Received: 7 April 2023 | Revised: 31 July 2023 | Accepted: 10 August 2023

DOI: 10.1002/ppp3.10431

Plants People Planet PPP Open Access

REVIEW

Most of the world's largest flowers (genus *Rafflesia*) are now on the brink of extinction

Pastor Malabrigo Jr.[1,2,3] | **Adriane B. Tobias**[1,4] | **Joko Witono**[5] | **Sofi Mursidawati**[6] | **Agus Susatya**[7] | **Mat Yunoh Siti-Munirah**[8] | **Adhityo Wicaksono**[9] | **Reza Raihandhany**[10,11] | **Sarah Edwards**[12,13] | **Chris J. Thorogood**[12,14]

[1]Department of Forest Biological Sciences, College of Forestry and Natural Resources, University of the Philippines Los Baños, College, Los Baños, Laguna, Philippines

[2]Museum of Natural History, University of the Philippines Los Baños, College, Los Baños, Laguna, Philippines

[3]Land Grant Management Office, University of the Philippines Los Baños, College, Los Baños, Laguna, Philippines

[4]Graduate School, University of the Philippines Los Baños, College, Los Baños, Laguna, Philippines

[5]Research Center for Biosystematics and Evolution, National Research and Innovation Agency of Indonesia (BRIN), Jakarta, Indonesia

[6]Directorate of Scientific Collection Management, National Research and Innovation Agency (BRIN), Cibinong, Indonesia

[7]Department of Forestry, Faculty of Agriculture, University of Bengkulu, Bengkulu, Indonesia

[8]Forest Research Institute Malaysia (FRIM), Kepong, Malaysia

[9]Study Group of Bioinformatics, Synthetic Biology Indonesia (Synbio.Id, Jl. Raya Lintas Sumbawa-Bima, Sumbawa, Indonesia

[10]Division of Botany, Genbinesia Foundation, Gresik, Indonesia

[11]Faculty of Biology, Gadjah Mada University, Yogyakarta, Indonesia

[12]University of Oxford Botanic Garden, Oxford, UK

[13]Institute of Human Sciences, Oxford, UK

[14]Department of Biology, University of Oxford, Oxford, UK

Societal Impact Statement

Rafflesia is the genus that contains the world's largest flowers. Despite their global appeal, most of the 42 known species are now at risk of extinction. Urgent action is needed to protect these remarkable flowers. A combined approach to conservation is recommended, including a greater level of habitat protection and support for local community action groups. *Rafflesia* is a suitable new icon for conservation in the Asian tropics.

Summary

The genus *Rafflesia*, which includes the world's largest flowers, has aroused curiosity among scientists for centuries and features prominently in local culture across Southeast Asia. The plant has long been used in ethnobotanical medicine and, more recently, as a source of revenue from ecotourism. But despite its acclaim, *Rafflesia* remains poorly understood in many respects. Taxonomy is disputed, new species are described each year, and the plant has proven recalcitrant to cultivation. This has hindered conservation, and most of the 42 known species are now severely threatened, yet only one is listed by the International Union for Conservation of Nature (IUCN). We estimate that 60% of *Rafflesia* species face a severe risk of extinction (equivalent to Critically Endangered [CR]). Moreover, we predict that at least 67% of known habitats fall outside protected areas, exacerbating their vulnerability. Alarmingly, recent observations suggest taxa are still being eradicated before they are even known to science. We present recent scientific discoveries and probable extinctions and highlight case studies of conservation success, with a focus on the role of local people. We propose a multi-pronged conservation approach combining strengthened taxonomy, ex situ propagation, ecotourism, and an extension of protected areas. We suggest action devolved to local communities and awareness campaigns linked to social media networks will be crucial outside of protected jurisdictions. Finally, we propose to establish *Rafflesia* as a new icon for plant conservation in the Asian tropics. A

Correspondence
Chris J. Thorogood, University of Oxford Botanic Garden, Rose Lane, Oxford Ox1 4az, UK.
Email: chris.thorogood@obg.ox.ac.uk

combined approach might just save some of the world's most remarkable flowers, most of which are now on the brink of being lost.

KEYWORDS
conservation, ethnobotany, Flora Malesiana, parasitic plants, threatened species

1 | INTRODUCTION

Southeast Asia is one of the most plant-rich regions on earth (Brummitt et al., 2021). *Rafflesia* R.Br. (1821:207), the genus with the largest solitary flower, is restricted to this region, especially the Philippines, Borneo, Java, Sumatra, and Peninsular Malaysia. A remarkable spate of species descriptions in the last two decades has improved our knowledge about the diversity and distribution of *Rafflesia*. Since the beginning of the 21st century, the species count has doubled from the number described between 1821 and 1984 (Brown, 1821; Mat Salleh & Latiff, 1989). The last treatment of the genus by Meijer in 1997 described 13 species. Today, 42 species of *Rafflesia* (Figure 1) are known to science (Adam et al., 2022; POWO, 2023), and still more taxa await description. In line with the theory of island biogeography (MacArthur & Wilson, 1967; Wilson & MacArthur, 2016), a greater number of *Rafflesia* species occur on larger islands. However, the island of Luzon (Philippines) hosts a number of species similar to those of Borneo, which is seven times larger.

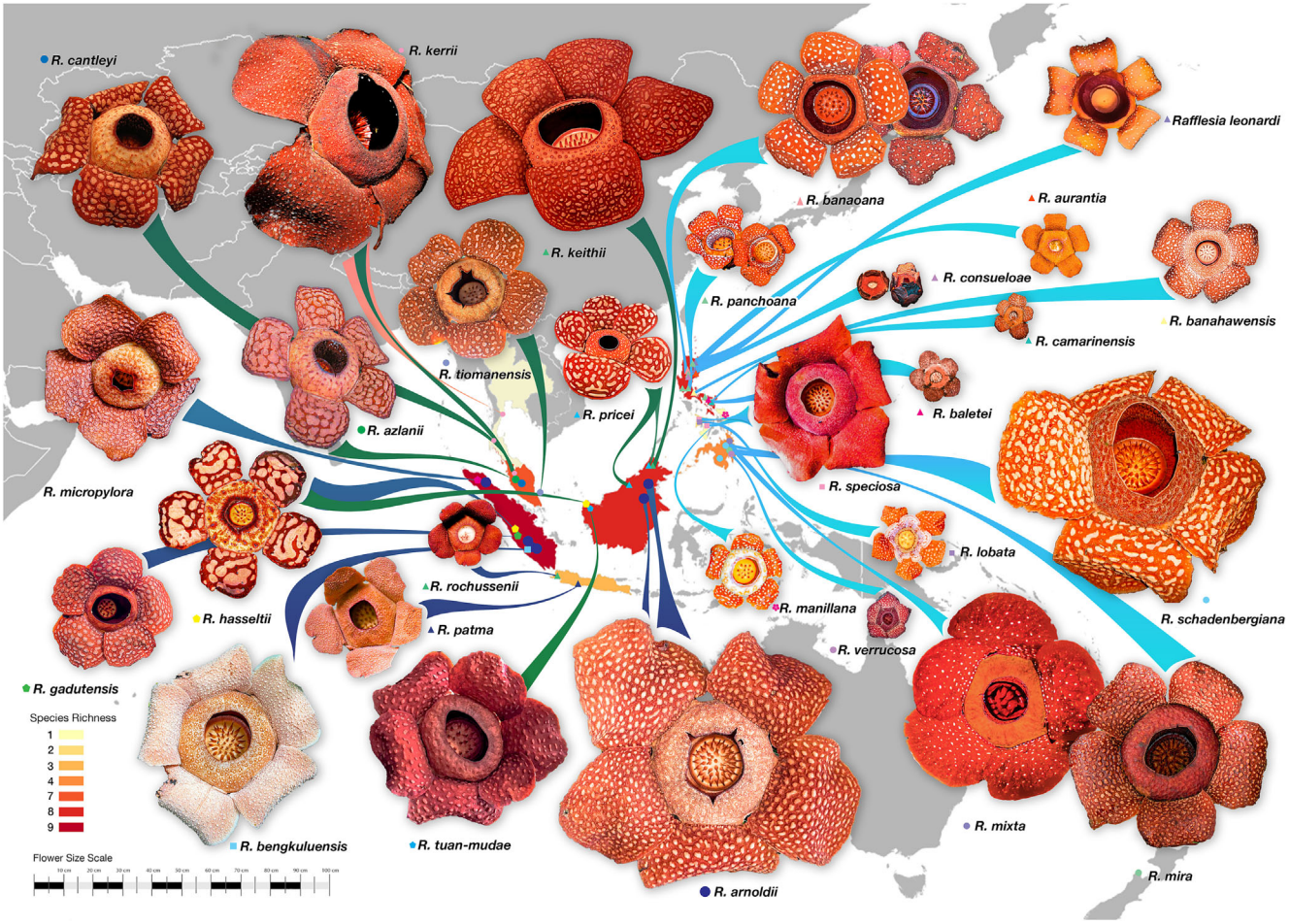

FIGURE 1 Map showing the diversity in the genus *Rafflesia* across the Malesian Floristic Region. Photos/illustrations credits: Indonesia (*Rafflesia arnoldii*, *Rafflesia bengkuluensis* – AB Tobias; *Rafflesia gadutensis* – Septian Andriki; *Rafflesia hassletii* – Jeremy Holden; *Rafflesia micropylora* – Jan Vrsovsky; *Rafflesia patma* – BRIN; *Rafflesia rochussenii* – BBTN Gede Pangarango); Malaysia (*Rafflesia azlanii*, *Rafflesia cantleyi*, *Rafflesia kerrii*, *Rafflesia tiomanensis* – Siti-Munirah MY; *Rafflesia pricei*, *Rafflesia keithii* – CJ Thorogood; *Rafflesia tuan-mudae* – Anthonia Chia); Philippines (*Rafflesia aurantia*, *Rafflesia lobata*, *Rafflesia manillana*, *Rafflesia mixta* – drawn by ABT based on photos of Danilo S. Balete, Renee Galang, SINP PAMO and CENRO Tubod; *Rafflesia banaoana*, *Rafflesia consueloae*, *Rafflesia baletei*, *Rafflesia banahawensis*, *Rafflesia panchoana* – AB Tobias; *Rafflesia leonardi* – Erwin Agbayani; *Rafflesia mira* – Celine Murillo; *Rafflesia speciosa* – PL Malabrigo; *Rafflesia schadenbergiana* – Ramil Alcala; *Rafflesia verrucosa* – Sidic Nobair); Base map by Gerald Eduarte.

Pelser et al. (2019) proposed that *Rafflesia* species have a limited dispersal capacity and therefore exhibit a high level of island endemism. Most species are restricted to a single island. Only five species (*Rafflesia arnoldii* R.Br., 1821; *Rafflesia hasseltii* Suringar, 1879; *Rafflesia rochussenii* Teijsman & Binnendijk, 1850:427, 429; *Rafflesia cantleyi* Solms-Laubach, 1910; and *Rafflesia speciosa* Barcelona & Fernando, 2002) occur on more than one island. In Indonesia, *R. arnoldii* and *R. hasseltii* span Borneo and Sumatra, while *R. rochussenii* occurs on both Java and Sumatra. Meanwhile, in the Philippines, *R. speciosa* occurs on the islands of Negros and Panay. Most species are highly restricted, known only in one or two localities, and some have been collected just once (Siti-Munirah et al., 2020).

Since the documented discovery of *Rafflesia*, taxonomy in the genus has been challenging and in a state of flux. Type specimens are often poor or missing, and living material is often difficult to access. Of the 42 known species, some have been described from very poor specimens or sometimes only a bud (for example *Rafflesia horsfieldii* R.Br., 1821; *Rafflesia ciliata* Koorders, 1918; *Rafflesia witkampi* Koorders, 1918; *Rafflesia lagascae* Blanco, 1845:595; and *Rafflesia philippensis* Blanco, 1845:565). The taxonomic validity of some species has been questioned, while other taxa have been considered cryptic or conspecific by some authors (Hidayati & Walck, 2016), leading to a lack of consensus. Without a robust and objective taxonomic framework, effective conservation is problematic. Conservation is further complicated by the fact that all species of *Rafflesia* are endoparasitic, living within their host vines, *Tetrastigma* (Miq.) Planchon (1887:423), and being invisible for most of their life cycle (Thorogood et al., 2021). Furthermore, the genus *Tetrastigma*, which comprises approximately 137 species from tropical and subtropical Asia to the Southwest Pacific (POWO, 2023), is itself taxonomically complex. Indeed, host identification is problematic for *Rafflesia* because *Tetrastigma* species are challenging to identify with certainty in the field, which has further hindered our understanding of the ecology of *Rafflesia*. Little is known about the host specificity of *Rafflesia*. Research by Pelser et al. (2016) in the Philippines shows that most of the eight *Tetrastigma* lineages present on the islands are hosts to multiple *Rafflesia* species, while four *Rafflesia* species parasitize multiple *Tetrastigma* lineages. This suggests *Rafflesia* may be less host-specific than previously thought, at least in the Philippines, but broad-scale studies of host specificity across the genus are absent.

Population genetics may also help inform conservation practice, for example via habitat protection targeted at particular areas (Pelser et al., 2018) or the identification of cryptic taxa that may be overlooked by existing conservation strategies (Pelser et al., 2017). Nevertheless, most species are poorly understood, and the infection process of *Rafflesia* in the host vine remains unknown two centuries after the genus' introduction to science. Moreover, the lack of seed banking and propagation techniques makes ex situ conservation extremely challenging (Thorogood et al., 2022).

Southeast Asia has the fastest-disappearing forests on the planet (Miettinen et al., 2011; Sodhi et al., 2004; Werth & Avissar, 2005). The highly restricted distributions of most *Rafflesia* species in their vanishing habitats (Figure 2), combined with the challenges associated with their propagation, call for an urgent, joined-up, cross-regional approach to prevent the extinction of the world's most remarkable flowers (Thorogood et al., 2022). In compiling this research, we have established the first coordinated network of scientists from across the globe to examine the conservation status (CS) of *Rafflesia*. Together, we combine decades of field observation, propagation experimentation, and working with Indigenous people to present a synthesis of known diversity, provisional CS, threats, and ongoing conservation efforts for *Rafflesia* and related genera across the Malesian region. We unite isolated successes to propose a harmonized international conservation approach to conserving one of the world's greatest botanical enigmas.

2 | CONSERVATION STATUS ACROSS SOUTHEAST ASIA

2.1 | Brunei

Brunei has just one species of *Rafflesia*—*Rafflesia pricei* Meijer (1984:214). It is found in Ulu Temburong National Park, one of the major parks in the country and the first established national park since 1991. It is a lowland forest covering approximately 500 km^2. Brunei's government enforces rigorous conservation measures to safeguard its protected areas (PAs) and biodiversity, as stipulated in the Wildlife Protection Act of 1978, and has established national legislation for the protection of endangered species and their trade under the Wild Flora and Fauna Order of 2007, which aligns with the Conservation on International Trade in Endangered Species (CITES) agreement.

Non-governmental organizations (NGOs) such as the World Wildlife Fund (WWF) offer projects for climate change mitigation and sustainable management of tropical forests. In 2007, the governments of Brunei, Malaysia, and Indonesia issued a joint declaration as part of the Heart of Borneo Initiative, which was led by the WWF. The program aims to strengthen the preservation of Borneo's remaining undisturbed forests, which are crucial habitats for rare plants such as *Rafflesia*.

The academic community also plays a crucial role in conservation efforts, particularly in leading collaborative efforts. In the Kuala Belalong Field Studies Centre (KBFSC), which is located in the Batu Apoi Forest Reserve, the Universiti Brunei Darussalam monitors a 25-ha forest dynamics plot with funding from HSBC Brunei, the Centre for Tropical Forest Science, and the Arnold Arboretum of Harvard University. *Rhizanthes lowii* (Beccari) Harms (1934:287), a relative of *Rafflesia*, is also found in the forest reserve.

2.2 | Indonesia

Rafflesia is celebrated as one of Indonesia's national flowers. Indonesia is considered one of the centers of diversity for *Rafflesia*, with at least 15 accepted species recorded (POWO, 2023). It is also home to four species of Rafflesiaceae in the genus *Rhizanthes*:

FIGURE 2 Diversity of *Rafflesia* in the Philippines ((a) *Rafflesia banaoana*, (b) Habit of *Rafflesia banaoana*, (c) *Rafflesia baletei*, (d) *Rafflesia panchoana*, (f) Site of *Rafflesia baletei*, (g) Site of *Rafflesia panchoana*), Malaysia ((e) *Rafflesia cantleyi*, (h) Site of *Rafflesia cantleyi*) and Indonesia ((i) Cleared land for African oil palm plantation near the habit of *Rafflesia bengkuluensis*, (j) *Rafflesia bengkuluensis*). Photo credits: Figures 2a–c; E-1: AB Tobias, Figure 2d,i–j: CJ Thorogood.

Rh. deceptor (Bänziger & Hansen, 2000:130), *Rh. infanticida* (Bänziger & Hansen, 2000:127), *Rh. lowii*, and *Rh. zippellii* (Blume) (Spach, 1841:554). The Indonesian government places emphasis on *Rafflesia* conservation through Regulation Decree of the Minister of Environment and Forestry No. P.20/MENLHK/SETJEN/KUM.1/6/2018. The Ministry of Environment and Forestry in Indonesia has also prioritized conservation efforts for the genus. For example, an in-situ conservation campaign has been initiated at the Bogor Botanic Garden (BBG) in West Java. The success of ex situ conservation of *Rafflesia* was marked by the blooming of *Rafflesia patma* (Blume, 1825) in 2010, following a campaign of trials combining grafting, in vivo and in vitro seed propagation, and tissue culture. In 2004, *Tetrastigma* scions infected with *R. patma* were obtained from the Pangandaran Natural Reserve, West Java, and grafted onto a non-infected rootstock using veneer and cleft grafting (Mursidawati & Irawati, 2017; Mursidawati & Wicaksono, 2020). A *Tetrastigma* vine nursery has been established at BBG to support further propagation and ex situ conservation efforts by grafting. *Rafflesia tuan-mudae* (Beccari, 1868:197) was grafted in 2011 and yielded buds in 2022; these were later aborted. However, another species, *R. patma* has bloomed 16 times on three vines. In sum, an average of less than one flower has completed its life cycle in nearly two decades. Notwithstanding, BBG remains the center for best practices in *Rafflesia* propagation. We recommend extending the knowledge and experience gained at BBG to other regions where conservation efforts are urgently needed.

Reports of successful *Rafflesia* propagation by seed are scarce, but there are some notable exceptions. In Bukittinggi, West Sumatra, local gardener Joni Hartono applied seed from the ripe fruits of *R. arnoldii* onto a *Tetrastigma* vine in his garden, yielding buds several years later (Wicaksono et al., 2016). Similar reports exist for *Rafflesia keithii* in Malaysia (Molina et al., 2017). In BBG, seeds of *R. arnoldii* were also spread onto a well-established vine in 2012 and bloomed a decade later. While there are other isolated anecdotal reports, documentation is lacking, suggesting an opportunity for better coordination between researchers and local communities. Recent research by Molina et al. (2023) into the seed transcriptome of *Rafflesia* found no evidence of genes involved in mycorrhizal symbiosis or strigolactone responsiveness. Their work suggests that future efforts focused on germination experiments should deprioritize searching for elicitors of mycoheterotrophy, or strigolactones, and instead prioritize experiments applying laccases and karrikin (an enzyme that degrades lignin and a plant growth regulator, respectively).

Biotechnology, including plant tissue culture and in vitro seed germination, has long been a line of inquiry for *Rafflesia* propagation and conservation in Indonesia. In 2001, the first documented attempts at tissue culture using *R. arnoldii* bud tissue samples and in vitro seed germination trials all failed (Sukamto, 2001). The work was repeated in the late 2000s, and for the first time, *Rafflesia* tissue calli were generated following induction using synthetic auxin (Sukamto & Mujiono, 2010). However, in the absence of living host tissue, the calli soon aborted. Later, this work was repeated using *R. patma* and *Rafflesia meijeri* bud material (Mursidawati & Handini, 2009; Wicaksono & Da Silva, 2017), and with *R. arnoldii* seeds on host tissue (Mursidawati, Ngatari, et al., 2015); all attempts failed and were abandoned. Notwithstanding, cultured buds showed signs of swelling (Mursidawati & Handini, 2009). These early observations might be a platform for future research. For example, the in vivo injection of auxin apparently induced bud growth in *R. patma*, and may be important in the advanced development from bud to flower (Mursidawati & Wicaksono, 2021). Together, these trials demonstrate that biotechnology is challenging in *Rafflesia* propagation, and despite decades of endeavor, the breakthroughs have been small.

Experience from Bengkulu shows how conservation can benefit from a devolved level of ownership and responsibility commensurate with the habitat and distribution of *Rafflesia*. In recent years, multiple sites have enjoyed conservation success from "Pokdarwis" (tourism awareness groups) linked to a smartphone and social media network. *Pokdarwis* comprise groups of young villagers who are passionate about natural history and linked to potential revenue from ecotourism. Komunitas Peduli Puspa Langka Rejang Lebong (KPPL) (Figure 3b) is a network of 11 local *Pokdarwis* across Bengkulu. They connect to share best practices and promote blooming events to increase awareness and boost ecotourism. However, these groups lack financial support and capacity-building. We recommend a greater role could be played by the University of Bengkulu, IPB Agriculture University, and the National Research and Innovation Agency (BRIN) to assist the groups. Groups analogous to *Pokdarwis* also occur in Malaysia (see Section 2.3) but are absent from much of the range of *Rafflesia*, including the Philippines, which is the center of diversity.

2.3 | Malaysia

Rafflesia has long been known and celebrated in Malaysian Borneo, where it is an important source of revenue from ecotourism. In Peninsular Malaysia, *Rafflesia*, also known as "Bunga Pakma" (vernacular name), is native from northern Perak south to Kelantan, Pahang, and Terengganu; in recent years, *Rafflesia* tourism has also become more popular in this region. Thirteen species have been recorded in Malaysia, of which eight occur in Peninsular Malaysia and a further five in the states of Sabah and Sarawak (Borneo). *Rafflesia* habitats usually belong to the states rather than to the federal government, and generally, each state has the authority to designate land status. However, in Peninsular Malaysia, most forests are managed by state forestry departments; therefore, in practice, most fall under federal law. In Bornean Malaysia, each state has its own regulations. In Sarawak, all *Rafflesia* species are listed as "Total Protected Plants" under the Wildlife Protection Ordinance of 1998 by the Commissioner of Law Revision, Sarawak, while in Sabah, all *Rafflesia* species, together with their host *Tetrastigma* species, are listed under Total Protected Plants under the Wildlife Conservation Enactment 1997.

In general, *Rafflesia* populations in Malaysia occur in forested habitats, especially pristine forests (Figure 2h). However, habitats also occur in secondary forests near villages, agricultural land, and other disturbed areas. Currently, there are few sites in Malaysia where

FIGURE 3 Examples from a social media campaign on iNaturalist and Facebook to promote awareness and community science. The map shows the number of observations recorded on iNaturalist (indicated by red squares); the other infographics are used to promote awareness in the Philippines when species are in bloom (in these examples, *Rafflesia consueloae*, *Rafflesia* cf. *mixta* and *Rafflesia speciosa*). Such infographics could be deployed for any species in-habitat in Southeast Asia, where plants are readily accessible, to foster greater care and awareness.

populations are monitored under so-called "park administration." These include Sandakan-Poring, managed by Sabah Parks, and Gunung Gading National Park-Lundu, managed by the National Parks Administration in Sarawak. In Sabah, *R. keithii* is protected in Poring (Peters & Ting, 2016) and *R. pricei* in a "Rafflesia Forest Reserve" in Tambunan, while *Rafflesia tengku-adlini* grows in a fully protected area (PA) on Mount Trus Madi. In addition, there are a considerable number of *Rafflesia* populations in Sabah, some of which are on private land and are carefully maintained by the local landowners. According to a report by Peters and Ting (2016), the Dusun community has used *Rafflesia* sites in a variety of ways, including for tourism, which indirectly supports conservation efforts. In Peninsular Malaysia, the main approach to conserve and protect *Rafflesia* populations is to designate *Rafflesia* habitats either as high conservation value forests

(HCVFs) or high conservation value areas (HCVAs). HCVFs were established in 1993 by the Forest Stewardship Council (FSC), an international independent non-profit organization, to promote responsible forest management by forest-based industries (Areendran et al., 2020; Rietbergen-McCracken et al., 2007). The HCV approach encompasses six themes: *Species Diversity*, *Landscape Level Ecosystems*, *Ecosystems and Habitats*, *Ecosystem Services*, *Community Needs*, and *Cultural Values*; together, these unite social and environmental priorities shared by a range of stakeholders (Halmy & Salem, 2015). Establishing HCVFs for *Rafflesia* can be a means of protection as part of a broader conservation approach. Several HCVFs have been established in Malaysia; the Pahang Forestry Department has designated such an area in the Lata Jarum Forest Reserve for *Rafflesia* (Jabatan Perhutanan Negeri Pahang, 2022). In Perak State, the Perak Forestry Department designated two areas of 10 ha each in the Gerik Forest Reserve as HCVFs for *Rafflesia cantleyi* (Jabatan Perhutanan Negeri Perak, 2022). In addition, the Forest Research Institute Malaysia (FRIM), in collaboration with Felda/FGV, has been allocated an area for the development of the *Rafflesia* Interpretation Centre (PPIR). This is currently a work in progress in the Bersia, Gerik district. This initiative was approved by the government under the Eleventh Malaysia Plan (Rancangan Malaysia Ke-11 [RMK 11]) and supported by stakeholders including the Federal Land Development Authority (FELDA), Felda Global Ventures Holdings Berhad (FGV), and the Forestry Department. Similarly, in Kelantan State, the local government has designated a 50-ha area in Lojing Highlands in Gua Musang District as an HCVF for *Rafflesia kerrii* (Fauzan et al., 2021). Some *Rafflesia* populations are located in PAs. For example, the Royal Belum State Park (TRBSP) is one of the most important habitats for *Rafflesia*. Three species have been recorded in this PA (Siti-Munirah, 2012), including an unusual mutant specimen with 10 perigone lobes reported in 2012 (Siti-Munirah, 2020). Taman Negara is a PA that spans three states (Kelantan, Pahang, and Terengganu); most populations here are inaccessible. In Pulau Tioman, *Rafflesia* occurs in a Wildlife Forest Reserve under the care of PERHILITAN, which also falls within a PA (Siti-Munirah et al., 2020). In summary, PAs are an important means of protection for *Rafflesia* in Malaysia.

As in Indonesia, local people have attempted *Rafflesia* propagation in Malaysia with some success. Molina et al. (2017) describe a "*Rafflesia* garden" at Ranau, Poring Springs (Sabah). *Rafflesia* appears to occur naturally within the plot; the owner inoculates vines, reputedly augmenting the population. The garden yields about seven blooms a year, earning about RM2500 (approximately 550 USD) from tourists.

Despite the initiatives and conservation foci summarized above, significant concern remains. Land use change because of agricultural land expansion and the establishment of plantations is a severe threat in the regions discussed. For example, *R. kerrii* populations in the Gunung Berangkat Forest Reserve in Kelantan State have already vanished because of such practices, a phenomenon that worryingly appeared to go unnoticed by local communities. By contrast, through long-term observation, community relationship-building, unofficial documentation, and then scientific publications, the documentation of a new species, *Rafflesia tiomanensis*, was made in Pulau Tioman, Rompin, in the state of Pahang (Siti-Munirah et al., 2021). As described for Indonesia, in Malaysia, local residents' involvement was crucial to this work, which presents a case study for the importance of community involvement in *Rafflesia* research and conservation. Again, greater intentionality around community involvement would benefit from small funds for sustainable development, for example, for training guides for the effective local conservation and management of *Rafflesia*. Most local people rely on clients from ecotourism agencies in cities and towns or advertise flowering populations autonomously, for example, with banners on roadsides and via social media (Figure 3g–j). Training local specialist guides, government officials, and foresters would be an effective means of safeguarding knowledge and ground-level conservation of *Rafflesia*. This would harness the enthusiasm and passion among communities that already exist across Malaysia and could generate a template or package that could be disseminated elsewhere across Southeast Asia where community involvement is scarce or embryonic (for example, in the Philippines).

2.4 | Philippines

The Philippines, despite a relatively small land area, is the center of diversity for *Rafflesia*, with 15 known species (POWO, 2023) (Figure 1). Most were described remarkably recently: 13 species were reported in the last two decades (Balete et al., 2010; Barcelona, Co, et al., 2009; Barcelona & Fernando, 2002; Barcelona et al., 2006, 2011, 2014; Fernando & Ong, 2005; Galang, 2007; Galindon et al., 2016; Madulid, Buot, & Agoo, 2007; Madulid, Villariba-Tolentino, & Agoo, 2007; Malabrigo, 2010; Valenzuela et al., 2017); another is currently under consideration by authors ABT, PM, and CJT. Prior to 2002, there were only two species of *Rafflesia* known in the Philippines: *Rafflesia manillana* (Teschemacher, 1844:65) and *Rafflesia schadenbergiana* Göpp. ex (Hieronymus, 1885). Because the number spiked to 15, the Philippines has been established as the most *Rafflesia*-rich country.

The high level of endemism, compounded by continued forest degradation and the lack of existing conservation strategies, necessitates the need for an urgent concerted conservation action for the Philippine *Rafflesia* in particular. Many of the populations documented in the last two decades are remote and fall outside PAs. In addition, they consist of few individuals and are highly threatened by logging, slash-and-burn agriculture, and other human disturbances; this emphasizes the need for local conservation strategies, as recommended by Barcelona, Pelser, et al. (2009). In the Updated National List of Threatened Plants and Their Categories (DENR-BMB, 2017), a total of 12 species have been classified as threatened. Among these, four species are categorized as Critically Endangered (CR), five as Endangered, and three as Vulnerable (VU).

Unlike Malaysia and Indonesia, the Philippines lacks a comprehensive conservation strategy for the genus. On the island of Mindanao, some *Rafflesia* sites, for example those in Maragusan and Lantapan in Bukidnon, are being monitored by the local government unit. Meanwhile, the site of *Rafflesia mixta* has been declared as a Critical

Habitat Area (CHA) through a Municipal Ordinance. On Panay, *R. speciosa* and *Rafflesia lobata* are both celebrated by local people. A community-based tourism association dedicated to promoting these species has been established. On Luzon Island, the Indigenous people play a vital role in monitoring and conserving species (for example, *Rafflesia banaoana* and *Rafflesia leonardi*) (Figure 3a). In recent decades, blooming events have been announced on social media through infographics (Figure 4), promoting awareness and community-driven protection.

2.5 | Thailand

Only one *Rafflesia* species, *R. kerrii*, is native to Thailand, where it is restricted to the southern Surat Thani province within the Khao Sok National Park. The plant is a symbol of Surat Thani province, and the plant is considered a delicacy by local communities (see Section 3). Trampling young buds, which are concealed beneath leaf litter, is a likely risk to the plant, which is a focus of ecotourism. Thailand is also home to two species of *Sapria*. *Sapria ram* is protected in the Kaeng Krachan National Park, Phetchaburi, while *Sapria himalayana* occurs in Doi Suthep National Park, which is also under co-protection with the Queen Sirikit Botanic Garden, Chiang Mai. Concerted conservation efforts for these species are completely lacking.

3 | THE ROLE OF INDIGENOUS COMMUNITIES

Indigenous peoples—who represent only 5% of the globe's human population—are the stewards of 80% of the Earth's biodiversity (Ogar et al., 2020). Intergenerational transfer of their traditional ecological knowledge (TEK), including traditional land management and practices, is clearly key to maintaining biocultural diversity, defined as "the diversity of life in all its manifestations: biological, cultural, and linguistic – which are interrelated (and possibly coevolved) within a complex socio-ecological adaptive system" (Maffi, 2007). The strong correlation observed between languages and hotspots of biological diversity suggests that there is a functional connection between the two (Gorenflo et al., 2012; Maffi, 2001). The threats to biodiversity and languages are parallel (Sutherland, 2003), with current species extinction rates estimated to be about a thousand times or greater than historic rates of loss and predictions that 50%–90% of all languages will no longer be spoken by the end of the century (Gorenflo et al., 2012). Conservation programs are far more likely to be successful if they include a biocultural conservation approach, engaging with and including equal participation from local and Indigenous communities, who are generally the best guardians of their local environments and the species that co-inhabit them (Garnett et al., 2018; Sze et al., 2022). Indigenous peoples have long used and celebrated *Rafflesia* and play a crucial role in the plant's conservation.

In Indonesia, *Rafflesia* is used by Indigenous communities as a tonic—an energy drink specifically for men to improve stamina (Kanchanapoom et al., 2007; Refaei et al., 2011), as well as a supplement for women to increase fertility (Zuhud, 1999) or to cure fever and backache (Hikmat, 2006; Ismail, 1988; Meijer & Elliott, 1990). *Rafflesia* buds are used locally to make a tonic for the treatment of postpartum depression; the commonly used species include *R. hasseltii* (Wiart et al., 2004) and *Rafflesia zollingeriana* (Koorders, 1918; Zaman, 2009). Similarly, in Thailand, *R. kerrii* is used for ethnobotanical purposes as a boiled concoction of buds and flowers to cure fever and backache, and it is considered to be a sexual stimulant. *Rafflesia* buds are also reportedly used by the people in Peninsular Malaysia for their perceived effects in staunching internal bleeding and shrinking the womb in postpartum treatment; however, the species used here are unrecorded (Nais, 2001, p. 20). *Rafflesia* is also a perceived aphrodisiac for men, while in Perak, Malaysia, *Rafflesia* is one of the ingredients for traditional medicinal preparations known as "Faizal tonic" and "pil buasir," which are sold (Bänziger, 1991). Indigenous peoples such as the Orang Asli are an important original source of information about the location of the *Rafflesia* populations in Malaysia.

In the Philippines, *Rafflesia* is not used in ethnobotany to the authors' knowledge. This could be attributed to unfamiliarity because of scarcity and the inaccessibility of most species. Of the current known locations of the 15 *Rafflesia* species in the Philippines, only *Rafflesia banahawaensis* on Mt. Banahaw and *Rafflesia panchoana* on Mt. Makiling are accessible by a short mountain trek. For the rest, the search is extremely challenging, often requiring a 1–2-day trek under challenging field conditions. In the Banao Protected Landscape in the province of Kalinga, a challenging 5-h trek is necessary to reach the nearest population of *R. banaoana* (Figure 4a); the other populations are farther by almost double, and few people have seen them. In the province of Aurora, where new populations of *R. leonardi* were recently observed, an overnight stay in the forest is necessary to see the largest population. Despite the diversity of *Rafflesia* in the Philippines, most people are unfamiliar with the genus. Indigenous people who do have access to *Rafflesia* are often afraid to approach the flowers. The Banao tribe in Kalinga believes the flowers possess an evil spirit that will bring misfortune to anyone who disturbs them. Author PLM, during his documented discovery of *R. banaoana* in 2009, was hard put to convince the local people to accompany him and collect specimens (Malabrigo, 2010). The Agta Indigenous Community in the province of Aurora holds similar superficial beliefs towards *R. leonardi*. Such traditional beliefs may afford the populations of *Rafflesia* some protection.

Other genera in the Rafflesiaceae have been used in ethnobotanical medicine besides *Rafflesia*. It was reported that local Bhutanese used the flower *Sapria himalayana* Griff. as one of the main constituents for ethnomedicine preparations as a remedy for liver diseases and fever; spiritually, the flower was believed to deter "malevolent underworld spirits" (Wangchuk, Keller, et al., 2011; Wangchuk, Pyne, & Keller, 2011). Meanwhile, the people of Banjarmasin, South Kalimantan, Indonesia, use *Rh. lowii*, which they refer to as "ulur-ulur" in traditional medicine. The flower is treated as a fruit, which is dried and then boiled. A decoction is believed to treat hemorrhage, coronary disease, cholesterol, and to be an effective supplement for

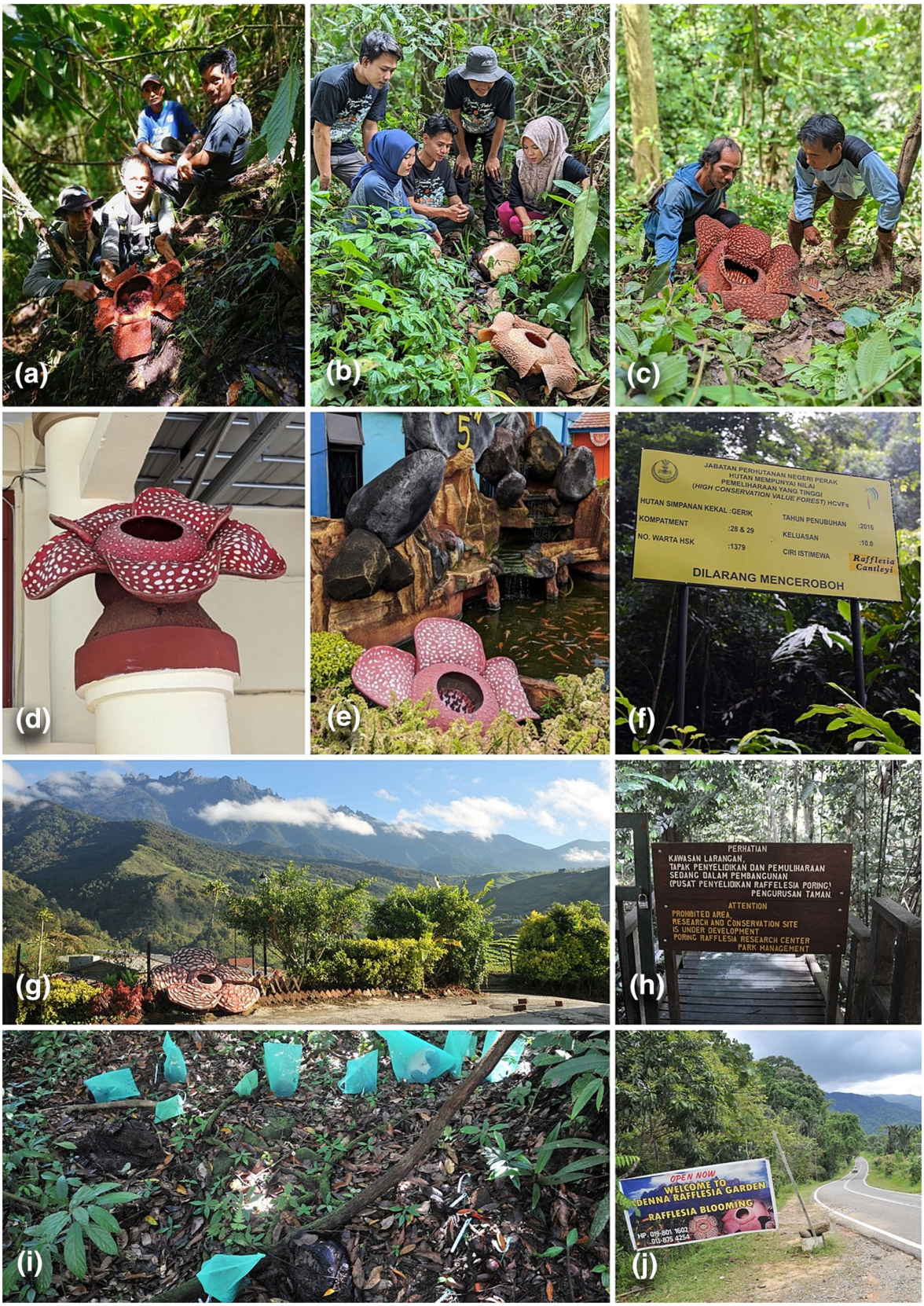

FIGURE 4 The various habitats of *Rafflesia* across Southeast Asia, with local people and promotional activities. (a) The Banao Indigenous Community with *Rafflesia banaoana* in the Balabasang forest, Kalinga, Philippines; (b) KPPL (Komunitas Peduli Puspa Langka Rejang Lebong) with *Rafflesia bengkuluensis* in Bengkulu, Sumatra; (c) Local foresters with *Rafflesia arnoldii* in Bengkulu, Sumatra; (d–e) Examples of *Rafflesia* "celebratory models" in Kota Bengkulu, Sumatra; (f–h) Public displays advertising *Rafflesia* blooming in Malaysian Borneo. (i) Buds protected from harm in Malaysia. (j) Blooming event advertised on a roadside in Malaysian Borneo. Photos (a–e): CJ Thorogood; photos (f–j): Siti-Munirah MY.

female fertility. Moreover, people of Murung B Village in South Kalimantan use flower buds of *Rh. lowii* as a treatment for hemorrhages, back pain, stomachache, and haematuria (Syaifuddin et al., 2018). The dried flower bud is boiled, reduced, and then consumed periodically. In Sumatra, *Rh. deceptor* is used to cure diarrhea and stomachaches by burning the buds on an open fire to yield a powder, which is then brewed with water and consumed (Quattrocchi, 2012). Uluk et al. (2001) reported that an unidentified species of *Rhizanthes* known as "aka kepun" is used by the Dayak Tribe that live around the Kayan Mentarang National Park to make rope; it is likely this refers, in error, to the host vine, *Tetrastigma*.

In summary, multiple species of Rafflesiaceae play an important role in ethnobotanical medicine in Indigenous communities across Southeast Asia. Harvesting may pose a threat where populations are already at risk from land conversion and anthropic change. Conversely, Indigenous communities also play an important role in the conservation of populations; some of the rarest and most poorly understood species of *Rafflesia* fall within remote and inaccessible areas that remain largely unexplored. These communities will be a vital source of knowledge in mapping and conserving these populations.

4 | PHARMACOLOGICAL PROPERTIES OF *RAFFLESIA* EXTRACTS

While the Rafflesiaceae have played an important role in traditional medicine to treat multiple conditions (see above), there are limited published studies on these plants' pharmacological properties—which is unsurprising given the current threat faced by most species in the family and their recalcitrance to cultivation. The chemistry of most Rafflesiaceae is largely unknown, although several of the species have been reported to be rich in tannins. One study investigating the phytochemistry of fresh flowers of *R. kerrii* identified four hydrolysable tannins (galloyl-glucose derivatives) and one phenylpropanoid (syringin) (Kanchanapoom et al., 2007). Another study found that the methanol fraction of an aqueous-ethanolic *R. kerrii* flower extract possessed a high level of antioxidant activity. Phytochemical assays demonstrated that this fraction contained an extremely high phenolic content, with gallic acid being the major component. In addition, the authors found that the antioxidant activity was relatively stable, even under heat and relative humidity stress over 4 months, showing a higher stability compared with other antioxidants including quercetin, catechins, and anthocyanin (Puttipan & Okonogi, 2014).

In an in vitro study screening for the antimicrobial activity of traditional plant medicines, *R. hasseltii* whole-plant methanol extracts displayed broad-spectrum inhibition against four bacteria (*Bacillus cereus*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus*) (Wiart et al., 2004). Another in vitro study investigating the effects of different plant extracts on apoptotic (cell death) induction in human skin cancer cell lines found that 50% hydroglycol extract from the flowers of *R. kerrii* demonstrated a time- and dose-dependent antiproliferative effect on the cancer cells. A further study corroborated this and established a mechanism of action through down-regulation of extracellular signal-regulated kinase (ERK) and serine/threonine protein kinase Akt signaling (de Silva & Tencomnao, 2018; Tancharoen et al., 2013).

Results from in vivo studies are mixed. A topical application *R. hasseltii* bud and flower extracts on Sprague Dawley rats were found to significantly increase the rate of wound closure; histology findings showed markedly more collagen and proliferating fibroblasts in granulating tissue, with the absence of inflammatory cells (Abdulla et al., 2009). Reports from a Malaysian study investigating the effects of administering compounds (not specified) from buds of *Rafflesia azlanii* for 14 days to mice that had delivered offspring found that their internal organs, including the liver, reduced in size. Concerns were raised that *Rafflesia* may cause liver and spleen failure (Tan, 2010). Additionally, an in silico study has confirmed the potential of *Rafflesia* and *Sapria* metabolites as multi-disease drugs (e.g., anticancer and anti-cholesterol) as well as antivirals and antimicrobials. Importantly, these metabolites are available in many other popular, edible plants (Wicaksono et al., 2022). Therefore, harvesting endangered populations of Rafflesiaceae is strongly discouraged.

5 | EXTINCTION RISK AND CONSERVATION CHALLENGES

Here, we present the initial assessment of the extinction risk for the genus *Rafflesia* (see Table 1). Among the 42 species examined, 25 are currently classified as CR, 15 as Endangered, and two as VU. Our conservation assessment primarily relies on the best available data regarding the geographic distribution, particularly the Extent of Occurrence (EOO) and Area of Occupancy (AOO) for each species. *Rafflesia* species often have highly restricted distributions, making them particularly VU to habitat destruction. Moreover, the unique challenges associated with their propagation and seed-banking add to the urgency of the situation. In the iNaturalist database, there have been 500 observations of 32 species across Southeast Asia, contributed by over 350 observers (iNaturalist, 2023).

The provisional CSs we report here should inform the IUCN Red List of Threatened Species, which is currently woefully inadequate in its representation of Rafflesiaceae. Of the 42 known *Rafflesia* species, only *Rafflesia magnifica* (=*Rafflesia mira*) is listed. However, utilizing similar conservation criteria, Susatya (2011) classified all Indonesian *Rafflesia* species as CR, with the exception of *R. arnoldii*, which was categorized as VU. In an IUCN Red List assessment for Philippine *Rafflesia* (data not shown), all species are categorized as threatened: nine as CR, five as Endangered, and one as VU. This highlights how global conservation efforts geared towards plant families—however iconic—have lagged behind those of animals.

The Indonesian Government, through the Ministry of Environment and Forestry Act (2018), classifies all *Rafflesia* as protected species. Three years prior to this, the Indonesian Government Act, *Rafflesia* Strategic Action Plan (RSAP), was developed (Mursidawati, Yuzammi, et al., 2015). The plan functions as a policy umbrella for all

TABLE 1 Provisional conservation status of *Rafflesia* spp. based on geographic distribution range data. Initial conservation assessment was based on Criterion B (geographic distribution range and number of locations) of the International Union for Conservation of Nature (IUCN) standards. Extent of Occurrence (EOO) and Area of Occupancy (AOO) were estimated based on the known localities for each species with GeoCat: AOO refers to the "Area within the EOO which is actually occupied by the taxon (usually measured by overlaying a grid and counting number of occupied cells); EOO refers to the 'Area contained within the shortest continuous imaginary boundary (minimum convex polygon) which can be drawn to encompass all known, inferred, or projected sites presently occupied by the taxon." (Terms used here as defined in the Key Terms and Concepts for IUCN Red List).

Species	EOO	AOO	Provisional CS (EOO and AOO based assessment)
Rafflesia aurantia, *Rafflesia baletei*, *Rafflesia borneensis*, *Rafflesia camarinensis*, *Rafflesia ciliata*, *Rafflesia consueloae*, *Rafflesia gadutensis*, *Rafflesia hasseltii*, *Rafflesia keithii*, *Rafflesia kemumu*, *Rafflesia lawangensis*, *Rafflesia manillana*, *Rafflesia meijeri*, *Rafflesia parvimaculata*, *Rafflesia pricei*, *Rafflesia sharifa-hapsahiae*, *Rafflesia su-meiae*, *Rafflesia tengku-adlinii*, *Rafflesia tiomanensis*, *Rafflesia tuan-mudae*, *Rafflesia tuanku-azizahiae*, *Rafflesia tuanku-halimii*, *Rafflesia verrucosa*, *Rafflesia witkampii*, and *Rafflesia zollingeriana*	<100 km^2	<10 km^2	Critically Endangered
Rafflesia cantleyi, *Rafflesia azlanii*, *Rafflesia banahawensis*, *Rafflesia banaoana*, *Rafflesia bengkuluensis*, *Rafflesia kerrii*, *Rafflesia leonardi*, *Rafflesia lobata*, *Rafflesia micropylora*, *Rafflesia mira*, *Rafflesia mixta*, *Rafflesia patma*, *Rafflesia rochussenii*, *Rafflesia schadenbergiana*, and *Rafflesia speciosa*	<5000 km^2	<500 km^2	Endangered
Rafflesia arnoldii and *Rafflesia panchoana*	<20,000 km^2	<2000 km^2	Vulnerable

Abbreviation: CS, conservation status.

Rafflesia species and appears to be a powerful approach to conservation cross-genus. However, "on the ground," it has proved challenging and largely ineffective. This appears to be because *Rafflesia* has gained less attention to similar plans for animals, precipitating less financial support from both government and non-government organizations. Meanwhile, the remote, dispersed, and inaccessible populations, often occurring alongside communities from diverse social and cultural backgrounds, pose practical difficulties for conservation in action. This highlights: (1) a discord in understanding at a global and regional level; and (2) the need for grass-roots regional and community-level action rather than a dependency on umbrella schemes.

In situ conservation in Indonesia is challenging and interdependent on multiple variables, including economic growth, increasing pressure on habitats linked to land use, and a poor understanding of the ecology and distribution of most species; it is impossible to conserve populations not known to exist. Less-explored Kalimantan is likely to host poorly known species of uncertain taxonomic status. For example, three unassigned taxa were documented on Mount Sekerat in northeast Kalimantan (Meijer, 1997). Recently, a team from the Indonesian National Research and Innovation Agency (BRIN) examined the area and found no extant *Rafflesia* populations; they appear to have been lost to land conversion. Hitherto unreported, this is a highly concerning example whereby three species may have been lost before they were even known to science. Elsewhere in Kalimantan, Atmoko (2014) recorded the presence of *R. pricei* in Kayang Mentarang National Park as well as an undescribed species of *Rafflesia* within a timber concession area in addition to *R. tuan-mudae* and *R. hasseltii*, which were already known to occur in the region (Susatya, 2011). *R. pricei* was formerly believed to be restricted to Sabah, Brunei, and Sarawak in Malaysian Borneo (Meijer, 1997). Meanwhile, in West Kalimantan, another team from BRIN recently identified thriving populations of *R. tuan-mudae* on Mount Poteng of the Raya Pasai Nature Conservation Area, and Bengkayang. This recent spate of records suggests further populations of *Rafflesia* may await discovery; some may be new species. Further exploration and survey work in the interior forests of the National Parks of Kalimantan and Sumatra are clearly needed.

R. arnoldii, *R. patma*, *Rafflesia bengkuluensis*, and *R. zollingeriana* are the most well-documented species in Indonesia (see, for example, Susatya, 2020; Susatya et al., 2017). These are the targets of community conservation focus. Other species are scarcely known and at severe risk of extinction from land conversion. These include *Rafflesia atjehensis*, *R. rochussenii*, *R. hasseltii*, *R. cantleyi*, *Rafflesia micropylora*, *Rafflesia lawangensis*, and *Rafflesia meijerii*. We recommend special attention is required for *R. atjehensis* and *R. rochussenii* in particular. Both have been reported from Gunung Leuser National Parks. *R. atjehensis* was described by Koorders (1918) and last reported in 1980 (Meijer, 1997). It has not been reported since and is most likely extinct. Meanwhile *R. rochussenii* has two disjunct populations spanning the Salak and Gede Mountains of West

Java and the minor range around Leuser Mountain and the Berastagi area of North Sumatra (Meijer, 1997; Zuhud, 1999). Again, the Sumatran population has not been reported since 1980 (Meijer, 1997). Furthermore, it is also unclear whether *R. rochussenii* of Sumatra is a variant of Javanese *R. rochussenii*, or a distinct species; in the absence of living or preserved material to scrutinize, taxonomic status remains unresolved.

Threats to *Rafflesia* vary across the islands of Java and Sumatra. The three species in Java, *R. rochussenii*, *R. patma*, and *R. zollengeriana*, all occur in highly fragmented habitats subject to severe pressure from a growing human population. Most of their ranges fall under the management of National Parks, Nature Conservation Areas (Zuhud et al., 1998), and specifically the Northern Banyuwangi Forest Management Unit (KPH Banyuwangi Utara). Despite anthropic pressure, the species have evaded extinction, most probably because of a keen awareness of the communities surrounding their habitats, the protected status of the species, and the close observation and monitoring of local offices. Nevertheless, all three are restricted to diminished and disjunct populations (Susatya, 2020) with high rates of mortality (Latiff, 2018), and their long-term outlook is precarious, to say the least. The populations are expected to decline owing to a steady decrease in the rate of flowering and seed-set (Susatya, 2011). Similar circumstances may explain the local extinction of *R. arnoldii* in five conservation areas across Indonesia (Susatya, 2011).

In Sumatra, six species occur in forests protected by the government: *R. micropylora*, *R. lawangensis*, *R. rochussenii*, *Rafflesia gadutensis*, *R. meijerii*, and *R. hasseltii*. *R. arnoldii*, *R. bengkuluensis*, and *Rafflesia kemumu* fall mainly outside such jurisdiction, though they also occur in the Gunung Leuser National Park (Mat-Salleh et al., 2010; Susatya, 2011; Zuhud et al., 1998), Batang Gadis National Park (Rambey, 2022, personal observation), Sicikeh Nature Tourism Area, North Sumatra, and the Bukit Tiga Puluh National Park (Zuhud et al., 1998), as well as the Kerinci Seblat National Park (Susatya, 2011), respectively. All are presumably protected in designated areas, though data on these populations are lacking. The Province of Bengkulu is a "hotspot" for *Rafflesia*, with four co-occurring species: *R. arnoldii*, *R. gadutensis*, *R. bengkuluensis*, and *R. kemumu*. Of the 24 sites in which *Rafflesia* is recorded to occur, half the populations fall in conservation areas such as Protection Forests, Nature Conservation Areas, and National Parks (12 sites); the remaining populations occur in areas that fall outside a conservation remit on private land (12 sites) (Susatya, 2011). The latter are clearly of concern yet pivotal to the future survival of the species; unfortunately, these areas are already subject to high rates of land conversion—the major threat to *Rafflesia* across its range (Hidayati & Walck, 2016) (Figure 2i). Komunitas Peduli Puspa Langka (Bengkulu Community Care for Rare Flower) (KPPL) recorded 71 blooms of *Rafflesia* in Bengkulu from January to December 2022; 40 of these were on private land, in areas facing an accelerated conversion of primary forest to coffee and oil palm plantations. The future survival of *Rafflesia* here hinges on efforts to convince landowners to protect these populations. It is of note that on Sumatra, several community-led initiatives have been established in which *Rafflesia* blooming is announced on social media platforms to build awareness among populations. Ecotourism is now a growing source of revenue for local communities in Bengkulu. As community awareness appears to have saved the remaining populations of *Rafflesia* on Java, this might just save those on private land in Sumatra. Conservation efforts for other genera in the Rafflesiaceae are lacking in Indonesia, as elsewhere. This is of concern because the genus *Rhizanthes* is still widely used in ethnomedicine in Banjarmasin.

Most *Rafflesia* species in the Philippines are rare and threatened. With the exception of *R. speciosa*, which occurs in Negros and Panay (Malabrigo, 2013); all species are island endemics. Deforestation is the single greatest cause of species extinction in the Philippines, and *Rafflesia* is not spared. Many of the *Rafflesia* species occur in severely degraded forests, while others occur in regenerating forests adjacent to human settlements; all are VU to extinction. For instance, *Rafflesia baletei*, a species previously recorded in three locations in Mount Isarog National Park, is now known only from a small (<500m^2) and isolated patch of secondary forest between abaca (*Musa textilis* Née) plantations (Figure 2f). Meanwhile, in Barangay Bolos Point in the Cagayan Province of Luzon Island, *R. leonardi* is possibly extinct in its type locality, which was devastated by a strong typhoon in 2018 (Tobias, personal observation).

In March 2023, authors PMJ, ABT, and CJT attempted the Philippines' first ex situ propagation of *Rafflesia* using vines infected with *R. panchoana*, deploying techniques shared by the staff at BBG. This was the first attempt at *Rafflesia* propagation in the Philippines. If successful, this work will be extended to the most threatened taxa in the country. Ex situ attempts at propagation have also been made with Philippine *Rafflesia* in the United States Botanic Garden, Washington (Molina et al., 2017); attempts at ex situ propagation outside the native range of *Rafflesia* are becoming increasingly challenging because of restrictions in the movement of material from and within countries.

6 | TOWARDS A HOLISTIC CONSERVATION APPROACH

We estimated the provisional CS (EOO and AOO based assessment) by collating CS and AOO from across Southeast Asia, and identified the the total number of localities that fall within nationally declared PAs, and those that fall outside PAs. Based on these data, we estimate that 25 species, representing 60%, are at CR. Moreover, 67% are absent from a conservation strategy at a regional or national level. Based on these alarming indicators, we propose a multi-pronged approach to conserve *Rafflesia* and related genera:

- A strengthened taxonomic framework to inform decision-making
  Within the last two decades, 57% of species (24 of 42 species) in the genus *Rafflesia* were described, while within the same period, 12% of total species (five of 42 species) across Southeast Asia have become VU due to land conversion and habitat destruction (GFW, 2023). We believe it is highly likely that multiple taxa were lost to extinction before they were known to science. Indeed, we

report three such possible examples for the first time in this paper (see above: Indonesia). Comprehensive sampling from across the region is required because, while we have a steady grasp on taxonomy in some regions, the precise number of *Rafflesia* species across Southeast Asia as a whole remains uncertain. Such sampling would benefit from enhanced digitisation of herbarium specimens and digital records of extant plants, for example, on iNaturalist (a scientific data repository). Presently, there are just 500 observations on iNaturalist and 252 digitized herbarium specimens, representing 22 species (Teixeira-Costa et al., 2023). In summary, comprehensive sampling combined with molecular phylogenetics, morphology, and ecology are needed to resolve taxonomic limits in this poorly known genus. A taxonomic framework is the bedrock of conservation: we cannot protect what we do not know to exist.

- The deployment of propagation techniques inter-regionallyThe only consistently successful propagation program for the ex situ conservation of *Rafflesia* is at BBG, Indonesia. Deploying this international center of excellence's expertise locally will enable the establishment of local ex situ conservation collections in the countries where species are most at risk. Authors PM, ABT, and CJT are currently trialing the establishment of *Rafflesia* ex situ in the Philippines, and Molina et al. (2017) have established ex situ trials in the USA. If successful, this will provide a template for ex situ conservation.
- The introduction of ecotourism initiativesCase studies from Bengkulu in West Sumatra demonstrate the effectiveness of community conservation and devolved ownership. *Pokdarwis* linked to social media networks have elevated local awareness and community-level celebration of *Rafflesia*, affording the sites in which they occur some protection. While trampling is a risk to such an approach, this may be offset by the benefits yielded by awareness and habitat projection. Such groups are absent from most regions—notably in the Philippines, where the center of diversity for *Rafflesia* lies. Such groups also require funding and capacity building.
- An extension of PAs for populations most at risk.Many of the extant populations exist in unprotected areas and are at critical risk of land conversion. Notable examples are those linked to the *Pokdarwis* in Indonesia, described above. In the Philippines, localities also fall outside areas with protected status; however, local government units have declared "Critical Habitat Area" status, which enables additional funding and the implementation of conservation measures at a local level. Ultimately, the continued survival of *Rafflesia* and related genera cannot depend on taxonomy, ex situ propagation, and community groups; habitat protection is the single best tool for conservation.

AUTHOR CONTRIBUTIONS

All authors contributed to the writing of this manuscript: Chris J. Thorogood, Pastor Malabrigo Jr., Adriane B. Tobias, Joko Witono, and Agus Susatya conceived the research in November 2022; Pastor Malabrigo Jr., Chris J. Thorogood, and Adriane B. Tobias drafted the manuscript; Adriane B. Tobias wrote content on Brunei; Joko Witono, Sofi Mursidawati, Agus Susatya, Reza Raihandhany, and Adhityo Wicaksono wrote content on Indonesia; Mat Yunoh Siti-Munirah wrote content on Malaysia; Pastor Malabrigo Jr. and Adriane B. Tobias wrote content on Philippines; Sarah Edwards wrote content on ethnobotany; Adhityo Wicaksono, Reza Raihandhany, and Sarah Edwards wrote content on pharmacological properties, and on *Rhizanthes*; all authors contributed to other sections; Adriane B. Tobias (with input from Chris J. Thorogood) compiled distribution data, created the figures and helped coordinate content from co-authors.

ACKNOWLEDGMENTS

We are grateful for the many Indigenous peoples, foresters, rangers, and local conservationists across the region for sharing their knowledge and allowing access to remote *Rafflesia* populations. Thanks in particular to the Banao Indigenous Community, Kalinga, Philippines, Deki Andriki and Regi Sunandar, and KPPL (Komunitas Peduli Puspa Langka Rejang Lebong) in Bengkulu, Sumatra. Author CJT is grateful to the Helen Roll Charity for supporting field work in Southeast Asia.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study were derived from the following resources available in the public domain: GeoCat at https://www.kew.org/science/our-science/projects/geocat-geospatial-conservation-assessment-tool; INaturalist at https://www.inaturalist.org/projects/rafflesiaceae-of-the-world-6f7651b6-3d85-431b-b6d9-a2568da9792d.

ORCID

Pastor Malabrigo Jr. https://orcid.org/0000-0002-4254-751X
Adriane B. Tobias https://orcid.org/0000-0003-3134-7982
Joko Witono https://orcid.org/0000-0003-0946-0559
Sofi Mursidawati https://orcid.org/0000-0002-3737-2081
Agus Susatya https://orcid.org/0000-0002-9369-5651
Mat Yunoh Siti-Munirah https://orcid.org/0000-0002-5062-9988
Adhityo Wicaksono https://orcid.org/0000-0003-3298-3577
Reza Raihandhany https://orcid.org/0000-0002-1568-6952
Sarah Edwards https://orcid.org/0009-0003-7703-310X
Chris J. Thorogood https://orcid.org/0000-0002-2822-0182

REFERENCES

Abdulla, M. A., Ahmed, K. A., Ali, H. M., Noor, S. M., & Ismail, S. (2009). Wound healing activities of *Rafflesia hasseltii* extract in rats. *Journal of Clinical Biochemistry and Nutrition*, *45*(3), 304–308. https://doi.org/10.3164/jcbn.09-17

Adam, J. H., Aizat-Juhari, M. A., Ariff, N. N.-F. N., Khamis, S., Yasin, M. H. M., & Wan, K.-L. (2022). *Rafflesia tunku-azizahiae* (Rafflesiaceae), a New Species from Pahang, Malaysia. *Sains Malaysiana*, *51*(11), 3843–3855. https://doi.org/10.17576/jsm-2022-5111-27

Areendran, G., Sahana, M., Raj, K., Kumar, R., Sivadas, A., Kumar, A., Deb, S., & Gupta, V. D. (2020). A systematic review on high conservation value assessment (HCVs): Challenges and framework for future

research on conservation strategy. *Science of the Total Environment*, *709*, 135425. https://doi.org/10.1016/j.scitotenv.2019.135425

Atmoko, T. (2014). Catatan terbaru *Rafflesia* di Kalimantan Timur (new notes on Raffflesia sp in East Kalimantan). *Swara Samboja*, *3*(1), 27–28.

Balete, D. S., Pelser, P., Pieter, B., Nickrent, D. L., & Barcelona, J. F. (2010). *Rafflesia verrucosa* (Rafflesiaceae), a new species of small-flowered Rafflesia from eastern Mindanao, Philippines. *Phytotaxa*, *10*(1), 49–57. https://doi.org/10.11646/phytotaxa.10.1.8

Bänziger, H. (1991). Stench and fragrance: Unique pollination lure of Thailand's largest flower, Rafflesia kerrii Meijer. *Natural History Bulletin of the Siam Society*, *39*, 19–52.

Bänziger, H., & Hansen, B. (2000). A new taxonomic revision of a deceptive flower, Rhizanthes Dumortier (Rafflesiaceae). *Natural History Bulletin of the Siam Society*, *48*, 117–143.

Barcelona, J., Pelser, P., Balete, D., & Co, L. (2009). Taxonomy, ecology, and conservation status of Philippine Rafflesia (Rafflesiaceae). *Blumea-Biodiversity, Evolution and Biogeography of Plants*, *54*(1–2), 77–93. https://doi.org/10.3767/000651909X474122

Barcelona, J. F., Cajano, M. A. O., & Hadsall, A. S. (2006). *Rafflesia baletei*, another new Rafflesia (Rafflesiaceae) from the Philippines. *Kew Bulletin*, 231–237.

Barcelona, J. F., Co, L. L., Balete, D. S., & Bartolome, N. A. (2009). *Rafflesia aurantia* (Rafflesiaceae): A new species from northern Luzon, Philippines. *Gardens' Bulletin Singapore*, *61*(1), 17–27.

Barcelona, J. F., & Fernando, E. S. (2002). A new species of Rafflesia (Rafflesiaceae) from Panay Island, Philippines. *Kew Bulletin*, *57*, 647–651. https://doi.org/10.2307/4110994

Barcelona, J. F., Fernando, E. S., Nickrent, D. L., Balete, D. S., & Pelser, P. B. (2011). An amended description of *Rafflesia leonardi* and a revised key to Philippine *Rafflesia* (Rafflesiaceae). *Phytotaxa*, *24*, 11–18. https://doi.org/10.11646/phytotaxa.24.1.2

Barcelona, J. F., Pelser, P. B., & Manting, M. M. E. (2014). *Rafflesia mixta* (Rafflesiaceae), a new species from Surigao del Norte, Mindanao, Philippines. *Phytotaxa Phytotaxa*, *174*(5), 272–278. https://doi.org/10.11646/phytotaxa.174.5.3

Beccari, O. (1868). *Rafflesia tuan-mudae*. XI, (p. 196).

Blanco, M. (1845). *Flora de Filipinas:segun el sistema sexual de Linneo* (pp. 1–678). Impr. de M. Sanchez. https://www.biodiversitylibrary.org/item/102888

Blume, C. L. (1825). *Rafflesia patma*. Batav. Cour (Vol. 12, p. 4).

Brown, R. (1821). *An account of a new genus of plants, named Rafflesia* (Vol. 13). Taylor. https://doi.org/10.5962/bhl.title.140121

Brummitt, N., Araújo, A. C., & Harris, T. (2021). Areas of plant diversity—What do we know? *Plants, People, Planet*, *3*(1), 33–44. https://doi.org/10.1002/ppp3.10110

de Silva, M. B., & Tencomnao, T. (2018). The protective effect of some Thai plants and their bioactive compounds in UV light-induced skin carcinogenesis. *Journal of Photochemistry and Photobiology B: Biology*, *185*, 80–89. https://doi.org/10.1016/j.jphotobiol.2018.04.046

DENR-BMB. (2017). *Updated National List of Threatened Plants and Their Categories*. DENR-BMB. https://elibrary.bmb.gov.ph/elibrary/wp-content/uploads/2023/05/dao2017-11.pdf

Fauzan, M., Muhammad-Hapiz, A. M., Azizul, R., Rosilan, S., Hamidi, A. H., Zahari, I., Aweng, E. R., Mohamad-Faiz, M. A., Abas, M. A., & Kamarul-Ariffin, H. (2021). Managing and protecting of endangered Rafflesia species in Kelantan, Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science*, *842*(1), 012069. https://doi.org/10.1088/1755-1315/842/1/012069

Fernando, E. S., & Ong, P. S. (2005). The genus *Rafflesia* R. Br.(Rafflesiaceae) in the Philippines. *Asia Life Sciences*, *14*(2), 263–270.

Galang, R. (2007). Population study of *Rafflesia lobata* in the northern section of the central Panay Island mountain ranges, Philippines. *Folia Malaysiana*, *8*(2), 87–98.

Galindon, J. M. M., Ong, P. S., & Fernando, E. S. (2016). *Rafflesia consueloae* (Rafflesiaceae), the smallest among giants; a new species from Luzon Island, Philippines. *PhytoKeys*, *61*, 37.

Garnett, S. T., Burgess, N. D., Fa, J. E., Fernández-Llamazares, Á., Molnár, Z., Robinson, C. J., Watson, J. E., Zander, K. K., Austin, B., & Brondizio, E. S. (2018). A spatial overview of the global importance of Indigenous lands for conservation. *Nature Sustainability*, *1*(7), 369–374. https://doi.org/10.1038/s41893-018-0100-6

GFW. (2023). *Interactive World Forest Map & Tree Cover Change Data|GFW*. https://www.globalforestwatch.org/map/

Gorenflo, L. J., Romaine, S., Mittermeier, R. A., & Walker-Painemilla, K. (2012). Co-occurrence of linguistic and biological diversity in biodiversity hotspots and high biodiversity wilderness areas. *Proceedings of the National Academy of Sciences*, *109*(21), 8032–8037. https://doi.org/10.1073/pnas.1117511109

Halmy, M. W. A., & Salem, B. B. (2015). Species conservation importance index (SCI) for comparing sites' conservation value at landscape level. *Brazilian Journal of Botany*, *38*, 823–835. https://doi.org/10.1007/s40415-015-0197-z

Harms, H. A. (1934). *Repertorium specierum novarum regni vegetabilis* (Vol. 36, p. 287).

Hidayati, S. N., & Walck, J. L. (2016). A review of the biology of Rafflesia: What do we know and what's next? *Buletin Kebun Raya*, *19*(2), 67–78.

Hieronymus, G. H. E. W. (1885). Ueber eine neue, von Dr.A. Schadenberg und O. Koch auf Süd-Mindanao entdeckte Art der Gattung Rafflesia. *Gartenflora*, *34*, 3–7.

Hikmat, A. (2006). Kecenderungan popalis Rafflesia zollingeriana Kds. DI TAMAN NASIONAL MERU BETIRI, JAWA TIMUR (Population Trend of *Rafflesia zollingeriana* Kds. In Meru Betiri National Park, East Java). *Media Konservasi*, *11*(3).

iNaturalist. (2023). *Rafflesiaceae of the World*. INaturalist. https://www.inaturalist.org/projects/rafflesiaceae-of-the-world-6f7651b6-3d85-431b-b6d9-a2568da9792d

Ismail, G. (1988). Conservation of the giant Rafflesia in Sabah, Malaysia. *Trends in Ecology & Evolution*, *3*(12), 316–317. https://doi.org/10.1016/0169-5347(88)90084-5

Jabatan Perhutanan Negeri Pahang. (2022). *HCVF*. https://forestry.pahang.gov.my/index.php/info-perhutanan/mc-i/hcvf

Jabatan Perhutanan Negeri Perak. (2022). *Jabatan Perhutanan Negeri Perak—Kawasan Hutan Bernilai Pemeliharaan Tinggi HCVFs*. https://www.perakforestry.gov.my/index.php/perhutanan/sumber-hutan/mc-i/kawasan-hutan-bernilai-pemeliharaan-tinggi-hcvfs

Kanchanapoom, T., Kamel, M. S., Picheansoonthon, C., Luecha, P., Kasai, R., & Yamasaki, K. (2007). Hydrolyzable tannins and phenylpropanoid from *Rafflesia kerrii* Meijer (Rafflesiaceae). *Journal of Natural Medicines*, *61*, 478–479. https://doi.org/10.1007/s11418-007-0181-4

Koorders, S. H. (1918). *Botanisch Oversicht der Rafflesiaceae van Nederlandsch-Indie*. G. Kolff & Co.

Latiff, A. (2018). Viability of having the gigantic *Rafflesia* flowers in our park. *Open Access Journal of Science*, *2*(2), 106–107. https://doi.org/10.15406/oajs.2018.02.00053

MacArthur, R. H., & Wilson, E. O. (1967). *The Theory of Island Biogeography* (p. 203). Princeton Univ. Press.

Madulid, D. A., Buot, I. E., & Agoo, E. M. G. (2007). *Rafflesia panchoana* (Rafflesiaceae), a new species from Luzon island, Philippines. *Acta Manilana*, *55*, 43–47. https://doi.org/10.3860/psci.v43i0.370

Madulid, D. A., Villariba-Tolentino, C., & Agoo, E. M. G. (2007). *Rafflesia banahawensis* (Rafflesiaceae), a new species from Luzon, Philippines. *The Philippine Scientist*, *43*, 43–51. https://doi.org/10.3860/psci.v43i0.370

Maffi, L. (2001). Introduction: On the interdependence of biological and cultural diversity. In *On Biocultural Diversity. Linking Language, Knowledge, and the Environment* (pp. 1–50).

Maffi, L. (2007). *Biocultural diversity and sustainability* (pp. 267–277). The SAGE Handbook of Environment and Society. https://doi.org/10.4135/9781848607873.n18

Malabrigo, P. L. Jr. (2010). *Rafflesia banaoana* (Rafflesiaceae): Another new species from Luzon, Philippines. *Asia Life Sciences-The Asian International Journal of Life Sciences*, *4*, 139–146.

Malabrigo, P. L. Jr. (2013). Vascular Flora of the Tropical Montane Forests in Balbalasang-Balbalan National Park, Kalinga Province, Northern Luzon, Philippines. *Asian Journal of Biodviersity*, *4*. https://doi.org/10.7828/ajob.v4i1.294

Mat Salleh, K., & Latiff, A. (1989). A new species of *Rafflesia* and notes on other species from Trus Madi Range, Sabah (Borneo). *Blumea: Biodiversity, Evolution and Biogeography of Plants*, *34*(1), 111–116.

Mat-Salleh, K., Mahyuni, R., Susatya, A., & Veldkamp, J. (2010). *Rafflesia lawangensis* (Rafflesiaceae) A new species from Bukit Lawang, Gunung Leuser National Park, North Sumatra, Indonesia. *Reinwardtia*, *13*(2), 159–165. https://doi.org/10.14203/REINWARDTIA.V13I2.2136

Meijer, W. (1984). New species of *Rafflesia* (Rafflesiaceae). *Blumea*, *30*(1), 209–215.

Meijer, W. (1997). Rafflesiaceae. *Flora Malesiana-Series 1. Spermatophyta*, *13*(1), 1–42.

Meijer, W., & Elliott, S. (1990). Taxonomy, ecology and conservation of Rafflesia kerrii Meijer in southern Thailand. *Natural History Bulletin of the Siam Society*, *38*(2), 117–133.

Miettinen, J., Shi, C., & Liew, S. C. (2011). Deforestation rates in insular Southeast Asia between 2000 and 2010. *Global Change Biology*, *17*(7), 2261–2270. https://doi.org/10.1111/j.1365-2486.2011.02398.x

Molina, J., McLaughlin, W., Wallick, K., Pedales, R., Marius, V. M., Tandang, D. N., Damatac, A., Stuhr, N., Pell, S. K., & Lim, T. M. (2017). Ex situ propagation of Philippine *Rafflesia* in the United States: Challenges and prospects. *Sibbaldia: The International Journal of Botanic Garden Horticulture*, *15*, 77–96. https://doi.org/10.24823/Sibbaldia.2017.224

Molina, J., Wicaksono, A., Michael, T. P., Kwak, S.-H., Pedales, R. D., Joly-Lopez, Z., Petrus, S., Mamerto, A., Tomek, B., Ahmed, S., Maddu, V., Yakubova, K., Tandang, D., Morin, J. W., Park, S.-Y., Lee, H.-O., McLaughlin, W., Wallick, K., Adams, J., … Purugganan, M. D. (2023). The seed transcriptome of *Rafflesia* reveals horizontal gene transfer and convergent evolution: Implications for conserving the world's largest flower. *Plants, People, Planet*, 1–19. https://doi.org/10.1002/ppp3.10370

Mursidawati, S., & Handini, E. (2009). Biologi konservasi tumbuhan holoparasit: Percobaan kultur in vitro. In *Proceedings of "Indonesian Flora Conservation in Addressing the Impact of Global Warming"* (pp. 158–162).

Mursidawati, S., & Irawati, I. (2017). *Biologi Konservasi Rafflesia*. LIPI Press.

Mursidawati, S., Ngatari, N., Irawati, I., Cardinal, S., & Kusumawati, R. (2015). Ex situ conservation of *Rafflesia patma* Blume (Rafflesiaceae): An endangered emblematic parasitic species from Indonesia. *Sibbaldia: The International Journal of Botanic Garden Horticulture*, *13*, 99–110. https://doi.org/10.24823/Sibbaldia.2015.77

Mursidawati, S., & Wicaksono, A. (2020). Tissue differentiation of the early and the late flower buds of *Rafflesia patma* Blume. *Journal of Plant Development*, *27*, 19–32. https://doi.org/10.33628/jpd.2020.27.1.19

Mursidawati, S., & Wicaksono, A. (2021). A preliminary study of in vivo injection of auxin and cytokinin into *Rafflesia patma* Blume flower bud. *Buletin Kebun Raya*, *24*(2). https://doi.org/10.14203/bkr.v24i2.670

Mursidawati, S., Yuzammi, A., Sugiarti, J., Risa, A. R., Gunawan, H., Hugroho, A., & Rahmat, U. M. (2015). Strategi dan Rencana Aksi Konservasi (Rafflesiaceae) 2015–2019. In *Kementrian Lingkungan Hidup dan Kehutanan*. Lembaga Ilmu Pengetahuan Indonesia. Pemerintah Provinsi Bengkulu. Dewan Riset Daerah Bengkulu. http://lipi.go.id/publikasi/strategi-dan-rencana-aksi-konservasi-rafflesia/24060

Nais, J. (2001). *Rafflesia of the World*.

Ogar, E., Pecl, G., & Mustonen, T. (2020). Science must embrace traditional and indigenous knowledge to solve our biodiversity crisis. *One Earth*, *3*(2), 162–165. https://doi.org/10.1016/j.oneear.2020.07.006

Pelser, P. B., Nickrent, D. L., & Barcelona, J. F. (2016). Untangling a vine and its parasite: Host specificity of Philippine *Rafflesia* (Rafflesiaceae). *Taxon*, *65*(4), 739–758. https://doi.org/10.12705/654.4

Pelser, P. B., Nickrent, D. L., & Barcelona, J. F. (2018). A conservation genetic study of *Rafflesia speciosa* (Rafflesiaceae): Patterns of genetic diversity and differentiation within and between islands. *Blumea-Biodiversity, Evolution and Biogeography of Plants*, *63*(2), 93–101. https://doi.org/10.3767/blumea.2018.63.02.01

Pelser, P. B., Nickrent, D. L., Gemmill, C. E., & Barcelona, J. F. (2017). Genetic diversity and structure in the Philippine *Rafflesia lagascae* complex (Rafflesiaceae) inform its taxonomic delimitation and conservation. *Systematic Botany*, *42*(3), 543–553. https://doi.org/10.1600/036364417X696186

Pelser, P. B., Nickrent, D. L., van Ee, B. W., & Barcelona, J. F. (2019). A phylogenetic and biogeographic study of *Rafflesia* (Rafflesiaceae) in the Philippines: Limited dispersal and high island endemism. *Molecular Phylogenetics and Evolution*, *139*, 106555. https://doi.org/10.1016/j.ympev.2019.106555

Peters, R. F., & Ting, Y. Y. (2016). Protection of *Rafflesia* through the Appreciation of the Dusunâ€™s Indigenous Knowledge; A Preliminary Case Study at Poring-Sabah. *Journal of Tropical Biology & Conservation (JTBC)*, *13*. https://doi.org/10.51200/jtbc.v13i0.395

Planchon, J. E. (1887). Tetrastigma. In *Monographiæ phanerogamarum: Prodromi nunc continuatio, nunc revisio* (Vol. 5, p. 423). Masson & Cie. https://www.biodiversitylibrary.org/item/100121

POWO. (2023). Rafflesia R.Br. Ex Gray|Plants of the World Online|Kew Science. In *Plants of the World Online*. http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:77089854-1

Puttipan, R., & Okonogi, S. (2014). Antioxidant activity of *Rafflesia kerrii* flower extract. *Drug Discoveries & Therapeutics*, *8*(1), 18–24. https://doi.org/10.5582/ddt.8.18

Quattrocchi, U. (2012). *CRC world dictionary of medicinal and poisonous plants: Common names, scientific names, eponyms, synonyms, and etymology (5 Volume Set)*. CRC press.

Refaei, J., Jones, E., Sakayaroj, J., & Santhanam, J. (2011). Endophytic fungi from Rafflesia cantleyi: Species diversity and antimicrobial activity. *Mycosphere*, *2*(4), 429–447.

Rietbergen-McCracken, J., Steinlegger, G., & Koon, C. S. (2007). High Conservation Value Forests: The concept in theory and practice. In *Forests for Life Program*. WWF International.

Siti-Munirah, M. Y. (2012). *Rafflesia* blooms in Royal Belum. *Conservation Malaysia*, *16*, 6–9.

Siti-Munirah, M. Y. (2020). Notes on a ten-perigoned *Rafflesia azlanii* from the Royal Belum State Park, Perak, Peninsular Malaysia. *Malayan Nature Journal*, *72*(1), 11–17.

Siti-Munirah, M. Y., Salamah, A., & Razelan, M. S. (2020). On the morphological variation of Rafflesia cantleyi (Rafflesiaceae) on Pulau Tioman, Pahang, Peninsular Malaysia. *Blumea-Biodiversity, Evolution and Biogeography of Plants*, *65*(1), 75–82. https://doi.org/10.3767/blumea.2020.65.01.09

Siti-Munirah, M. Y., Salamah, A., & Razelan, M. S. (2021). *Rafflesia tiomanensis* (Rafflesiaceae), a new species from Pulau Tioman, Pahang, Malaysia. *Malayan Nature Journal*, *73*(1), 19–26.

Sodhi, N. S., Koh, L. P., Brook, B. W., & Ng, P. K. (2004). Southeast Asian biodiversity: An impending disaster. *Trends in Ecology & Evolution*, *19*(12), 654–660. https://doi.org/10.1016/j.tree.2004.09.006

Solms-Laubach, H. (1910). Uber eine neue species der Gattung Rafflesia. *Annales du Jardin Botanique de Buitenzorg: Supplément*, *3*(1), 2.

Spach, E. (1841). Genre RHIZANTHE. - Rhizanthes Dumort. *Histoire Naturelle Des Végétaux. Phanerogames*, *10*, 554.

Sukamto, L. A. (2001). *Upaya menumbuhkan Rafflesia arnoldii Secara in vitro* (pp. 31–34). Prosiding Nasional Puspa Langka. Bogor.

Sukamto, L. A., & Mujiono, M. (2010). In vitro culture of holoparasite *Rafflesia arnoldii* R. Brown. *Buletin Kebun Raya*, *13*(2), 79–85.

Suringar, F. (1879). Acta Societatis Regiae Scientiarum Needlandicae. In *Rafflesia hasseltii*.

Susatya, A. (2011). *Rafflesia pesona bunga terbesar di dunia*. Direktorat Kawasan Konservasi Dan Bina Hutan Lindung.

Susatya, A. (2020). The growth of flower bud, life history, and population structure of *Rafflesia arnoldii* (Rafflesiaceae) in Bengkulu, Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, *21*(2). https://doi.org/10.13057/biodiv/d210247

Susatya, A., Hidayati, S. N., & Riki, S. (2017). Rafflesia kemumu (Rafflesiaceae), a new species from Northern Bengkulu, Sumatra, Indonesia. *Phytotaxa*, *326*(3), 211–220. https://doi.org/10.11646/phytotaxa.326.3.5

Sutherland, W. J. (2003). Parallel extinction risk and global distribution of languages and species. *Nature*, *423*(6937), 276–279. https://doi.org/10.1038/nature01607

Syaifuddin, A. S., Suryanto, E., Nisa, L., Wardana, A., & Kurniawan, N. (2018). *Kajian pemanfaatan tumbuhan obat sebagai obat tradisional di Kabupaten Hulu Sungai Tengah Propinsi Kalimantan Selatan* (pp. 317–325).

Sze, J. S., Carrasco, L. R., Childs, D., & Edwards, D. P. (2022). Reduced deforestation and degradation in Indigenous Lands pan-tropically. *Nature Sustainability*, *5*(2), 123–130. https://doi.org/10.1038/s41893-021-00815-2

Tan, R. (2010). Malaysian study finds *Rafflesia* can cause liver, spleen failure. *Wild Singapore News*. https://wildsingaporenews.blogspot.com/2010/05/malaysian-study-finds-rafflesia-can.html

Tancharoen, W., Teeraaungkul, S., Krajarng, A., Nilwarangoon, S., & Watanapokasin, R. (2013). Apoptosis induction by *Rafflesia kerrii* Meijer flower extract via caspasedependent and down-regulation of ERK signaling pathway in epidermoid carcinoma cells. *Journal of Modern Medicinal Chemistry*, *1*, 37–42.

Teijsman, J. E., & Binnendijk, S. (1850). Over Eene Nieuwe Soort van Rafflesia. In *Natuurkundig tijdschrift voor Nederlandsch Indië* (Vol. 1, pp. 1–522). Lange. https://www.biodiversitylibrary.org/item/110300

Teixeira-Costa, L., Heberling, J. M., Wilson, C. A., & Davis, C. C. (2023). Parasitic flowering plant collections embody the extended specimen. *Methods in Ecology and Evolution*, *14*(2), 319–331. https://doi.org/10.1111/2041-210X.13866

Teschemacher, J. E. (1844). Art. VIII.-On a new species of Rafflesia, from Manilla. *Boston Journal of Natural History*, *4*(65). https://www.biodiversitylibrary.org/page/5362948

Thorogood, C., Teixeira-Costa, L., Ceccantini, G., Davis, C., & Hiscock, S. J. (2021). Endoparasitic plants and fungi show evolutionary convergence across phylogenetic divisions. *New Phytologist*, *232*(3), 1159–1167. https://doi.org/10.1111/nph.17556

Thorogood, C., Witono, J. R., Mursidawati, S., & Fleischmann, A. (2022). Parasitic plant cultivation: Examples, lessons learned and future directions. *Sibbaldia: The International Journal of Botanic Garden Horticulture*, *21*(6).

Uluk, A., Sudana, M., & Wollenberg, E. (2001). *Ketergantungan masyarakat Dayak terhadap hutan di sekitar Taman Nasional Kayan Mentarang*. Cifor.

Valenzuela, F. B., Jaucian-Adan, G. G., Agoo, E. M. G., & Madulid, D. A. (2017). *Rafflesia camarinensis* (Rafflesiaceae), a new species from Mt. Asog, Camarines Sur, Luzon Island, Philippines. *Philippine Journal of Systematic Biology*, *10*, 1–5.

Wangchuk, P., Keller, P. A., Pyne, S. G., Taweechotipatr, M., Tonsomboon, A., Rattanajak, R., & Kamchonwongpaisan, S. (2011). Evaluation of an ethnopharmacologically selected Bhutanese medicinal plants for their major classes of phytochemicals and biological activities. *Journal of Ethnopharmacology*, *137*(1), 730–742. https://doi.org/10.1016/j.jep.2011.06.032

Wangchuk, P., Pyne, S. G., & Keller, P. A. (2011). Ethnobotanical authentication and identification of Khrog-sman (lower elevation medicinal plants) of Bhutan. *Journal of Ethnopharmacology*, *134*(3), 813–823. https://doi.org/10.1016/j.jep.2011.01.034

Werth, D., & Avissar, R. (2005). The local and global effects of Southeast Asian deforestation. *Geophysical Research Letters*, *32*(20), L20702. https://doi.org/10.1029/2005GL022970

Wiart, C., Mogana, S., Khalifah, S., Mahan, M., Ismail, S., Buckle, M., Narayana, A., & Sulaiman, M. (2004). Antimicrobial screening of plants used for traditional medicine in the state of Perak, Peninsular Malaysia. *Fitoterapia*, *75*(1), 68–73. https://doi.org/10.1016/j.fitote.2003.07.013

Wicaksono, A., & Da Silva, J. T. (2017). Attempted callus induction of holoparasite *Rafflesia patma* Blume using primordial flower bud tissue. *Jurnal Nasional*, *7*(2), 96–101.

Wicaksono, A., Mursidawati, S., Sukamto, L. A., & Teixeira da Silva, J. A. (2016). *Rafflesia* spp.: Propagation and conservation. *Planta*, *244*, 289–296. https://doi.org/10.1007/s00425-016-2512-8

Wicaksono, A., Raihandhany, R., Zen, T. V., da Silva, J. A. T., Agatha, A., Cristy, G. P., Ramadhan, A. T. K., & Parikesit, A. A. (2022). Screening *Rafflesia* and *Sapria* metabolites using a bioinformatics approach to assess their potential as drugs. *The Philippine Journal of Science*, *151*(5), 1771–1791. https://doi.org/10.56899/151.05.20

Wilson, E. O., & MacArthur, R. H. (2016). *The theory of island biogeography*. Princeton University Press.

Zaman, M. (2009). *Etnobotani Tumbuhan Obat di Kabupaten Pamekasan Madura Provinsi Jawa Timur*.

Zuhud, E. A. (1999). *Pelestarian Rafflesia hasseltii Suringar Ditaman Nasional Bukit Tigapuluh Riau-Jambi*.

Zuhud, E. A. M., Hikmat, A., & Jamil, N. (1998). Rafflesia Indonesia: Keanekaragaman, ekologi, dan pelestariannya. In *Diterbitkan atas kerjasama Yayasan Pembinaan Suaka Alam dan Suaka Margasatwa Indonesia (The Indonesian Wildlife Fund) dan Laboratorium Konservasi Tumbuhan*. Institut Pertanian Bogor.

How to cite this article: Malabrigo, P. Jr., Tobias, A. B., Witono, J., Mursidawati, S., Susatya, A., Siti-Munirah, M. Y., Wicaksono, A., Raihandhany, R., Edwards, S., & Thorogood, C. J. (2023). Most of the world's largest flowers (genus *Rafflesia*) are now on the brink of extinction. *Plants, People, Planet*, 1–16. https://doi.org/10.1002/ppp3.10431