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Feeding and avoided plants of Sumatran elephants and their implications for human elephant conflict mitigation in a fragmented landscape, Bengkalis, Indonesia

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Abstract. *Yoza D, Saputra D, Mubarak, Metananda AA, Pebriandi, Darlis VV, Zulfahmi, Lubis A. 2026. Feeding and avoided plants of Sumatran elephants and their implications for human elephant conflict mitigation in a fragmented landscape, Bengkalis, Indonesia. Asian J For 10 (1): r100136. https://doi.org/10.13057/asianjfor/r100136.* Human-Elephant Conflict (HEC) is one of the most critical conservation challenges in Riau Province, Indonesia, driven primarily by rapid habitat fragmentation and agricultural expansion. Understanding feeding preferences and avoiding plant species of the Sumatran elephant (*Elephas maximus sumatranus*) is essential for developing evidence-based vegetation management strategies to mitigate conflict. This study was conducted in secondary forests and surrounding agricultural landscapes of the Balai Raja Wildlife Sanctuary, Pinggir Sub-district, Bengkalis District, Indonesia, during both the late dry and early rainy seasons. Vegetation surveys were conducted using systematic transects (500 m × 20 m) along identified elephant movement routes, complemented by semi-structured interviews with local communities and elephant handlers. Vegetation data were analyzed using density, frequency, dominance, Important Value Index (IVI), and Shannon-Wiener Diversity Index (H'). Feeding preference was quantified through direct observation of feeding signs and controlled observation of two tame elephants. Statistical differences in biomass consumption between preferred and non-preferred species were tested using the Mann-Whitney U test. A total of 15 species were consumed at the seedling level and 16 species at the sapling level, whereas 10 economically important plant species were identified as avoided by elephants. Poaceae, Cyperaceae, Euphorbiaceae, and Zingiberaceae dominated the consumed vegetation, particularly in shrub and secondary forest habitats. The Mann-Whitney U test showed a significant difference in biomass consumption between preferred and non-preferred species. These findings indicate that early-successional vegetation plays a critical role in sustaining Sumatran elephants in fragmented landscapes in Balai Raja. The identification of avoided crops, such as chili (*Capsicum annuum*), citrus (*Citrus* spp.), lemongrass (*Cymbopogon citratus*), and cocoa (*Theobroma cacao*), highlights opportunities for vegetation-based buffer strategies that provide both ecological and economic benefits. This study provides practical ecological evidence to support sustainable, landscape-level HEC mitigation planning in Balai Raja.

Keywords: Agricultural landscape, feeding preference, mitigation strategy, secondary forest, vegetation management

INTRODUCTION

The Sumatran elephant (*Elephas maximus sumatranus*) is one of the most endangered large mammals in Southeast Asia and is currently classified as Critically Endangered on the International Union for Conservation of Nature (IUCN) Red List. Over the past three generations, elephant populations have declined by more than 80%, primarily due to extensive habitat loss and fragmentation, and increasing human populations and associated pressures across the Sumatran lowland landscape (IUCN 2020; Sitompul et al. 2013). Rapid land-use change, driven by agricultural expansion, especially oil palm plantations, and infrastructure development, has eliminated more than two-thirds of the island of Sumatra's elephant-roaming area (Margono et al. 2014; Santika et al. 2017). Consequently, the remaining elephant population is increasingly limited to small, isolated habitat fragments within human-dominated landscapes (Yoza et al. 2019).

One of the most critical habitats of Sumatran elephants is the Balai Raja Wildlife Sanctuary in Bengkalis District, Riau, Indonesia. This area has undergone extensive land-use changes, with a large portion converted into plantations, agricultural land, and mining areas. Consequently, the elephant population in Balai Raja is increasingly susceptible, with frequent reports of crop damage and direct human encounters (Sukmantoro et al. 2019). The persistence of elephants in this fragmented landscape highlights the urgent need for site-specific ecological studies to inform management and mitigation strategies for elephant-human conflicts.

Originally designated as the Balai Raja Wildlife Sanctuary in 1986 with an area of approximately 18,000 ha, this landscape was intended to protect elephant habitats and associated biodiversity. However, land conversion has been uncontrolled since the 1970s, driven by oil exploration, timber plantations, oil palm expansion, and settlement development, resulting in the loss of most of the natural forest cover. At the beginning of the 2010s, less than 5% of the original reserve remained as degraded forest patches (WWF Indonesia 2018; Sukmantoro et al. 2019)

Consequently, the local elephant population has experienced a dramatic decline and fragmentation. After supporting many elephant groups, SM Balai Raja is now believed to house only one to two wild elephants or very small groups of remains, making it one of the most vulnerable elephant landscapes in Sumatra (WWF Indonesia 2019). The Pinggir Sub-district, which serves as a transition zone between residual forests, small-scale farms, and large-scale plantations, has become a focus area for repeated HEC incidents. Crop damage, destruction of houses built along elephant corridors, and occasional human casualties have been documented, contributing to the public's negative perception of elephant conservation (Abdullah et al. 2019; Yoza et al. 2022). This landscape is thus an important case study for understanding how elephants adapt to their foraging behavior in highly modified environments and how those adaptations affect the dynamics of elephant-human conflict

Understanding the ecology of elephant feeding is essential for effective conservation planning. Elephants are generalist herbivores with a wide range of dietary preferences; however, the selection of certain plant species greatly influences their movement patterns, habitat use, and possible conflicts with humans (Campos-Arceiz and Blake 2011). Identifying preferred and avoided vegetation species can provide valuable insights for designing vegetation-based mitigation strategies, such as planting support crops, habitat restoration, and land-use zoning (Berliani et al. 2018). Aligning vegetation composition with elephants' dietary preferences can help create designated foraging areas and reduce encroachment on agricultural lands, representing an applied ecological approach to mitigating human-wildlife conflict.

Despite the importance of feeding ecology, A notable gap remains in understanding elephant food preferences within secondary forests and plantation-dominated landscapes. Most previous research has focused on natural forests or semi-captive populations, leaving a limited understanding of how elephants adapt their foraging strategies to human-modified environments (Tohir 2018; Imtiyaaz et al. 2021). This gap is especially critical in areas such as Balai Raja, where elephants coexist with extensive agricultural and plantation systems and human settlements.

This study aimed to identify the diversity of plant species consumed and avoided by Sumatran elephants in the Balai Raja landscape and in the vicinity of the Pinggir Sub-district. By integrating ecological field data with local community knowledge, this study sought to provide a comprehensive understanding of elephants' feeding preferences and their implications for mitigating elephant–human conflicts. The study hypothesized that elephants selectively preferred higher-nutrient plant species and avoided those that were detrimental to them.

MATERIALS AND METHODS

Study area

This study was conducted at the Balai Raja Wildlife Sanctuary in Pinggir Sub-district and its surroundings, Bengkalis District, Riau Province, Indonesia (01°13′30"N, 101°12′38"E to 01°11′50"N, 101°14′59"E). Mosaics of secondary peat swamp forests, degraded lowland forests, oil palm plantations, rubber plantations, agricultural fields, and settlements characterize the land-use pattern of this area. The location's elevation ranges from 25 to 75 m above sea level, with a humid tropical climate and annual rainfall of 2,500-2,750 mm. The research location is shown in Figure 1.

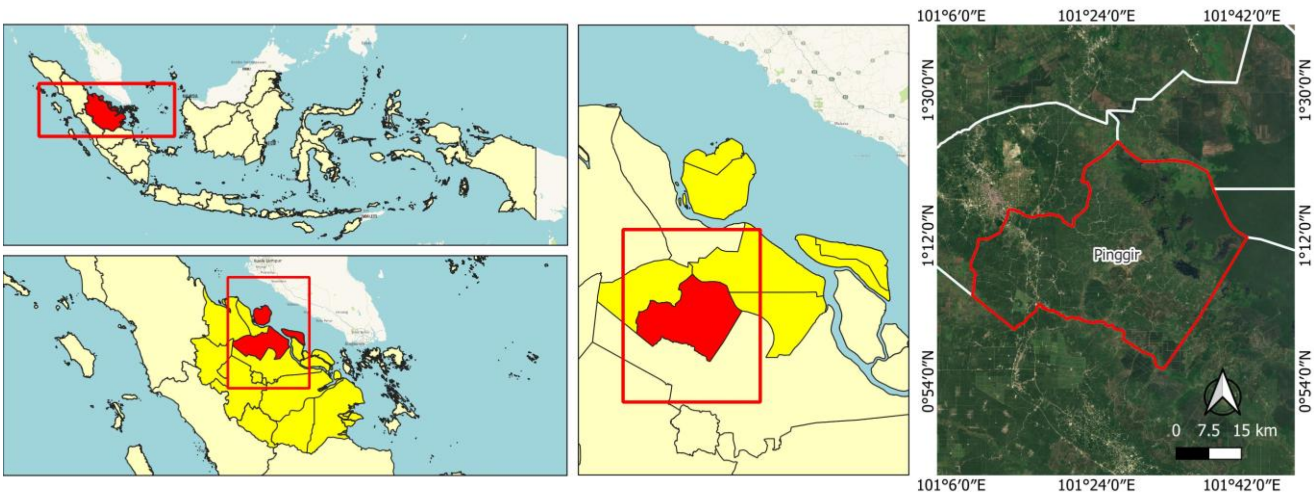

Figure 1. Map of research location in Balai Raja Wildlife Sanctuary, Pinggir Sub-district, Bengkalis District, Riau Province, Indonesia

Sampling design and justification

Fieldwork was conducted from May to September 2024, spanning the late dry season and the early rainy season. Transects were purposively placed along elephant roaming trails to ensure representative coverage of habitat types (secondary forests, plantations, agricultural land, and shrubs). Transect surveys were conducted along 40 km of transect lines, representing 10% of the total available transect network, and were selected based on elephant signs. The transects were divided into eight sections: three in secondary forests, two in shrubland, two in oil palm plantations, and one in mixed agricultural land. Each transect was 500 m long and 20 m wide, with an area of 1 ha.

Identification of elephant movement routes

Elephant locations were assessed using a combination of direct and indirect approaches. Direct detections were obtained through opportunistic visual observations of elephants. Indirect detections relied on systematic tracking and documentation of elephant signs, including footprints, dung piles, feeding signs, sleeping marks, rub marks, and evidence of crop raiding or barrier damage (e.g., broken fences and damaged oil palm trees) (Figures 2 and 3). Observations were conducted at 7-day intervals for each transect to ensure temporal independence between sampling events.

Vegetation sampling

Vegetation composition was recorded at the seedling, sapling, pole, and tree levels. The main categories included seedlings (height <150 cm), saplings (height >150 cm, diameter <10 cm), poles (diameter 10-20 cm), and trees (diameter >20 cm). Vegetation sampling was conducted along a 1 ha elephant path, purposively stratified by vegetation type and plotted in a line.

Feeding preference assessment

To identify types of elephant feed plants, the researchers observed elephant bite marks and vegetation remnants and interviewed elephant handlers about elephants' feed preferences. This research selected sample plot positions based on observations of feed-source locations and adjusted the number of sample plots to account for field conditions. The parameters of elephants' feeding preferences included the types of food most commonly eaten in each plot, the diversity of vegetation types in the feed, and the distribution of feed. For controlled feeding observations, two tame elephants were observed independently during 15 replicated observation sessions. In each session, the number of plant species consumed and the number of plant individuals damaged were recorded.

Interview methodology

Semi-structured interviews were conducted with 10 key informants: local farmers (n = 7), community leaders (n = 1), and elephant handlers (n = 2). The selection of informants was based on plantation ownership over 5 years and had experienced conflicts with elephants. Questions to informants generally include: (i) preferred crops, (ii) avoided crops, and (iii) perceived mitigation strategies.

Data analysis

Vegetation composition was analyzed using the Importance Value Index (IVI), calculated as the sum of relative density, relative dominance, and relative frequency. The most important value indices for tree and stand growth, and for seedling and sapling growth, were 300% and 200%, respectively (Purnama et al. 2019). Quantitative vegetation data were extracted from the vegetation analysis results to assess the potential of elephant feed at SM Balai Raja. The important value could thus be interpreted and classified into three groups: low, high, and very high (Rawana et al. 2022).

The feeding preferences of Sumatran elephants were determined through direct field observations using two parameters: the amount of food consumed and the amount of food waste. Feed preferences/palatability were determined by the difference between the initial and final weights of the elephant food. A Mann-Whitney U test was applied to compare consumption between preferred and non-preferred feed categories, and further tested using Jacobs Index.

Figure 2. Broken fences

Figure 3. Damaged oil palm tree

RESULTS AND DISCUSSION

Elephant distribution and habitat characteristics

Elephants were detected in secondary forests, oil palm and rubber plantations, bushlands, and agricultural areas in the Pinggir Sub-district, with indirect signs (tracks, dung, and fence damage) concentrated around ex-PT Chevron Pacific Indonesia/CPI (now Pertamina Hulu Rokan/PHR), Talang Forest, and PT Kojo's forest. The land cover types and estimated elephant habitat areas are shown in Table 1.

A land cover analysis revealed a fragmented mosaic at the study site, dominated by plantations and agriculture, secondary forests with varying canopy densities (high, medium, and low), and extensive underfloor/bush layers. The topography was mostly flat, with canals and small rivers, providing favorable conditions for elephant movement and access to water. The land cover analysis showed that oil palm plantations accounted for the largest proportion of elephant habitat (26.56%), followed by rubber plantations (9.18%), shrub (3.45%), and secondary forest mosaics with varying canopy densities (approximately 10%). Settlements and other land uses occupied more than 50% of the landscape, underscoring the habitat's fragmented nature. The distribution of elephant habitats around SM Balai Raja is shown in Table 2.

Field observations recorded multiple signs of elephant presence and conflict across several locations within the former ex-PT. CPI (PHR) concession area and surrounding landscapes. Evidence included elephant tracks, dung, and direct indicators of crop raiding and infrastructure damage. Signs of single elephants were detected at three sites within the ex-fence and access roads of ex PT. CPI (PHR) in the Duri area, as indicated by the presence of traces and dung, especially on flat topography characterized by secondary vegetation such as *Macaranga* spp. (mahang), *Pandanus* spp. (*mengkuang*), forest ginger, shrubs, and riparian plants. In contrast, more severe incidents of human-elephant conflict were documented in Area 7, the former CPI (PHR) concession, and in Pematang Pudu, where an elephant group damaged fences and the destruction of crops indicated the presence of more than three individuals. The location of this conflict is associated with agricultural mosaics; bananas, oil palms of various ages, rattan, *Imperata cylindrica*, and former subsistence farmland dominate it. Collectively, the spatial distribution of the findings suggests that solitary elephants tend to use flatter areas with semi-natural vegetation. In contrast, elephant groups are more often involved in conflicts in the modified agricultural landscape adjacent to the elephant movement corridor.

Composition of elephant feed types in each type of land cover

The composition of feed plants varied across land-cover types at the research site. This difference is due to variations in growing conditions, which can be influenced by factors such as temperature, humidity, and light. The composition of elephant feed plants across land cover types around SM Balai Raja is shown in Table 3.

Vegetation surveys recorded 1,292 individuals across three land-cover types, with bushlands contributing the highest counts (786), followed by secondary forests (435) and plantations (165). Poaceae, Cyperaceae, Asteraceae, and Zingiberaceae dominated open habitats, while Myrtaceae, Moraceae, and Euphorbiaceae were more abundant in secondary forests. Elephants consistently consumed grasses and sedges, particularly *Echinochloa colonum*, *I. cylindrica*, *Leersia hexandra*, and *Paspalum conjugatum*, as well as aromatic understory plants, including *Alpinia* and *Zingiber* species. In secondary forests, elephants consumed most of the growth of seedlings and saplings of *Syzygium*, *Macaranga*, *Artocarpus*, and *Vitex*. Meanwhile, in plantations, they relied on grasses and herbs and sometimes targeted palm oil spruce.

Table 1. Land cover at research sites and elephant habitat

Pinggir Sub-district			Elephant habitat		
Land cover	**Width (Acre)**	**Percentage**	**Land cover**	**Width (Acre)**	**Percentage**
Plantation forest	39.154,04	23%			
Open ground	8.905,02	5%			
Bush	869,661	1%		174,62	3,45
Plantation/farming	66.052,44	38%	Oil palm	1.343,32	26,56
			Rubber	464,63	9,18
Settlement	4.311,56	2%		671,17	13,27
Building				11,18	0,22
Secondary Swamp Forest	2.673,96	2%	PHR forests medium density	387,38	7,66
			Talang natural forest	79,69	1,58
			Kojo forest with low density	0,76	0,02
			Kojo forest with medium density	3,74	0,07
			Kojo forest with high density	61,67	1,22
Swamp bushes	7.601,24	4%			
Dryland agriculture	9.876,13	6%			
Mix Dryland agriculture	28.517,86	17%			
Mining	2.657,18	2%			
Swamp	2.049,23	1%			
Others				1.860,44	36,78
Total	172.668,32	100%		5.058,60	100%

Source: Badan Informasi Geospasial (2023)

Table 2. Distribution of elephant habitat around Balai Raja Wildlife Sanctuary, Bengkalis District, Riau Province, Indonesia

Location	Finding	Estimated number	Coordinate	Topography/vegetation
In the ex Fence of PT. CPI in the Duri area	Elephant tracks	An estimated 1 elephant (single elephant)	N 01^0 23' 20,7" E 101^0 12' 30,2"	Flat, vegetation consists of mahang, mengkuang, forest ginger (*Zingiber* sp.)
In addition, the area ex PT. CPI	Elephant dung	An estimated 1 elephant (single elephant)	N 01^0 22' 34,9" E 101^0 12' 26,5"	Flat, bush vegetation
In addition, the area ex PT. CPI	Elephant dung	An estimated 1 elephant (single elephant)	N 01^0 23' 17,7" E 101^0 12' 09,7"	Flat, mahang (*Macaranga griffithiana*), mengkuang (*Pandanus* sp.), anggrung (*Trema* sp.), pedada (*Sonneratia caseolaris*), waru (*Hibiscus tiliaceus*)
Area 7 ex PT. CPI	Location of elephant attack (crooked fence)	Estimated >3 head	N 01^0 16' 35,7" E 101^0 15' 36,0"	Flat, banana (*Musa* sp.), oil palm (*Elaeis guineensis*), rattan (*Calamus* sp.) dan forest ginger
Area 7 ex PT. CPI	Location of elephant attack (fence destroyed)	Estimated >3 head	N 01^0 16' 35,7" E 101^0 15' 36,0"	Flat, ten-year-old oil palm, (*Imperata cylindrica*), and one-year-old oil palm
Pematang pudu	Location of elephant attack	Estimated >3 head	N 01° 14' 34.3" E 101° 10' 39.1"	Slope, a former papaya (*Carica papaya*) and banana farmland that was destroyed

Table 3. Composition of feed plants in each land cover

Local name	Scientific name	Family	Individual number
Farming			
Belulang	*Echinochloa colonum* (L.) Link	Poaceae	48
Ilalang	*Imperata cylindrica* (L.) Raeusch.	Poaceae	22
Senggani	*Melastoma malabathricum* L.	Melastomataceae	26
Bandotan	*Ageratum conyzoides* L.	Asteraceae	12
Pakis	*Nephrolepis biserrata* (Sw.) Desv.	Lomariopsidaceae	17
Rumput bento	*Leersia hexandra* Sw.	Poaceae	11
Rumput israel	*Asystasia gangetica* (L.) T.Anderson	Acanthaceae	29
Total			165
Bush			
Waltheria indica	*Waltheria indica* L.	Malvaceae	117
Senggani	*Melastoma malabathricum* L.	Melastomataceae	80
Ilalang	*Imperata cylindrica* (L.) Raeusch.	Poaceae	35
Weldelia	*Sphagneticola trilobata* (L.) Pruski	Asteraceae	256
Alamanda	*Allamanda cathartica* L.	Apocynaceae	20
Putri malu	*Mimosa pudica* L.	Fabaceae	144
Sidaguri	*Sida rhombifolia* L.	Malvaceae	49
Rumput kerbau	*Paspalum conjugatum* P.J.Bergius	Poaceae	8
Rumput israel	*Asystasia gangetica* (L.) T.Anderson	Acanthaceae	51
Krisan	*Scleria sumatrensis* Retz.	Cyperaceae	26
Total			786
Natural forest			
Senggani	*Melastoma malabathricum* L.	Melastomataceae	20
Pakis	*Nephrolepis biserrata* (Sw.) Desv.	Lomariopsidaceae	87
Palem merah	*Cyrtostachys renda* Blume	Arecaceae	4
Gandarusa	*Justicia gendarussa* Burm.fil.	Acanthaceae	2
Kadaka	*Asplenium scolopendrium* L.	Aspleniaceae	4
Liana	-	-	12
Laos hutan	*Alpinia galanga* (L.) Willd.	Zingiberaceae	3
Kelakai	*Stenochlaena palustris* (Burm.fil.) Bedd.	Polypodiacea	150
Teki	*Cyperus rotundus* L.	Cyperaceae	65
Krisan	*Scleria sumatrensis* Retz.	Cyperaceae	33
Bento	*Leersia hexandra* Sw.	Poaceae	10
Belulang	*Echinochloa colonum* (L.) Link	Poaceae	45
Total			435

Source: Data analysis

Overall, the combined vegetation data suggest that secondary forests, shrubs, and disturbed habitats play an important role in maintaining elephant populations in fragmented landscapes. However, when natural forage becomes scarce due to habitat degradation, elephants may shift to alternative food sources, such as oil palm, increasing the risk of human-elephant conflict. These findings highlight the need for habitat management strategies that maintain diverse early-successional vegetation, reinforce natural forage availability, and integrate elephant dietary requirements into landscape-level conservation and land-use planning.

Types of elephant feed in secondary forest types

Based on survey results of elephant feed along the transect, interviews with mahouts, and observations of tame elephants at the research site. The types of elephant feed in the SM Balai Raja area are shown in Table 4.

Table 4 shows that Myrtaceae plants were dominant among seedlings in secondary forests. Most plants at the seedling level served as elephant feed. Elephant feed types were more frequently found at the seedling and sapling growth levels than at the stand and tree growth stages. At the latter levels, elephants ate only the bark and fruits and disregarded the trunks because the trees' complex textures hampered easy digestion (Sach et al. 2019). Nonetheless, regarding plants at the seedling and sapling stages, elephants ate all parts, including stems, leaves, and branches. Priyadharshana and Vadivel (2022) proposed that Indian elephants (*Elephas maximus indicus*) fed on a wide range of plant species, but most frequently consumed certain ordos. The most commonly eaten plants belonged to the ordo Malvales (Malvaceae, Sterculiaceae, and Tilliaceae) and the family Leguminosae (Fabaceae).

Based on observations and interviews with the community, elephants did not eat certain plant species at the stand level because they could not reach them. Elephants, which are herbivores, eat leaves (grazers), grasses (browsers), leaves (folivores), fruits (frugivores), and, mainly, Sumatran elephants also eat barks, roots, and tubers. Poaceae and Cyperaceae families were grass groups, 28 elephant feed types. Zahrah (2002) stated that 11 plant species from the groups could be found in eastern Aceh and Langkat. Priyadharshana and Vadivel (2022) suggested that elephants' preferences for grasses are connected to their preferences for certain grasses at certain growth levels. Elephants only eat grass during the rainy season. Furthermore, elephants prefer to eat plants at the sapling, stand, and tree levels (Ong et al. 2023; Winarno et al. 2024). Based on observations, elephants ate sapling leaves, including those of species in the family Euphorbiaceae. Meanwhile, they ate the bark of ground-level plants, such as *Dillenia axcelsa* and *Mallotus paniculatus.* Regarding the composition of vegetation types in bushes, elephants ate and avoided some.

Important Value Index (IVI) of vegetation

Based on the survey results and vegetation data processing, the important values for vegetation types at each growth level were obtained. This is presented in Table 5.

As shown in Table 5, the highest IVI was acquired by rubber and *leban* at each growth level. Their high IVI values indicated their adaptability to the environment in which they grew, as argued by Chairul and Arwin (2023), with a high relative density suggesting a better ability to self-adjust to the environment compared with other types. Meanwhile, a low relative density indicated that individuals belonging to existing types lacked the capacity to self-adjust to the environment, resulting in their presence in small numbers.

Field observations demonstrated that bushes were the preferred habitat sites for elephants because they provided grasses and herbs that met their nutritional requirements. This finding aligns with Koirala et al. (2016), who reported that elephants eat grasses and other feed, such as leaves, twigs, and the trunks of higher plants, at sapling, stand, or tree-growth levels. Elephants select specific plant parts as food based on their preferences and seasonal factors (Das et al. 2022). They preferred grasses because the plant group contained high levels of carbohydrates and protein and had leaves. They also ate bark, which was allegedly correlated with a lack of essential fatty acids in their diet (Zahrah 2002) and with particular minerals, such as manganese (Mn), iron (Fe), and cuprum (Cu), present in the bark (Zahrah 2002). Alahakoon et al. (2017) reported that elephants in dry areas east of Sri Lanka had a wider range of food, including leaves (browsers).

Using types of plants for KGM mitigation

Based on public interviews, elephant food was both liked and disliked. This information is important as a scientific basis for mitigating elephant–human conflicts. The interviews with the community involved 10 respondents who owned gardens that elephants often entered. The results of the interviews with the garden owner respondents are shown in Table VI.

Table 6 shows that the public's knowledge of which plants elephants like and dislike is based on years of experience and observation. Semi-structured interviews with 10 informants revealed a consistent set of economically valuable crops that elephants avoided. These included lemongrass (*Cymbopogon citratus*), chili (*Capsicum annuum*), and citrus (*Citrus aurantiifolia*). Respondents attributed avoidance to strong odors, bitterness, or latex content and reported fewer incursions in fields where buffer rows of these species were planted.

The following are the reasons why elephants avoid the types of plants listed in Table 6 based on the content or aroma of the plants. The plant types and their contents are listed in Table 7.

If a particular plant is often consumed or consumed in large quantities, it does not necessarily indicate that elephants prefer it. The selection of this feed depends on its availability and cost. It is difficult to determine an elephant's preferred food in habitats with a mixture of shrubs, grasses, and trees because measuring the relative availability of plant types is difficult. Therefore, the level of liking for certain plants or plant parts can be inferred from observations of elephants' feeding behavior in the presence of several plant types (English et al. 2014).

Elephants also exhibit preferences and palatability in their food choices. Palatability is the performance of feed ingredients as a result of the physical and chemical conditions possessed by feed ingredients, which are reflected by their organoleptics, such as appearance, smell, taste (bland, salty, sweet, sour, bitter), texture, and temperature, which attract and stimulate animals to consume them (Tohir 2018). Furthermore, the test of preference for elephant feed conducted on captive elephants is shown in Table 8.

The results of the Mann-Whitney U test showed a highly significant difference in the consumption of feed categories liked and disliked by Sumatran elephants. This value confirms that the difference in consumption did not occur by chance but rather reflects the elephants' real preference for a certain type of feed.

Table 4. Composition of the types of elephant feed vegetation at different strata in secondary forest (PT Kojo's Forest, Hutan Talang, Hutan PHR)

Local name	Scientific name	Family	Elephant feed (P)			
			Seedling	Sapling	Stand	Tree
Marapuyan	*Rhodamnia cinerea* Jack	Myrtaceae	P	P	-	-
Meranti	*Shorea leprosula* Miq.	Dipterocarpaceae	P	-	√	√
Karet	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	P	P	√	√
Petai	*Parkia speciosa* Hassk.	Fabaceae	P	P	-	-
Akasia	*Acacia mangium* Willd.	Fabaceae	P	P	√	√
Pisang-Pisang	*Polyalthia rumphii* (Blume ex Hensch.) Merr.	Annonaceae	√	-	-	√
Jengkol	*Archidendron jiringa* (Jack) I.C.Nielsen	Fabaceae	P	P	√	√
Cempedak	*Artocarpus integer* (Thunb.) Merr.	Moraceae	P	P	P	P
Mahang	*Macaranga griffithiana*	Euphorbiaceae	P	P	√	√
Sukun	*Artocarpus communis* J.R.Forst. & G.Forst.	Moraceae	P	P	√	√
Laban	*Vitex pinnata* L.	Verbenaceae	P	P	√	√
Nasi-Nasi	*Syzygium zeylanicum* (L.) DC.	Myrtaceae	P	-	-	-
Pulai	*Alstonia scholaris* (L.) R.Br.	Apocynaceae	P	P	√	√
Salam	*Syzygium polyanthum* (Wight) Walp.	Myrtaceae	√	-	√	
Palem	*Cyrtostachys renda* Blume	Arecaceae	√	-	-	√
Marak	*Caesalpinia pulcherrima* (L.) Sw.	Fabaceae	P	-	√	√
Kelat	*Litsea firma* (Blume) Hook.fil.	Myrtaceae	P	P	-	√
Medang	*Litsea umbellata* (Lour.) Merr.	Myrtaceae	P	P	√	√
Sendok-sendok	*Endospermum diadenum* (Miq.) Airy Shaw	Elaeocarpaceae	-	√	-	√
Kedondong hutan	*Spondias pinnata* (L.fil.) Kurz	Burseraceae	-	P	√	-
Tembalun	*Parashorea aptera* Slooten	Dipterocarpaceae	-	P	-	√
Kopi-kopi	*Adina polycephala* Benth	Rubiaceae	-	√	-	-
waru	*Hibiscus tiliaceus* L.	Malvaceae	-	√	-	-
Pasir-pasir	*Stemonurus secundiflorus* Blume	Icacinaceae	-	√	-	-
Petatal	*Lithocarpus hancei* (Benth.) Rehder	Fagaceae	-	√	-	√
Balam	*Palaquium burckii* H.J.Lam	Sapotaceae	-	P	-	-
Darah-darah	*Gymnacranthera paniculata* (A.DC.) Warb.	Myristiceae	-	P	-	-
Jambu jambuan	*Syzygium buxifolium* Hook. & Arn.	Myrtaceae	-	-	-	√
Rambutan	*Nephelium mutabile* Blume	Sapindaceae	-	-	-	√
Kempas	*Koompassia malaccensis* Maingay	Fabaceae	-	-	-	√
Nangka hutan	*Artocarpus champeden* (Lour.) Spreng.	Moraceae	-	-	-	P
Ludai	*Barringtonia racemosa* (L.) Spreng.	Lecythidaceae	-	-	-	√
Meranti putih	*Shorea agami* P.S.Ashton	Dipterocarpaceae	-	-	-	√
Total			21	21	13	23

Note: P: Elephant feed, -: Not found, √: Found

Table 5. Composition and diversity of the types of plants with the highest three IVI

Growth level	Number of elephant feed	Number of species	Species with the highest IVI	(H') diversity
Seedling	15	21	Rubber (43.30%), *leban* (39.30%), *meranti* (25.61%)	2.38
Sapling	16	21	Rubber (27.17%), *pasir-pasir* (26.12%), *kelat* (25.02%)	2.57
Stand	1	13	*Leban* (118.61%), rubber (48.71%), *meranti* (36.30%)	2.02
Tree	2	23	Rubber (56.71%), *leban* (33.59%), *meranti* (28.07%)	2.56

Table 6. Results of interviews with informants

Question	Respondents									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
The condition of used plants eaten by elephants (can still grow or die)	Can't grow anymore	Death	Can't grow anymore	Some died, and some were alive	Die	It can't grow anymore, except for watermelon plants	Can't grow anymore	Some can grow again, and some die completely	Sweet potato and sugarcane plants can still grow back	Some can grow, and some die completely
Types of plants that are damaged by elephants but not eaten	Rubber (*Hevea brasiliensis*), mango (*Mangifera indica*), cocoa (*Theobroma cacao*), bitter melon (*Momordica charantia*), and eggplant (*Solanum melongena*) were dried.	Rubber, bitter melon, chili (*C. annum*), *jengkol* (*Archidendron jiringa*), eggplant, cocoa	Old rubber, *ubi*	*Ubi* (*Manihot esculenta*)	rubber	crops	*Ubi*	*Ubi* and rubber	rubber	*Ubi*
Plants that elephants don't want to eat	Lemongrass (*Cymbopogon citratus*), cocoa, Sour oranges (*Citrus* sp.)	Rubber, bitter melon, chili, *jengkol*, eggplant, cocoa	rubber, cocoa, avocado (*Persea americana*), mango, chili, bitter melon, and jengkol	Old rubber, cocoa, avocado, mango, *jengkol*	rubber, *akasia*, mango, jengkol, petai	rubber and coffee, cocoa	Eggplant, vegetables, paper, and rubber	rubber	*Serai*	Don't know
Plants that elephants like	Palm Oil, Coconut (*Cocos nucifera*), Banana (*Musa* sp.)	Palm Tree, Coconut Tree, Banana	Palm trees, bananas, coconut stems, watermelon (*Citrullus lanatus*)	Palm trees, bananas, coconut stems	Palm Tree, Banana, Coconut Stem	Bananas, palm oil, and coconut	Bananas, watermelons, coconuts, and oil palms	Oil palm and coconut crops	Sweet potato, oil palm, and coconut crops	Oil palm

Source: Results of community interviews

Table 7. Crops not liked by elephants of economic value

Plants	Scientific name	Types of prevention/reasons	Source
Sereh	*Cymbopogon citratus*	Unpleasant aroma or smell	Darmarathne et al. (2020)
Chilli	*Piper* sp.	Eyeburn, oleo resin capsicum, pepper crackers, hot pepper oil According to Musfiroh et al. (2013), in chili extract, there is a capsaicin compound that causes chili to taste spicy	Musfiroh et al. (2013)
Coffee	*Coffea* sp.	Elephants do not favor coffee plants because they contain 8.85% tannins and 1.18% fat-resin (Yusianto 1999), thereby reducing their palatability.	Suba (2017)
Candlenut	*Aleurites moluccana*	Sangat et al. (2000) found that the flesh of hazelnut seeds, leaves, and roots contains lignin, saponins, flavonoids, and polyphenols. In addition, the seeds' flesh contained a laxative oil that could not be digested directly.	Sangat et al. (2000)
Cocoa	*Thebroma cacao*	Schmitt et al. (2018) states that brown plants contain alkaloid compounds that give them a bitter taste; therefore, elephants avoid them.	Schulte and LaDue (2021)

Table 8. Types of feed that elephants like and dislike: Preference test

Treatment	Elephant	n	Mean (g)	Median (g)	Min-Max (g)	SD	U-value	Z-score	p-value	Interpretation
P1 (Preferred)	E1	15	980	1000	800-1000	63.2	0.00	-6.12	< 0.001	Significant
P1 (Preferred)	E2	15	966.7	1000	750-1000	91.3				
P2 (Non-preferred)	E1	15	15.9	0	0-162	42.1				
P2 (Non-preferred)	E2	15	8.9	0	0-133	34.3				

Note: Effect size (r) ≈ 0.79 (strong effect), P1: Elephant grass (*Pennisetum purpureum*); Sugarcane (*Saccharum officinarum*); Banana (*Musa* sp.); Bamboo (*Bambusa* sp.); Wild grass (Juluk-juluk), P2 : Lime (*Citrus aurantiifolia*); Coffee leaves (*Coffea* sp.); Cocoa leaves (*Theobroma cacao*); Lemongrass (*Cymbopogon citratus*); Durian leaves (*Durio zibethinus*), E1 and E2: Elephants 1 and 2)

Table 9. Jacobs' index (D) indicating elephant feeding preference

Feed Type	Category	r (E1)	r (E2)	Jacobs' Index (E1)	Jacobs' Index (E2)	Preference category
Elephant grass (*Pennisetum purpureum*)	P1	1.00	1.00	1.00	1.00	Strongly preferred
Sugarcane (*Saccharum officinarum*)	P1	1.00	1.00	1.00	1.00	Strongly preferred
Banana (*Musa* sp.)	P1	1.00	0.75-1.00	1.00	0.80-1.00	Strongly preferred
Bamboo (*Bambusa* sp.)	P1	0.85-0.90	0.75	0.65-0.80	0.60	Moderately preferred
Wild grass (Juluk-juluk)	P1	1.00	1.00	1.00	1.00	Strongly preferred
Lime (*Citrus aurantiifolia*)	P2	0.00	0.00	-1.00	-1.00	Avoided
Coffee leaves (*Coffea* sp.)	P2	0.10	0.13	-0.75	-0.70	Avoided
Cocoa leaves (*Theobroma cacao*)	P2	0.02	0.00	-0.95	-1.00	Strongly avoided
Lemongrass (*Cymbopogon citratus*)	P2	0.00	0.00	-1.00	-1.00	Strongly avoided
Durian leaves (*Durio zibethinus*)	P2	0.00	0.00	-1.00	-1.00	Strongly avoided

The effect size was calculated as r ≈ 0.79, which falls within the large effect category; therefore, it can be said that Sumatran elephants have a strong preference for natural feed such as grass, sugarcane, and bamboo. Bananas were partially consumed, indicating an intermediate preference, whereas durian, coffee, and cocoa leaves were hardly eaten, confirming that elephants consumed significantly more biomass from preferred species. Vegetation that elephants dislike and has economic value can be used to repel them. This is a good idea because the community can accept it, as it is planted on community land and accounts for land suitability. Jacobs'index analysis revealed variation in feed preference among plant species (Table 9). These findings suggest that elephant feeding preference is species-specific rather than strictly group-based. This aligns with newer findings that elephants differentiate between grazing (grasses) and browsing (woody plants), selecting foods based on digestibility and nutritional trade-offs rather than availability alone (Gautam et al. 2025).We have mentioned the table in the paragraph below it as requested.

Discussion

Feeding patterns in fragmented landscapes vs. natural forests

In this fragmented mosaic, elephants rely heavily on open habitats, such as bushes and plantation floors, for accessible forage (grass, sedge, and herbs). Simultaneously, secondary forest areas provide preferred seedlings and saplings, cover, and shelter. Compared to more intact forests, where a wide variety of roaming and fruiting trees are available, the diet here tends towards early-succession plants and underfloor plants, with opportunistic bark and fruit consumption in the higher strata. This shift reflects reduced vertical accessibility and changes in plant community structure due to fragmentation, increasing the likelihood of crop raiding when natural forage is seasonally or spatially limited (Naha et al. 2020).

This study shows that the diet of Sumatran elephants differs substantially between fragmented landscapes and relatively intact secondary forests, reflecting variations in forage availability and forest structure. In natural forest habitats, elephants primarily consume grasses, other plants, and the early growth stages of woody plants, which provide ample nutrients without requiring extensive movement into dense forest areas. Similar patterns have been reported in other Asian forest systems, where elephants rely on heterogeneous underground vegetation and natural regeneration to meet their food needs (Fernando et al. 2008; Ong et al. 2023). In contrast, fragmented landscapes dominated by plantations and agriculture tend to concentrate elephant foraging activities along forest edges and in disturbed areas, where forage diversity is reduced, and human-elephant interactions are becoming more frequent.

Forest fragmentation and the conversion of natural forests into plantation-dominated landscapes alter elephant feeding behavior. Studies from South and Southeast Asia have shown that elephants that inhabit fragmented forest-agricultural mosaics are more likely to forage outside forest plots, especially when the size, quality, or connectivity of natural forage is limited (Hedges et al. 2005; Krishnan et al. 2019). In such landscapes, elephants often exploit undergrowth vegetation within adjacent plantations and agricultural fields as an alternative food source. These findings suggest that an altered diet is not driven by chiliference alone, but by limited access to forest-based forage, highlighting the importance of maintaining forest connectivity within managed landscapes.

Clear dietary selectivity in elephants

Beyond statistical significance, the effect size is large in ecological terms. The absolute difference in average inter-category consumption exceeded 1,200 g, indicating the near-total exclusion of certain plant species from the elephant diet. From a conservation perspective, the magnitude of this difference is more informative than the values alone, as it reflects real foraging decisions with direct implications for habitat use and conflict dynamics.

The statistical results clearly show dietary selectivity in elephants. The preferred bait, which is dominated by grass, bamboo, sugar-rich plants, and soft-stemmed plants, is consumed whole, whereas wood leaves or those that are chemically preserved are almost completely avoided. This pattern is consistent with established knowledge of elephant foraging ecology and selection, in which elephants maximize their food intake and digestible energy while minimizing exposure to secondary plant compounds.

Grasses and sugar-rich crops, such as sugarcane and bananas, provide high levels of soluble carbohydrates and low fiber resistance, enabling rapid intake and efficient digestion. In contrast, leaves of coffee, cocoa, durian, and Ficus species contain tannins, alkaloids, latex, or other secondary metabolites that reduce palatability and digestibility. The near-zero consumption observed in this study strongly suggests that chemical deterrents, rather than availability, govern feeding decisions.

Mechanisms underlying the avoidance of certain crops

The mechanism of avoidance is driven by: (i) Chemical defense: Capsaicin (chili), tannins (coffee), alkaloids (cocoa), saponins/flavonoids (hazelnuts), chilitter terpenoids (bitter gourd, jengkol) reduce palatchiliy and may cause gastrointestinal irritation or discomfort; (ii) Volatile repellent odor: Strong essential oils (lemongrass, orange) produce aversive olfactory cues; (iii) Physical defense/latex: Latex rubber and sap prevent feeding; prickly crown in a mature state oil palm reduces access. These mechanisms, corroborated by interview insights and field observations, explain consistent avoidance patterns and can be harnessed for management. (iv) Practical application for HEC mitigation: buffer planting with "disliked" economic species.

The findings support a vegetation-based mitigation strategy that integrates the following: (i) buffer rows: planting belts of lemongrass, citrus, chili, coffee, cocoa, and bitter gourd along field margins and access corridors to create olfactory/chemical deterrent zones, (ii) zoning: placing high-risk, highly palatable crops (banana, sugarcane) away from forest edges and known movement routes and interspersing them with deterrent species, (iii) habitat provisioning: maintaining/restoring secondary forest patches with preferred natural forage (grasses, Zingiberaceae, semantung, understory herbs) to reduce crop-raiding pressure, (iv) seasonal planning: anticipating dry-season forage bottlenecks by enhancing natural forage in safe zones and reinforcing buffer belts before peak conflict periods, and (v) community adoption: prioritizing economically viable deterrent crops to ensure farmer uptake and sustained maintenance.

The findings of this study have direct implications for forest and plantation management in areas frequented by elephants or along elephant corridors. Maintaining diverse understory vegetation, promoting natural regeneration, and conserving forest corridors can reduce elephants' reliance on crops. Previous studies have emphasized that landscapes with heterogeneous vegetation structures and functional connectivity are more effective in supporting elephant foraging needs while minimizing conflict (Hedges et al. 2005; Owen-Smith et al. 2006). For forestry practitioners, integrating wildlife considerations into land-use planning is essential for balancing production objectives with biodiversity conservation.

In the context of sustainable forestry in Asia, understanding elephant feeding ecology provides a critical foundation for coexistence strategies or harmonization. As forest landscapes continue to be modified by plantation expansion and infrastructure development, the maintenance of early successional habitats and the minimization of fragmentation should be prioritized. Aligning forest management with elephant ecological requirements supports species conservation and enhances the resilience of forest ecosystems and structure. These findings reinforce the relevance of integrating wildlife ecology into forestry policy and conservation practice.

In conclusion, this study provides new insights into the feeding preferences and avoidance patterns of Sumatran elephants (*E. m. sumatranus*) in the fragmented landscape of the Balai Raja Wildlife Sanctuary and Pinggir Sub-district, Bengkalis District. Field surveys revealed that elephants rely heavily on grasses, sedges, and herbs in bushland and plantation understories. At the same time, secondary forest patches provide preferred seedlings and saplings of families such as Myrtaceae, Euphorbiaceae, Moraceae, and Fabaceae. The Important Value Index (IVI) analysis confirmed the structural dominance of *Hevea brasiliensis* and *Vitex pinnata* across growth strata, reflecting the altered vegetation composition of this landscape as an elephant habitat. Semi-structured towardews further identified economically valuable crops consistently avoided by elephants, including lemongrass, chili, citrus, coffee, cocoa, and rubber, with avoidance likely driven by chemical defenses, strong odors, or latex content. Then, Maintaining secondary forest patches, strategically planting deterrent species, and incorporating local knowledge into management and land-use planning are essential steps toward mitigating human-elephant conflict in the fragmented landscapes at Balai Raja. By applying these strategies, conservation efforts can simultaneously safeguard elephant populations in Balai Raja and support local communities' livelihoods, contributing to long-term coexistence and the preservation of one of Sumatra's most endangered megafauna.

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