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New Evidence for Flower Predation on Three Parasitic *Rafflesia* Species From Java

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Abstract

Rafflesia (Rafflesiaceae) is a genus of parasitic plants that is endemic to Southeast Asia. Many species in this genus are of high conservation concern in many countries due to their rare and threatened status. However, the ecology of *Rafflesia* species is not yet fully understood, particularly in terms of flower predation. Here, we present new observations of predation on a *Rafflesia patma* flower bud using a camera-trap study, together with the results of a survey of flower damage in the three *Rafflesia* species that occur on Java, Indonesia. We found that two small mammals predated a flower bud of *R. patma* in Pangandaran (West Java, Indonesia), one of which has not previously been identified as a predator of *Rafflesia* flowers. We also detected wasp infection in *Rafflesia rochussenii* and predation by another animal on *Rafflesia zollingeriana*. Overall, flower bud predation by animals damaged up to 10.65% of the surveyed flowers.

Keywords

camera trap, conservation, florivory, Rafflesia, small mammals

Introduction

Plants in the genus *Rafflesia* (Rafflesiaceae) are not only famous among botanists and ecologists but are also attractive to the public due to their exceptionally large flowers that smell unpleasant. *Rafflesia* species are endoparasitic, infecting vines of members of the grape family (Vitaceae), in the genus *Tetrastigma* (Meijer, 1997). The plants are only visible during the generative stage, being entirely contained inside the host during the vegetative stage (Nikolov & Davis, 2017). This genus, which is endemic to Southeast Asia (Meijer, 1997), split from *Rhizanthes* approximately 74 MyBP and experienced rapid species diversification between 12 and 5 MyBP (Bendiksby et al., 2010).

There are three known species of *Rafflesia* in Java, Indonesia: *Rafflesia patma* Blume, *Rafflesia zollingeriana* Koords., and *Rafflesia rochussenii* Teijm. & Binn. (Jafarsidik & Meijer, 1983). Although The Plant List (2013) treated *R. zollingeriana* as a synonym of *R. patma* and adopted *R. horsfieldi* R. Br. as the accepted name, we have retained these as separate species in this study based on their different morphological characteristics (Nais, 2001) and phylogenetic analysis (Bendiksby et al., 2010). *R. patma* is mainly distributed in the central to western part of Java, particularly in lowland forests (Meijer, 1997), while *R. zollingeriana* specifically occurs in lowland forests on the southern coast of East Java (Jafarsidik & Meijer, 1983). By contrast, *R. rochussenii* is the only *Rafflesia* species in Java that is confined to mountainous areas at altitudes >1,000 m above sea level (a.s.l.) and is restricted to West Java (Meijer, 1997). All three species are currently threatened with extinction, primarily due to forest degradation and habitat loss (Mursidawati et al., 2015).

Rafflesia plants are known to have unisexual flowers (Nikolov & Davis, 2017), so pollinators play a significant role in successful reproduction, with fruit set ranging from 0% to 50% (Nais, 2001). Plants in this genus also have a long flower development time of up to 4 years (Hidayati & Walck, 2016). Therefore, any

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disturbance to the reproductive process will interfere with the regeneration cycle of these species.

Flower predation is defined as any type of damage that is caused by consumption of any part of the flower, including the bracts, sepals, petals, stamens, pistils, pollen, or ovules (McCall & Irwin, 2006) and can be detrimental to the fitness of a plant population (Irwin, Brody, & Waser, 2001; McCall & Irwin, 2006; Washitani, Okayama, Sato, Takahashi, & Ohgushi, 1996). Although there have been few reports of flower predation in *Rafflesia* species (e.g., see Hidayati, Meijer, Baskin & Walck, 2000; Nais, 2001; and references therein), it is important to their ecology because, when it does occur, the impact can be severe. Therefore, in this study, we investigated flower predation in the three Javanese *Rafflesia* species and used the findings to gain an insight into its consequences for the conservation of these species.

Methods

Study Area

Java is one of the largest islands in Indonesia, with an area of 132,000 km^2 (Whitten, Soeriaatmadja, & Afiff, 1996). It has been estimated that 0.8 million hectares of primary forest remain on Java (Margono, Potapov, Turubanova, Stolle, & Hansen, 2014) and there are more than 80 conservation areas (Ministry of Environment and Forestry, 2016). We selected six conservation areas on Java as study sites: Bojong Larang Jayanti Nature Reserve (NR), Cipeucang Protected Forest, Gunung Gede Pangrango National Park (NP), Leuweung Sancang NR, Meru Betiri NP, and Pangandaran NR (Figure 1).

In general, Java has an annual rainfall of approximately 1,500 mm per year with a distinct wet and dry season, a minimum temperature of 22°C to 24°C, and a maximum temperature of 31°C to 33°C. Tropical lowland and montane forests are the dominant habitat (Whitten et al., 1996).

Camera Trap

We set up a camera trap (Bushnell Trophy Cam HD; Bushnell Outdoor Products, Overland Park, Kansas) in the center of the forest in Pangandaran NR (7°43′13.18″S, 108°39′46.87″E) approximately 1.5 m from an *R. patma* flower bud. The camera was operated continuously for 22 days from September 3 to September 25, 2014, and was automated using a passive infrared sensor, which triggered recording for 30 s upon the detection of movement. The camera was also programmed to automatically record using night vision during the nighttime.

Population Survey and Flower Damage Inventory

From March 2017 to October 2017, we visited the six conservation areas and randomly searched for *Tetrastigma* species and the three *Rafflesia* species. All *Rafflesia* plants encountered were recorded and enumerated. We also carefully examined each living flower for the presence of damage caused by animals.

Results

A total of 51 videos were recorded, 15 of which captured sightings of wild animals that were attracted to the *R. patma* flower bud (Figure 2(a)). A total of six species were recorded: the Asian palm civet (*Paradoxurus hermaphroditus*), the Javan langur (*Trachypithecus auratus*), the Java mouse deer (*Tragulus javanicus*), the long-tailed monkey (*Macaca fascicularis*), the Sunda pangolin (*Manis javanica*), and the Sunda porcupine (*Hystrix javanica*). Eleven of these videos were recorded during the nighttime, and two of these videos showed animals exhibiting direct predatory activities (Table 1): The first video (Figure 2(b), Online Supplementary Movie S1) showed a Sunda porcupine was observed digging the ground and foraging on the flower bud, while the second video (Figure 2(c), Online Supplementary Movie S2) recorded a Java mouse deer consuming the flower parts of *R. patma* (Figure 2(d)).

During the field survey, we discovered that flower bud predation also occurred in the other two species of *Rafflesia* on Java. We observed wasp infection of *R. rochussenii* flower buds and signs of animal predation for instance scattered flower parts of *R. zollingeriana*. In total, up to 10.65% of the flowers (18 of the 169 living buds and blooms surveyed) were damaged by animal predation, which was observed at three of the six study sites, namely, Gunung Gede Pangrango NP, Meru Betiri NP, and Pangandaran NR.

Discussion

Flower predation has not been well studied in *Rafflesia* spp., partly due to the suspected predators being cryptic mammals that are easily alarmed by humans. One study directly observed treeshrews (*Tupaia tana*) and squirrels (*Callosciurus notatus*) licking and scooping out the pulp of *R. keithii* fruit in Borneo (Emmons, Nais, & Briun, 1991), while another, which presumably used indirect observation, reported that treeshrews (*Tupaia javanica*) and Sunda porcupines consumed *R. patma* in Pangandaran, Java (Hidayati et al., 2000). In addition, Hidayati et al. (2000) suspected that some other animals, such as Asian leopard cats (*Felis bengalensis*), wild boars (*Sus scrofa*), Sunda sambar (*Cervus timorensis*), barking deer (*Muntiacus muntjak*), banteng (*Bos javanicus*), and

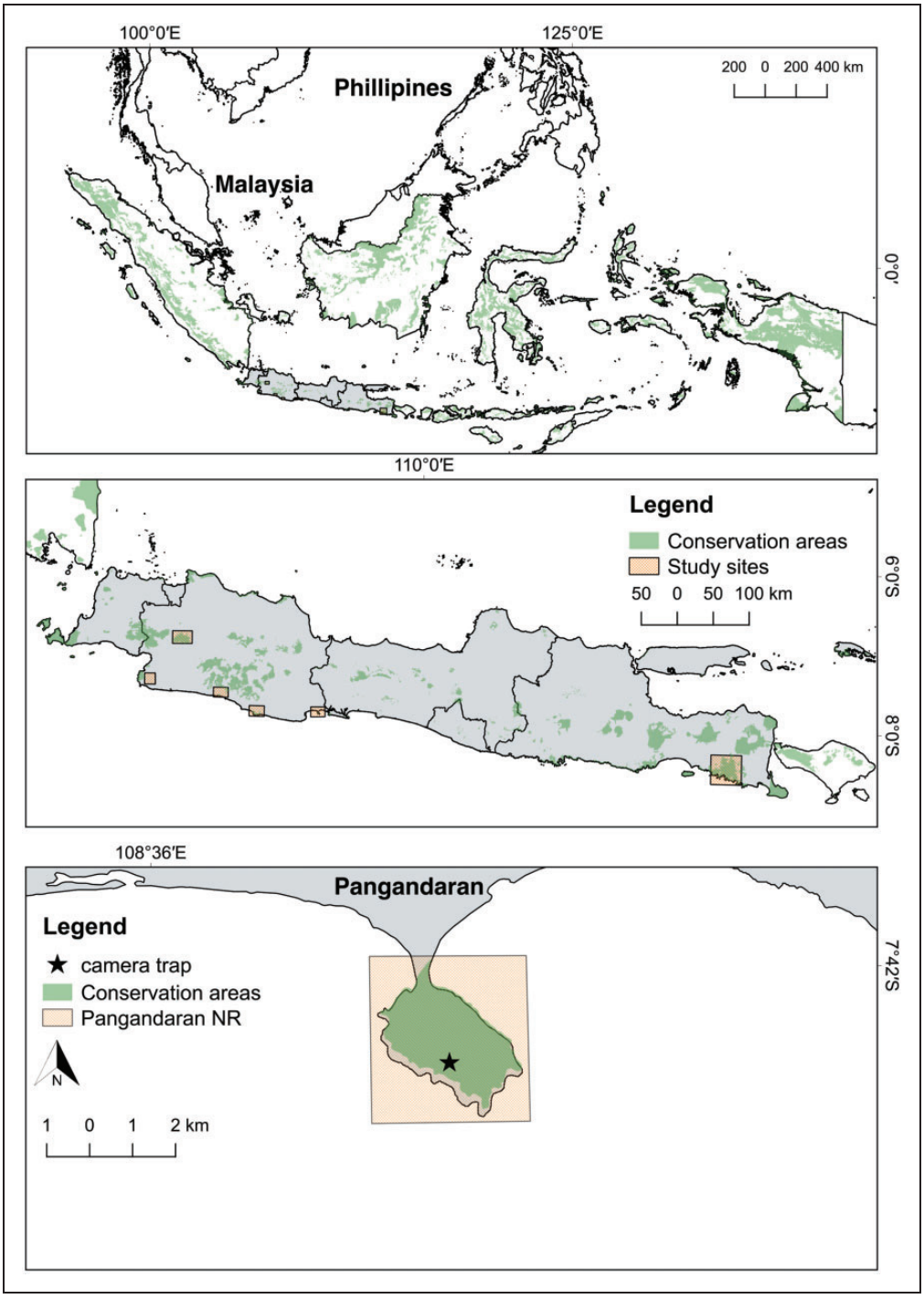

Figure 1. The map of the study sites for surveying on flower damage of three *Rafflesia* species in Java (Indonesia), and the location of the camera trap.

crows (*Corvus* spp.), also damage the flower buds of *R. patma* at the same site, while Nais (2001) suggested that long-tailed mountain rats (*Niviventer rapit*) predate the flower buds of *Rafflesia* species in Borneo.

The use of a camera trap in this study verified some of these reports and also showed that the Sunda porcupine and Java mouse deer predated a flower bud of *R. patma*, representing the first report of *Rafflesia* flower predation by the Java mouse deer. Sunda porcupines and Java mouse deer are considered to be predominantly frugivorous, consuming mainly fruits (Corlett, 1998). However, this study showed that these mammals are also florivorous on *Rafflesia* species, particularly *R. patma*.

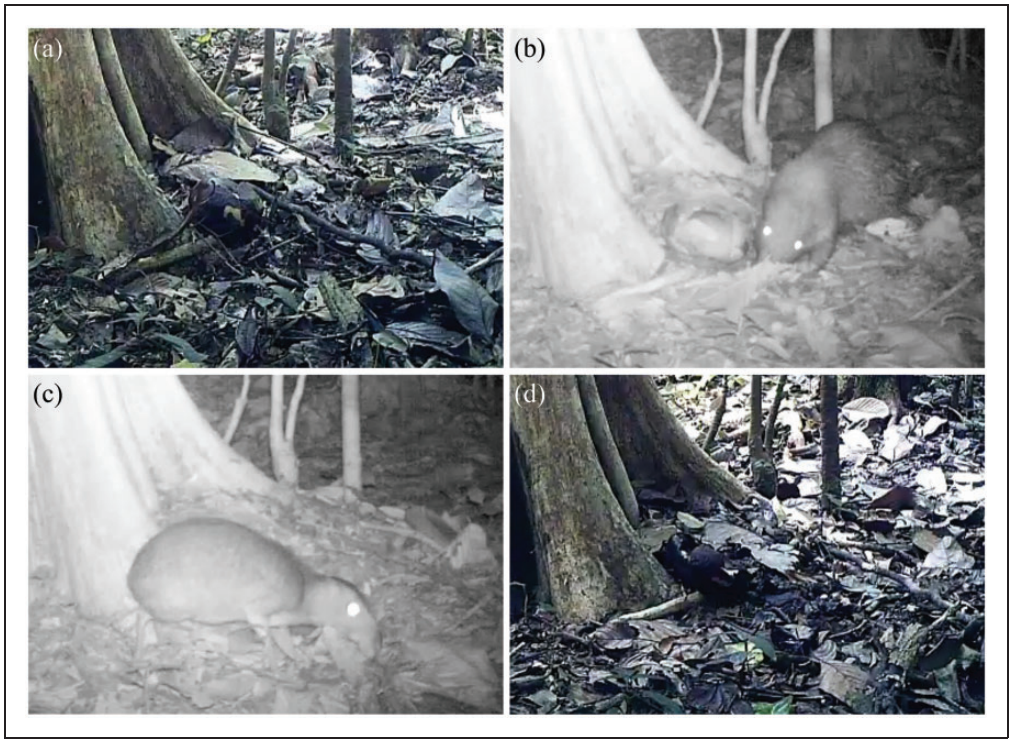

Figure 2. Animal sightings captured during the camera-trap study. (a) Mature and intact bud of *Rafflesia patma* (recorded on September 4, 2014); (b) The Sunda porcupine approaches the *R. patma* and scratches beneath it (recorded on September 19, 2014); (c) The Java mouse deer eats the perigone of *R. patma* (recorded on September 21, 2014); (d) *R. patma* flower, partially eaten by the porcupine and the mouse deer (recorded on September 22, 2014).

Table 1. List of Animals Captured With Camera Trap.

Animal species	Total recorded videos	No. of videos recorded during the day	No. of videos recorded during the night	Predation action
Asian palm civet (*Paradoxurus hermaphroditus*)	1	1	0	Absent
Javan langur (*Trachypithecus auratus*)	1	1	0	Absent
Java mouse deer (*Tragulus javanicus*)	6	0	6	Present
Long-tailed monkey (*Macaca fascicularis*)	2	2	0	Absent
Sunda pangolin (*Manis javanica*)	1	0	1	Absent
Sunda porcupine (*Hystrix javanica*)	4	0	4	Present

Note. A total of 54 videos were recorded during 22 days of study, with animal sightings present in 15 of these videos.

Flower bud predation can cause minor impairment to severe damage to the flower. We found that mammalian predation caused severe damage to small *Rafflesia* flower buds in the early growth stage. Indeed, in some cases, animals almost entirely consumed the flower buds of *R. patma* and *R. zollingeriana*, leaving only a few pieces of flower debris (Figure 3(a) and (b)). By contrast, damage to the blooms was very rare and often only caused minor damage, having no significant effect on the blooming stage (Figure 3(d)). However, this was also very serious in some cases (Figure 3(c)). Flower predation by insects, such as the wasp infection we observed in *R. rochussenii* flowers in Gunung Gede Pangrango NP, can also be detrimental to the flower buds. Although we only detected this in one flower bud out of the 54 living flowers surveyed, Nais (2001) showed that approximately 6.7% of all bud mortality in *Rafflesia* species in Sabah (Borneo) was associated with wasp infection.

Flower predation during the bud stage is expected to have direct effects on the flowers of *Rafflesia* species (McCall & Irwin, 2006), as the animals either consume the whole flower or severely damage all of the reproductive parts, including the pollen and ovules. In addition, flower predation may have indirect effects on the plants (McCall & Irwin, 2006), such as decreasing the

Figure 3. Some damages were found on the flower of three *Rafflesia* species in Java. (a) Remaining parts of *Rafflesia zollingeriana* after eaten by animals; (b) decayed bud of *Rafflesia patma*, partially eaten by animals; (c) *R. patma* with broken perigone lobes, likely caused by animals; (d) minor damage on the perigone lobe of the *R. zollingeriana* (white circle); and (e) wasp larvae was found inside the bud of *R. rochussenii.*

pollinator visitation rate through flower damage, although this has not been confirmed. Both direct and indirect effects can negatively impact on the maternal fitness of *Rafflesia* species (Kelly, Ladley, Robertson, & Crowfoot, 2008). The flower mortality rate in *Rafflesia* has been estimated to be between 50% and 90% and is mostly attributed to flower bud predation (Nais, 2001), indicating that flower predation is one of the most important factors that affects the persistence of *Rafflesia* populations in the wild. Therefore, it is crucial that predator populations are considered when developing conservation strategies for *Rafflesia* species.

Implications for Conservation

The predation of *Rafflesia* flowers during their development can affect the reproductive success of the plants, particularly in terms of the blooming process, pollination rate, and fruit set. Furthermore, it may have negative consequences on the regeneration of *Rafflesia* populations in the wild. In this study, we observed flower predation on all three of the species of *Rafflesia* that occur on Java. Therefore, comprehensive and continuous monitoring of *Rafflesia* populations and any potential predators is necessary. In addition, further research is required to explore the consequences of flower predation on *Rafflesia* species to improve our understanding of the ecology of this genus and to develop appropriate management strategies.

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Supplemental Material

Supplemental material is available for this article online.

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