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Research Article

The Invasive Plant *Maeopsis eminii*: A Key Dietary Resource for Primates in the Tropical Rainforests of West Java, Indonesia

Mohamad Isnin Noer*, Alvita Dwi Lestari, Kiky Ramadhini, Priya Yuga Prasetya, Agung Sedayu, Ratna Komala

Biology Study Program, Faculty of Mathematics & Natural Sciences, Universitas Negeri Jakarta, Jakarta 13220, Indonesia

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ABSTRACT

Animal-plant interactions are crucial for understanding the ecological dynamics and predicting ecosystem changes. This study explores the role of the invasive plant *Maesopsis eminii* in the Bodogol Nature Reserve, Gunung Gede National Park, West Java, Indonesia, focusing on its interaction with diurnal vertebrate species. Primates, including Javan gibbon and Javan langur, were identified as primary consumers of *Maesopsis eminii*, with Javan gibbon showing the highest consumption rates. Dietary analysis revealed that both primate species utilized *M. eminii* fruits and leaves, whereas Javan gibbons relied more on *Maesopsis eminii* than Javan langurs. Other vertebrates, such as squirrels and birds, are occasional visitors with minimal fruit consumption. This study highlights that *Maesopsis eminii* is a primary resource of Javan gibbon, Javan langur, and Javan surili. This nearly year-round fruiting plant is crucial for supporting primate populations, especially given its contribution to their diet. Considering the mutualistic interaction between *Maesopsis eminii* and its visitors, the Javan gibbon was the only species that probably dispersed seeds through endozoochory, making this primate species a crucial part of the dispersal of *Maesopsis eminii* in Gunung Gede National Park. Because invasive plants can threaten native flora and fauna, future studies must emphasize balancing the beneficial and detrimental effects.

1. Introduction

Investigating animal-plant interactions is key to behavioral and ecosystem studies. Ecosystem changes can be predicted and evaluated based on interaction networks occurring in particular habitats (Bascompte & Jordano 2006), focusing on the important aspect of the network that facilitates a high degree of mutualistic income. Mutualistic income involves a reciprocal exchange of resources or services from interacting species, such as pollination, seed dispersal, and nutrient exchange. Mutualistic income generated from these interactions over time dictates the ecosystem (Donatti 2011; Corral *et al.* 2021; Santos & de Souza Ribeiro 2023).

Invasive plants have been a global issue for a decade and have continued to escalate over time owing to the increasing mobility of humans (Gioria *et al.* 2023). These invasive plants risk deteriorating ecosystems and reduce the biological diversity in certain areas once colonized (Vantarová *et al.* 2023). Their establishment threatens the existence of any native plant species and can reduce the number of animal species by disintegrating or changing the animal-plant mutualistic interaction structures (Lenda *et al.* 2023). With the evolving dynamics of mutualistic interactions, invasive plants can provide new resources for native animal species by offering alternative food sources, particularly during scarcity (Chan *et al.* 2021; Reinegger *et al.* 2023; Kraehe *et al.* 2024). The potential role of invasive plant species in providing food is particularly valuable for various animal species (Sedayu & Noer 2024), including vulnerable ones (Rahman *et al.* 2019; Kraehe *et al.* 2024). Preferences for invasive plants over native plants would consequently increase the potential for invasive plants to be widely dispersed and change the plant species composition (Hulme 2003;

*Corresponding Author
E-mail Address: mohamadisnin@unj.ac.id

Lenda *et al.* 2023). A study concerning this problematic issue must be conducted, particularly in nature reserves, to develop a better conservation strategy and better understand the risks and benefits of native plant species in a particular ecosystem.

Maesopsis eminii is an invasive plant species that has colonized many regions worldwide (CABI 2022). This plant was formerly introduced as an alternative source for the Indonesian wood industry because it can overgrow and is easy to maintain (Karlinasari *et al.* 2018). In some regions, including Indonesia, *M. eminii* has been planted near nature reserves without any significant separation, making the generalist and synanthropic animals easily exploit the fruits of this plant and disperse them into the nature reserve areas (Binggeli & Hamilton 1993). Establishing *M. eminii* in nature reserves has become widespread (Padmanaba *et al.* 2017). Some studies have reported anecdotal observations regarding the role of this invasive plant as a food source for important animal species that reside in nature reserves (Sadili *et al.* 2023; Allasselcida *et al.* 2024). However, a study that elaborates on the role of *M. eminii* as a resource for some important animal species has not been conducted. Thus, balancing the benefits and risks of this plant species in nature reserves remains unaddressed. In this study, we investigated diurnal, arboreal vertebrates that utilize *M. eminii* as a source of their diet and identified those that rely heavily on *M. eminii* by observing their feeding occurrences. Since natural reserves typically contain many protected animals, we also observed a mutualistic interaction between *M. eminii* and these high-conservation-value animals.

M. eminii is among the plant species obtained in Gunung Gede Pangrango Park. This invasive plant species exists throughout Gunung Gede National Park, especially in Bodogol. Therefore, the invasiveness of this plant species needs to be evaluated. The widespread distribution of *M. eminii* in Bodogol suggests successful coexistence with its mutualistic partners that have already been established (Rozak *et al.* 2016; Sadili *et al.* 2023). Some species have anecdotally been documented as having mutualistic interaction with *M. eminii*, including primate species such as Javan gibbon (*Hylobates moloch*), Javan langur (*Trachypithecus auratus*), Javan surili (*Presbytis comata*), and Javan slow loris (*Nycticebus javanicus*) (Sadili *et al.* 2023; Allasselcida *et al.* 2024). To our knowledge, the interaction between *M. eminii* and its animal partners has not been examined elsewhere, highlighting the urgency of this study. By investigating the interactions between this invasive plant species and its mutualistic partners, we can shed light on the role of invasive species in nature reserves, providing valuable insights that can be integrated into conservation management strategies.

2. Materials and Methods

2.1. Study Area

We observed vertebrate visitors to *M. eminii* in the lowland forests of Bodogol from May to July 2023. Bodogol is the western part of Gunung Gede National Park at an altitude of 800-900 meters above sea level, making Bodogol the only area of Gunung Gede National Park that belongs to the lowland forest (Noer *et al.* 2023). This lowland forest offers environmental conditions that support the abundance of *M. eminii*, as this plant species thrives in lowland and submontane regions (Epila *et al.* 2017). Vertebrate visitors observed in this study were exclusively selected on arboreal vertebrates that consumed the fruit of *M. eminii* during the day. We included neither nocturnal nor terrestrial (secondary consumers) vertebrates because of the limitation of our equipment in applying point-count observations for nocturnal and terrestrial vertebrates.

Recent studies have reported that *M. eminii* is more numerous and widely distributed in Bodogol than in other Gunung Gede National Park areas. Bodogol also hosts a variety of animal species, including some protected by Indonesian law due to concerns about their populations (Nomor P.20/MENLHK/SETJEN/KUM.1/6/2018). Some of these species have anecdotally been documented as having mutualistic interaction with *M. eminii*, especially primate species such as Javan gibbon, Javan langur, Javan surili, and Javan slow loris (Sadili *et al.* 2023; Allasselcida *et al.* 2024).

2.2. Visitors of *Maesopsis eminii*

A point count was used to observe the diurnal vertebrates that visited and consumed *M. eminii*. We designed three circular plots of 100 m in diameter, where the observer was in the center of the plots to observe any vertebrate species visiting *M. eminii* from 06:00 to 17.00 WIB. Each plot was purposively selected based on the highest concentration of *M. eminii* and ease of access for conducting circular observations. All three plots were spaced at least 200 m apart to account for visitor variability. In the visitor survey section, we focused only on fruiting trees to record vertebrate species that consumed the fruits of *M. eminii*. We classified fruit-handling activities into three categories: gulping,

dropping, and pecking, following Blendinger (2017), and quantified the number of fruits managed by animal species during the visit.

2.3. Dietary Preferences of the Javan gibbon and Javan langur

During preliminary surveys and as reported in previous studies (Sadili *et al.* 2023), primates were the most common species observed in *M. eminii*. To gain detailed information about the importance of *M. eminii* as the primary source in their diet, we observed the two most common species of primates in Bodogol, the Javan gibbon and Javan langur. Focal observations were used to record the feeding behavior of these two primates over two months. We followed four available routes intermittently (two days per route) from 06.00 to 17.00. These routes were selected based on the relatively high number of encounters documented in preliminary surveys, national park expert recommendations, and previous studies. Focal sampling was used to observe the Javan gibbon and Javan langur. To record feeding activities for all class categories evenly, we alternately observed each class category for 10 min, starting from the oldest to the youngest class. Selecting a focal individual to observe the Javan gibbon was straightforward because of the species' small group size; therefore, we chose an adult male to represent the adult class category. In Javan langur, we randomly selected an individual to represent each class category.

2.4. Data Analysis

The diurnal vertebrate visitors of *M. eminii* were quantified based on the number of visits and fruits consumed during one month of observation across three different areas. We divided the visit data into 10-minute observations to ensure a fair comparison among visitors, taking into account the duration of their stay, as primates typically spend a relatively longer time in *M. eminii* during each visit. A chi-squared test was used to compare these categories among diurnal vertebrate visitors. Using the chi-square test, we also compared vertebrate species based on how they manage their fruits (gulping, dropping, and pecking). We analyzed resource selection patterns by comparing the types of resources consumed to those available, employing the Manly selection index (Manly 2013). We used the data collected by Sadili *et al.* (2023) to explain the relative degree of availability of all plant species consumed by Javan gibbon and Javan langur. The Manly selectivity index (± CI) for each resource use type ranged from 0 (complete avoidance) to infinity (strong preference), with an index of 1 indicating usage proportional to availability. The Manly index was calculated using the AdehabitatHR package, and selection curves were visualized using the WidesI function in R 4.3.0.

3. Results

We found a significant association between visitors and the number of visits (χ^2 = 647.7, df = 4, p<0,001) and fruits consumed (χ^2 = 98.3, df = 4, p<0,001). Among vertebrates, primates are familiar visitors who consume many *M. eminii* fruits. Four of the five primate species consumed *M. eminii* fruits in their diets. Javan gibbon was the primate visitor that consumed the most *M. eminii* fruits, followed by Javan langur and Javan surili (Table 1). In contrast, long-tailed macaques have been reported to utilize *M. eminii* fruit only rarely and consume a low number of fruits. Our study also documented other vertebrate species consuming *M. eminii* fruits, including two species of squirrels and two species of birds. The plantain squirrel (*Callosciurus notatus*) and black giant squirrel (*Ratufa bicolor*) were observed feeding on the fruit, as were the Yellow-eared barbet (*Psilopogon australis*) and Coppersmith barbet (*Psilopogon haemacephalus*)-however, squirrels and birds consumed only a few fruits and only on infrequent occasions.

Regarding the mechanism of fruit handling, some mammal species consumed the fruit by eating part of it and dropping the remainder directly beneath the parent tree (Figure 1, χ^2 = 1069.3, df = 14, p<0.001). No signs of epizoochory mechanisms were documented for nearly all these species except the plantain squirrel, which carried the fruits by storing them in their cheeks. Javan gibbon was the only species of mammal that managed almost all the fruits by swallowing them,

Table 1. Visitors of ki Afrika (*Maesopsis eminii*) in the protected lowland forest of Bodogol incorporating the number of feeding occurrences and number of fruits

Order	Species	Feeding occurences	Number of fruits
Primates	*Hylobates moloch*	46	384
	Trachypithecus auratus	34	172
	Presbytis comata	16	119
	Macaca fascicularis	1	2
Rodentia	*Callosciurus notatus*	5	11
	Ratufa bicolor	1	2
Piciformes	*Callosciurus notatus*	2	2
	Ratufa bicolor	1	2

and only a very low number of fruits dropped on the ground. For birds, both of them just only plucked the fruit without dropping it.

Our observations on the diet of the most common visitors of *M. eminii* (Javan gibbon dan Javan langur) demonstrated that *M. eminii* is among the preferred foods eaten by both species. Javan gibbon exhibited their preferences on eight plant species in which *M. eminii* was among the preferred foods for Javan gibbon, which has a selection score of more than 2 (Figure 2). Javan langur preferred a broader range of plant species, but *M. eminii* remained a key part of their

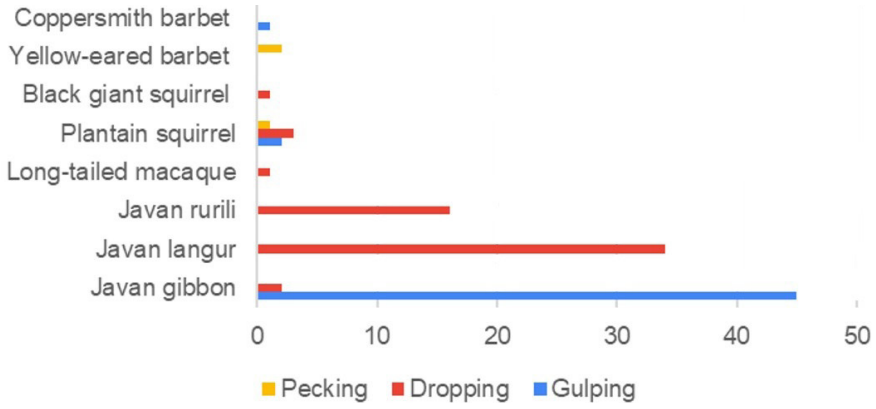

Figure 1. Differences in the fruit-handling mechanism of *M. eminii* for all diurnal vertebrate visitors were used as a baseline to predict the pattern of *M. eminii* dispersal in Bodogol. Javan gibbon was the only visitor that played a role as the primary disperser of *M. eminii*

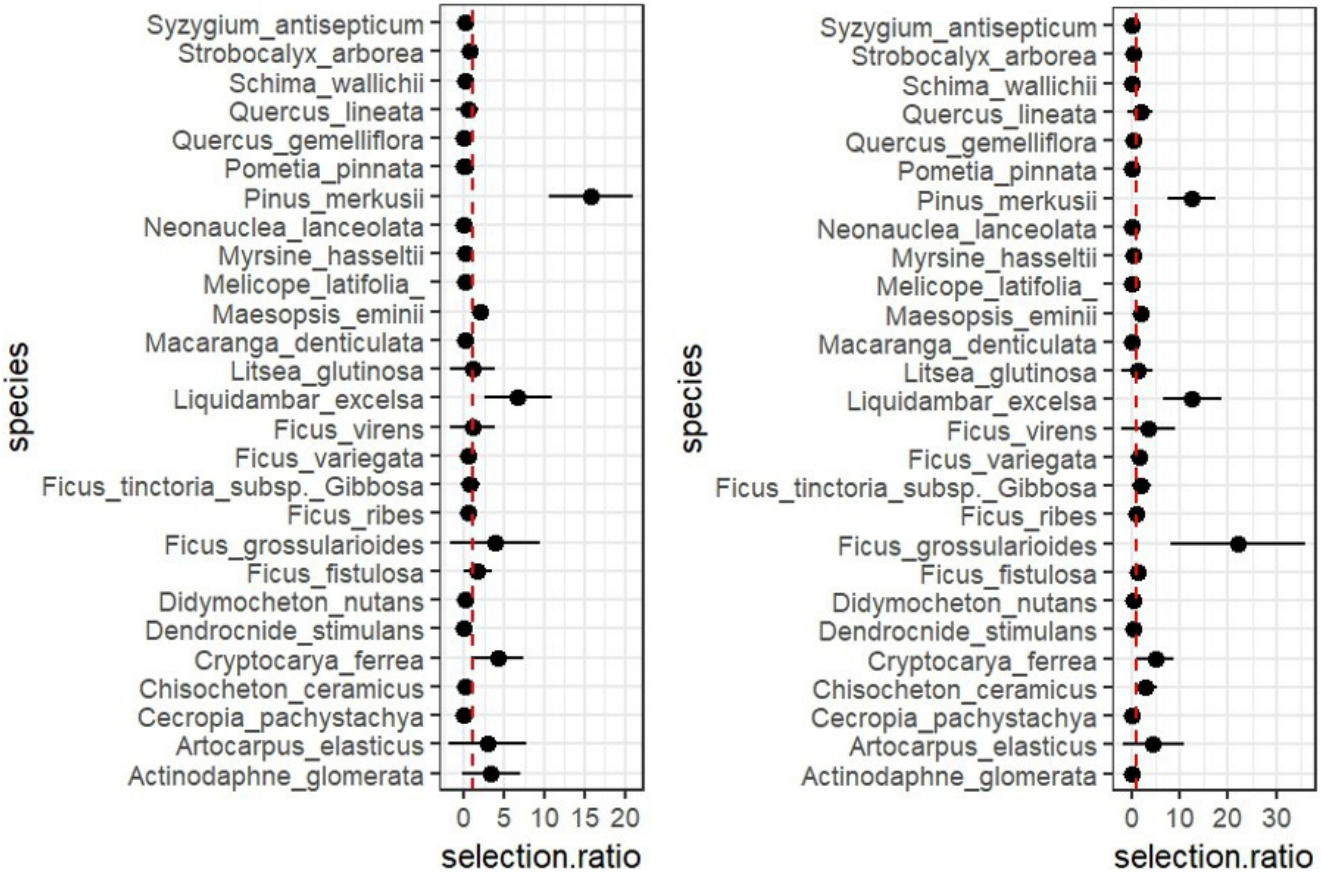

Figure 2. The list of the preferred plant species of Javan gibbon (left) and Javan langur (right) in Bodogol was based on the fruit consumed using the Manly selection ratio. C++ value greater than 1 indicates a preferred food source. The results for pine and rasamala may be slightly overestimated due to the incomplete availability of data

diet. Additionally, our findings demonstrated that Javan gibbon and Javan langur consumed *M. eminii* fruit and its leaves, incorporating them into their diets (Figure 3). However, our analysis appears to overestimate the preference of Javan gibbon and Javan langur for *Pinus merkusii* and *Liquidambar excelsa* because the data on food availability collected by Sadili *et al.* (2023) did not cover pine and rasamala plantation areas, whereas our observations included these regions.

Contrary to the Javan langur, Javan gibbon seemingly utilized leaves as an additional source in their diet, as demonstrated by the high number of fruits consumed relative to leaves for nearly all plant species, including *M. eminii*. Preference for *M. eminii* as a dietary source was also observed in all age class categories in Javan gibbon. However, more individuals determined the number of fruits consumed, in which adults consumed more fruits and leaves than young individuals and juveniles (Figure 4).

4. Discussion

Based on the number of vertebrate species visiting *M. eminii*, as well as their degree of fruit utilization, we found that *M. eminii* interacted with various numbers of animal partners in the Bodogol Nature Reserve, which indicated that the coexistence of *M. eminii* and its partners had already occurred (Gioria *et al.* 2023). Primates were important in this mutualistic interaction since their visitation of *M. eminii* was significantly greater than that of other taxa, such as squirrels and birds. *M. eminii* is widely distributed and has colonized a range of ecosystems from tropical to subtropical regions (Binggeli & Hamilton 1993; Viisteensaari *et al.* 2000; Epila *et al.* 2017). In its natural habitat, *M. eminii* mutualistically interacts with some birds, particularly hornbills (Epila *et al.* 2017). Beyond its native range, *M. eminii* easily adapts to a novel environment by interacting with native animals, including some important native species (Nandini

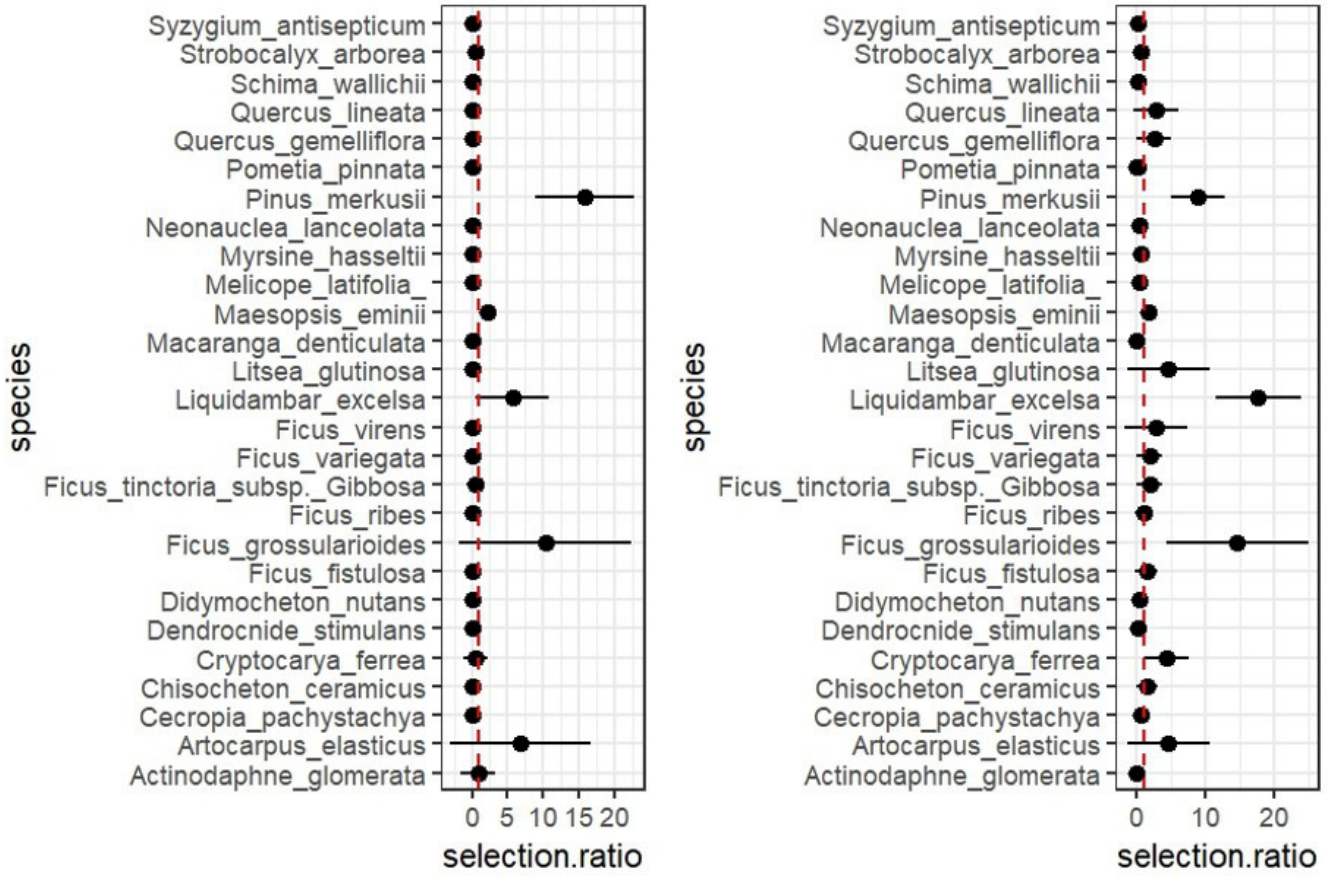

Figure 3. The preferred plant species visited by Javan gibbon (left) and Javan langur (right) for the leaves as part of their diet, based on the number of visits relative to the availability of these plant species in Bodogol. The results for pine and rasamala may be slightly overestimated due to the incomplete availability of data

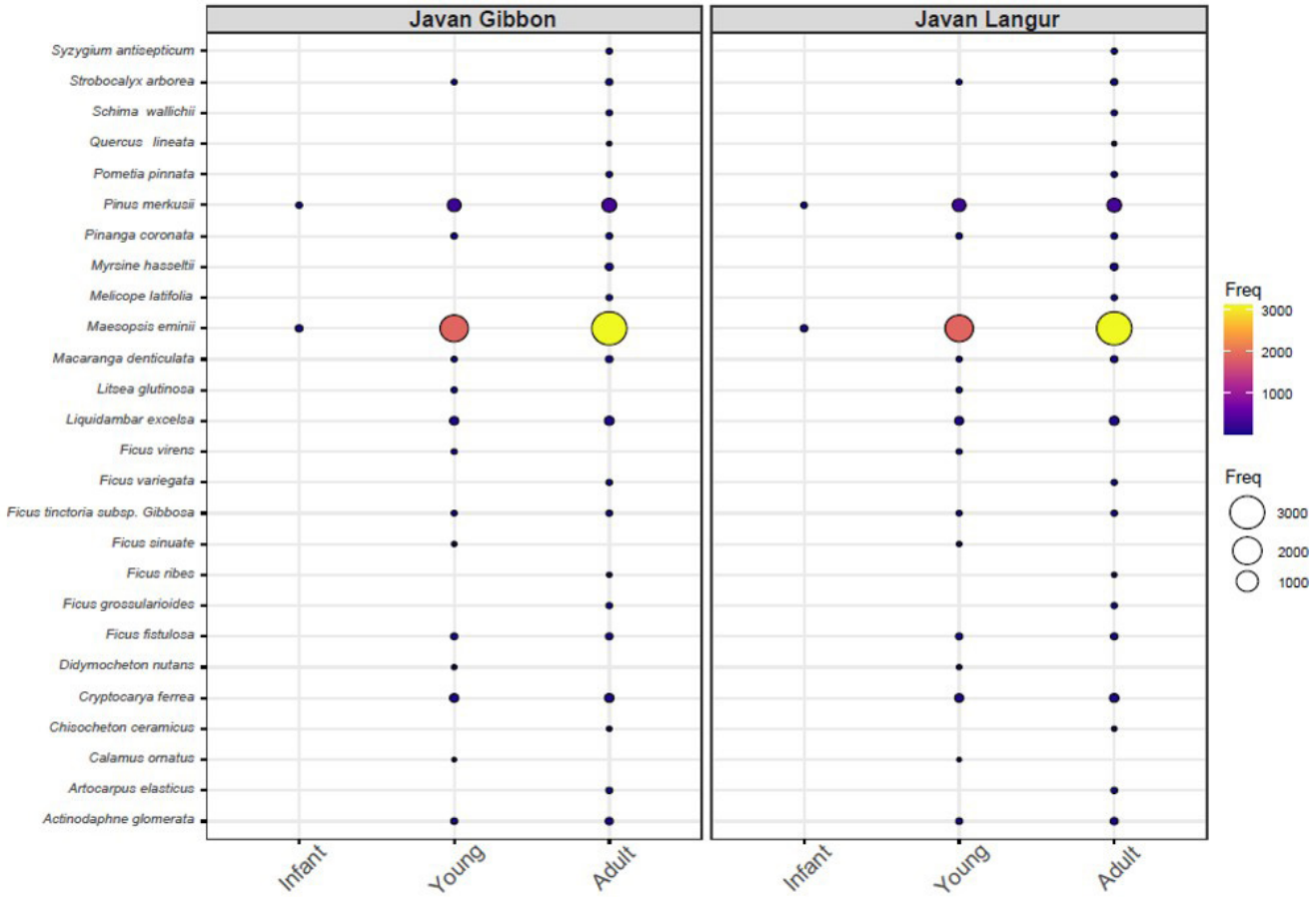

Figure 4. The number of fruits consumed by Javan gibbon and Javan langurs across various plant species is presented for different age categories. The variation in circle color and size represents the quantity of fruits consumed

& Parthasarathy 2008). Primates have been reported to easily and quickly interact with *M. eminii* outside their native range, including some threatened primate species (Reynolds 2005; Plumptre 2006). In this study, we report novel interactions between *M. eminii* and some primates that inhabit tropical rainforests, suggesting that *M. eminii* has features that attract other native species to interact with (Epila *et al.* 2017). For primates, *M. eminii* was also used as a sleeping tree and was a preferred choice for social activities, seemingly because of its favorable structure.

M. eminii in this study could probably be classified into primary and secondary resources based on the degree of fruit consumption and number of visits. All primate species utilized *M. eminii* as a primary resource, as evidenced by their frequent visits, highlighting the crucial role of *M. eminii* in their diet. Primates in Bodogol are classified as protected species, with some endemic to the montane forests of Java (Cotton *et al.* 2016; Supriatna 2022; IUCN 2024). The presence of *M. eminii* can potentially fill the food availability gap because it produces fruit in large numbers nearly every year (Reynolds 2005; Epila *et al.* 2017). Furthermore, *M. eminii* is utilized by all age classes of Javan gibbon, not just adults, as observed in the consumption of this plant species. This observation underscores the importance of *M. eminii* in supporting the growth and development of this species. Since young individuals often have less developed digestive systems and microbiota (Jia *et al.* 2018), they are more reliant on consistent resources like *M. eminii* to manage their diet effectively. The remaining species had a very low number of visits and consumed very low quantities of fruit, indicating that the role of *M. eminii* in these species is negligible. Squirrels and birds are common vertebrates in Bodogol, but their low utilization implies that this plant is unlikely to be their preferred food. They used *M. eminii* as a secondary or fallback resource when other foods were scarce or had high competition for favored foods. Thus, mutualistic interactions between *M. eminii* and these species are considered unimportant, referring to either the benefits or risks of invasive *M. eminii* in Bodogol to these species.

Considering how the fruits of *M. eminii* are managed by animal eaters, the Javan gibbon is the only species that swallowed the fruits of *M. eminii*. Although squirrels were observed when swallowing the fruit, they did not ingest it into their digestive system but temporarily stored it in their mouths. Investigating how animals manage their food is crucial for predicting the invasive potential of a plant species. Our findings showed a strong mutualistic interaction between Javan gibbons and *M. eminii*. Gibbons have been studied for their pivotal role as seed dispersers of plant species in tropical rainforests (Chivers & Burton 1988; McConkey *et al.* 2003). Gibbons do not destroy the seed but instead help remove its outer layer, making it easier and faster to germinate once it falls to the ground (Chivers & Raemaekers 1986; McConkey 2000). Moreover, *M. eminii* and Javan gibbons have similar distribution patterns in Gunung Gede National Park, in which both are more abundant in lowland areas than in other areas (submontane and montane) (Uji & Tihurua 2012; Alhamd & Rahajoe 2013; Sadili *et al.* 2023), indicating the possible role of Javan gibbon as a potential seed disperser of *M. eminii*. Future studies are needed to map the overlapping distribution hotspots of *M. eminii* and Javan gibbons and to investigate the germination success of seeds ingested by Javan gibbons. Javan langur and Javan surili are the second and third most common fruit eaters of *M. eminii* after Javan gibbon. Javan langur has been identified as a potential seed disperser through the endozoochory mechanism, though the case likely pertains more specifically to small-sized fruits (Tsuji *et al.* 2017). However, we did not observe any significant seed dispersal in these monkeys. Javan langur and Javan surili commonly spitted and dropped the seed of *M. eminii* beyond the tree, thus restricting the seed from being dispersed in a wide range area and prone to broken down by fungi and seed predators unless eaten by secondary disperser (McConkey *et al.* 2015). As we did not observe terrestrial visitors to *M. eminii*, we could not confirm the role of secondary dispersers in mediating seed dispersal success. However, we frequently found a significant number of rotten fruits under the mother tree, indicating that the dietary activities of secondary eaters are of little importance. We also could not explain the role of nocturnal arboreal species, particularly bats, in utilizing and dispersing the seeds of *M. eminii* in this study. However, other studies have reported that *M. eminii* is not the type of diet preferred by bats (Cordeiro *et al.* 2004) and is probably not favored by tropical rainforest bats, as no reports have documented a high association between *M. eminii* and bats, including the generalist species *Cynopterus brachyatus* (Sheherazade *et al.* 2017). Seed dispersal effectiveness is influenced by many factors, including the number of dispersers mutually associated with the plant species (Schupp *et al.* 2010). The most important dispersers are endozoochorous animals that retain undisrupted seeds (fruits or pulp eaters). Based on our observations, the Javan gibbon is the only species regarded as an endozoochorus disperser of *M. eminii* in Bodogol. Moreover, the Javan gibbon was among the species that strongly interacted with *M. eminii* based on the number of visits and seeds consumed. These findings could be a fundamental baseline for predicting the dispersal range of *M. eminii* in the future and for building management strategies to control the invasion of this plant species. However, *M. eminii* also plays a beneficial role in some protected primates (Viisteensaari *et al.* 2000; Epila *et al.* 2017). Conservation authorities must balance the detrimental and beneficial effects of this invasive plant in Gede Pangrango National Park and other forests in Java. *M. eminii* is listed as an invasive species that can eliminate native species and deteriorate ecosystems if not properly managed. However, the invasive rate of *M. eminii* in Gunung Gede National Park is probably not as high as that of other invasive species, such as *Eupatorium* sp. (Tjitrosoedirdjo 2016); thus, it is not yet listed as an invasive species by the Indonesian Ministry of Forestry and Environment.

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