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CHAPTER 7

Rafflesia and *Rhizanthes* (Rafflesiaceae): Their natural history and conservation in Malaysia

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Abstract: Over the past 35 years or so, there has been an impressive and positive development in the conservation biology of *Rafflesia* and *Rhizanthes* in Malaysia. In 1990, the existence of seven species of *Rafflesia* and their state of conservation were reported, namely *R. cantleyi*, *R. kerrii*,, *T. pricei*, *R. keithii*, *R. tengku-adlinii*, *R. tuan-mudae* and mistakenly, *R. arnoldii.* Currently, more than ten species are recognised, with *R. azlanii*, *R. su-meiae*, *R. parvimaculata*, *R. hasseltii* and *R. tiomanensis* being new additions. In addition, one species of *Rhizanthes*, *R. infanticida* (formerly identified as *R. lowii*) in Peninsular Malaysia, while *R. lowii* is found in Sabah and Sarawak. In Malaysia, *in situ* conservation efforts have largely been incidental as these species occur within forest reserves, national parks and conservation areas, that are well-managed and protected by the respective stakeholders. However, direct efforts have also been undertaken to protect and conserve these species through community incentive schemes, particularly in Sabah. *Rafflesia* conservation sanctuaries have been established for *R. keithii* at Poring and for *R. pricei* and *R. keithii* and at Tambunan in Sabah; for *R. kerrii*, *R. cantleyi* and *R. azlanii* in Peninsular Malaysia; and for *R. tuan-mudae* and *R. hasseltii* in Sarawak. In this decade, conservation efforts and initiatives have been planned and implemented not only by the Forestry Departments, but also by the Forestry Research Institute Malaysia (FRIM) at Bersia, Ulu Perak, Sabah Parks, State Parks in Perak and Kelantan, National Parks in Sarawak, and the private sectors, particularly Tenaga Nasional Berhad. There has been a pragmatic shift in conservation strategy by various sectors and interested parties as the species have great national and state heritage value and economic potentials in ecotourism.

INTRODUCTION

History and early records of *Rafflesia* R. Br.

According to Nais (2001) the gigantic and iconic holoparasitic plant, *Rafflesia* was not actually first discovered by Sir Stamford Raffles and Dr. Joseph Arnold along with their entourage at Bengkulu, Sumatera, Indonesia in 1818. According to historical records, it was Louis Auguste Deschamps who discovered the flower in Java in 1797, some 21 years earlier, and that species was possibly *R. patma*. When Deschamps first discovered the flower, which was then the largest known in the Plant Kingdom, it was treated as the "prima donna" and hailed by the botanical fraternity as the greatest botanical marvel of the age.

Deschamps made an illustration and collected a specimen of the flower, but the French research ship was taken by the British navy in 1803 and declared to be a war booty. According to the historical record, Dr. Joseph Arnold saw the illustration of Deschamps, which had by then became the property of the British, but deliberately ignored it. Subsequently, all the specimens and illustrations collected by Deschamps were bought by John Reeve and Co. and donated to the British Museum in 1861.

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In Malaysia the first *Rafflesia* species described was *R. tuan-mudae* in Sarawak in 1868, while in Sabah it was *R. pricei* and *R. keithii* in 1984 and in Peninsular Malaysia, *R. cantleyi* in 1910. As for *Rhizanthes*, the first species described was *R. lowii* in Sarawak.

RAFFLESIA SPECIES OF PENINSULAR MALAYSIA

Rafflesia cantleyi Solms-Laubach, *Ann. Jard. Bot. Buitenzorg* 20: Suppl. 3 (1910): 1-5; Meijer, *Fl. Males*. 13 (1997): 23-24; Nais, *Rafflesia of the World* (2001): 126-131.
Diagnostic characteristics: Fully open flowers are 30 – 55 cm across the perigone lobes; white warts on the reddish perigone lobes are clearly large, irregular and discrete; frequently the warts are larger and elongate and the ramenta are branched with swollen apices.
Distribution and range: *R. cantleyi* is endemic to Peninsular Malaysia and its known distribution is in Perak (its type locality), Kelantan, Terengganu and Pahang. Nais (2001) included Perlis and Selangor as its distribution range but, the species has not been observed, photographed, reported and verified in these two states.
Notes: Being the first species discovered and described from Peninsular Malaysia, it was first collected in Bukit Berapit, Perak, in 1881. However, Ridley (1924) identified and recorded it as *R. hasseltii* Suringar, a species discovered and described from Sumatera, Indonesia in 1789.

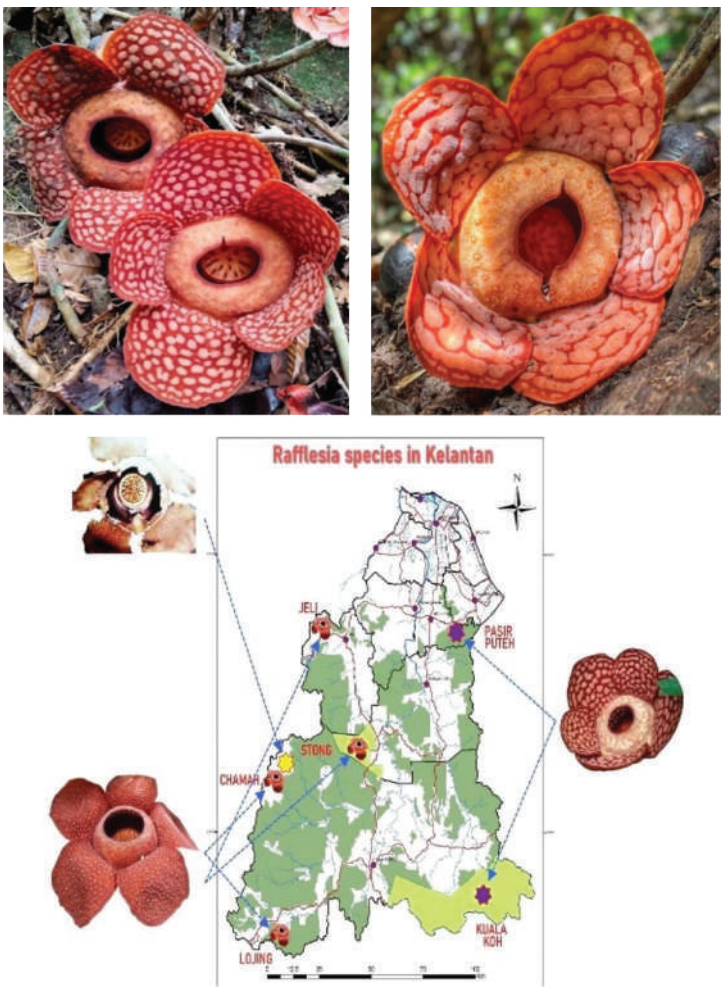

Figure 1. ***(Top left)*** The twin flower of *Rafflesia cantleyi*, ***(top right)*** The flower of *R. azlanii*, and ***(bottom)*** the distribution of *Rafflesia* in Kelantan.

R. azlanii Latiff & M. Wong, *Folia Malaysiana* 4 (3 & 4) (2003): 137-138.
Diagnostic characteristics: Fully open flowers are 42–45 cm across the perigone lobes; white warts on the reddish-brown perigone lobes are totally coalesced across the perigone lobes.
Distribution and range: Recorded in Belum-Temengor in Perak.

R. hasseltii sensu Ridley non Suringar, Latiff *et al*., *Mal. Nat. J*. 48(3 & 4) (1995): 184; Latiff & Mat-Salleh, *Fl. Males. Bill.* 12(7/8) (2001): 394; Nais, *Rafflesia of the World* (2001): 136-138 in part.
Diagnostic characteristics: Fully open flowers are 30 – 50 cm across the perigone lobes; the white warts on the reddish perigone lobes are clearly coalesced, almost cover the entire perigone surfaces and the ramenta filiform with swollen apices.
Distribution and range: Currently, its known distribution is in Perak and Pahang. It is endemic to Peninsular Malaysia and allied to *R. hasseltii*.
Notes: This species was discovered in September 1993 by participants of the Malaysian Nature Society's Scientific Expedition to Temengor Forest Reserve, Perak, in 1991 (Latiff *et al*. 1995).

R. su-meiae M. Wong, J. Nais & F. Gan, *Folia Malaysiana* 10(2) (2009): 90-91.
Diagnostic characteristics: Fully open flowers are ca. 80 – 92 cm across the perigone lobes; the white tiny warts on the reddish perigone lobes are clearly discrete and numerous, the diaphragm aperture with tongue-like appendages; circular dots on diaphragm two rings; upper ramenta branched; processi 55 – 62 cm; anthers ca. 48 cm
Distribution and range: Its only known distribution is at Gunung Chamah at the border of Perak and Kelantan.

R. kerrii Meijer, *Blumea* 30 (1984): 212; Meijer, *Fl. Males.* 13 (1997): 26; Nais, *Rafflesia of the World* (2001): 147-153.
Diagnostic characteristics: Fully open flowers are 65 – 95 cm across the perigone lobes; the tiny white warts on the reddish perigone lobes are clearly discrete and very numerous, and the ramenta are unbranched, slightly swollen at apices.
Distribution and range: *R. kerrii* is found in Kelantan, Perak, and Pahang.
Notes: *R. kerrii* was first collected by Dr. A.F.G. Kerr at Ranong Province, Kho Pawta Luang Keo, Peninsular Thailand. In Peninsular Malaysia it was first observed at Bukit Tepuh, Jeli, at the Thailand-Kelantan border, observed by a mining engineer, Mr. H. William, in 1935. The flower from Gunung Chamah was photographed by Mr. Forest Gan in 1992. It is the species with the largest flower in Peninsular Malaysia.



Figure 2. (a) *Rafflesia kerrii*, **(b)** *R. su-meiae;* and **(c)** *R. parvimaculata*.

R. parvimaculata Sofiyanti, Mat-Salleh, Khairil, Zulailah, Mohd. Ros & Burslem, *Phytotaxa* 253 (3) (2016): 208-209.
Diagnostic characteristics: Fully open flowers are ca. 41 cm across the perigone lobes; the white small warts on the reddish perigone lobes are clearly discrete and numerous; ramenta slender, unbranched, capitate.
Distribution and range: It is known from Lata Jarum, Pahang and Perak, Peninsular Malaysia, endemic.

R. tuanku-halimii Adam, Aizat-Juhari, Azilah & Wan, *Sains Malaysiana* 45(11) (2016): 1589-1590.
Diagnostic characteristics: Fully open flowers are 43 – 60 cm across the perigone lobes; the white warts on the reddish perigone lobes are clearly coalesced and the authors differentiated it from the closest species *R. azlanii* by trivial character that the window is almost covered with white rings.
Note: The authors consider this species as conspecific with *R. azlanii.*

R. sharifah-hapsahiae Adam, Mohamed, Aizat-Juhari & Wan, *Turkish J. Bot*. 37: 1039-1040.
Diagnostic characteristics: Fully open flowers are 47 – 49.5 cm across the perigone lobes; the white warts on the reddish perigone lobes are clearly coalesced, and the ramenta branched.
Distribution and range: This species is known from Ulu Dong, Raub, Pahang, Peninsular Malaysia.
Notes: The authors consider this species as conspecific with *R. azlanii.*

R. tunku-azizahiae Adam, Aizat-Juhari & Wan, *Sains Malaysiana* 51(11) (2022): 3845–3846.
Diagnostic characteristics: Fully open flowers are 63 – 80 cm across the perigone lobes; the white warts on the reddish perigone lobes are clearly discrete but have a tendency to show coalescence.
Notes: The authors differentiated it from *R. azlanii* and *R. tuanku-halimii* by its larger size and the character of white warts is somewhat intermediate from those species. We consider this species as conspecific with *R. cantleyi* but further collection must be made to ascertain its true identity.

R. tiomanensis M. Y. Siti Munirah, A. Salamah & M. S. Razelan *Mal. Nat. J*. 73(1) (2021): 21–22.
Diagnostic characteristics: Fully open flowers are 40 – 42 cm across the perigone lobes; the small white warts on the reddish perigone lobes are clearly discrete and radially arranged, there are no warts on the diaphgam surfaces,and processi are absent.
Distribution and range: This species is endemic to Pulau Tioman, Pahang.

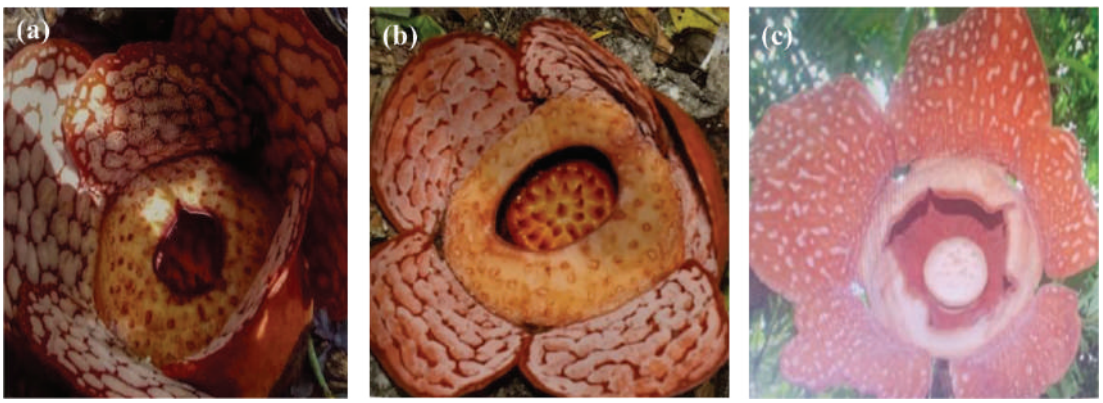

Figure 3. (a) *Rafflesia sharifah-hafsahiae*, **(b)** *R. tuanku-halimii*, and **(c)** *R. tiomanensis.*

RAFFLESIA SPECIES OF EAST MALAYSIA

In Sabah and Sarawak, only three species of *Rafflesia* were known to science prior to 1989: *R. pricei*, *R. keithii* and *R. tuan-mudae* (Meijer 1997; Nais 2001). In 1989, a fourth species *R. tengku-adlinii*, discovered in the Trus Madi Range, Sabah was added to the list. Five years later in 2004, the fifth species, *R. hasseltii*, was recorded from Sarawak and added to the Malaysian *Rafflesia* list (Ong 2004; Ahmad Puad *et al*. 2020).

In Sarawak, four species are known, namely *R. pricei* (on Gunung Murud), *R. keithii* (possibly on Gunung Hose), *R. tuan-mudae* and *R. hasseltii* in south-western Sarawak. The occurrence of *R. keithii* on Gunung Hose, Sarawak is assumed based on a report that the specimens of its host plant, *Tetrastigma diepenhorstii*, were collected from that locality. However, *R. tuan-mudae* also parasitise *T. diepenhorstii* (Ahmad Puad *et al*. (2020). The possibility that the specimen may be *R. keithii* is because Gunung Hose is considered distant from the known distribution range of *R. tuan-mudae*. Gunung Hose is approximately 2,000 m above sea level, representing a highland habitat. *Rafflesia keithii* is known to occur in highland areas, whereas *R. tuan-mudae* is known to occur only in the lowlands.

R. tengku-adlinii Mat-Salleh & Latiff, *Blumea* 34 (1989): 111-116; Meijer, *Fl. Males.* 13 (1997): 34; Nais, *Rafflesia of the World* (2001): 176-181.
Diagnostic characteristics: Fully open flowers are 20 – 25 cm across the perigone lobes; the white-reddish warts on the orangish perigone lobes are clearly discrete and numerous, and the ramenta are filiform and apices swollen.
Note: This species is endemic to Sabah, Borneo and has the smallest flower known in Malaysia.

R. pricei Meijer, *Blumea* 30 (1984): 214; Meijer, *Fl. Males*. 13 (1997): 23-24; Nais, *Rafflesia of the World* (2001): 163-168.
Diagnostic characteristics: Fully open flowers are 16 – 45 cm across the perigone lobes; the white warts on the reddish perigone lobes are clearly discrete and of intermediate size; frequently the warts are larger and elongate laterally.
Distribution and range: This species is endemic to Borneo. Meijer (1997) stated this species has been mostly found in Gunung Kinabalu National Park and Crocker Range National Park in Sabah. Today it is known widely in Sabah especially in Tambunan area. It is also found near the field station in Serian, Brunei (K.M. Wong, pers. comm.) and Gunung Murud and Serian area in Sarawak and most likely also occur in Upper Kayan near Long Ampin, Kalimantan (Meijer 1997). This is a highland species occurring between 400 to 1,300 m above sea level (Meijer 1997; Nais 2001).

The Tambunan *Rafflesia* Conservation and Information Centre, Sabah is a well-known site where populations of the species bloom regularly and attracted many visitors from Sabah, Malaysia and even overseas. Another area is the Poring-Mamut *Rafflesia* Sanctuary within the Mamut copper mine area is also well-known to visitors. Because of the establishment of the two areas above, *R. pricei* may be considered one of the most protected species in Malaysia though it is still considered rare by some scientists. As the species has attracted many observers and enthusiasts locally and abroad, Nais and Wilcock (1998) had proposed a model to empower the local communities to protect and conserve the species in their areas. On top of protecting and conserving the species in their areas, the local communities could earn some incomes as incentives through permits and fees.

The only published study on the pollination of *Rafflesia* was conducted on *R. pricei* by Beaman *et al.* (1988), based on a thorough study on the specimens from Crocker Range National Park, Sabah. Pollination was mediated by bluebottle flies of the genera *Lucilia* and *Chrysomia*. Large bluebottle flies were found to be more effective in picking up pollen from the male flowers and transferring them to the female flowers. The pollination syndrome is sapromyophily, in which the flower closely parallels trap flower of several other plant families, although it is not a trap. The flower provides no reward for pollination but deceives them by an apparent offering of food and possibly a site for brooding. A similar interpretation has been suggested for *Rhizanthes* flowers by Bänziger and Hansen (2000), when they described two new species, *R. infanticida* and *R. deceptor*. According to their study, the findings raised more questions than answers. Further studies on the pollination biology of other Rafflesia species are therefore warranted, especially in Jawa, Sumatera and the Philippines, where comparative studies could provide greater insights into the pollination mechanisms of *Rafflesia* and *Rhizanthes*.



Figure 4. (a) *Rafflesia pricei* at Tambunan, Sabah, note the white elongated warts and small discrete warts in between the elongated ones on the perigone lobes and mosaic-like pattern of the warts on the diaphragm, the diaphragm surface is white, unlike those of other species in Borneo; **(b)** *Rafflesia* bud; and **(c)** *R. keithii*.

R. keithii Meijer, *Blumea* 30 (1984): 211; Meijer, *Fl. Males*. 13 (1997): 25-26; Nais, *Rafflesia of the World* (2001): 140-145.
Diagnostic characteristics: Fully open flowers are 80 – 94 cm across the perigone lobes; white warts on the reddish perigone lobes are clearly discrete, small and numerous; there are numerous smaller warts in between the intermediate-size warts; and the ramenta are fasciculate.
Distribution and range: It is endemic to and the largest species in Borneo and allied to *R. arnoldii* and *R. tuan-mudae*. In Sabah it occurs in Crocker Range National Park, Keningau, Tambunan, Kimanis, Tenom, Kota Marudu, Kota Belud, Sayap-Ranau, Poring, Takutan, Singgaron, Lahad Datu and Danum Valley Conservation area, among other areas.

R. tuan-mudae Becc., *Atti. Soc. Ital. Sci. Nat.* 11 (1868): 197-198; Nais, *Rafflesia of the World* (2001): 182-186.
Diagnostic characteristics: Fully open flowers are 44 – 92 cm across the perigone lobes; the white-reddish warts on the reddish perigone lobes are clearly discrete and numerous, and rarely there are small warts in between the intermediate-sized warts; and the raments are filiform with papillose apices.
Distribution and range: In Sarawak it is distributed widely at Gunung Gading National Park at Lundu, Gunung Pueh, and Gunung Penrissen. In Kalimantan, it is distributed at Cagar Alam Gunung Rara Pasi, near Singkawang, up to 900 m above sea level. Hence, this species could be described as both a lowland and highland species. Meijer (1997) reduced this species to *R. arnoldii.*

R. hasseltii Suringar, *Verslagen Meded. Afd. Natuurk. Kon. Akad. Wetensch*., ser. 2, 1879–1880(4) (1879): 5; Aida Shareena *et al.*, *Mal. Nat. J*. 72(1) (2020): 21.
Diagnostic characteristics: Fully open flowers are 30 – 50 cm across the perigone lobes; white warts on the reddish perigone lobes are clearly coalesced, with 3 – 4 rings laterally, there are two rings of warts on the diaphragm, and the ramenta are linear with swollen apices.
Distribution and range: This species is originally known from Sumatera and currently is recorded in south-west Sarawak and Kalimantan.

RHIZANTHES SPECIES OF MALAYSIA

Meijer (1997) revised the genus *Rhizanthes* and recognised only two species, namely *R. lowii* and *R. zippelii*. Subsequently, Banziger and Hansen (2000), rerevised the genus and recognised a total of four species, in which two are new to science as a result of subdividing *R. lowii* sensu lato. They maintained *R. zippelii*, which occurs only in west Jawa, and is therefore endemic to Jawa and not found in Sumatera as claimed by Meijer (1997). *Rafflesia lowii* sensu Meijer is differentiated into three distinct species, *R. lowii* sensu stricto which only occurs in Borneo, *R. infanticida* which occurs in Peninsular Malaysia, Peninsular Thailand and Sumatera and *R. deceptor* which occurs in west Sumatera. Hence the current taxonomy of *Rhizanthes* in Malaysia is as follows:

Rhizanthes infanticida Bänziger and B.Hansen, *Nat. Hist. Bull. Siam Soc*. 48 (2000): 127–130.
Diagnostic characteristics: Flowers always unisexual; the female flower tends to have the largest crater aperture; buds 14.7 – 20.5 cm, tepals 58 – 90 mm long, caudal appendages 20 – 38 mm long, tepals covered with furry hairs near tepal vortex.
Distribution and range: The species is known from Sumatera, Thailand and Perak, Kelantan and Terengganu, Peninsular Malaysia.

Rhizanthes lowii (Becc.) Harms, *Repert. Spec. Nov. Regni Veg*. 36 (1934): 287.
Diagnostic characteristics: Flowers always unisexual; concolorous white to reddish; buds ovoid-pyriform up to 12 by 2 cm; open flower infundibuliform, 18 - 38 cm in diameter; perigone lobes 6 - 12 mm wide at base, gradually narrowed; the tepals and caudal appendages are the longest of the four species, giving the flower at anthesis the largest span of 25 – 43 cm, which is up to twice the size of the smallest species *R. infanticida*.
Distribution and range: The species is known from Sabah and Sarawak.

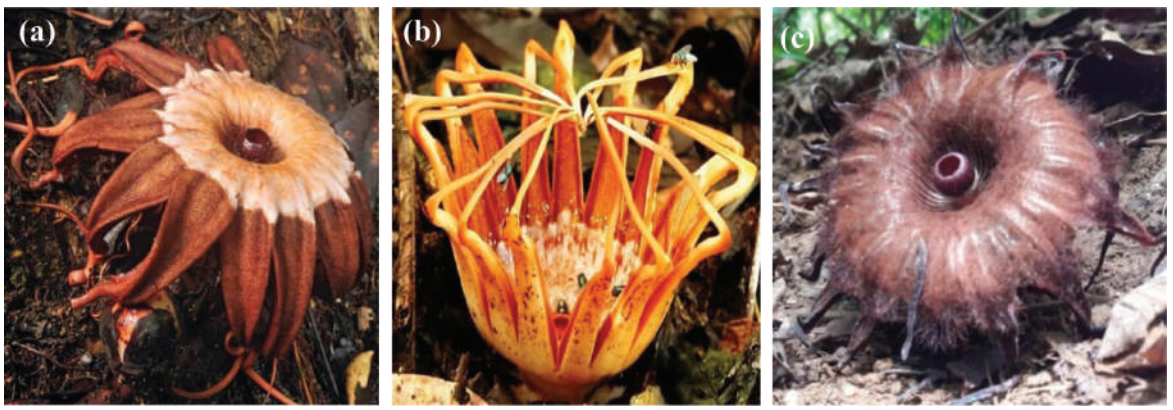

Figure 6. (a) *Rhizanthes lowii* of Sabah and Sarawak, opened flower, note the white coloured base of perianth lobes, *(b)* the flower was about to open with the appendages forming like a crown before they reflexed downwards, and **(c)** *R. infanticida* of Peninsular Malaysia.

HOSTS OF *RAFFLESIA*

Rafflesia species are known to parasitise specific host plants, particularly woody lianas belonging to the genus *Tetrastigma* (Vitaceae, wild grapes plant) (Latiff 1983; Nais 2001; Chen *et al.* 2011). Although the distribution of *Tetrastigma* species is wide, it does not coincide closely with the distribution of *Rafflesia* species, which is restricted to specific Southeast Asian countries (Latiff 1983, 2001; Chen *et al.* 2011). Nais (2001) reported seven *Tetrastigma* species as hosts of *Rafflesia*, namely *T. rafflesiae*, *T. diepenhorstii*, *T. curtisii*, *T. quadrangulum*, *T. scortechinii*, *T. glabratum*, and *T. papillosum* and this is widely open to verification. Of these records, *T. rafflesiae*, *T. diepenhorstii*, and *T. papillosum* can be confirmed with certainty as known hosts, while the host status of the remaining species remains uncertain.

Table 2. An update on the host plant species parasitised by *Rafflesia* in Malaysia.

Host species	***Rafflesia* species**
Tetrastigma rafflesiae, *T. diepenhorstii*	*R. tuan-mudae, R. keithii*
T. rafflesiae	*R. azlanii, R. cantleyi, R. keithii, R. kerrii, R. parvimaculata, R. pricei, R. sharifah-hapsahiae, R. su-meiae, R. tengku-adlinii, R. tuan mudae, R. tuanku-halimii*
T. hookeri, *T. quadrangulum*	*R. kerrii*

Globally, there are approximately 95 species of *Tetrastigma*, most of which are tropical, with a few occuring in subtropical regions (Wen 2007). Its distribution ranges from Sri Lanka, India, Bangladesh, Myanmar, Thailand, Laos, Kampuchea, southern China, Taiwan through Malesia to northern Australia. In Malesia, there are 32 species (Latiff 2017) while Peninsular Malaysia only harbour 12 of these species (Latiff 1983).

Nais (2001) reported the host of *Rafflesia* as *T. lanceolarium* (Roxb.) Planch., a species that has since been synonymised under *T. rafflesiae* (Miq.) Planch. Veldkamp (2009) subsequently claimed that the host was *T. coriacea* (DC.) Planch., a species that occurs in Timor Leste. Upon examination of the specimens by the author, it was confirmed that although *T. coriacea* is recognised as a distinct species from *T. rafflesiae*, it is not a host of *Rafflesia*. Furthermore, *Rafflesia* is not known occur in Timor Leste.

Nais (2001) tabulated the recorded hosts species of *Rafflesia*. Accordingly, *R. keithii*, *R. pricei*, *R. tengku-adlinii*, *R. kerrii*, *R. arnoldii*, *R. manillana*, *R. micropylora*, *R. patma*, *R. tuan-mudae*, and *R. cantleyi* parasitised *T. lecucostaphyllum* (now *T. rafflesiae*). However, observations have shown that *R. keithii* and *R. tuan-mudae* also parasitise *T. diepenhorstii*, and *R. kerrii* also parasitise *T. hookeri*. The host of other *Rafflesia* species are specifically *T. rafflesiae*. However, in Peninsular Thailand, *T. quadrangulum* is also reported as the host for *R. kerrii* (Meijer and Elliot 1990; Banziger 1991).

Rafflesia pricei and *R. kerrii* have not been observaed to parasitise *T. papillosum*, although *T. papillosum* occurs within the distribution range of both *Rafflesia* species. The report that claimed *R. hasseltii* parasitises *T. scortechinii* is erroneous because *R. hasseltii*, a species that occur in Sumatera, Sarawak and Kalimantan was initially misidentified by Ridley (1924) and Meijer (1983) and *T. scortechinii* is a species endemic to Peninsular Malaysia, only known from the limestone hill forests in Perak and Pahang.

Elsewhere, it was reported that *R. patma* in Jawa parasitises *T. glabratum* (Meijer 1997) and *R. arnoldii* also parasitises *T. curtisii*. These are possible as *T. glabratum* occurs in Jawa and *T. curtisii* also occurs in Sumatera. However, *T. curtisii* is a highland species and *R. arnoldii* in Sumatera occurs in the lowland forests.

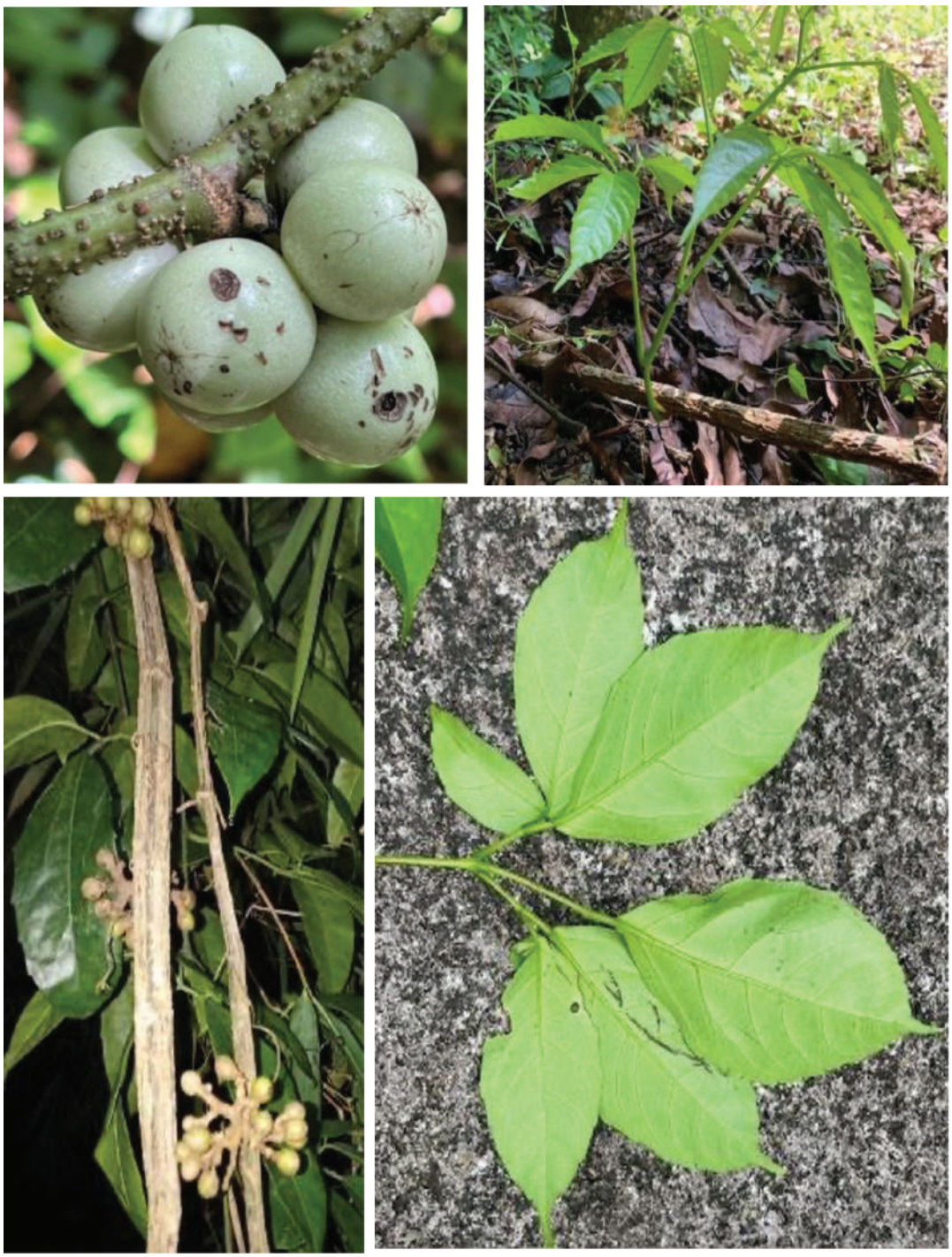

Figure 6. (a) the large, cream and succulent berries of *Tetrastigma hookeri*, note the pustules on the peduncle; **(b)** the most common 5-foliolate leaves of *T. hookeri*, **(c)** strap-like stem of *T. hookeri* with immature berries and **(d)** the rarely 6-foliolate leaves of *T. rafflesiae*.

RESEARCH ON *RAFFLESIA*

The only researcher known to have begun research on *Rafflesia* in Peninsular Malaysia was Prof. Dr. Willem Meijer. In 1974, he travelled to Perak in search of *Rafflesia.* During this work, he was reported to have exploited the local helpers, whom he called "natives", to collect several specimens of *R. cantleyi* from Ulu Geroh Forest Reserve. When Dr. Kamarudin Mat Salleh joined the Botany Department of Universiti Kebangsaan Malaysia in 1983, he continued his research on *Rafflesia* and travelled throughtout Peninsular Malaysia and Sarawak, including Sumatera.

Research on *Rafflesia* in Sabah was started by Prof. Dr. Willem Meijer himself, who described two species, namely, *R. pricei* and *R. keithii* (Meijer 1984). Dr. Willem Meijer spent many years at the Department of Forestry Sabah at Sepilok and did many field works in the state. He claimed that he had stumbled onto a decaying *R. tengku-adlinii* in the vicinity of Telupid. Following this, there has been a great interest by the local botanists, especially Dr. Jumaat Adam and Dr. Kamarudin Mat Salleh from the Universiti Kebangsaan Malaysia Sabah Campus (Mat-Salleh 1991; 1996). Both Dr. Ghazally Ismail and Tengku Zainal Adlin Tengku Mahmood also took some interests in protection and conservation efforts especially when the populations of *R. tengku-adlinii* in Crocker Range were in jeopardy.

In Sarawak, unlike in Sabah, there were no significant research on *Rafflesia* species during the 1980s. The staff of the Forestry Department Sarawak such as Ms. Julia Sang, Ms. Connie Geri, Mrs. Nur Safinas Jelani and possibly others had also taken interest in *Rafflesia*, especially *R. tuan-mudae*, which is common at Gunung Gading National Park (Ngadin *et al.* 2018). The late Dr. Kamarudin Mat Salleh also went to the nearby Samunsam Wildlife Sanctuary to observe the elusive species. He had sent Ms. L.P. Ong, his Honours student, to study the species and thought it constitutes an undescribed species, which he wanted to name as *R. taibii*. Following further discussion, however, he agreed that the species was *R. hasseltii*, a species previously known from Sumatera and now recorded in Sarawak.

Life cycle of *Rafflesia*

According to Mursyidah *et al*. (2023) and Nikolov *et al*. (2014b), *Rafflesia* species maintain a long embryonic state that can abruptly transition to the flowering stage without forming an elaborate vegetative body. The vegetative phase begins with the seed germination that exists in the host plant as a filament that resembles a substance called endophytes (Kuijt 1969; Nikolov *et al*. 2014b). A recent study by Wicaksono *et al*. (2021) reported that the *Rafflesia* endophyte forms a clonal network of vegetative meristematic cells, separated by the dividing host tissue where each meristematic cell clusters ultimately developing into primordial floral bud or protocorm. The exact information on the period of *Rafflesia* in the vegetative phase is uncertain or not known. However, the continuous flowering and blooming in the rainforest habitat possibly on the same host plant (*Tetrastigma* species) suggests that the holoparasite spends an extensive time in the vegetative phase in the host tissue before continuing to the reproductive phase (blooming phase), which is indicated by the occurrence of the bud (Nikolov and Davis 2017).

Nais and Wilcock (1998) reported that the blooming flowers can be found all year round and are not seasonal. However, it is noteworthy that seasonality has been observed in *Rafflesia* species with northerly distribution (Philippines and Thailand) compared to the documented equatorial species (Nais 2001). The more distinct periods in day-length and seasonal differences in the higher latitudes may be responsible for this mild seasonality. Its development, life cycle and anatomy of the host *Tetrastigma* have been recently described by Sharifah Haneira *et al.* (2021).

Dr. Kamarudin Mat Salleh and his student identified three distinct stages in the life cycle of *R. hasseltii*. In the first stage, the buds swell while remaining partially embedded in the bark of the host vine. The second stage is when the buds are about 6 cm diameter, when the bracts turned from cream-coloured to dark brown. In the third stage, the bracts loosened from the base of the buds and exposed the underside of the perigone lobes. The perigone lobes are initially light orange in colour, before turning dark orange and at this time, the buds are about 20 cm in diameter. It was assumed when the buds have reached the third stage, they may take about one week to bloom. The average growth rate for the species is about 1.25 cm/month in stage one, 3.39 cm/month for the second stage and 9.6 cm/month in the final stage. Similar growth rate pattern has been shown by other species such as *R. keithii* and *R. tengku-adlinii* in Sabah (Nais 2001) and *R. zippelii* (which in fact is *R. infanticida*) in Thailand (Banziger 1995).

According to Dr. Francis S.P. Ng, the theory proposing that the *Rafflesia* flower is produced by an endophytic body that lives and grows as a persistent repeat-flowering parasite within the *Tetrastigma* host is flawed. This theory does not explain why *Rafflesia* has been so difficult to propagate through the propagation of infected host plants, why *Rafflesia* may disappear spontaneously from its host plants, and why the host plants do not appear to suffer significant effects from invasion by such a persistent parasite. Dr. Francis Ng attempted to provide evidence to support a alternative theory, whereby *Rafflesia* is a hapaxanthic plant, i.e. a plant that flowers once at the end of its life, each flower would develop from a seed that germinates at the site where it is deposited. The associated endophyte would then die together with the plant rather than persist as a permanent parasite within the host. Repeated flowering would be the result of recolonisation or reinfection by the *Rafflesia* seeds deposited at the same site. The dependence of each *Rafflesia* plant on its host would be minimal compared to the vast resources available to its host vine, which is a visibly aggressive vine with an indefinite size and life span, branching and clambering over other plants to reach the forest canopy.

Dr. Francis S.P. Ng attempted to provide evidence from the disappearance of *Rafflesia* from *Tetrastigma* hosts in natural sites, a phenomenon reportedly observed regularly by naturalists in the field. There is an important *Rafflesia* colony in the Royal Belum State Park, Perak that is carefully protected through the construction of a raised boardwalk to enable visitors to view the flowers from afar without trampling on the stems of the *Tetrastigma* host plants. This project was carried out in 2017 by Universiti Kebangsaan Malaysia, funded by the Tenaga National Berhad, at a site known as 'X-Ray' (Mazlan Mohd. Som *et al*. 2019). It was expected that the *Tetrastigma rafflesiae* plants would continue to produce *Rafflesia* flowers indefinitely. However, in the six years since the construction of the boardwalk, *Rafflesia* flowers have failed to reappear although the host plants have been strictly protected (Zubir Ismail, staff member of the Royal Belum State Park pers. com., 2023).

The endophyte itself was detected only recently through the use of differential staining of cells and tissues (Nikolov *et al.* 2014). Microscopic sections of infected *Tetrastigma* vines were examined. They found endophyte tissue in the form of short uniseriate strands of cells running alongside the host tissues, in an approximately radial direction, with nuclei at least twice the diameter of the nuclei of host cells. The amount of endophytic tissue was minute in relation to host tissue and there was no visible damage to host cells. The authors speculated that each endophyte strand may be the product of a seed, or the result of original strands breaking up into daughter strands.

IN SITU THREATS

Most, if not all, *Rafflesia* were listed as rare plant species and considered vulnerable to extinction in certain areas. The rarity and vulnerability of *Rafflesia* in the wild remain concerns among researchers studying the genus, both within the region and elsewhere. Unlike other species of plants, *Rafflesia* are elusive. While some species such as *R. arnoldii* and *R. kemumu* in Sumatera seem to bloom almost the year round, other species are seldom observed to bloom. This natural phenomenon had baffled many biologists and naturalists.

The natural factors that contribute to rarity and vulnerability of *Rafflesia* in the wild include:

- **Imbalance in sex ratio (two male flowers to one female flower).** No researcher had ever determined the actual imbalance between the sex of the flower, except in the Philippines. No researcher also had ever determined what is the minimum number of male flowers and female flowers in the same locality is necessary to facilitate pollination. Only assumptions exist.
- **Low percentage of bud reaching maturity.** Aida Shafeena and Wan Nuur Fatiha (pers. comm) when studying *R. tuan-mudae* in Gunung Gading National Park, Sarawak, and Fatimah Mohamad and Nor Nafizah Mohd. Noor (pers. comm) when studying *R. azlanii* in Sungkai Forest Reserve, Perak had discussed the high mortality of the buds. This is compounded by the constant collection of buds both by the Orang Asli and local Malays to either sell or utilise as traditional medicine.
- **Short anthesis period.** Most researchers and observers in the field recognised the short anthesis period of the male flowers in the wild, with the flowering period generally lasting only 2 – 3 days. The life span of female flowers are equally short, allowing only a brief period to facilitate pollination and fertilisation.
- **Random occurence of male and female flower blooming in the same area.** Most researchers have reported observing either male or female flowers in bloom, while observations of both sexes in bloom simultaneously are relatively uncommon.
- **Low percentage of pollination success.** This was assumed by researchers as they seldom observed the fruit set.
- **Long period between post-blooming to new flower formation.** Again, this was assumed by researchers as they seldom observed the whole process of fruit setting and dispersal.
- **Insect or other animal infestation.** This was assumed by researchers but they seldom observed the flowers were degraded by animals.

Whereas the human-induced factors that have contributed to the potential loss and brought *Rafflesia* to the the brink of extinction are:

- **Habitat loss (due to deforestation, agriculture expansion area, development).** This happened throughout the range of *Rafflesia* distribution, especially in Malaysia, Sumatera and the Philippines, and possibly Brunei, where *R. pricei* occurs.
- **Collection by local communities for medicinal purposes.** Even though there is no basis for these claims, yet the indigenous communities have collected the buds either for sale to middlemen or for processing themselves.
- **Uncontrolled tourist activities.** Lojing Highlands in Kelantan, Poring and Tambunan in Sabah (Borneo), and Bengkulu in Sumatera are three of the popular sites visited by local and foreign tourists to observe *Rafflesia* flowers in bloom. In July 2025, Mrs. Nor Hazlini Mat Zain observed a careless tourist damaging the aerial stem of *T. rafflesiae* supporting a blooming *R. kerrii* at Lojing Highlands. Standard of Procedures (SOPs) have been established at these sites to address the potential impacts from tourism. It is likely that measures have also been undertaken at other sites.

Every life form, whether plants or animals, faces threats in their natural habitats. Environmental factors such as rainfall, temperature, humidity and soil are among the most important influences. Lack of rainfall can deprive plants and animals of their water supply while excessive rainfall can cause floods that affect their survival. Change in diurnal and nocturnal temperatures also affect the behaviour of plants and animals, especially those residing in highland areas. Humidity generally has less influence on most plants and animals, except for those occuring in the cloud forests. Plant lives are also dependent on the supply of chemical elements in the soil. Some plants like *Rinorea* (Violaceae) are known to accumulate heavy metals like copper. However, natural catastrophes such as floods, forest fires, erosion and excessive rainfall, which may erode the slopes where *Rafflesia* populations occur, are among the factors that are particularly difficult to address.

One of the most understood natural threats related to the biology and ethology of the species itself. The *Rafflesia* species are dioecious, with male and female flowers blooming separately. The possibility of synchronising their bloom and anthesis is very low. When the male flower undergoes anthesis, the female flower may not be receptive or available. Likewise, when the female flower blooms and becomes receptive, the male flower may not be at anthesis or present nearby. Consequently, successful pollination is a critical factor for all *Rafflesia* species. Furthermore, the sex ratio appears to be highly imbalanced across the species. Even when the male and female flowers are found in close proximity, sometimes the insect pollinators may not be present.

Pollination biology of any *Rafflesia* species warrants further study. Such research requires considerable patience, as observers may need to remain beside the flowers during anthesis to observe and capture visiting insects. The large size and the colour of the flowers are sufficient to attract the insects; however, the volatile oils produced by the flowers at anthesis also attract insects (Wee *et al*. 2018). In the plant kindom, floral odour is considered to be of ecological and evolutionary significance in plant-insect interactions. Many studies of pollination ecology have therefore focused on floral odour and fragrant blossoms, particularly those associated with the attraction of bees, butterflies and moths.

Among the visiting insects observed on *Rafflesia* are those of the order Diptera (carrion flies). Among the genera of flies reported for *R. kerri* are *Chrysomya*, *Lucillia*, *Phumosia*, *Hypopygiopsis*, *Sarcophaga*, and *Hemipyrellia*, with *Chrysomya* and *Lucilia* being the most abundant (Hor *et al.* 2021). Wee *et al.* (2018) observed *Chrysomya chani* visiting the flower of *R. cantleyi*, where it also acted as pollen removers. Banziger (1991) also observed *Chrysomya villenuvei*, *C. rufficacies* and *Lucillia porphyrina* visiting *R. kerrii*, with these species functing as pollen removers. Beaman et al. (1988) observed *Lucillia papuensis* and *Chrysomya pinguis* visiting blooming flowers of *R. pricei*.

MAN-INDUCED THREATS

While we are unable to predict and control the natural threats, man-induced threat are much discussed in literatures. The fate of lowland dipterocarp forests, where most species occur, is well-known in Malaysia, especially during the colonial period and in the years following Independence. When the country embarked in massive socio-economic development to develop the nation, much of the lowland forests were logged for timber and foreign exchange earnings. If loggings had been done in a sustainable manner practicing selective logging, the forests would have been less devastated. The greater culprits were irresponsible and profit-driven logging operators who failed to adhere to sustainable practices, resulting in extensive habitat degradation and destruction, including habitats supporting *Rafflesia* populations. This was personally witnessed by the author near Sungai Halong in the Temengor Forest Reserve.

When most of lowland dipterocarp forests in Peninsular Malaysia had been mostly logged, the highland forests were also given concessions either for agriculture and forest plantation. There were examples in Perak and Kelantan where forested lands were given to eucaluptus, Musang King and Timber latex clone plantations. The degradation of highland forest may affect the populations of *R. kerrii*, *R. su-meiae* in Peninsular Malaysia, and *R. keithii* in Sabah.

Slash-and-burn agriculture has been reported mainly in Sabah and Sarawak. In Sabah, *R. pricei* is likely to be particularly vulnerable as this species occurs in lowland forests. However, slash-and-burn agriculture is not restricted to lowlands and may also occur in highland areas, where hill forests are cleared for cultivation. In this case, both *R. tengku-adlinii* and *R. keithii* could be threatened. The potential conflict between agricultural expansion and *Rafflesia* conservation was evident when *R. tengku-adlinii* was first discovered on the Trus Madi Range. At that time, villagers sought to use parts of the forest for agriculture, while the authorities planned to conserve the area for *R. tengku-adlinii*. In Sarawak, slash-and-burn agriculture may similarly threaten populations of *R. tuan-mudae*, particularly those occurring on privately owned land.

Loss of pollinating (e.g., carrion flies) and dispersal agents (e.g., shrew-faced ground squirrel *Rhinosciurus laticaudatus*, bearded pig *Sus barbatus*, and greater mouse-deer *Tragulus napu*) may be directly due to loss of forests and vegetations. The conversion of natural forests into forest plantations, as has occurred in Sabah, Sarawak, and Peninsular Malaysia, may further reduce suitable habitats and consequently affect populations of these pollinating and dispersal agents.

Furthermore, there have been reports of over-collection of *Rafflesia* buds by the Orang Asli and Malays for medicinal use. They believed that drinking the decoction prepared by boiling *Rafflesia* buds can help to shrink the uterus after childbirth. This practice was witnessed by the author among the Orang Asli community of Kuala Betis in Kelantan. *Rafflesia* buds were collected in gunny sacks and sold to middlemen. Malay villagers in Jerantut and Temerloh, Pahang were witnessed collecting buds, either for personal use or for sale as a source of income. In the 1990s, *Rafflesia* buds were observed being sold in open stalls in Baling, Kedah and also at the Tapah R&R in Perak.

IN SITU CONSERVATION

In the National Physical Plan (NPP), the Environmentally Sensitive Area (ESA) was proposed to protect the highland biodiversity from uncontrolled development and habitat loss, especially in highlands. Furthermore, through the National Forestry Policy 1978 and National Forestry Act 1984, the Forestry Department Peninsular Malaysia (FDPM) and the State Forestry Departments are entrusted to manage the sustainable utilisation of forest and its products.

In Sabah, the state has implemented the Forest Enactment 1968, classifying the forest into several classes under various categories of protection. In Sarawak, the Forest Department Sarawak is responsible in conserving the flora and fauna; establishing and maintaining the Totally Protected Areas (TPAs) such as National Parks, Nature Reserves, Wildlife Sanctuaries and Permanent Forest Estates (PFEs); conduct management and research activities on nature conservation and wildlife; and issue permits and licenses for the activities in the forest. The state governments of Sabah and Sarawak are responsible in managing the cases in the forest due to their nearness to the source of forest problems and in better position to control the issues. Whereas the interstates forest issues require the federal and state government actions.

In 2010, Malaysia recorded 14.5 million hectares of Permanent Reserved Forest (PRF)/Permanent Reserved Estates (PRE) and committed to maintain the figures from decreasing. The establishment of these protected areas is able to protect the biodiversity through *in-situ*. The High Conservation Value Forests (HCVFs) purportedly to protect the forest biodiversity, ecosystem and species from encroachment activities. Documentation efforts undertaken by research institutes, non-government organisation (NGOs) and state level biodiversity centres are very important in proposing the area as protected areas.

The Wildlife Protection Ordinance (WLPO) 1998 in Sarawak lists all *Rafflesia* species as Totally Protected Species under the Second Schedule. Section 30 of the WLPO establishes strict prohibitions on any form of handling, exploitation, or possession of Totally Protected Plants, including *Rafflesia* spp. without written permission from the Controller. Any breach constitutes a serious offence and carries heavy penalties of up to two years' imprisonment and a fine of RM 25,000. Protected Plants are also safeguarded, though with slightly lower penalties. However, the WLPO is currently under revision, with considerations being given to the importance of host plants for the sustainability of *Rafflesia* species.

The Forest Department Sarawak (FDS) has implemented a range of research and conservation initiatives focused on Rafflesiaceae species. The Heart of Borneo (HoB) initiative—a voluntary transboundary collaboration among Malaysia (Sabah and Sarawak), Indonesia (Kalimantan), and Brunei—aims to promote biodiversity conservation and environmental protection, while supporting sustainable development for communities across Borneo. Under the HoB Sarawak programme, FDS has conducted numerous scientific expeditions over recent years, leading to the identification of multiple habitats supporting Rafflesiaceae species and contributing to the publication of several scientific reports.

The Sarawak Delta Geopark (SDGp), located in the southern part of Sarawak and designated as Malaysia's first national geopark in 2022, encompasses a mosaic of ecologically and geologically significant landscapes. Rafflesiaceae species have mostly been documented in this region, particularly from Sematan to Kuching, which overlaps with two major conservation frameworks: the Heart of Borneo (HoB) Initiative and the Sarawak Delta Geopark (SDGp) Programme. This overlap provides strong justification for intensified conservation efforts targeted at Rafflesiaceae species. FDS also prioritises conservation within the Permanent Forests (PFs). For example, as part of sustainable forest management within these areas, several Forest Management Units (FMUs) with documented *Rafflesia* occurrences have designated such sites as High Conservation Value Areas (HCVAs), thereby ensuring enhanced protection and targeted management of the species highly specialised habitats.

Long-term monitoring and research were also conducted by the Sarawak Herbarium of FDS, focusing on two species, *R. tuan-mudae* and *R. lowii* in Gunung Pueh. They have successfully documented the reproductive characteristics of Rafflesiaceae in the area (Meekiong *et al.* 2020). This research has recorded the blooming periods of both species and examined the influence of environmental factors on their reproduction, providing an important foundational reference for future conservation and research on Rafflesiaceae in Sarawak. Gunung Gading National Park is an area inhabited by *R. tuan-mudae*.

Furthermore, active ecosystem restoration can contribute to the long-term conservation of *Rafflesia*. The Tropical Rainforest Conservation Research Centre (TRCRC) has undertaken efforts to restore the ecosystem in *Rafflesia* Conservation Area by replanting the host plant species so that *Rafflesia* could thrive and survive. Such restoration efforts should be complemented by broader conservation education programmes that reach different levels of society. For example, *R. parvimaculata* has been recorded within a Forest Reserve. In

such cases, the Forestry Department should adopt appropriate conservation measures in collaboration with local communities, while improving their awareness on the species' ecological importance.

Challenges of *in situ* Rafflesia conservation

All species of *Rafflesia* throughout their known distribution range in Peninsular Thailand, Borneo, Brunei, Sumatera, Jawa and the Philippines are regarded as rare and highly endemic. Species occurring in the Malay Peninsula are endemic to the region, while most species in Borneo are endemic to the island. Exceptions include *R. hasseltii* and *R. tuan-mudae*, which are also reported from Sumatra. The apparent rarity of *Rafflesia* is partly associated with its unusual biology and the difficulty of detecting populations in the forest, added to the fact that there were very few biologists studying *Rafflesia*. In fact, historically, many *Rafflesia* blooms were discovered by chance, except populations monitored by researchers, such as those at Poring and Tambunan in Sabah, Bengkulu in Sumatera and other localities.

Not just that, the populations of *Rafflesia* are highly dynamic and difficult to detect because the germination of seeds within the host stems is unpredictable. The presence of a population may only become apparent when buds begin to develop. Even after buds are detected, development is slow and mortality is high, with only a small proportion reaching full anthesis. The flowers themselves remain open for only a few days, generally around four to five days. Successful pollination and fertilisation result in fruits containing thousands of minute seeds. However, the mechanisms by which these seeds are dispersed and subsequently deposited within the tissues of suitable host vines remain poorly understood. Therefore, the apparent disappearance of a population does not necessarily confirm local extinction, as dormant or undetected infections may remain within host vines. Claims of local or species-level extinction should be treated cautiously unless supported by adequate field evidence and long-term monitoring.

EX SITU CONSERVATION

Due to the above uncertainties in *in situ* protection and conservation throughout its range of distribution, scientists had embarked on *ex situ* methods to conserve the species. Nais and Wilcock (1999) tried to propagate sections of infected vines by cuttings and air layering but failed to propagate the parasitic *Rafflesia*. Stem cuttings of *Tetrastigma* are easy to root especially if cuttings are taken from leafy shoots but cuttings from young shoots of infected plants have never produced *Rafflesia* flowers indicating that the endophyte does not spread from its site of infection to newer parts of the vine. In an experiment reported by Linton *et al.* (2005), six pieces of infected vines (50 – 60 cm long and 1 cm thick) were 'whip-grafted' to uninfected vines. Whip-grafting is done by making two cuts on the recipient vine, into which the two ends of an infected piece are fitted. After 8 years, *Rafflesia* buds appeared. It was not mentioned where these buds were located—whether the original grafted piece or whether they had spread to other parts of the host vine.

In Sabah, Dr. Jamili Nais and his team was successful in conserving *R. keithii* on host vine, *T. diepenhorstii* via *ex situ* conservation. While in Peninsular Malaysia, Dr. Francis S.P. Ng and Ms. Norseha Ayub had embarked on *ex situ* trials at FRIM. With the assistance of technical expertise from Sabah Parks who had the experience in the *ex situ* conservation of *R. keithii* at Poring, they experimented on *R. cantleyi* using the stem of *T. rafflesiae*. The Peninsular Malaysia trial benefited from the availability of several host plants growing within the FRIM grounds. Consequently, rather than having to establish the host plants first, the team only needed to obtain *R. cantleyi* seeds from Bersia, Ulu Perak, and inoculate them onto the stems of the putative host plants.

IMPLICATIONS FOR MANAGEMENT

For *in situ* conservation and management, the evidence to support the hapaxanthic scenario is substantial, according to Dr. Francis Ng. It would therefore be prudent to adopt this scenario as a working basis for conservation management: each flower is assumed to originate from a single seed, while repeated flowering at a site results from the reinfection of host vines by seeds, which may remain dormant for several years before becoming active. Under this scenario, each *Rafflesia* site can be regarded as an ecological "island", with its population maintained by a dynamic balance between the rate at which *Rafflesia* plants die after flowering and the rate at which new seeds arrive and establish within suitable host vines. Small and isolated populations would therefore be more likely to die out than larger populations. In the management of such sites, it would vital to protect the sources of seeds as well as to identify and protect the agents that disperse the seeds.

Besides, ecotourism areas require proper planning and management to prevent further degradation. Several policies, laws and acts are needed to be implemented in order to; i) ensure ecotourism sites are able to provide services with good management, ii) ensure the ecotourism resources are totally protected, iii) protect the site's integrity as a national ecotourism site in the long run, iv) provide ample buffers zone to the adjacent non-forested area, v) provide alternatives within the surrounding areas such as nature experience zones and adventure park, vi) to accommodate wildlife corridors and potential flora and fauna connectivities, and vii) provide connectivity to other symbiotically important ecosystems. A sustainable site plan is required for ecotourism destinations to reduce the environmental impact, where collaboration from landscape architects, engineers, environmental experts, botanists, biologists, researchers, and local community stakeholders such as Orang Asli and land owners, are able to create a good input in sustainable site plan.

PUBLIC AWARENESS AND ECOTOURISM

When *Rafflesia* species were first discovered and described from Sarawak (*R. tuan-mudae*) and Peninsular Malaysia (*R. cantleyi*) in the 19th and 20th centuries, respectively, these discoveries attracted little attention from the public. At the time, publications on such discoveries were largely regarded as academic or scientific matters and were primarily of interest to colonial administrators, naturalists, and scientists. It was only in the 1984s when Dr. Willem Meijer described *R. pricei* and *R. keithii* from Sabah and *R. kerrii* from Peninsular Thailand that greater attention began to be directed towards these gigantic flowers, especially the foresters in Sandakan, Sabah. Subsequently, when more *Rafflesia* species were discovered and described both from Sabah (*R. tengku-adlinii*) and Peninsular Malaysia (*R. azlanii*, *R. su-meiae*). In Malaysia generally, however, flora has historically received less public attention than fauna and are considered less charismatic to the general public.

By the 1990s, Sabah is well-known for its *Rafflesia*. These perceptions stayed until today, in spite of the fact that Sabah has only three species of *Rafflesia* while Peninsular Malaysia harbours more than six species now. The prominence of *Rafflesia* in Sabah during the 1990s reflected a relatively strong public awareness of the flower as an iconic species. *Rafflesia* flowers were featured on the body of mini buses and even in political rallies. In 1998, Nais and Wilcock promoted *Rafflesia* conservation incentive scheme in Sabah, through which local communities were encouraged to protect the forest habitats and the *Rafflesia* buds from damage and monitor their development. In Ranau, Kota Kinabalu, the communities would alert hotels when the *Rafflesia* flowers bloom. Hotel managers would then inform their guests of the opportunity to view the flower in its natural habitat. Many visitors were enthusiastic about seeing the world's largest flower in the wild, with many taking the opportunity to photograph beside the blooms.

In Perak, the Malaysian Nature Society established a similar scheme at Ulu Geroh Forest Reserve near Gopeng and Batu Gajah. In the 1990s, where populations of *R. cantleyi* occur quite abundantly, the Orang Asli caretakers living in the vicinity of Ulu Geroh Forest Reserve became guides to the visitors. They were given monetary incentives to look after the forest habitats and the buds of *R. cantleyi*. When the flowers bloom, they would alert hotel managers in Ipoh and its vicinity. The hotel guests were guided by the Orang Asli, with visitors paying a fee for the guiding service. The scheme proved highly successful as the Orang Asli developed a strong sense of ownership and responsibility towards the species occurring within the forest reserve.

With the help of staff of Forestry Department Pahang, the senior author attempted to introduce a similar incentive scheme in Benta-Lata Jarum area through a cooperative-based approach. However, the proposal did not materialise. Nevertheless, the area is of considerable importance for *Rafflesia* conservation as a few species of *Rafflesia* occur in the area such as *R. cantleyi*, *R. tuanku-halimii*, *R. parvimaculata*, *R. sharifah-hafsahiae*, and *R. tuanku-azizahiae*.

FRIM has established a conservation area at Bersia, Gerik, Perak for *Rafflesia azlanii*, *R. cantleyi*, *R. kerri* and *R. infanticida* . These species are constantly monitored and fully protected from collectors. Similarly, in Kelantan, the Universiti Malaysia Kelantan has identified two sites, namely Lojing Highlands for *R. kerri* and Ulu Sat Forest Reserve for *R. cantleyi* conservation. In Sabah, Sabah Parks has been instrumental in protecting and conserving *R. pricei* and *R. keithii* at Tambunan and Poring, respectively. While in Sarawak, the Forestry Department Sarawak has been monitoring *R. tuan-mudae* at Gunung Gading National Park.

CHALLENGES AND FUTURE OF *RAFFLESIA* AND *RHIZANTHES*

Despite the rapid progress made within the past three decades on understanding the biology of *Rafflesia* and *Rhizanthes*, many questions remain unanswered and many aspects unexplored. DNA sequencing was introduced to study genetic variation between *Rafflesia* species in the early 2000s. Next-generation sequencing technologies and bioinformatics analyses further revealed the molecular aspects of taxonomy and phylogeny, developmental biology, horizontal genetic transfer, flower development and senescence in *Rafflesia*.

One of the main challenges in studying the biology of *Rafflesia* and *Rhizanthes* is the difficulty sampling the species in their habitat in the wild. The different developmental stages of *Rafflesia* and *Rhizanthes* flowers makes them extremely difficult to find, especially due to their short blooming period. In addition, *Rafflesia* and *Rhizanthes* buds have a high mortality rate due to lack of resources as well as impacts from herbivore and pathogen attack as well as disturbance from human activities. The formation of *Rafflesia* and *Rhizanthes* flowers therefore requires a conducive environment and right timing (for pollination) for ensuring the success of the species life cycle. *Rafflesia* and *Rhizanthes* are considered two of the most endangered plant genera due to their limited distribution, specific host plant, large sex imbalance and increased threats by rapid habitat lost due to tropical rain forest degradation and disturbances.

More extensive experiments should be conducted in the coming years, focusing on the analysis of genomes and transcriptomes of different *Rafflesia* and *Rhizanthes* species over several generations. Unique mutations and the modifications in gene expression can be studied in greater detail, while the molecular coevolutionary processes can be observable as they occur. Knowledge gained from this wealth of data, including their morphology, could highlight the complex interaction between *Rafflesia* and *Rhizanthes* with their hosts. This

will be crucial to preserve the diversity and population of these enigmatic plants. Besides, information on their habitat preferences, host specificity and reproductive biology of the species would be helpful in biodiversity and conservation by revealing the environmental conditions that the populations require to survive.

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