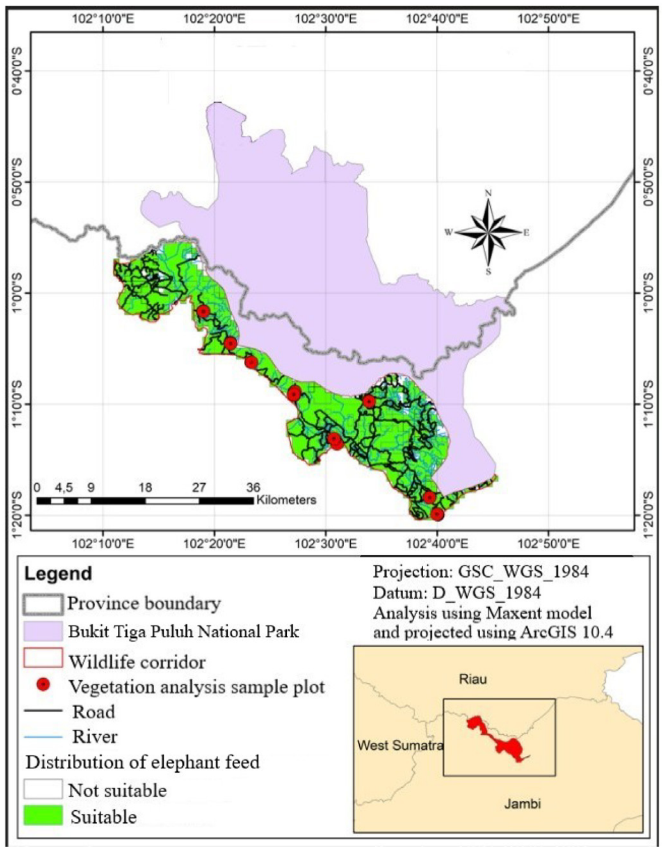


**Fig. 3** Habitat suitability for elephant forage plant growth in Datuk Gedang Wildlife Corridor

**Table 5** Area under the curve (AUC) values for elephant forage plants species distribution

| Vegetation class | Scientific name | AUC value |
|---|---|---|
| Understorey | *Miconia crenata* (Vahl) Michelang | 0.835 |
| | *Scleria sumatrensis* Retz. | 0.972 |
| | *Phrynium pubinerve* Blume | 0.834 |
| | *Austroeupatorium inulifolium* (Kunth) R.M.King | 0.974 |
| Seedling and sapling | *Ochanostachys amentacea* Mast. | 0.849 |
| | *Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg. | 0.965 |
| | *Beilschmiedia kunstleri* Gamble. | 0.822 |
| | *Lepisanthes amoena* (Hassk.) Leenh. | 0.953 |

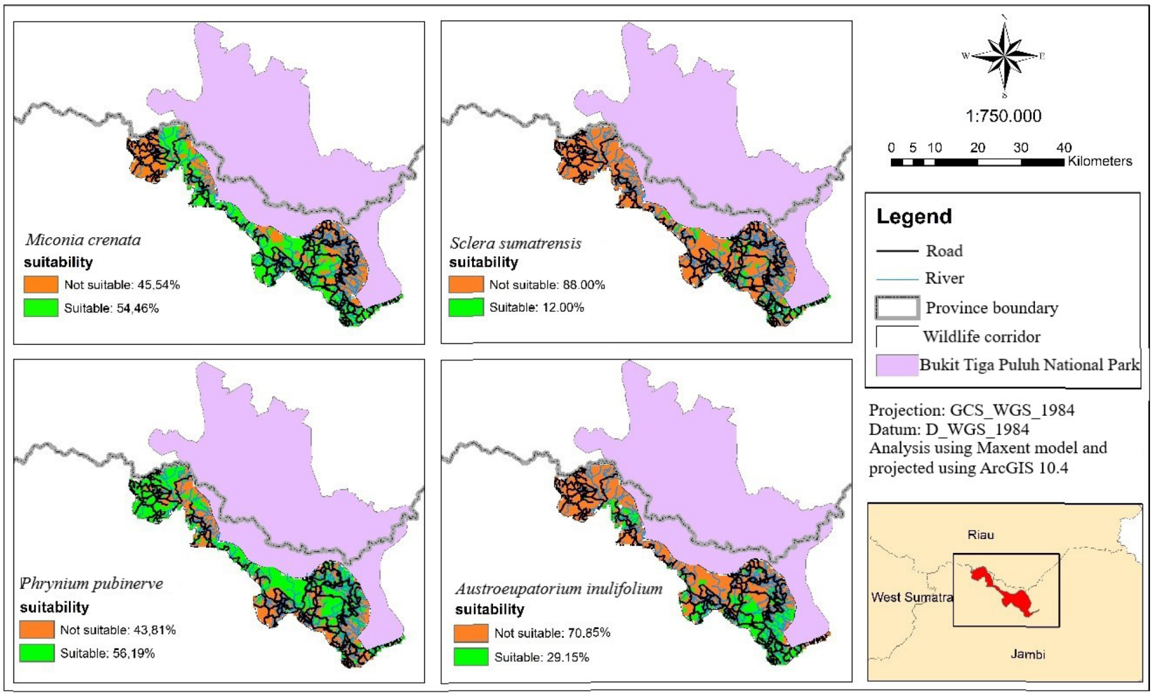


**Fig. 4** Habitat suitability of four dominant forage plants at understorey level

*A. inulifolium* were mostly distributed in the southeastern part of the DGWC, dominated by less cover (rubber plantation, open area and industrial plantations). These two species are more suited to areas with low canopy cover or high sun exposure. In contrast, *M. crenata* and *P. pubenerve* are more tolerant to low sun exposure and so were distributed across all types of land cover. This result was consistent with Purnomo et al. (2018), who mentioned a higher value of canopy cover reduces the number of undergrowth plants, and *vice versa*. *S. sumatrensis* needs a large amount of sunlight to grow (Wiguna et al., 2015), while only around 30% of the study area had less canopy cover that suited *S. sumatrensis* and *A. inulifolium*.

At the seedling and sapling growth levels, the four dominant species of elephant forage plants in the DGWC were *M. gigantea, B. kunstleri, O. amentaceae and L. amoena*. The number of plants of those species run in the analysis were 722, 723, 724 and 723, respectively. Based on the jackknife analysis, the land cover was again the most important variable for all species in the distribution prediction model. The distribution of growth suitability of the four plants is presented in Fig. 5.

*B. kunstleri* was identified as very suitable for growing in the DGWC, with a suitability percentage of 64.35%. The other three species were less suitable, with values lower than 40% across the study sites. For *O. amentaceae,* 34.49% of the DGWC area was identified as suitable, mostly distributed in primary forest. This result indicated that *O. amentaceae* was suitable for high canopy cover areas or those with low sun radiation. The two other plants, *M. gigantean* and *L. amoena,* were mostly distributed in open areas and secondary forest. Another study stated that *M. gigantean* needs full sun exposure and tends to be clumped (Latifah et al., 2020), with high temperature increasing the possibility of seeds germinating, as with *L. amoena* growth (Amirta et al., 2017). These environmental conditions increase the distribution of *M. gigantean* and *L. amoena* in more open and lowland areas. In the current site, these species were found on burnt areas.

Overall, the suitable areas for the plants in the sapling class were located in the plantation, young and secondary forest areas. The high suitability of the DGWC for the growth of forage plants at the sapling level was possibly caused by the land use and land cover changes there that had increased the canopy openness, along with the small variation in the annual precipitation that could be tolerated by plants at the sapling growth level. Most of the tropical sapling species have a higher correlation with the intensity of solar radiation and precipitation (Pamoengkas and Assifa, 2018).

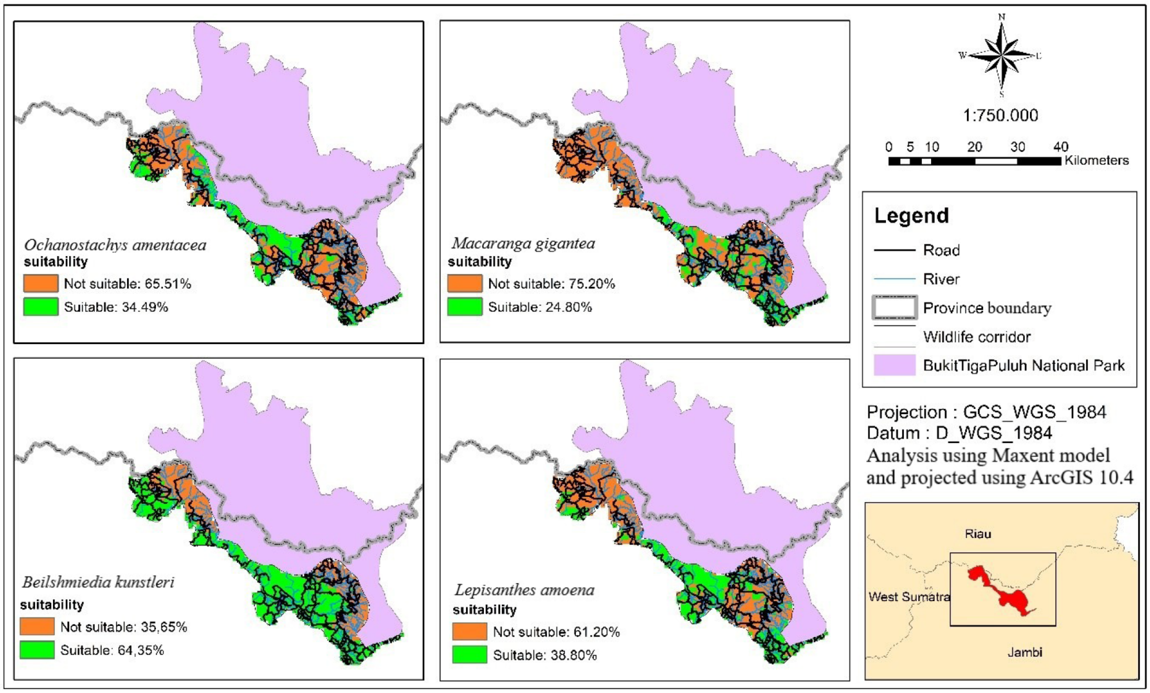


**Fig. 5** Habitat suitability of dominant elephant forage plants at sapling level

### *Implications from study for elephant conservation program*

The elephant habitat in the DGWC is very important for linking elephant meta-populations in the north and south of Sumatra Island (BKSDA of Jambi, 2020). If managed properly, the remaining habitats which have various types of land cover can support the conservation of Sumatran elephants. The forage vegetation in the DGWC can fulfil elephant food needs if barriers are reduced that result in human-elephant conflicts (Gunaryadi et al., 2017). Based on the current research findings, the following programs could be implemented to conserve elephants in the DGWC: 1) maintain the secondary and primary forests as sites to for the elephants to find food and shelter and as elephant hunting locations; 2) monitor the movement of elephants while foraging on open land areas because they are adjacent to human areas where there is a high likelihood of elephants being killed where they come into difect conflict with human settlement; 3) enrich elephant food species by replacing rubber plantation with *A. mangium* and *E. pellita* to increase the diversity of forage species in former plantation and concession areas designated as elephant corridors; and 4) plant forage species on suitable land to increase the carrying capacity of elephants. To minimize conflicts in the areas that are close to settlements and community plantations, local people need to be encouraged to grows plants that are disliked by elephants but have economic value to people.

## Conclusion

In total, 125 species of elephant forage plants were identified in the elephant corridor (DGWC), which represents one of the important habitats of the Sumatran elephant. The characteristics of this habitat were evaluated based on the availability of elephant forage plants. In the DGWC the secondary forest contained the greatest number of elephant forage species, while the densest coverage of these species was in opened areas. Plants from the families *Moraceae, Euphorbiaceae* and *Aracaceae* dominated the DGWC, based on the IVI test. Specifically, the results showed that *P. pubinerve*, *M. crenata, S. sumatrensis* and *A. inulifolium* were the most dominant plants at the understudy growth level, with *M. gigantea, B. kunstleri, O. amentaceae* and *L. amoena* at the seedling and sapling levels. Overall, 94.5% of the DGWC was identified as suitable for the growth of the 125 plants that were identified. However, of the eight dominant species, *P. pubinerve*, *M. crenata,* and *B. kunstleri* had high levels of suitability (above 50%). Differences in land cover could have a major effect on the vegetation characteristics of the elephant corridor.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

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