Picky eaters or desultory foragers?:

Semi-captive Asian elephant (*Elephas maximus*) foraging preferences in Siem Reap, Cambodia

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Abstract

This study explores the foraging behavior of six semi-captive Asian elephants at Kulen Elephant Forest in Cambodia, analyzing the relationship between walking time and plant preference. I hypothesized that the elephants would walk further to find specific forage items, meaning that the elephants were willing to expend energy to acquire food items which may be "preferred". I also predicted that these relationships between foraging movement and forage materials would vary across 3 timescales (10-, 60-, and 120-minute intervals)—specifically, that preference would be more apparent during micro-time scales. Data were collected over nine days in April 2023 and recorded at two-minute intervals during a two-hour window between 10:00 a.m. and 1:00 p.m., analyzing the plants' anatomical part, form, and family consumed, as well as the walking time preceding each feeding. Single factor ANOVA tests were conducted for each of the study groups (plant form, plant part eaten, and plant family) for each of the 3 time scales, and Tukey's HSD tests were conducted for ANOVA models with $p<0.05$. Results indicated that only plant form and plant family has significant correlations during a micro-timescale (10-minute intervals). These findings suggest that elephants preferentially target plants with higher nutritional value and easier digestibility, supporting the hypothesis that walking time correlates with foraging effort for more preferred plants. This study contributes to the broader understanding of the foraging behavior of Asian elephants, with recommendations for conservation and management practices in reforestation areas. Further research is ultimately needed to explore the impact of plant preferences on Asian elephant energetic budgets and foraging behavior tradeoffs.

Introduction

Current Status of Asian Elephants

The population of Asian elephants (*Elephas maximus*) has been declining significantly due to habitat loss, fragmentation, and illegal poaching, according to the International Union for the Conservation of Nature (IUCN, 1986). Recent estimates suggest that the wild population ranges between 48,323 and 51,680 individuals, with approximately 15,000 in captivity (Menon & Tiwari, 2019). The IUCN Red List classifies the Asian elephant as Endangered, and it is listed in Appendix I of the Convention on International Trade in Endangered Species (CITES). Their habitat covers diverse regions across Asia, including grasslands, tropical evergreen forests, semi-evergreen forests, moist and dry deciduous forests, and dry thorn forests (Choudhury, 1999). They are also found in cultivated forests, secondary forests, and scrubland (ibid.). Despite their broad use of habitat types, conservation is still critical, as the species has lost up to 95% of its overall historical range (Sukumar, 2006).

Ecological Significance

Asian elephants are classified as keystone species due to their profound impact on their ecosystems. As megaherbivores and generalist consumers, they play a crucial role in maintaining ecological balance and promoting biodiversity in seasonally dry forest habitats (Fernando et al., 2011). Their activities, such as trampling vegetation, help to stimulate new plant growth and maintain ecosystem resilience. As allogenic ecological engineers, Asian elephants also significantly enhance their habitats through seed dispersal and by creating openings in dense vegetation. By consuming large quantities of plants, they facilitate seed distribution via their dung; this seed dispersal supports diverse plant species and provides a stable food source for other herbivores and omnivores (Campos-Arceiz et al., 2011; Kitamura et al., 2007).

Previously Observed Foraging Trends

Asian elephants are observed to prefer grasslands, mixed forests, and diverse landscapes, although they avoid foraging in areas with steep topography (Neupane, 2019). Their diet in India consists primarily of grasses and shrubs, with a nutritional composition of 48.25% nitrogen-free extract, 23.95% crude fiber, 11.80% protein, 11.55% ash, and 2.85% ether extract (Borah & Deka, 2008).

More specifically, a study analyzing the foraging preferences of wild Asian elephants in India also showed that they consumed mostly Fabaceae and Poaceae (Priyadharshana & Vadivel, 2022). To corroborate this, Poaceae and Fabaceae have been declared as two of the plant families most rich in carbohydrates, proteins, vitamins, minerals, fiber, and essential amino acids (Ara et al., 2019). Legumes, or Fabaceae, are also a significant source of nitrogen (N) and phosphorus (P) which are important for animal growth and reproduction (Rubiales & Mikic, 2015). Understanding the dietary needs of Asian elephants is crucial for improving the welfare of both captive and wild elephants—especially in regions such as Cambodia where dietary research is limited.

Foraging is a significant aspect of Asian elephants' lives as they spend about 18 hours eating per day, consuming roughly 150kg (Haynes, 2012). For example, the distribution of nutrient rich food sources, like legumes and grasses, may be important drivers for elephant movement due to the need to maximize their intake (Pretorius et al., 2012). Furthermore, it has been discovered that elephants either prefer to forage many small patches of high nutrient concentration, or few large patches of low-quality nutrients per 2,500m (Pretorius, 2009). This gives us great insight into elephants' motives behind feeding on either a micro or macro scale. As such, it is important to understand whether Asian elephants in lesser-studied areas, like Cambodia, also seek to optimize the scale of their movements with intake of nutrient-rich plants.

Walking Significance

As generalist herbivores, elephants must walk a significant distance to have access to their broad foraging diet. Walking behavior typical of wild populations has even been observed in captive elephants. For example, one study observing African elephants showed that they walked an average of 9.82km per day in the wild (Botswana), and 8.65km in captivity (San Diego Zoo) (Miller et al., 2016). Moreover, walking distance in captive elephants has been shown to be positively correlated with diverse feeding regimens, unpredictable feeding schedules, and highly social groupings, while being negatively correlated with age (Holdgate et al., 2016). Since walking in search of food is, in and of itself, an energetic cost to an individual elephant, it is important to determine whether walking behaviors are maximining foraging and nutritional opportunity. Foraging tradeoffs are also important for managing semi-captive Asian elephants, who reside on smaller landscapes with fewer forage options, and who may walk less due to advanced age (Holdgate et al. 2016).

Goal of research

I conducted a study in Kulen Elephant Forest, Cambodia, to observationally document foraging behavior and preferences of six resident, semi-captive female elephants. I hypothesized that the elephants would be willing to walk further to find specific forage items, meaning that the elephants were willing to expend energy to acquire food items which may be “preferred”. I also predicted that these relationships between foraging movement and forage materials would vary across time-scales—specifically preference being more apparent during micro-time scales. This implies that more frequent search activities between patches (10-minute intervals) may be more important than small-scale foraging movements (120-minute intervals). Finally, I also analyzed the preference of the parts of plants (e.g. fruits versus leaves), forms of plants (e.g., tree versus a grass), and plant families (e.g., Fabaceae versus Poaceae) that elephants selected.

I believe this study is extremely important for the progression of locational Asian elephant conservation efforts because research in Cambodia is not currently as robust as other countries where the species resides, such as India. It is predicted that Cambodia only has 400-600 Asian elephants left, which is only about 0.8-1.5% of the species’ worldwide population (Fernando & Pastorini, 2011; Maltby & Bourchier, 2011; Gray et al., 2014). Increased research regarding semi-captive Asian elephants must be encouraged, as they may be given less daily foraging time than their counterparts in the wild, as seen at KEF. This may be linked to low dietary health, as these semi-captive elephants are not given enough opportunity to fulfill their dietary needs. Asian elephants hold significant historic, cultural, and ecological significance to the country of Cambodia, which is why this study is needed to provide greater insight into their complex behaviors and foraging activity. Thus, this research is extremely important to contribute to the broader knowledge of Asian elephant diets in Cambodia, as well as their more specific preferences and foraging patterns.

Methods

Research Site

Data was collected over nine days at Kulen Elephant Forest (KEF) from April 10-13 and April 18-22 of 2023. KEF is located in the Bos Thom Community Forest which is in the Sout Nikom district of Siem Reap, Cambodia. This reserve is composed of approximately 1,100 acres of protected forest, mainly consisting of secondary tropical deciduous forest. The Bos Thom Village Community, comprising 106 families, borders Kulen Elephant Forest and partakes in various forms of agriculture (Kulen Elephant Forest, n.d.).

(a)

(b)

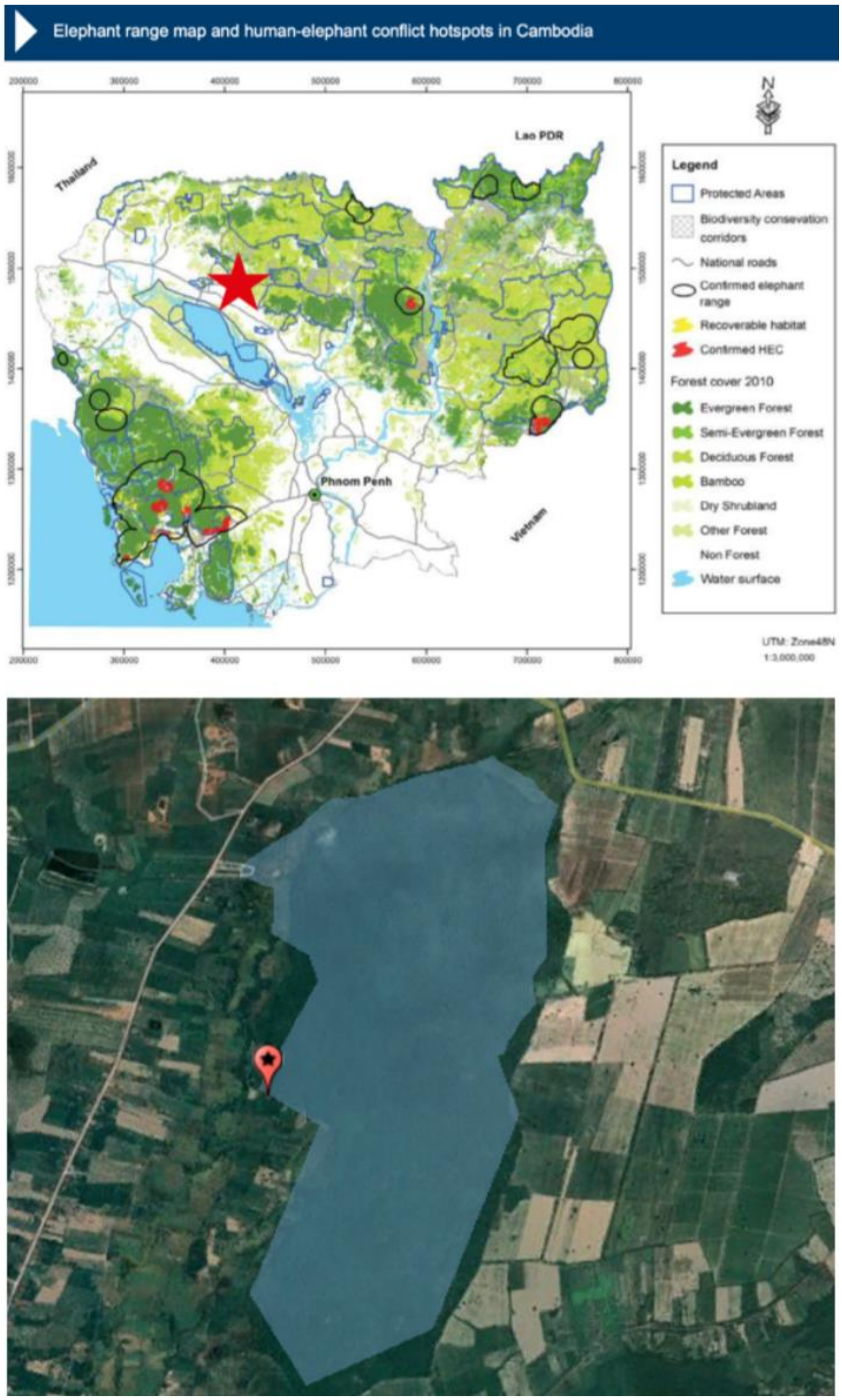

Figure 1: A map of Cambodia displaying the location of KEF, indicated as a red star (GDANCP, 2020) (a), and a map of the reserve's boundaries where the focal elephants were allowed to forage, also called O Ta Yu. The red starred bubble indicates the tourism center in KEF (b).

In previous years, the Bos Thom Forest has faced overexploitation, losing a majority of its tree species to firewood collection and other resources, because of a lack of strong management of the area (APFNet, 2022). To combat this issue, the Institute of Forest and Wildlife Research and Development ran a project that intended to reconstruct and restore the area. Because this project occurred in 2019, it will take many years for the forest to grow back to its original state. Currently, Kulen Elephant Forest is inhabited by high canopies and full understories, with a mixture of evergreen and deciduous forests (ibid.). The forest is currently in its beginning stages of regrowth and consists primarily of patchy areas and juvenile trees. To guarantee a successful reforestation process, mahouts, or the elephants' caretakers, are required to limit the number of trees their elephants can push down and encourage them to avoid areas that are undergoing significant regrowth.

Focal Elephants

Kulen Elephant Forest cares for twelve Asian elephants—ten females and two males—all of which were previously used in tourism for riding (D. Koehl, pers. comm. April 11, 2023). Dan Koehl, Kulen Elephant Forest's director of mahout training and elephant welfare, explained that many of the elephants at Kulen were previously overworked as loggers, or worked as tourist attractions at Angkor Wat, but now live with improved welfare conditions. For example, each elephant receives daily health care, including body condition checks and foot treatments. The elephants are divided into small subgroups consisting of two to three individuals, based on their social compatibility. The elephants' daily foraging time depends on the tours they are scheduled to give each day. Thus, if their subgroup participates in two to three tours in a day—

typically lasting roughly two hours each— they are not provided extra foraging time. Additionally, all elephants are constrained by chains from 4:00 p.m. to 9:00 a.m. each day, during which they are not closely monitored. The female and male elephants are fed roughly two and four kilograms of additional daily supplements, respectively. The supplements include tamarind, sugar cane, bananas, sticky rice, salt, and rice bran (D. Koehl, pers. comm. April 11, 2023).

In this study, we were provided with six different focal elephants to follow in order to analyze their individual foraging activities. The list of focal elephants are as follows: Itok (age likely ranging from 40-60 years), Gom Phoy (61 years old), Chi Mean (49 years old), Chi Ole (52 years old), Chi Youl (age unknown), and I Plok (age unknown). All six elephants were females. They have been cared for by mahouts their entire lives. The elephants have been living at the sanctuary since December of 2019, approximately twenty-six months before the beginning of the study.

Data Collection

Activity budget was recorded at 2-minute intervals for 2 hours between 10:00 a.m. to 1:00 p.m., totaling 61 daily entries per elephant. An initial study was researching a basic understanding of the focal elephants' behaviors by analyzing the plant taxonomy of the species they consumed, as well as their activity budget. The activity budget included feeding, walking, food prepping, conspecific interaction, dusting, environmental exploration, standing, and spraying water onto body. The elephants were only recorded performing one activity for each 2-minute interval. Elephants were required to take at least two, intentional steps within that 2-minute period to be considered as "Walking". If the researcher observed the elephant displaying another activity in addition to “Walking”, they were only recorded as “Walking”. Although, the only activity that was recorded as a higher priority to walking was “Feeding”. The initial study’s methodologies did not account for the hypotheses of this thesis. A more ideal data set would have been continuous, and the only activity recorded would have been feeding and walking.

Two elephants were recorded per day, with the exception of one elephant on Day 1, due to refining data collection techniques. Daily focal elephants were selected based on the availability of subgroups, considering those not being used for tours. Itok was recorded on April 10th, Itok and Gom Phoy were recorded on April 11th, 20th and 21st, Chi Mean and Chi Ole were recorded on April 12th, 13th and 22nd, Chi Youl and I Plock were recorded on April 18th, 19th.

The elephants were allowed to freely roam during this time, with slight guidance from mahouts, when necessary, to avoid damage to newly planted trees. The researchers attempted to keep a minimum of 10 meters between themselves and the elephants, while staying close as a group, to reduce the stress for the elephants while ensuring visibility for data collection. To account for observer biases, the two data collectors switched focal elephants after an hour to ensure potential discrepancies would be accounted for in our data analysis.

When a focal elephant actively began “Feeding” at the start of each interval, the species name, part eaten, and form of the plant was noted. Plant “Part” included bark, roots, branch, fruit, all, leaves, and stem. Plant “Form” included sapling, shrub, grass, vine, and tree. For identification, a photo was also taken of the plant once the elephant moved on. A plant was not taken or recorded if the elephant was Food Prepping during the recorded interval. Food Prepping referred to the elephant using her trunk to collect food or preparing the plants for consumption in ways such as slapping off excess dirt.

To identify the plants, a translator asked the Mahouts for the names in Khmer, as well as specific details of the species, such as whether or not the species flowers, fruits, or has medicinal or consumption uses. This was noted, and the plant was labeled a number for later, thorough identification. We then used various search engines, encyclopedias, and books to identify the plant to the species' scientific name and family. If a new species was identified, it was added to a cumulative taxonomy of consumed plant species. It is important to note that due to lack of time and experience, sedges were classified as grasses.

The total Walking time assigned to each consumed plant was counted directly after the focal elephant's last Feeding instance, until the new plant was consumed. This summarizes the amount of time they spent Walking from one feeding location to the new plant.

Computing Data

I defined a "preferred forage item" as a plant that an elephant spent more time walking to, as opposed to grazing randomly wherever the elephant was standing. As such, my hypothesis was that walking time would be positively associated with feeding for particular plants. The null hypothesis states that there is no significant difference in Walking time for any plant type, and thus Walking time will not be significantly correlated with Feeding for any plant species that the elephants were observed eating during the study. In the null model, foraging would be 100 percent opportunistic, without seeking out specific plants. It is also important to note that this is not the only method to measure preference; it can also be measured by other numerical values such as the total quantity of plants consumed.

In addition to testing preference for each species of forage consumed, I also compared preferences for various plant parts (e.g. leaves versus fruit), plant form (e.g. grasses versus shrubs), and plant family (e.g. Fabaceae versus Poaceae). This analysis was conducted to determine if the elephants were walking towards coarse-level search images (like targeting fruits or shrubs), rather than specific plant species. I also tested my hypotheses over three different time scales: Data collected every 10 minutes, data consolidated over one hour, and data for the entire observation period (2 hours). Movements at small time scales were assumed to show movement within micro-scale forage patches, while 60- and 120-minute intervals were considered to look at food searches at a more macro-scale, between habitat patches.

I logged the number of species consumed in each plant group, as well as their Walking time, which was the response variable. A single factor ANOVA test (CI=95%) was then conducted for each predictor variable (plant form, plant part eaten, and plant family) comparing their species consumed to Walking time on a 10-, 60-, and 120-minute scale—a total of 9 ANOVA tests. If the p-value was below 0.05, then a Tukey's HSD test was performed to determine which plant groups were responsible for the significant correlation. Plant groups identified with significant means from Tukey's HSD test implied that the elephants may have intentionally spent more time and energy walking to the specific plant group, thus demonstrating preference.

Results

Data Summary

The focal elephants were recorded consuming 41 different species during 82 total instances. Additionally, they were recorded Walking a total of 97 times prior to Feeding instances via 2-minute intervals. The significant overlap of plant species in each study group allowed for viable comparisons to be made between Walking time and the selected independent variables. **Table 1** shows the number of times a species was consumed and its total average Walking time, while **Tables 2-4** show each plant group's average Walking time and number of times consumed throughout each 2-minute interval of data collection.

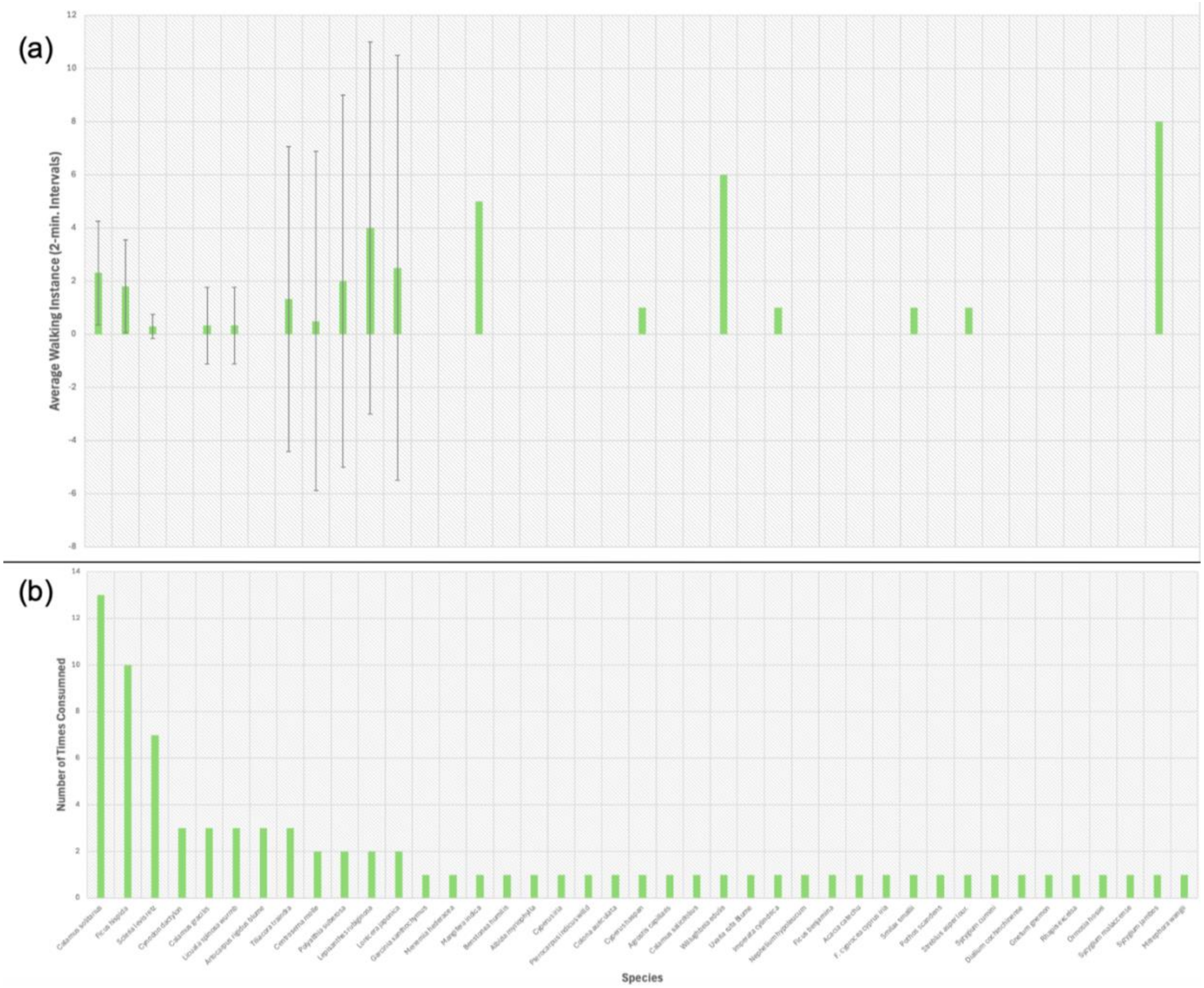

Table 1: A histogram of each plant species' average Walking time (a) and the number of times it was consumed (b) throughout the entirety of data collection (95% CI).

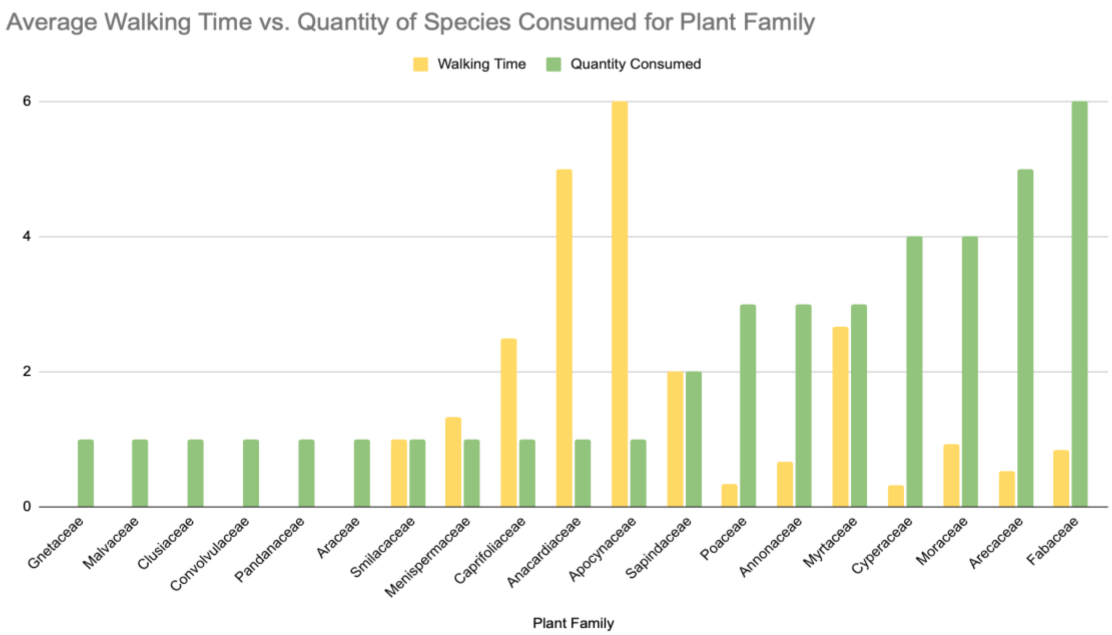

Table 2: Average Walking time compared to the number of species consumed per Plant Family.

Fabaceae was the Plant Family with the greatest number of plant species consumed (n=6). Furthermore, its Walking count was only recorded an average of 0.83 times prior to their Feedings. This is much less than Apocynaceae, which only had 1 species consumed from its Plant Family, but conversely had the greatest number of average Walking instances recorded prior to its Feeding ($\bar{x}$=6).

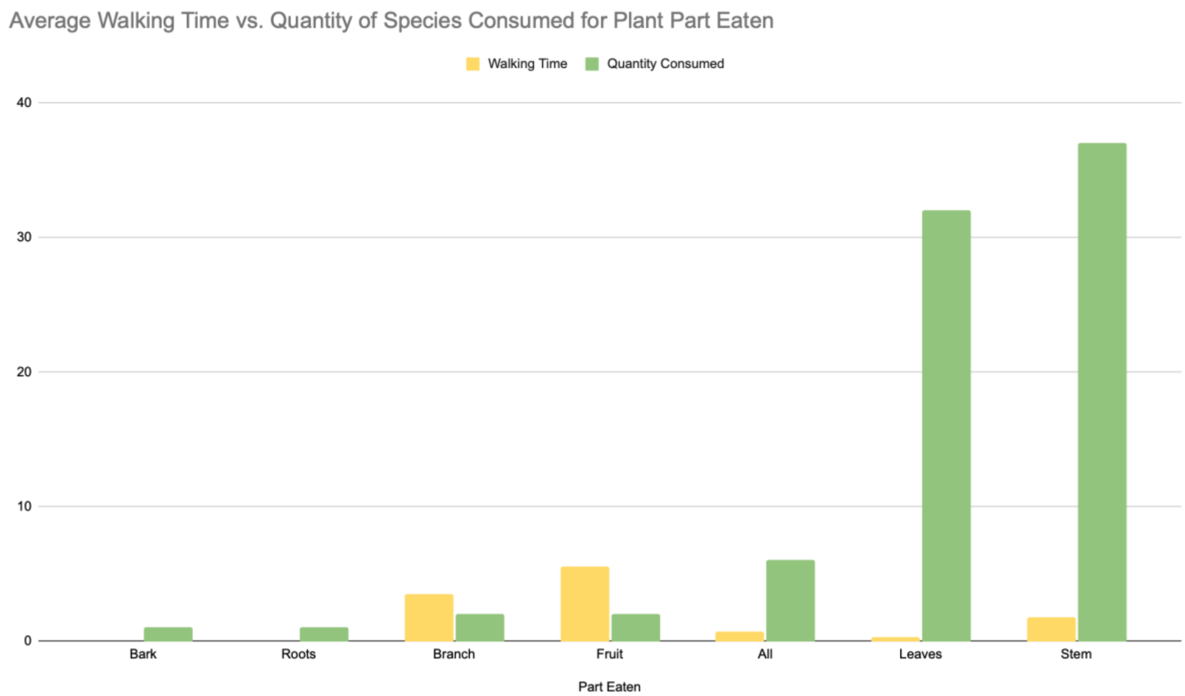

Table 3: Average Walking time compared to the number of species consumed per Plant Part Eaten.

The focal elephants were recorded consuming the plant stem most often (n=37) but were only recorded Walking an average of 1.78 times before they were eaten. On the other hand, the fruit was only consumed 2 times but had the greatest average number of Walking instances ($\bar{x}$=5.5).

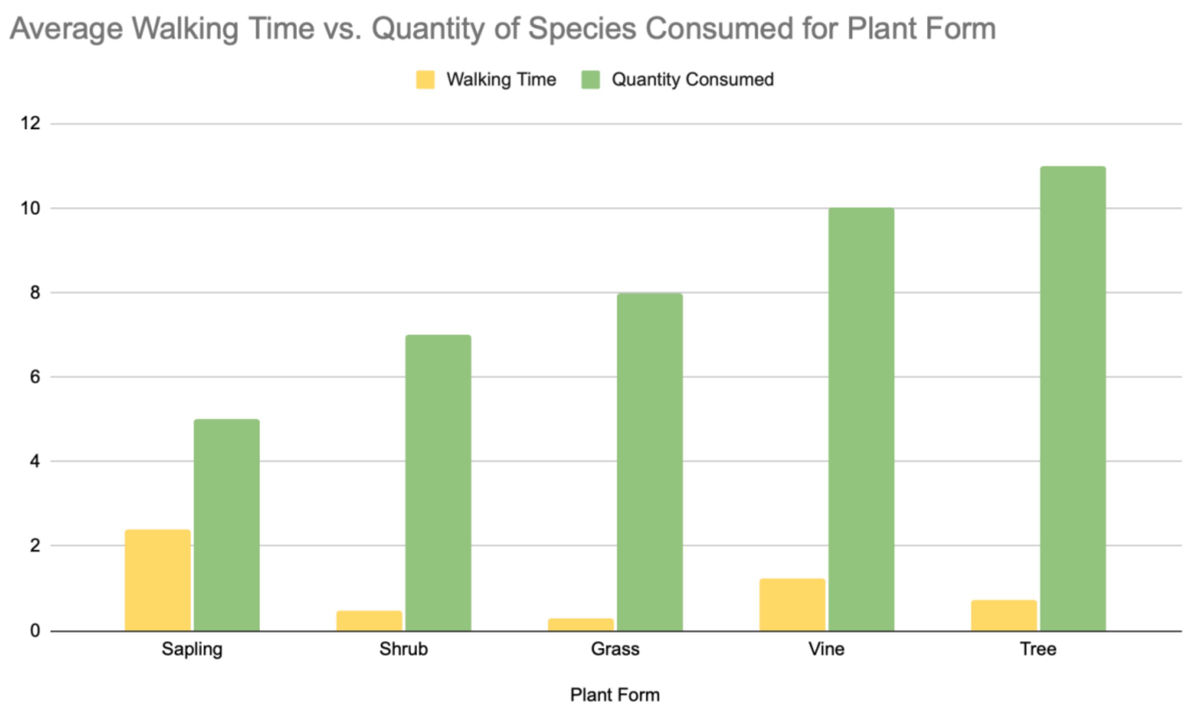

Table 4: Average Walking time compared to the number of species consumed per Plant Form.

Saplings were consumed the least (n=5) out of the other Plant Forms, but the focal elephants were still recorded Walking the most prior to their feedings ($\bar{x}$=2.4). Moreover, 8 different grass species were consumed with an average Walking time of 0.286.

Finalized Results

Plant species were consolidated into Families for statistical testing, due to the many "zero" encounter recordings during the finer-grain (10-minute) timeframes. After running the single-factor ANOVA tests, it was determined that out of the three study groups in each timescale, only plant form ($p < 0.001$) and plant family ($p < 0.001$) in the 10-minute intervals were significant (APPENDIX A). This tells us that the focal elephants' Feeding may have been more closely correlated to Walking time on a micro-scale, rather than a macro scale, as I had originally predicted. This also tells us that the focal elephants' walking times were influenced by the plant form and plant family, and not by the plant part eaten. The Tukey's HSD test determined that saplings ($\bar{x}=1.21$) and trees ($\bar{x}=0.73$) were responsible for the variation in plant form's walking time. It was also found that the plant families responsible for the variation in walking time were Apocynaceae ($\bar{x}=2$), Caprifoliaceae ($\bar{x}=1.5$), Sapindaceae ($\bar{x}=1.25$), Myrtaceae ($\bar{x}=1$), Anacardiaceae ($\bar{x}=1$), and Moraceae ($\bar{x}=0.74$). **Figure 2** show graphs of each plant groups mean Walking times from the 10-minute intervals with a confidence interval of 95%.

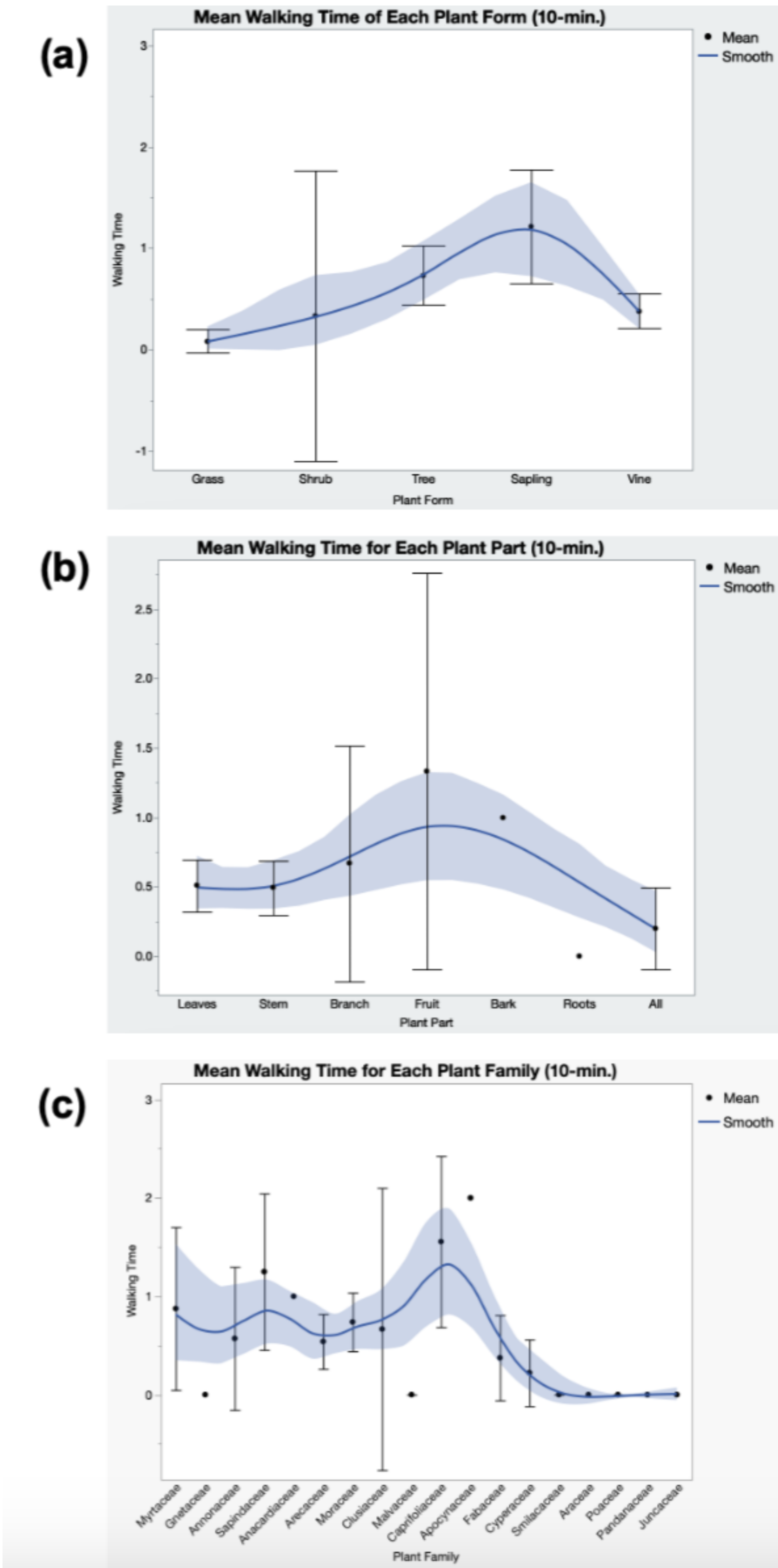

Figure 2: Mean Walking time for each plant form (a), plant part eaten (b), and plant family (c) during 10-minute intervals (95% CI).

Discussion

Spatial Significance of Feeding

It was discovered that plant form and plant family had a significant association with Walking time in the 10-minute interval, while the 60- and 120-minute intervals were found to be insignificant. This may imply that the Feeding times were more specific on a micro-timescale as opposed to a larger, macro scale, which confirms my hypothesis. Thus, I assume that the elephants may have consumed a plethora of lower-value plants in between their journey to the most preferred, nutrient-rich plants. As generalist herbivores, Asian elephants have a wide array of plant species incorporated into their diet. This foraging technique may help them maintain their extremely high daily caloric and nutrient demand— especially as these semi-captive elephants were only provided with roughly one-third of the daily foraging time seen from wild Asian elephants.

In a recent study, it was shown that Asian elephants either prefer large patches of low-quality plants, or small patches of high-quality plants depending on accessibility and growth (Pretorius, 2009). Unfortunately, the Bos Thom Community Forest has not had any reliable vegetation surveys done on the land, so there is no information on its patch qualities. However, due to the focal elephants' Feeding times being more pronounced on a micro- timescale, this may imply that the patches that they preferred were in close proximity to one another, whether they were small, high-quality patches or large, low-quality patches. The two plant families predicted to be favorable based on their nutrients, Fabaceae and Poaceae, did not have significant Walking times. However, it is important to note that they were the first and fifth most consumed plant families, respectively. This implies that these nutrient-rich plants are readily available for the focal elephants throughout their walk with the mahouts.

Implications of Preferred Plant Types

The fact that the feeding of plant forms and plant families were all significantly correlated with Walking time confirms my hypothesis that there is a positive link between the two variables. I believe there are two primary reasons, other than sheer availability, as to why the focal elephants may have intentionally selected certain plant types over others: Nutritional composition and lack of innate plant defense. This connects as far back as Darwin's theory of natural selection, stating that organisms with traits that better enable them to survive and reproduce in their environment are more likely to pass on those traits to their offspring, leading to gradual changes in a population over generations, essentially causing species to evolve and adapt to their environment. This theory is also known as his coined term, "survival of the fittest". Thus, to corroborate what is already known about general animal behavior, the elephants are likely gravitating towards these nutrient-rich plants due to innate instincts of survival.

The two sapling species that had walking times greater than 0 were *Lepisanthes rubiginosa* and *Syzygium jambos.* A recent study analyzed *Lepisanthes rubiginosa* seeds for their nutritional and bioactive content (Bunyatratchata et al., 2023). The researchers determined that the species consists of approximately 10% protein, 2% fat, 16% fiber, 2% ash, and 42% carbohydrates, and is rich in essential amino acids like proline and methionine. Although there is limited research on the specific *Syzygium jambos* species, its genus, Syzygium, has been inspected. Syzygium species have been shown to possess significant sources of secondary metabolites such as flavonoids, tannins, and phenolics, which are known to have antioxidant, antimicrobial, anti-inflammatory, and antidiabetic properties (Aung et al., 2020). *Lepisanthes rubiginosa* is also known to have phenolic acids and flavonoids, further emphasizing why the focal elephants may have preferred these saplings (Bunyatratchata et al., 2023). These secondary metabolites can be known to deter herbivores away from plants due to toxic or bitter properties. However, these saplings likely do not produce enough to deter the elephants away, but rather attracted them due to their medicinal properties. Perhaps these plants produce enough of these bio-active molecules for smaller herbivores, but not for megaherbivores such as Asian elephants who were able to consume new-growth saplings without significant health concerns.

The four primary tree species that had walking times greater than 0 were *Mangifera indica*, *Ficus hispida*, *Streblus asper lour.*, and *Licuala spinosa wurmb*. *Mangifera indica*, a species of mango, is known to be rich in dietary fiber, sugars, Vitamins A, C, E, and B-complex, and minerals like potassium and magnesium (Shah et al., 2023). These properties of mangos have the ability to help lower blood sugar levels, enhance insulin production, and reduce lipid levels (ibid.). Furthermore, *Ficus hispida*, or the opposite leaf fig, is known for its high protein and carbohydrate composition, which can help herbivores maintain muscle tissues and metabolic energy demands. *Streblus asper lour* , or the Siamese rough bush, has limited nutritional profiling available. However, research shows that its leaves and bark contain flavonoids, alkaloids, and saponins, which provide antioxidant and antimicrobial uses (Chaurasiya & Ahmad, 2023). *Licuala spinosa wurmb*, or the mangrove fan palm, as well as its genus, has limited data on their biological properties. However, all four of these tree species are also known to have significant sources of secondary metabolites such as terpenoids, flavonoids, tannins, alkaloids, and phenolic compounds, which can be used as the plants' chemical defenses, but otherwise likely act as medicinal properties for the elephants (Khan et al, 2018; Kumar et al, 2021a; Kumar et al, 2022; Chaurasiya & Ahmad, 2023).

The Apocynaceae family is primarily known for their alkaloid-rich plants, which contribute to their therapeutic properties, as well as their abundance of triterpenoids, flavonoids, phytosterols, cardiac glycosides and lignans (Ekalu et al, 2019). These properties are known for their anti-inflammatory and anti-viral functions, which would be especially useful for the focal elephants who are older females. The elephants may be inclined to walk further for these medicinal plants to help maintain their relatively old bodies. *Willughbeia edulis,* or the Kouy fruit, was the one Apocynaceae plant consumed by the focal elephants. It is known for its fruit's pleasant flavor, methanol stem extract, and latex that is commonly used to treat dysentery and liver discomfort (Sami, 2022). The elephants likely favor these plant properties, thus walked for a longer time period to take advantage of their medicinal benefits.

Moreover, the one species consumed that is in the Caprifoliaceae family, *Lonicera japonica*, or Japanese honeysuckle, is known for its medicinal and edible value. It is high in antioxidant and anti-inflammatory bioactive compounds such as chlorogenic acid and flavonoids (Cao et al., 2022). Research regarding the broader family's nutritional composition is limited, but honeysuckles commonly follow similar biological trends (ibid.). As previously mentioned, these bioactive molecules also act as chemical defense mechanisms that fight off herbivores, but they were likely not strong enough to ward off megaherbivores such as elephants.

In a broad sense, Sapindaceae, or the soapberry family has been linked to species with high levels of carbohydrates, lipids, proteins, and fibers, namely from the rambutan plant (Jahurul et al., 2020). These nutritional contents can be extremely valuable for elephants' energy storage, digestive tract, and bodily tissue maintenance (Ullrey et al., 1997). *Lepisanthes rubiginosa*, the only species in the Sapindaceae family with a walking time over 0, has been discovered to possess significant concentrations of phenolics, flavonoids, and alkaloids (Hasan et al., 2017). This is important, as it follows the trend that we have been seeing regarding the focal elephants likely seeking out plants based on their nutrient and medicinal properties. The concentrations of secondary metabolites are not likely enough to cause any medical harm to the elephants, as previously mentioned.

Certain species of the Myrtaceae family, such as the guava fruit, have been known to possess significant quantities of carbohydrates, proteins, and dietary fibers, which contribute to their energy and digestive health benefits (Kumar et al., 2021b). *Syzygium jambos*, the only species in the Myrtaceae family that has a walking time over 0, is known to have high contents of protein, carbohydrates, crude fiber, and fats (Rajalakshmi et al, 2016). Futhermore, another study shows that S. jambos has significant phenolic compounds, including flavonoids, tannins, and ellagic acid derivatives, which contribute to their antioxidant and medicinal properties (Ochieng et al., 2022). The combination of nutritional and medicinal benefits of Myrtaceae plants likely contributed to the focal elephants showing a preference towards the family.

The Anacardiaceae family has been determined to be rich in various nutrients including fats (primarily unsaturated), proteins, and carbohydrates, primarily found in many edible fruits and nuts, supporting everyday metabolic activity for consumers such as elephants (Salehi et al., 2019). This family also encompasses *Mangifera indica* (mango), which was previously mentioned for its abundance of dietary fiber, sugars, Vitamins A, C, E, and B-complex, and minerals like potassium and magnesium. Furthermore, the plants' abundance in phenolic acids and flavonoids also contribute to the medicinal benefits likely sought out by the focal elephants.

The final significant plant family, Moraceae, encompasses the two plant families that were previously discussed (*Ficus hispida* and *Streblus asper*). These species have been appraised for their high contents of nutrients such as nitrogen, potassium, calcium, magnesium, zinc, and iron, as well as their antioxidant properties (Aziz & Hajar, 2017; Pandey & Rastogi, 2022). Nitrogen, a vital component of protein, is crucial for the muscle development, immune function, and overall health of elephants (Woolley et al., 2009). Studies show that oftentimes when nutrient availability is scarce, typically in the dry season, elephants prioritize nitrogen-rich plants to sustain their protein requirements (ibid.). In a broader sense, the Moraceae family is commonly rich in macronutrients, which contribute to overall bodily functions such as energy storage, cellular repair, and digestive processes, however, this does vary across species (Arshad et al., 2018).

To summarize, the focal elephants likely incorporated increased Walking time towards specific plant forms and families due to their high nutrient densities in terms of essential macromolecules, minerals, vitamins, and other medicinal properties. Consuming these plants may lead to greater reproductive, immune, bone, and muscle function for the individuals. These strategies mirror elephants' innate behavioral instincts to optimize nutrient intake, thus enhancing their ability to thrive in their environments.

Additionally, there is the possibility that these preferred plant groups did not exhibit strong innate defense mechanisms that adequately deter the focal elephants away—especially the young saplings. In terms of each "preferred" plant group, there was very limited research showing the plants' defense mechanisms that would be successful in discouraging megaherbivore consumption. However, it appears that many of these plants are known to have some chemical defenses against smaller herbivores including compounds such as tannins, alkaloids, flavonoids, and saponins (Mostafa et al., 2022). These chemical defenses may attempt to deter herbivores from consuming them, but little evidence shows that this works on megaherbivores such as Asian elephants, who have a large gut capacity to metabolize these plants (Ecology Center, 2023).

The focal elephants likely preferred plants with weaker innate defense mechanisms because they are easier to masticate and digest. No literature showed any of the preferred species to possess deterrents strong enough to ward off Asian elephants. Thus, the elephants may have shown increased Walking time for these species due to their easy access. It is possible that some of the other nearby plants that did possess strong chemical, or physical defenses may have been intentionally avoided by the focal elephants. However, this is tentatively unknown until a thorough vegetation survey is done on the area.

Summary

Many variables play a role in any species' diet, but with limited research done on Asian elephant foraging in Cambodia, it is crucial to learn as much as possible about this species in order to promote their conservation efforts' success. This study's outcomes determined that the focal elephants appear to be foraging on a micro- timescale and focused on traveling further distances for nutrient-rich plant types. Elephants, along with all other wild animals, have a multitude of complex survival instincts that many of which are still waiting to be explained. This data may further suggest ideas for reforestation projects that encompass Asian elephants to prioritize preferred, nutrient-rich plants with known medicinal properties. Although this study provides a unique perspective to these instincts, it is clear that more directed research should be conducted in order to gain a more accurate comprehension of this species' behaviors.

Limitations

Mahouts were present during the entirety of data collection. Their role was to maintain the safety of the elephants and researchers throughout the study and assisted with their knowledge of the landscape to avoid getting lost or off-boundary. When a focal elephant headed towards agricultural land or started knocking down a protected tree, mahouts intervened to stop them. This variable appeared to slightly alter the elephants' behaviors, thus skewing the data to an extent. Furthermore, the original intent of this study was to simply form a plant taxonomy and activity budget to determine which independent variables altered elephant behavior. This thesis was not taken into consideration when planning out the Methodology of data collection. Thus, collecting continuous data that meticulously tracked the focal elephants' movements, and the time spent on foraging behaviors and consuming specific plants would have likely provided more accurate results.

References

Arshad, S., Rehman, R., Mushtaq, A., & Qayyum, A. (2018). Morphology, chemical composition and medicinal properties of Morus nigra L. A review. *IJCBS*, *13*, 100-103.

Ara, A., Sofi, P. A., Rather, M. A., Rashid, M., & Gull, M. (2019). Abiotic Stress Tolerance in Legumes–Critical Approaches. *Int J Curr Microbiol App Sci*, *8*, 1991-2000.

Asia-Pacific Network for Sustainable Forest Management and Rehabilitation. (2022).

Aung, E. E., Kristanti, A. N., Aminah, N. S., Takaya, Y., & Ramadhan, R. (2020). Plant description, phytochemical constituents and bioactivities of Syzygium genus: A review. *Open Chemistry*, *18*(1), 1256-1281.

Aziz, A., & Hajar, S. (2017). *Nutritional Composition And Biological Evaluation Of Ficus Hispida Leaves* (Doctoral dissertation).

Borah, J., & Deka, K. (2008). Nutritional evaluation of forage preferred by wild elephants in the Rani Range Forest, Assam, India. *Journal Gajaha*, *28*(1), 41-43.

Bunyatratchata, A., Chumroenphat, T., Saensouk, S., & Siriamornpun, S. (2023). Bioactive Compounds, Amino Acids, Fatty Acids, and Prebiotics in the Seed of Mahuad (Lepisanthes rubiginosa (Roxb.) Leenh). *Horticulturae*, *9*(10), 1159.

Campos-Arceiz, A., & Blake, S. (2011). Megagardeners of the forest–the role of elephants in seed dispersal. *Acta Oecologica*, *37*(6), 542-553.

Cao, W., Chen, J., Li, L., Ren, G., Duan, X., Zhou, Q., ... & Liu, X. (2022). Cookies fortified with Lonicera japonica Thunb. extracts: Impact on phenolic acid content, antioxidant activity and physical properties. *Molecules*, *27*(15), 5033.

Chaurasiya, N., & Ahmad, A. (2023). Medicinal Plants for Health Care. In *Omics Studies of Medicinal Plants* (pp. 1-24). CRC Press.

Choudhury, A. (1999). Status and conservation of the Asian Elephant Elephas maximus in north-eastern India. *Mammal Review*, *29*(3), 141-174.

Asia-Pacific Network for Sustainable Forest Management and Rehabilitation. Retrieved April 24, 2023, from https://www.apfnet.cn/plus/view.php?aid=4315

Ecology Center. (2023). *Elephant digestion system overview*. Retrieved November 12, 2024, from https://ramdigestivesystem.weebly.com/elephants.html

Ekalu, A., Ayo, R. G. O., James, H. D., & Hamisu, I. (2019). A mini-review on the phytochemistry and biological activities of selected Apocynaceae plants.

Fernando P., and Pastorini J. (2011) Range-wide status of Asian elephants. *Gajah* 35:15-20

Fernando, Prithiviraj, and Peter Leimgruber. "Asian elephants and seasonally dry forests." *Ecology and conservation of seasonally dry forests in Asia* (2011): 151-163.

GDANCP(2020). Asian Elephant Conservation Action Plan for Cambodia (2020-2029)

Gray T., Vidya T., Bharti S., and Sovanna P. (2014) Population size estimation of an Asian elephant population in eastern Cambodia through non-invasive mark-recapture sampling. *Conservation Genetics* 15:803-810

Hasan, M. M., Hossain, A., Shamim, A., & Rahman, M. M. (2017). Phytochemical and pharmacological evaluation of ethanolic extract of Lepisanthes rubiginosa L. leaves. *BMC Complementary and Alternative Medicine*, *17*, 1-11.

Haynes, G. (2012). Elephants (and extinct relatives) as earth-movers and ecosystem engineers. *Geomorphology*, *157*, 99-107.

Holdgate, M. R., Meehan, C. L., Hogan, J. N., Miller, L. J., Soltis, J., Andrews, J., & Shepherdson, D. J. (2016). Walking behavior of zoo elephants: associations between GPS-measured daily walking distances and environmental factors, social factors, and welfare indicators. *PloS one*, *11*(7), e0150331.

Jahurul, M. H. A., Azzatul, F. S., Sharifudin, M. S., Norliza, M. J., Hasmadi, M., Lee, J. S., ... & Zaidul, I. S. M. (2020). Functional and nutritional properties of rambutan (Nephelium lappaceum L.) seed and its industrial application: A review. *Trends in Food Science & Technology*, *99*, 367-374.

Khan, M. S., Yusufzai, S. K., Rafatullah, M., Sarjadi, M. S., & Razlan, M. (2018). Determination of total phenolic content, total flavonoid content and antioxidant activity of various organic crude extracts of Licuala spinosa leaves from Sabah, Malaysia. *ASM Science Journal*, *11*(3), 53-58.

Kitamura, S., Yumoto, T., Poonswad, P., & Wohandee, P. (2007). Frugivory and seed dispersal by Asian elephants, Elephas maximus, in a moist evergreen forest of Thailand. *Journal of Tropical Ecology*, *23*(3), 373-376.

Kulen Elephant Forest. (n.d.). Kulen elephant forest: the situation/eco. https://www.kulenforest.asia/the-situation-eco/

Kumar, M., Arif, M., Shafi, S., Al-Jaber, N., & Alsultan, A. A. (2022). Potential phytoconstituents of Ficus religiosa L. and Ficus benghalensis L. with special reference to the treatment of blood disorders. *Medicinal Plants-International Journal of Phytomedicines and Related Industries*, *14*(2), 221-232.

Kumar, M., Saurabh, V., Tomar, M., Hasan, M., Changan, S., Sasi, M., ... & Mekhemar, M. (2021a). Mango (Mangifera indica L.) leaves: Nutritional composition, phytochemical profile, and health-promoting bioactivities. *Antioxidants*, *10*(2), 299.

Kumar, M., Tomar, M., Amarowicz, R., Saurabh, V., Nair, M. S., Maheshwari, C., ... & Satankar, V. (2021b). Guava (Psidium guajava L.) leaves: Nutritional composition, phytochemical profile, and health-promoting bioactivities. *Foods*, *10*(4), 752.

Maltby M. and Bourchier G. (2011) Current status of Asian elephant in Cambodia. *Gajah* 35: 36-42.

Menon, V., & Tiwari, S. K. (2019). Population status of Asian elephants Elephas maximus and key threats. *International Zoo Yearbook*, *53*(1), 17-30.

Miller, L. J., Chase, M. J., & Hacker, C. E. (2016). A comparison of walking rates between wild and zoo African elephants. *Journal of Applied Animal Welfare Science*, *19*(3), 271-279.

Mostafa, S., Wang, Y., Zeng, W., & Jin, B. (2022). Plant responses to herbivory, wounding, and infection. *International journal of molecular sciences*, *23*(13), 7031.

Neupane, D., Kwon, Y., Risch, T. S., Williams, A. C., & Johnson, R. L. (2019). Habitat use by Asian elephants: Context matters. *Global Ecology and Conservation*, *17*, e00570.

Ochieng, M. A., Ben Bakrim, W., Bitchagno, G. T. M., Mahmoud, M. F., & Sobeh, M. (2022). Syzygium jambos L. Alston: An insight into its phytochemistry, traditional uses, and pharmacological properties. *Frontiers in pharmacology*, *13*, 786712.

Pandey, M. M., & Rastogi, S. (2022). Streblus asper: A phytochemical, ethnopharmacological and pharmacological research update. *Journal of Pharmacognosy and Phytochemistry*, *11*(3), 07-18.

Pretorius, Y. (2009). *Satisfying giant appetites: mechanisms of small scale foraging by large African herbivores*. Wageningen University and Research.

Pretorius, Y., Stigter, J. D., De Boer, W. F., Van Wieren, S. E., De Jong, C. B., de Knegt, H. J., ... & Prins, H. H. T. (2012). Diet selection of African elephant over time shows changing optimization currency. *Oikos*, *121*(12), 2110-2120.

Priyadharshana, M., & Vadivel, V. (2022). Fodder plants and foraging behaviour of Asian elephants in Srivilliputhur Elephant Reserve, Tamil Nadu, India. *Indian Journal of Natural Products and Resources (IJNPR)[Formerly Natural Product Radiance (NPR)]*, *13*(3), 391-397.

Rajalakshmi, P., Sumathi, V., Vadivel, V., & Pugalenthi, M. (2016). Determination of nutraceuticals in tropical medicinal plants of Syzygium jambos L.(Alston) and Syzygium travancoricum gamble. *Int. J. Med*, *4*(6), 150-152.

Rubiales, D., & Mikic, A. (2015). Introduction: legumes in sustainable agriculture. *Critical Reviews in Plant Sciences*, *34*(1-3), 2-3.

Salehi, B., Gültekin-Özgüven, M., Kırkın, C., Özçelik, B., Flaviana Bezerra Morais-Braga, M., Nalyda Pereira Carneiro, J., ... & C. Cho, W. (2019). Anacardium plants: chemical, nutritional composition and biotechnological applications. *Biomolecules*, *9*(9), 465.

Sami, S. A. (2022). New insights into the identification of bioactive compounds from Willughbeia edulis Roxb. through GC–MS analysis. *Beni-Suef University Journal of Basic and Applied Sciences*, *11*(1), 89.

Shah, B. V., Chopra, H., Medithi, S., & Ungarala, V. R. (2025). Nutritional Potency of Mangifera indica L.(Mango): Focus on Mango as Antioxidant. *Current Functional Foods*, *3*(1), E200324228150.

Sukumar, R. (2006). A brief review of the status, distribution and biology of wild Asian elephants Elephas maximus. *International Zoo Yearbook*, *40*(1), 1-8.

Ullrey, D. E., Crissey, S. D., & Hintz, H. F. (1997). *Elephants: nutrition and dietary husbandry* (pp. 1-20). East Lansing: Nutrition Advisory Group.

Woolley, L. A., Millspaugh, J. J., Woods, R. J., Van Rensburg, S. J., Page, B. R., & Slotow, R. (2009). Intraspecific strategic responses of African elephants to temporal variation in forage quality. *The Journal of Wildlife Management*, *73*(6), 827-835.

Appendix A.

Figure 3: Data analyses of plant form, plant part, and plant family for the 10-minute (a), 60-minute (b), and 120-minute (c) intervals.

(a)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Form 2	4	13.979464	3.49487	6.9629	<.0001*
Error	132	66.254113	0.50193		
C. Total	136	80.233577			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Part 2	6	3.656137	0.609356	1.0351	0.4051
Error	142	83.592186	0.588677		
C. Total	148	87.248322			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Family 2	17	26.934178	1.58436	2.3346	0.0049*
Error	99	67.185480	0.67864		
C. Total	116	94.119658			

(b)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Form	4	1.804113	0.451028	0.7253	0.5837
Error	23	14.303030	0.621871		
C. Total	27	16.107143			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Part	6	3.972727	0.662121	0.9829	0.4593
Error	23	15.493939	0.673650		
C. Total	29	19.466667			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Family	17	5.2952381	0.311485	0.9941	0.5237
Error	10	3.1333333	0.313333		
C. Total	27	8.4285714			

(c)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Form 4	4	0.5000000	0.125000	0.2500	0.8931
Error	3	1.5000000	0.500000		
C. Total	7	2.0000000			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Part 4	6	1.2222222	0.203704	0.4074	0.8336
Error	2	1.0000000	0.500000		
C. Total	8	2.2222222			

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Family 4	17	5.9523810	0.350140	1.0504	0.5623
Error	3	1.0000000	0.333333		
C. Total	20	6.9523810			