STATE OF NATURE CONSERVATION IN MALAYSIA 2025

Volume 1: Flora



Edited by
Vivian Soon
Ng Sean Fong
Donovan Louis

PERSATUAN PENCINTA ALAM MALAYSIA
MALAYSIAN NATURE SOCIETY

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State of Nature Conservation in Malaysia 2025

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Editors
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Malaysian Nature Society
2026


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Foreword: *Quo Vadis* Nature Conservation in Malaysia?

Jose I. dos R. Furtado[1] & Geoffrey W.H. Davison[2]

This volume on the State of Nature Conservation 2025 in Malaysia is dedicated to the late Gathorne Gathorne-Hardy, 5th Earl of Cranbrook, formerly Lord Medway (1933-2026) whose curiosity and enthusiasm about nature-human interactions and linkages incidentally led him to explore the natural history of cave-dwelling edible-nest swiftlets in Sarawak and Indonesia for his doctorate, and whose humility and generosity made him lasting friends especially with indigenous peoples and master the Malay language or Bahasa in which he composed poetry ('pantuns') and plays. Gathorne had a distinguished teaching and research career on birds and mammals at the University of Malaya in Kuala Lumpur, where he established the Field Studies Centre in Gombak, conducted numerous field trips to remote areas including 'black' areas under security curfew at the time, and inspired and nurtured numerous Malaysian and British students in field natural history. He had an enduring association with the Malaysian Nature Society and Malaysia, and used his influence after returning to the House of Lords to foster expeditions such as to Gunung Mulu, Sarawak, environment and conservation policy such as in the Malaysian State and National Conservation Strategies, indigenous community-forest relationships such as with the Kelabit in Sarawak and to foster nature conservation in Malaysia, while at the same time addressing issues pertaining to English Heritage, European environmental policy and international zoological nomenclature.

This State of Nature Conservation 2025 builds on two previous reviews by the Malayan Nature Society in 1991 (Kiew 1991) and more recently in 2021 (Cranbrook 2021). It has two papers on fungal species, 22 on plants and 23 on animals, five on indigenous peoples and 24 on nature's connectivity and sustainability for the Anthropocene. It is the first time the Society has focused on the Anthropocene – on ecological connectivity necessary to sustain the provision, regulation and acculturation of ecosystem goods and services based on species and biotope conservation. Presentations in this volume deal well with respective issues, identify threats and remedial conservation measures, when 1991 and 2021 presentations are included for an overview. Collectively, these presentations reflect individual, not necessarily institutional, concerns over the decline in Sundaland's megadiversity heritage that resides mostly in Bornean Malaysia. They reflect the absence of nationally (and regionally) coordinated systematic surveys of biodiversity richness in tropical rainforest and marine coral reef species addressed, and especially their ecological relationships, except for some groups in Sabah and Sarawak. They identify considerable gaps in understanding the structure and function of terrestrial, freshwater, coastal and marine ecosystems which provide resource harvests for markets or are converted to other uses; and superficially identify the intangible distortionary, displacement or irreversibility risks these ecosystems experience from selective harvests, or conversion to synthetic primary industries or infrastructure development, with inadequate qualification and quantification of such risks which, for species, use the IUCN threat categories that resemble resource categories without necessarily their ecological context.

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This rich Sundaland megadiversity heritage is being exploited, transformed or converted at an unprecedented pace without understanding its information value in autonomously providing ecosystem goods (e.g., timber, fish) and services (e.g., clean air and water) through ecological interactions with the environment (e.g., energy, space-time, water and minerals) and inter-species interactions (e.g., trophic, mutualistic, symbiotic) that advance adaptive evolution. Multicellular species perform numerous metabolic and exchange functions that are poorly understood except for obvious goods or services, and hence not quite amenable to risk assessment or evaluation developed for single resources or services. Unlike the temperate zone with its impoverished biodiversity on recent nutrient-rich glacial soils adapted to climatic pulses, Sundaland's megadiversity evolved over millions of years at the tropics at the mouth of the ancient Sea of Tethys on weathered soils or shallow seas exposed to high solar insolation, intense precipitation and without climatic (except Monsoonal) pulses that resulted in high gross production and biomass, rapid nutrient recycling and storage in the biomass, and homeorhesis of interspecies exchanges and linkages, with somewhat more efficient 'closed' ecosystems succeeding 'open' ones over several hundred years. Collectively, this volume of presentations, together with the previous ones, identify three imperatives for the Malaysian Nature Society to pursue and promote in conserving Malaysia's (and Sundaland's) megadiversity heritage under national and State jurisdictions (Figure 1).

(A) Threats to megadiversity:

1. Biodiversity surveys: Coordinated and concerted national and State surveys and repositories of unique megadiversity remaining in pristine ecosystems in all environments, and threats to them and their habitats especially species of potential economic value (*e.g.*, fibre, food, oils, resins, medicines, aromatics), as initiated by Sabah and Sarawak, to complement individual and institutional assessments.

2. Species and guild autecology: Coordinated studies of critical core and peripheral guild species and population dynamics in fractal biotopes in relation to stochastic environmental fluctuations (e.g., insolation & thermal stratification, wind turbulence & circulation, hydrological cycles, flows & circulations, nutrient cycles & flows, soils or substrates) at ecotones affecting trophic and mutualistic associations and life-cycles, potentially of value to ecosystem goods and services, so as to understand unintended distortionary, displacement and irreversible risks, and to design agroecological and technological offsets to destructive human interventions and perturbations.

3. Remote-sensing technology: Exploring remote sensing technology applications for use in identifying, typifying and monitoring species and guilds especially of potential economic value as ecosystem goods and services, and the health of ecosystem types.

(B) Under-supply of socio-ecological functions and operational conditions:

4.Socio-ecological functions: Coordinated multi-disciplinary socio-ecological exploration of species guild functions in biotope fractals in relation to stochastic environmental dynamics (e.g., energy, space-time, minerals, & biotic-informational) not only at natural ecotones (e.g., land-water, highland-lowland, canopy-ground, coastal-marine, inter-species) but, also, at synthetic ecotones (e.g., impacts of hunting & gathering, selective harvesting, shifting agriculture rotations, clearing habitats and landscape / seascapes by destructive technologies, degraded or synthetic agroecosystems, and shelterbelts or buffer zones of pristine or restored ecosystems) including traditional rights and sui generis knowledge, using comparative river basins as far as may be possible so as to define the range of variables at distortionary, displacement, and irreversible risk and to design potential remedial or restorative offsets for resilient terrestrial, freshwater, coastal and marine ecosystem transformations or conversions to continue sustained provision of ecosystem goods and services.

5. Operational conditions: Coordinated exploration and crafting of operational conditions for ecosystem transformations or conversions at ecotones in accordance with Lisbon Principles for securing the sustained flow of ecosystem goods and services:

■ Provisioning services: Water, Food & Nutrients, Fibre, Oils & Latex, Aromatics & Spices, Ornamentals, Raw materials, Minerals.

■ Regulatory services: Microclimate (Thermal, Turbulence, Atmospheric particulates & aerosols), Hydrological recycling (Interception, Retention, Inundation / Flood control, Flows / Flushing, Ocean circulation, Organic decomposition & purification, Bioaccumulation, Sedimentation), Soils and Benthos (Erosion, Turbidity, Water retention, Organic decomposition), Habitability (Temperature, Atmospheric & Dissolved gases, Buffering capacity, Protective layers), Nutrient recycling, storage & mobilisation, Carbon sequestration (Net & Gross productivity, Biomass accumulation), Pest & Vector control, Species, Habitat & Ecosystem protection.

6. Design engineering centres or network: Coordinated exploration by multi-disciplinary STEAM (science, technology, engineering, arts & mathematics) networks or teams of critical socio-ecological variables in ecosystem transformations or conversions causing unintended consequences to megadiversity (distortions, displacements, and irreversibility) in order to design and craft operational conditions for safe ecosystem and natural resources conversions or transformations, so as to foster engineering and technological innovations and design to offset and minimise unintended consequences, or restore ecosystems, for the sustained flow of ecosystem goods and services.

7. Capacity strengthening: Concerted efforts to strengthen capacity through megadiversity surveys, socio-ecological explorations and design of operational conditions beyond acquiring capability (i.e., knowledge and skills, or known-knowns), through individual empowerment by research or exploring known-unknowns or unknown-knowns often under supervision, to individual emancipation and independence by research or exploring unknown-knowns and unknown-unknowns, and fabricating technology and engineering innovations and/or incubating enterprises related to sustained ecosystem goods and services. Linking science to design engineering networks should facilitate strategic emancipation of individuals and institutions.

8.University-Research Networks: Concerted formation of autonomous multidisciplinary research and development (R&D) and innovation networks on specific objectives or tasks, with defined scope and duration, between experts at universities and research institutions at the national level, and through SEAMEO (South-East Asian Ministers of Education Organisation) at the regional level, to address specific emerging challenges to the sustained provision of ecosystem goods and services including technological offset and restorative measures.

(C) Under-use or Inadequacy of Provisions or Mechanisms for Governance (Synthetic 'Commons') for Sustainability:

9.Risk assessment and conservation mechanisms: Concerted efforts to qualify distortionary, displacement and irreversibility risks to megadiversity heritage of ecosystem transformations and conversions and natural resources uses based on scarce socio-ecological knowledge gained, including identifying unknowns, offsets and restorative measures, to review the Land Capability Classification based on soil suitability for primary production for its suitability for conserving biodiversity and ecosystem functions, and to competitively design and harmonise operational conditions defined with strategic stewardship policies and instruments (such as, information transparency or disclosure, regulations, market-based incentives, stakeholder / community participation & partnerships, and tenurial, usufruct & *sui generis* rights) for the sustained provision of ecosystem goods and services, countering as much as is possible 'rent-seeking' behaviour and simplified valuation, and conserving megadiversity as a 'common pool resource' (CPR) in ecoregions and especially in Sundaland.)

10.Federal-State harmonisation: Concerted harmonisation of differentiated and concurrent Federal-State authority and responsibility (Constitution, Art. 73, 74 (Schedule 9), & 77) for fragmented sectoral stewardship of natural resources and the environment to safeguard the unique biodiversity heritage as a 'global commons' (public good), involving a range of operational instruments and spatial scale (e.g., State & Federal agencies, Integrated River Basin Management (IRBM), Integrated Land-Use Management (ILUM), Large Marine Ecosystem Management (LMEM)) and consultative mechanisms.
11.Innovative financing: Seeking innovative mechanisms to raise diverse financing resources (including levies or cess, and stakeholder partnerships) to survey megadiversity in ecoregions, understand their socio-ecological threats and risks including offset technologies, and define operational conditions for governance instruments and at scale that maintain and enhance homeorhetic connectivity for sustained provision of ecosystem goods and services.)

Lord Cranbrook's career illustrated many of the above points and provided models of what could be achieved with simple tools, solid observations but excellent communication. His studies of swiftlets, for example, were seminal in developing the birds' nest industry in Malaysia and Indonesia. They were examples of species and guild autecology (A2) that looked at socio-ecological functions (B4) and operational conditions (B5). The work was multidisciplinary (B6), drawing together industry, local practitioners, government agencies and scientists in capacity-building (B7). Risk assessment of traditional harvesting and ownership led to the honing of conservation strategies (C9) influencing legislation and management practices that have established a lucrative industry that is not merely self-financing but highly lucrative across the region (C11). His role in State and National Conservation Strategies promoted discussion with the legislature on harmonising conservation interests with socioeconomic development plans (C10). Cutting edge technology may be useful but not essential for successful conservation: more fundamental are breadth of thinking to link diverse interests, strong communications, and persistence.

The highlights from the State of Nature Conservation 2025 symposium published here provide a basis for similarly broad approaches to other taxa and ecosystems, evident in papers such as those on fungi, dipterocarps, palms, and many of the contributions on the Anthropocene. Attaining sustainable flow of ecosystem goods and services appears difficult in the best of times due to capital control but not impossible, provided nature conservationists and development practitioners constantly review critical elements of dynamic interactions between megadiversity conservation and socioeconomic demands for alternative livelihoods and habitability, and for strategic security and resilience. Although Malaysian (and Sundaland's) megadiversity heritage has been neglected somewhat to address immediate demands of a demographic transition by attracting 'external' capital to mimic temperate zone production systems for short-term gains, impact analysis and capacity strengthening enables functional review of both megadiversity heritage and changing technological alternatives, so as to design reforms for long-term security especially unexpected transboundary perturbations. A megadiversity centre like the Amazon caught the attention of advanced country investors due to the Rio Summit (UNCED 1992) only after its regional cooperation Treaty established an association of universities and research institutions to explore natural resources – biodiversity linkages. South-East Asia has networks of regional centres under the South-East Asian Ministers of Education (SEAMEO) that could be mobilised under the Association of South-East Asian Nations to address Sundaland's megadiversity conservation potential and limits. In seeking dynamic survival strategies, societies within Sundaland may need to re-visit the tenets of eco-philosophy formulated in Vedic times to balance human utility with respect, reverence and aesthetics for nature in terms of collective responsibility and security, as embodied in resource stewardship in the *Pancasila* and proposed by the existential philosopher Arthur Schopenhauer (Rohde 2013). Furthermore, since information and energy is central

to all forms of capital formation (four natural and two synthetic) in the evolution of autopoietic human species and homeorhetic ecosystems within centrifugal-centripetal 'tension fields', societies may need to explore the extent to which capital may be mutable from one form to another for collective sustainability, resilience and security: Linkages between Philosophy / Religion (natural), Politics / Organisation (natural), and Economics / Finance (synthetic) forms of capital have managed wealth for societies over millennia; and, since the European Enlightenment and demographic transition, have been challenged by emerging Human / Social (natural) and Technology / Infrastructure (Synthetic) forms of capital in the human quest for freedom, exploration and creativity, and experienced or encountered limits to habitability in inherited Environment / Biodiversity (natural) form of capital. What critical ecosystems goods and services will be needed for the next phase of human exploration and development?

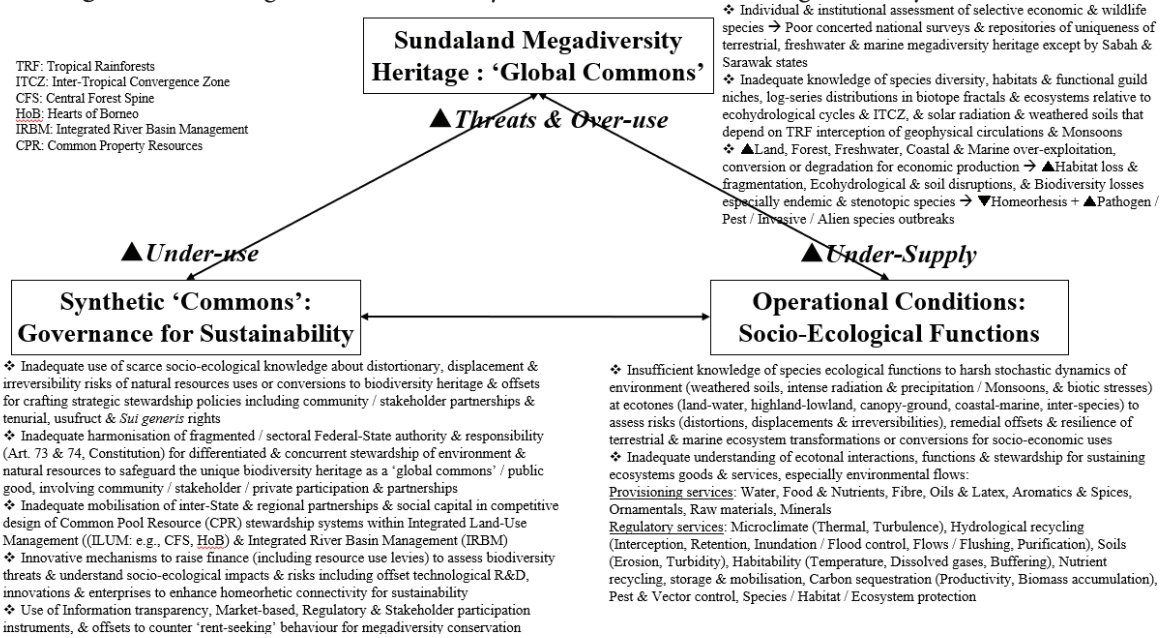
Golden Rule: *Tat Tvam Asi* / Thou art that or In that way are you.
[Chandogya Upanishad, VI, 8:7, of the Samaveda]

Cranbrook, Gathorne Gathorne-Hardy, 5th Earl of, 2021. Introduction. An anniversary of anniversaries. *Malayan Nature Journal 81st Anniversary* 2021: 1-3

Kiew, R., ed., 1991. *The State of Nature Conservation in Malaysia.* 245 pp. Kuala Lumpur, MY: Malayan Nature Society

Rohde, K., ed, 2013. *The Balance of Nature and Human Impact*. 450 pp. Cambridge, U.K.: Cambridge University Press

Figure 1: Challenges to Sustain Malaysia's and Sundaland's Megadiversity - Illustrative





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CHAPTER 1

Fungal diversity of Peninsular Malaysia

THI BEE KIN[1]* and NUR AQILAH MUSTAFA BAKRAY[2]

Abstract: Fungi can be found growing in a vast diversity of environments and substrates. Malaysia is one of the countries to have great diversity of micro- and macrofungi living in diverse habitats. In Peninsular Malaysia, the efforts to document micro- and macrofungal diversity of various ecosystems have been continuously carried out. A short review of the history of mycology in Malaysia, documentation activities and conservation efforts on micro- and macrofungi were presented here. New species and records of fungi found in Peninsular Malaysia were presented, especially interesting and noteworthy species. Some of these fungi, which are endemic, rare and threatened, were also highlighted. The importance and roles of fungi in balancing the ecological services in the forest ecosystem were discussed.

INTRODUCTION

Malaysia is one of the mega-diversity countries with rich diversity of flora, fauna, and fungi. Approximately 4,000 fungi, including both microfungi and macrofungi, were documented in Malaysia (Lee *et al*. 2012). However, the actual number of fungi species is expected to be much higher than what is documented. Earlier estimates suggested that approximately 70% of Malaysian macrofungi remained undescribed (Lee *et al.* 2008). Moreover, many new species or new records of fungi have been discovered and reported over the past 14 years.

In Malaysia, studies on microfungi are limited, but have received increasing attention with recent efforts focusing on soil fungi, marine fungi, and insect-associated fungi due to their crucial roles in ecosystems and advancement of molecular tools, particularly in DNA sequencing.

For macrofungi, intensive surveys and documentation have been ongoing since 2006 under the Ninth Malaysia Plan. Collections were conducted across various forest types in Peninsular Malaysia, including freshwater swamp forests, peat swamp forests, limestone forests, lowland and hill forests, highland forests and island forests. A total of 165 expeditions were documented, covering 145 localities in Peninsular Malaysia (Figure 1).

Sampling covered several island forests, such as Pulau Redang in Terengganu, Pulau Aur in Johor (Zainuddin *et al.* 2010), Pulau Pangkor in Perak (Thi and Lee 2012), Pulau Bidong in Terengganu (Tsia and Aqilah 2019), and Langkawi in Kedah (Noorlidah *et al*. 2005). Highland forests included Cameron Highlands (Thi and Lee 2011) and Fraser's Hill (Thi and Lee 2010; Thi *et al.* 2011), while inland locations included Terengganu National Park (Thi and Lee 2008), Royal Belum State Park (Thi and Lee 2010), Temengor Forest Reserve (Thi 2013), Gunung Ledang (Thi and Lee 2017) and Gunung Korbu (Nur Aqilah *et al.* 2020). Limestone ecosystems included Gunung Senyum (Thi and Lau 2012) and Perlis State Park (Ag. Ahmadni *et al*. 2024), alongside swamp forests such as Tasik Bera

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(Zainuddin *et al.* 2010). Additionally, fungal inventories were conducted in urban forests, including Kota Damansara Community Forest (Thi *et al.* 2012) and Pulai Trail in Bangsar (Nur Aqilah *et al.* 2026). Further inventories have been conducted by university lecturers and independent researchers across various sites in Peninsular Malaysia, including Sungkai Wildlife Reserve (Jaya Seelan 2014) and at the UiTM campus (Nur Amirah Sakinah *et al.* 2023). Although a diverse array of species was documented across these regions, the map indicates that several forest areas remain unexplored, whereas others are well-investigated. Based on the past and recent mycological studies, historical review of fungal research, micro- and macrofungal fungal diversity and ecological roles, fungal research and conservation in Peninsular Malaysia is presented in this chapter.

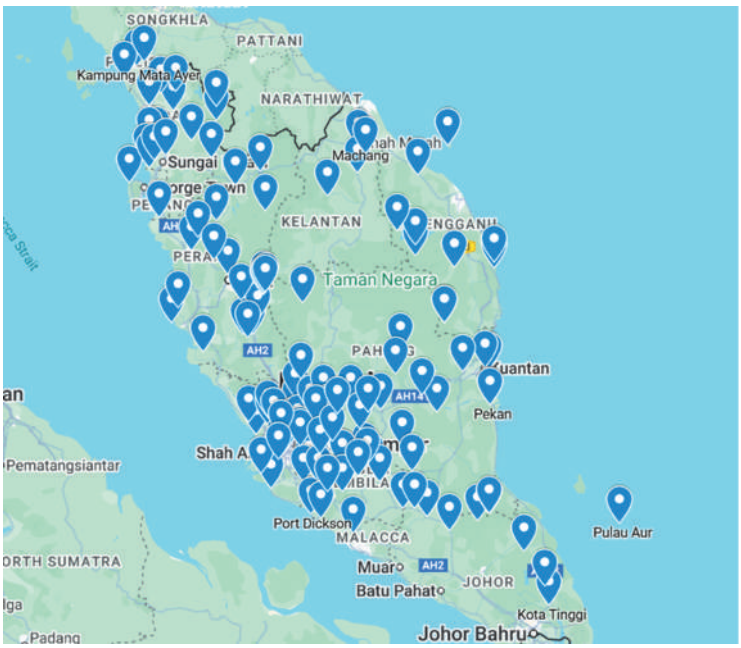

Figure 1. Distribution map of sampling sites across Peninsular Malaysia. Blue pins indicate the 145 localities visited during 165 fieldwork expeditions for macrofungi collection from 2006 to present.

Historical review of mycology in Malaysia

The history of mycology and fungal collecting in Malaysia dates back roughly 150 years, evolving from early colonial botanical surveys to modern systematic inventories. In Malaysia, the early fungal studies and collections were mainly on macrofungi, carried out by visiting scientists in the 19th centuries, including O. Beccari (1865 – 1879), W.B. M.C. Cooke (1878 – 1885), as well as H.N. Ridley and I.H. Burkill (1888 – 1912). E.J.H. Corner is one of the active mycologists in the 20th century and had collected a large number of macrofungi in Malaysia, followed by S.S. Lee and R. Watling on ectomycorrhizal fungi (1990 – 2000), and T. Hattori on polypores (1995 – 2025).

During the 19th century, V. Cesati examined Beccari's collections and described 20 new fungal species from Sarawak, Borneo (Cesati 1879), while M.C. Cooke described numerous new species from Peninsular Malaysia (Cooke, 1885). Subsequently, H.N. Ridley and I.H. Burkill (1888 – 1912) made extensive fungal collections in Singapore and Malaya. In the 20th century, E.J.H. Corner collected extensively across Peninsular Malaysia, Singapore, and Sarawak. His systematic publication of these collections across a series of comprehensive monographs (Corner 1932, 1950, 1962, 1967, 1968, 1970, 1974, 1980a, 1980b, 1981, 1984a, 1984b, 1992, 1993, 1994) laid the groundwork for tropical Basidiomycota taxonomy and established the foundational framework for Southeast Asian macrofungi.

Later in the 1990s, S.S. Lee carried out taxonomic research on macrofungi and ectomycorrhizal associations in the tropical rainforests of Peninsular Malaysia (Lee 1995, 2005; Lee *et al.* 1997, 2002, 2003). At the same time, T. Hattori extensively studied and identified polypore fungi in Malaysia (Hattori and Lee 1999, 2003, 2012; Hattori *et al.* 2025), while also conducting detailed type studies on Asian and West Pacific polypores originally described by the prominent British mycologist E.J.H. Corner (Hattori 2000, 2001a, 2001b, 2002, 2003a, 2003b, 2005). Since 2006, studies and documentation on macrofungi have been carried out by the Forest Research Insitute Malaysia (FRIM) researchers. Several guidebooks to macrofungi have been published, including *A Guidebook to the Macrofungi of Tasik Bera* (Zainuddin *et al.* 2010), *A Guidebook to the Macrofungi of Fraser's Hill* (Thi *et al.* 2011) and *A Field Guide to the Larger Fungi of FRIM* (Lee 2017). There are two formal checklists of fungi in Malaysia. In the documentation, Chip (1921) listed 861 fungi, while Lee *et al.* (2012) listed 3,804 fungi.

Historically, microfungi research in Malaysia began in the early 1900s, focused primarily on agricultural crop health and plant pathogens that infect and cause disease in crops. In the late 1910s and early 1920s, C.F. Baker collected specimens of microfungi and myxomycetes (slime molds) across Penang and Singapore. P.A. Saccardo subsequently described Baker's collection, documenting these Malaysian microfungi in his multi-volume work, *Sylloge Fungorum* (Saccardo 1882–1931). Concurrently, A.R. Sanderson working together with Baker on Malaysian myxomycetes and primitive lower fungi. Later, in 1921, T.F. Chipp gathered and organised this baseline data into a comprehensive checklist (Chipp 1921). Their collective work established the baseline species checklists that modern mycologists in Malaysia rely on today to study tropical microfungi, such as *Aspergillus*, *Penicillium*, and *Fusarium*.

In 1969, J. Kohlmeyer's pioneering work extended Malaysian microfungi research beyond farm crops and into marine and mangrove habitats. Jones and Tan (1987) listed 32 manglicolous species from Gelang Patah, Johor. This was expanded by Jones and Kuthubutheen (1989) to 82 species across Morib, Kuala Selangor, Port Dickson, and Sementa mangroves. Alias *et al.* (1995) documented 100 marine fungal species (82 ascomycetes, 15 asexual forms, and three basidiomycetes) from Kuala Selangor, Morib, and Port Dickson. Later studies by Alias and Jones (2000a, 2000b) detailed 53 species specifically associated with *Rhizophora apiculata* at Morib.

FUNGAL DIVERSITY AND RESEARCH IN PENINSULAR MALAYSIA

Occurrence, distribution, and roles of macrofungi

Macrofungi, commonly known as mushrooms, are visible fungi that have fruiting bodies (Lee *et al.* 2012). This group of fungi belongs predominantly to the phyla Basidiomycota and Ascomycota. Malaysia's tropical forests host a rich diversity of macrofungi. There are many different types of macrofungi, such as agarics, boletes, polypores, coral fungi, cup fungi, jelly fungi, stinkhorns, earthballs, and puffballs (Thi *et al.* 2011). Over 1,800 species of macrofungi have been documented in Malaysia (Lee *et al.* 2012), and this number continues to grow as novel species are discovered that have yet to be recorded in the national fungal checklist.

Many macrofungi species were documented from various types of forests. Specific examples of these are the following: 61 species from freshwater swamp forest at Tasik Bera (Zainuddin *et al.* 2010); 72 species from highland forest at Fraser's Hill (Thi *et al.* 2011); 123 species from regenerated lowland dipterocarp forest at FRIM (Lee 2017), and more than 300 species from old growth lowland dipterocarp forest at Endau Rompin National Park (Thi 2025).

Hattori *et al.* (2007) and Yamashita *et al.* (2015) demonstrated that polypore diversity is exceptionally high in Malaysian lowland rainforests. A survey in Pasoh Forest Reserve recorded 140 species and estimated around 188 polypore species in a single 2-hectare plot (Yamashita *et al.* 2015), with many recorded species likely endemic to tropical Asia (Hattori and Lee 2003). Globally, Zhao *et al*. (2026) ranked Malaysia 4th worldwide and 2nd in Asia (behind China) with a total of 179 type specimens. Type specimens are the most critical vouchers in a herbarium as they defined a species, serving as the permanent reference for the first specimen bearing a newly published scientific name. Some of the polypores are rare or endemic to a particular region, for example *Buglossoporus malesianus* found at Cameron Highlands and Mt. Kinabalu, is restricted to the highland areas in tropical forest (Hattori 2017). Similarly, *Climacodon sanguineus* is recorded from Cameron Highlands (Thi *et al.* 2008), while *Corneroporus subcitrinus* is a rare fungus known from lowland areas of the Malay Peninsula and Borneo (Corner 1989a; Hattori 2001b; Yamashita *et al.* 2009). Furthermore, *Podopostia stellifera* (previously *Postia stellifera*) is a rare, terrestrial stalked polypore described from lowland Peninsular Malaysia (Hattori *et al.* 2010).

In 2013, two additional new polypores discovered and described from the tropical rainforests of Peninsular Malaysia belong to the genus *Lignosus* (family Polyporaceae). Commonly known as Tiger Milk mushrooms, these fungi are highly valued medicinal species native to Malaysia (Tan *et al*. 2013). *Lignosus tigris* and *L. cameronensis* are sclerotium-bearing polypore discovered from tropical rain forests of Lata Iskandar, Pahang, Malaysia using taxonomic and phylogenetic studies.

Another new species discovered in Peninsular Malaysia is *Amanita malayensis* (Tang *et al.* 2017), an ectomycorrhizal fungus that grows gregariously on the ground under secondary or disturbed lowland forests and parks, often associated with ectomycorrhizal host trees. *Hebeloma radicans* (Eberhardt *et al*. 2021) belongs to the Hymenogastraceae, another ectomycorrhizal family of agarics. This fungus was collected from a lowland tropical dipterocarp-oak forest (*Dipterocarpus* and *Quercus*) in Endau-Rompin National Park, Johor. The discovery of *H. radicans* represented the first formal documentation that the genus *Hebeloma* and ectomycorrhizal members of Hymenogastraceae are naturally present in tropical forests of the Malay Peninsula (Eberhardt *et al*. 2021).

In addition, new records for Malaysia were also reported, including *Macrolepiota dolichaula* (Thi *et al.* 2018), *Climacodon sanguineus* (Thi *et al.* 2020), and *Spongispora temasekensis* (Mohd Salleh *et al.* 2020), which were found in Peninsular Malaysia. Furthermore, *Pleurocordyceps nipponica*, an entomopathogenic fungus, was reported as a new record for Malaysia after being isolated from a cicada nymph in Johor and an ant in Kedah (Shahbaz *et al.* 2026b). At present, a collection of macrofungi in FRIM's *Fungarium* is still being identified and some species are new to the region. The number of species of macrofungi is increasing with the recent new discoveries of macrofungi in Peninsular Malaysia, Sabah, and Sarawak. Many undiscovered species are expected to be found in our forests in the future.

Macrofungi play very important roles in the forest ecosystem, acting as saprophyte, mutualists and pathogens. Most of the polypores are saprobic, decomposing wood debris or leaf litter on forest floor for nutrient cycling (Hattori *et al.* 2012; Adarsh *et al.* 2015). Besides, macrofungi such as genus *Amanita*, *Russula*, *Lactarius*, boletes and include other ectomycorrhizal fungi that act as mutualists, forming symbiotic associations with the roots of trees in families, particularly with Dipterocarpaceae, Fagaceae and some Fabaceae, enhancing nutrient uptake. Some of the macrofungi are pathogens, for example *Rigidoporus microporus* and *Pyrrhoderma noxium*, maintaining forest ecosystems by regulating populations of the plants (Thi *et al*. 2011; Lee 2017). In addition to their ecological importance, macrofungi also has medicinal properties (Chang and Lee 2004).

Occurrence, distribution, and roles of microfungi

Microfungi are generally characterised by its microscopic fungi that lack visible fruiting bodies. reproductive structures that are not visible to the naked eye (e.g., yeast, mildew, mould, smuts, rusts, etc.), while macrofungi produce large conspicuous fruiting bodies (e.g., mushroom, bracket fungi, puffballs, morels, jelly fungi, etc.) (Lee *et al.* 2012). Compared to macrofungi, the microfungi taxa are larger, more diverse and widely distributed. It is important to note that the distinction between microfungi and macrofungi is not absolute as they are not mutually exclusive taxonomic divisions.

Most of the microfungi are grouped into the Phylum Ascomycota, with some from Basidiomycota, Glomeromycota, Mucoromycota and other taxa. These fungi include yeasts and mildews from Ascomycota, moulds mainly from Ascomycota and Mucoromycota, smuts and rusts from Basidiomycota, endomycorrhizae from Glomeromycota and marine fungi from Ascomycota, Basidomycota and minority group. Although microfungi is the largest group and found all over the world, Malaysia only recorded over 1,100 species (Lee *et al*. 2012), which is slightly lower than the macrofungi in Malaysia because these groups of fungi were understudied.

Based on our fieldwork observations and current sampling gaps, we estimate that numerous species of microfungi remain to be discovered in Malaysia. *The Checklists of Fungi in Malaysia* documented significant fungal diversity in Malaysia. However, the recorded diversity of microfungi in Malaysia is likely an underestimate of the actual diversity, as gaps remain in the study of particular fungi group (microfungi) and their microhabitats (Lee *et al.* 2012). A study by Foster *et al.* (2022) in Sabah also revealed previously undocumented fungal lineages, which could suggest the potential for further discoveries.

Based on the *Checklists of Fungi of Malaysia* (Lee *et al.* 2012), 1,141 species of ascomycete fungi have been recorded, including a small number of macrofungi such as cup fungi, and dead man's fingers (Lee *et al.* 2012). Records of 728 mould species (Lee *et al.* 2012), and 139 species of marine fungi (Jones *et al* . 2013) were documented. The number of smut fungi and rust fungi recorded from Malaysia were 15 species and 75 species, respectively (Lee *et al.* 2012, Ono *et al.* 2023). A total of 229 species of marine microfungi have been recorded in Peninsular Malaysia (Zainuddin *et al.* 2007). Alias *et al.* (2010) reported 33% of the world's total marine manglicolous fungi have been recorded in Malaysia, with a total of 390 marine mangrove fungi.

Over the past several years, numerous new species and new records of microfungi have been documented for Malaysia that have yet to be incorporated into the national checklist. Notably, this represents the first time microfungi from Peninsular Malaysia are being formally reported. These additional records include four yeast species from Perak (Ooi *et al.* 2016), 25 species of marine fungi (Jones et al., 2013), and 18 species of rust fungi, including one species recorded in Peninsular Malaysia for the first time (Ono *et al.* 2023); two species of enthomopathogenic fungi (Kin *et al.* 2017), and six new soil fungus from peat soil records for Malaysia (Noman *et al.* 2023). Approximately 20 species of endomycorrhizae (Glomeromycota) associated with *Eucalyptus* hybrids were reported (Thi *et al.* 2025). However, there are still a lot of undiscovered species of microfungi in Malaysia.

Microfungi act as saprobes, pathogens, endophytes, and epiphytes in the ecosystem. As saprobes, microfungi have the ability to break down organic matter, decomposing the components of soil, which are important for nutrient cycling and maintaining ecological balance (Rillig 2026). Some microfungi are plant pathogens that cause diseases to plants (Mohd Zainudin *et al.* 2025) while some are entomopathogenic fungi, parasitising and killing insects. These have the potential to be used as biocontrol agents (Yazid *et al.* 2020; Shahbaz *et al.* 2026a). Microfungi that act as endophytes live within a plant tissue and

epiphytes, colonising the surface without penetrating the plant's tissue. These are beneficial fungi, and essential for promoting plant health, enhancing stress tolerance, and producing bioactive compounds with potential for pharmaceutical application (Radu and Cheah 2002; da Silva *et al.* 2022).

Microfungi are also being used in both industrial and commercial purposes such as food, medicine, and chemical sectors. For instance, various cheeses are produced from *Penicillium* (Frisvad 2014), while *Aspergillus* species are utilised in the production of ingredients for producing soft drinks in the food industry as citric acid producer (Show *et al.* 2015). Microfungi are also being used in the medicinal industry, such as *Penicillium* species that naturally produce penicillin antibiotics (Charles 2018).

Ethnomycology studies in Peninsular Malaysia

Ethnomycology studies in Peninsular Malaysia focus primarily on documenting the traditional use of wild macrofungi for food and medicine. Ethnomycological knowledge in Malaysia is predominantly held by rural and indigenous communities, such as the Semai, Temuan, Bateq, Che Wong, and Jakun. Traditional ethnomycological knowledge transmission is largely oral, preserved and transmitted primarily by women and community elders, mainly for self-consumption. Several studies have been carried out by Chang and Lee (2004), Lee *et al.* (2009), Ayu *et al.* (2019), as well as Shyen and Aqilah (2020) in Peninsular Malaysia.

Chang and Lee (2004) documented nine species of macrofungi utilised by the Temuans of Johor, five of which were used for medicine (*Amauroderma* sp., *Lignosus* spp., *Microporus xanthopus*, *Pycnoporus sanguineus*, *Xylaria polymorpha*) and four for food (*Auricularia* spp., *Cookeina* spp., *Lentinus* spp., *Termitomyces* spp.). In the study by Lee *et al.* (2009), 31 species of macrofungi were collected for food, but only 14 species were used for medicinal purposes across the Semai, Temuan, Bateq, Che Wong, and Jakun sub-tribes. Ayu *et al.* (2019) documented the ethnomedical knowledge of the Jakun community at Kampung Peta in Endau Rompin Johor National Park, identifying 20 macrofungi species with medicinal properties. In Terengganu, the edible wild boletoid mushroom, *Tylopilus griseipurpureus* or locally known as the "*gelam* mushroom", is consumed by local communities in Setiu and Besut, Terengganu. Additionally, Mohammad and Hamzah (2015) documented ten macrofungal species utilised for food and traditional medicine by the Bateq indigenous community in Kampung Kuala Koh, Kelantan. Abdullah and Rusea (2009) listed 13 of the most common wild edible fungi species consumed primarily by the Malays and village communities across Peninsular Malaysia and Borneo. There is an urgent need for continued ethnomycological documentation to safeguard indigenous knowledge against loss and to accelerate scientific discovery.

THREATS AND CONSERVATION STATUS OF FUNGI

In Malaysia, fungi are facing various threats, which include deforestation, land development and conversion to agricultural lands, human activities, and climate change. All these are reducing fungal biodiversity and ecosystem functions (Qu *et al*. 2026).

Due to deforestation and conversion of land use, fungi are at risk of being wiped out due to habitat loss, even before we get to know much about them. Human activities such as over-collection for traditional medicine, like *Lignosus rhinocerus*, *Ganoderma* species or for food, like *Auricularia auricula-judae* from forests may also decrease the fungi populations. Trampling and compaction of forest floor when harvesting can reduce the sporophores produced (Simon *et al.* 2006). Climate change, specifically extreme changes of the surrounding temperatures and rainfall can disrupt fungal fruiting and life cycles (Mridu *et al.* 2024).

The conservation status of micro- and macrofungi in Malaysia are still poorly understood. Most of the fungi in Malaysia has yet to be evaluated using the International Union for Conservation of Nature (IUCN) Red List criteria. From approximately 80 macrofungi species that were proposed for IUCN assessment, only 25 species of macrofungi found in Malaysia currently have conservation status according to published data from the IUCN Red List. Five species are categorised as vulnerable (VU), three species are endangered (EN), four species with near threated (NT), six species with least concern (LC), and seven species with data deficient (DD) status. The fungi species with the status VU and EN are facing a high risk of becoming extinct in the wild. Therefore, more research is needed to assist in the conservation and protection of fungi.

Table 1. List of Malaysian macrofungal species and their conservation status.

No.	Species	Location	Conservation Status
1	*Amanita aporema*	Peninsular Malaysia	VU
2	*Buglossoporus magnus*	Peninsular Malaysia	VU
3	*Calostoma insigne*	Peninsular Malaysia and Sarawak	EN
4	*Cantharellus carneoflavus*	Sabah	EN
5	*Cantharellus cerinoalbus*	Peninsular Malaysia	LC
6	*Cantharellus cuticulatus*	Peninsular Malaysia and Sabah	NT
7	*Cantharellus diminutivus*	Peninsular Malaysia	DD
8	*Cantharellus fuligineus*	Sabah	NT
9	*Cantharellus inconspicuus*	Peninsular Malaysia	DD
10	*Cantharellus incrassatus*	Peninsular Malaysia	DD
11	*Cantharellus omphalinoides*	Peninsular Malaysia and Sabah	LC
12	*Cantharellus pudorinus*	Peninsular Malaysia	DD
13	*Cantharellus sordidus*	Malaysia (in general)	DD
14	*Cantharellus subcibarius*	Sabah	VU
15	*Cantharellus subamethysteus*	Peninsular Malaysia	DD
16	*Chlorogaster dipterocarpi*	Sabah	VU
17	*Craterellus hypolyssoides*	Sarawak	DD
18	*Craterellus aureus*	Peninsular Malaysia	LC
19	*Craterellus cornucopioides*	Peninsular Malaysia	LC
20	*Craterellus verrucosus*	Peninsular Malaysia and Sabah	NT
21	*Durianella echinulate*	Peninsular Malaysia, Sabah and Sarawak	VU
22	*Hydnum repandum*	Peninsular and Sabah	LC
23	*Lycoperdon perlatum*	Peninsular Malaysia, Sabah and Sarawak	LC
24	*Spongiforma squarepantsii*	Sarawak	EN
25	*Spongispora temasekensis*	Peninsular Malaysia	NT

There are challenges in the conservation efforts of fungi. Examples are the limited and lack of research funding, shortage of local mycologists, and the lack of public awareness, including limited understanding of the fungi's ecological roles, making conservation efforts difficult.

Overall, public awareness regarding diversity and the importance of fungi in our ecosystem, ongoing monitoring, and extensive sampling are required for effective macrofungal documentation and conservation programs in Malaysia. It is therefore crucial to document and highlight the richness of the diversity of both macrofungi and microfungi before they become extinct.

CONCLUSION

Malaysia has various forest ecosystems and harbours a vast diversity of fungi. Although fungi are essential for forest ecosystems and have economic importance, they are facing threats resulting from habitat destruction, climate change, and different types of pollution. Therefore, sustainable forest management and conservation are essential to maintaining fungi diversity and keeping the forest ecosystems that they thrive in healthy.

REFERENCES

Abdullah, F. and Go, Rusea. 2009. Documentation of inherited knowledge on wild edible fungi from Malaysia. *Blumea - Biodiversity, Evolution and Biogeography of Plants* 54: 35–38. https://doi.org/10.3767/000651909X475996

Ag. Ahmadni, A.S., Shamsul Kamar, N.A., Amir Hadi, M. and Terhem, R. 2023. Assessment of macrofungi diversity in Perlis State Park, Perlis, Malaysia. *Journal of Wildlife and Biodiversity* 8(1): 298–307. https://doi.org/10.5281/zenodo.10206965

Alias, S.A. and Jones, E.B.G. 2000a. Colonization of mangrove wood by marine fungi at Kuala Selangor mangrove stand, Malaysia. In *Aquatic Mycology Across the Millennium*, K.D. Hyde, W.H. Brief and S.B. Pointing (Eds.), pp. 9–21. Hong Kong: Fungal Diversity Press.

Alias, S.A. and Jones, E.B.G. 2000b. Vertical distribution of marine fungi on *Rhizophora apiculata* at Morib mangrove, Selangor, Malaysia. *Mycoscience* 41: 431–436.

Alias, S.A., Kuthubutheen, A.J. and Jones, E.B.G. 1995. Frequency of occurrence of fungi on wood in Malaysian mangroves. *Hydrobiologia* 295(1): 97–106.

Alias, S.A., Zainuddin, N. and Jones, E.B.G. 2010. Biodiversity of marine fungi in Malaysian mangroves. *Botanica Marina* 53: 545-554.

Chang, Y.S. and Lee, S.S. 2004. Utilisation of macrofungi species in Malaysia. *Fungal Diversity* 15: 15–22.

Charles, T. 2018. Mycology presents *Penicillin*. *Mycologia* 37: 460–475. https://doi.org/10.1080/00275514.1945.12024006

Chipp, T.F. 1921. A list of the fungi of the Malay Peninsula. *The Garden' Bulletin Straits Settlements* 2: 311–418.

Cooke, M.C. 1885. Fungi of Malayan Peninsula. *Grevillea* 14(70): 43–44.

Corner, E.J.H. 1932. The fruit-body of *Polystictus xanthopus* Fr. *Annals of Botany* 46: 71–111.

Corner, E.J.H.1950. Monograph of Clavaria and allied genera. London: Dawsons.

Corner, E.J.H. 1967. Notes on *Clavaria*. *Transactions of the British Mycological Society* 50: 33–44.

Corner, E.J.H. 1968. A monograph of *Thelephora* (Basidiomycetes). *Nova Hedwigia* 27: 1–110.

Corner, E.J.H.1971. Merulioid fungi in Malaysia. *Gardens' Bulletin, Singapore* 25: 355–381.

Corner, E.J.H. 1970. *Phylloporus* Quél and *Paxillus* Fr. in Malaya and Borneo. *Nova Hedwigia* 20: 793–822.

Corner, E.J.H.1974. *Boletus* and *Phylloporus* in Malaysia: further notes and descriptions. *Gardens' Bulletin, Singapore* 27: 1–16.

Corner, E.J.H. 1980. *Boletus longipes* Mass., a critical Malaysian species. *Gardens' Bulletin, Singapore* 33: 290–296.

Corner, E.J.H. 1980. *Entoloma* (Fr.) Kummer in the Malay peninsula. *Gardens' Bulletin, Singapore* 33: 297–300.

Corner, E.J.H. 1983. Ad Polyporaceas I. *Amauroderma* and *Ganoderma*. *Beih*. *Nova Hedwigia* 75: 1–182.

Corner, E.J.H. 1984. Ad Polyporaceas II. *Polyporus*, *Mycobonia* and *Echinochaete*. *Beih*. *Nova Hedwigia* 78: 1–129.

Corner, E.J.H. 1984. Ad Polyporaceas III. *Piptoporus*, *Buglossoporus*, *Laetiporus*, *Meripilus*, and *Bondarzewia*. *Beih. Nova Hedwigia* 78: 133–222.

Corner, E.J.H. 1981. The agaric genera *Lentinus*, *Panus*, and *Pleurotus* with particular reference to Malaysian species. *Beih. Nova Hedwigia* 69: 1–169.

Corner, E.J.H. 1992. Notes on the development of the fruit-bodies of four Malayan species of *Amanita* (Basidiomycetes). *Gardens' Bulletin Singapore* 44(1): 43–45.

Corner, E.J.H. 1993. *Psathyrella* (Agaricales) with ornamented spores in the Malay Peninsula. *Gardens' Bulletin Singapore* 45(2): 337–357.
Corner, E.J.H. 1994. Agarics in Malesia: I Tricholomatoid, II Myceniod. *Beih. Nova Hedwigia* 109: 1–271.
Corner, E.J.H. and Bas, C.1962. The genus *Amanita* in Singapore and Malaya. *Persoonia* 2(3): 241–304.
da Silva, S.G.M., de Melo, B.A., dos Santos, M.T., Rios, R.R.S., de Santa'Anaa Santos, C.M., Júnior, K.A.L.R., de Albuquerque Maranhão, F.C. *et al.* 2022. Endophytic fungi: Benefits for plants and biotechnological potential. *Research, Society and Development* 11(4): e9211427008. https://doi.org/10.33448/rsd-v11i4.27008
Eberhardt, U., Schütz, N., Beker, H.J., Lee, S.S. and Horak, E. 2021. *Hebeloma* in the Malay Peninsula: Masquerading within *Psathyrella*. *MycoKeys* 28(77): 117–141. https://doi.org/10.3897/mycokeys.77.57394
Frisvad, J.C. 2014. Penicillium: *Penicillium*/Penicillia in Food Production. In *Encyclopedia of Food Microbiology (2nd Ed.)*, C.A. Batt and M.L. Tortorello (Eds.), pp. 14–18. https://doi.org/10.1016/B978-0-12-384730-0.00249-4
Foster, R., Hartikainen, H., Hall, A. and Bass, D. 2022. Diversity and phylogeny of novel cord-forming fungi from Borneo. *Microorganisms* 10(2): 239. https://doi.org/10.3390/microorganisms10020239
Hattori, T. 2017. Biogeography of polypores in Malesia, Southeast Asia. *Mycoscience* 58(1): 58–69.
Hattori, T. 2000. Type studies of the polypores described by E.J.H. Corner from Asia and the West Pacific I. Species described in *Polyporus*, *Buglossoporus*, *Meripilus*, *Daedalea*, and *Flabellophora*. *Mycoscience* 41: 339e349. https://doi.org/10.1007/BF02463947
Hattori, T. 2001a. Type studies of the polypores described by E.J.H. Corner from Asia and West Pacific Areas II. Species described in *Gloeophyllum*, *Heteroporus*, *Microporellus*, *Oxyporus*, *Paratrichaptum*, and *Rigidoporus*. *Mycoscience* 42: 19e28. https://doi.org/ 10.1007/BF02463971
Hattori, T. 2001b. Type studies of the polypores described by E.J.H. Corner from Asia and West Pacific Areas III. Species described in *Trichaptum*, *Albatrellus*, *Boletopsis*, *Diacanthodes*, *Elmerina*, *Fomitopsis* and *Gloeoporus*. *Mycoscience* 42: 423–431. https://doi.org/10.1007/BF02464338
Hattori, T. 2002. Type studies of the polypores described by E.J.H. Corner from Asia and West Pacific Areas IV. Species described in *Tyromyces* (1). *Mycoscience* 43: 307e315. https://doi.org/10.1007/s102670200045
Hattori, T. 2003a. Type studies of the polypores described by E.J.H. Corner from Asia and West Pacific Areas V. Species described in *Tyromyces* (2). *Mycoscience* 44: 265e276. https://doi.org/10.1007/s10267-003-0114-3
Hattori, T. 2003b. Type studies of the polypores described by E.J.H. Corner from Asia and West Pacific Areas VI. Species described in *Tyromyces* (3), *Cristelloporia*, *Grifola*, *Hapalopilus*, *Heterobasidion*, *Ischnoderma*, *Loweporus*, and *Steccherícium*. *Mycoscience* 44: 453e463. https://doi.org/10.1007/s10267-003-0139-7
Hattori, T. 2005a. Type studies of the polypores described by E.J.H.Corner from Asia and West Pacific Areas VII. Species described in *Trametes* (1). *Mycoscience* 46: 303e312. https://doi.org/10.1007/s10267-005-0250-z
Hattori, T. 2005b. Diversity of wood-inhabiting polypores in temperate forests with different vegetation types in Japan. *Fungal Diversity* 18: 73e88.
Hattori, T. and Lee, S.S. 2003. Community structure of wood-decaying Basidiomycetes in Pasoh. In *Pasoh: Ecology of a Lowland Rain Forest in Southern Asia*, T. Okuda, N. Manokaran, Y. Matsumoto, K. Niiyama and S.C. Thomas (Eds.), pp. 163–170. Tokyo: Springer. https://doi.org/10.1007/978-4-431-67008-7_12
Hattori, T., Kozue, S., Ota, Y., Thi B.K., Lee, S.S. and Baharuddin, S. 2011. *Postia stellifera* sp. nov., a stipitate and terrestrial polypore from Malaysia. *Mycotaxon* 114(1): 151–161.
Hattori, T., Noraswati, M.N.R. and Salmiah, U. 2007. Basidiomycota: Diversity of Malaysian polypores. *Malaysian Fungal Diversity*: 55–68.
Hattori, T., Yamashita, S. and Lee, S.S. 2012. Diversity and conservation of wood-inhabiting polypores and other aphyllophoraceous fungi in Malaysia. *Biodiversity and Conservation* 21(11): 2721–2738.

Hattori, T., Akiba, M., Ota, Y., Mohd-Farid, A., Thi, BK. and Lee, S.S. 2025. Taxonomic reevaluation on *Pyrrhoderma* (Basidiomycota, Hymenochaetales) and reclassification of *Pyrrhoderma* species based on phylogenetic and type studies. *Mycoscience* 66(1): 88–108.

Jaya Seelan, S.S., Ahmad, A.H., Sepiah, M. and Tan, P.E. 2014. Biodiversity inventory of macrofungi at Sungkai Wildlife Reserve, Perak, Malaysia. *Journal of Wildlife and Parks* 27: 17–24.

Jones, E.B.G., Alias, S.A. and Pang, K.L. 2013. Distribution of marine fungi and fungus-like organisms in the South China Sea and their potential use in industry and pharmaceutical application. *Malaysian Journal of Science* 32 (SCS Special Issue): 95–106.

Jones, E.B.G. and Kuthubutheen, A.J. 1989. Malaysian mangrove fungi. *Sydowia* 41: 160–169.

Jones, E.B.G. and Tan, T.K. 1987. Observations on manglicolous fungi from Malaysia. *Transactions of the British Mycological Society* 89: 390–392.

Kin, P.K, Azmi, W.A., Kamarudin, N., Ali, S. and Moslim, R. 2017. The occurrence of entomopathogenic fungi on mineral and peat soils in Peninsular Malaysia. *American Journal of Agricultural and Biological Sciences* 12: 1–12.

Kohlmeyer, J. 1969. Ecological notes on fungi in mangrove forests. *Transactions of the British Mycological Society* 53: 237-250.

Lee, S.S. 1995. Fungi – Mushrooms. In *A Guidebook to Pasoh*, S.S. Lee (Ed.), pp.66–72. *FRIM Technical Information Handbook No.3*. Kepong: Forest Research Institute Malaysia.

Lee, S.S. 2005. Macrofungal diversity in Peninsular Malaysia focusing on the ectomycorrhizal fungi. *Clusiana* 44(1-2): 57–66.

Lee, S.S. 2017. *A Field Guide to the Larger Fungi of FRIM*. *Research Ramphlet No. 135*. Kepong: Forest Research Institute Malaysia. 174pp.

Lee, S.S., Alexander, I.J. and Watling, R. 1997. Ectomycorrhizas and putative ectomycorrhizal fungi of *Shorea leprosula* Miq. (Dipterocarpaceae). *Mycorrhiza* 7(2): 63-81.

Lee, S.S., Chang, Y.S. and Noraswati M.N.R. 2009. Utilization of macrofungi by some indigenous communities for food and medicine in Peninsular Malaysia. *Forest Ecology and Management* 257(10): 2062–2065. https://doi.org/10.1016/j.foreco.2008.09.044

Lee, S.S., Watling, R. and Yahya, N.S. 2002. Ectomycorrhizal basidiomata fruiting in lowland rain forests of Peninsular Malaysia. *Bois et Forêts des Tropiques* 274(4): 33–43.

Lee, S.S., Watling, R. and Turnbull, E. 2003. Diversity of putative ectomycorrhizal fungi in Pasoh Forest Reserve. In *Pasoh: Ecology and Natural History of a Southeast Asian Lowland Tropical Rainforest*, T. Okuda, N. Manokaran, Y. Matsumoto, K. Niiyama, S.C. Thomas and P.S. Ashton (Eds.), pp. 149–159. Tokyo: Springer-Verlag.

Lee, S.S., Alias, S.A., Jones, E.G.B., Zainuddin, N. and Chan, H.T. 2012. *Checklist of fungi in Malaysia. FRIM Research Pamphlet No. 132*. Kepong: Forest Research Institute Malaysia.

Mohd Salleh, S., Thi, B.K. and Patahayah, M. 2020. *Spongispora temasekensis* G. Wu, S.M.L. Lee, E. Horak & Zhu L. Yang. Malaysia Biodiversity Information System (MyBIS). https://www.mybis.gov.my/art/288

Mohd Zainudin, N.A.I., Rosli, M.N.H., Wan Ahmad Kamal, W.H.A-S., Azahar, N., Nordin, N.A., Salleh, S., Yusof, M.T. and Ikhsan, Z. 2025. Microfungi associated with leaf spot of cocoa in Pahang, Malaysia. *Jurnal Riset Perkebunan* 6(1): 36–44.

Mridu, Atri, N.S. and Kumar, J. 2024. Impact of climatic variations on fungi, mycorrhiza and lichens –an appraisal. *Current Research in Environmental & Applied Mycology (Journal of Fungal Biology)* 14(1): 89–107. https://doi.org/10.5943/cream/14/1/5

Noman, E.A., Al-Gheethi, A.A., Talip, B.A., Mohamed, R.M.S.R., Almoheer, R., Al-Wrafy, F.A., Al-Shorgani, N. and El Enshasy, H.A. 2023. New fungal strains from peat soil in Malaysia: Morphological and Molecular Characteristics. *Sustainability* 15: 5902. https://doi.org/10.3390/su15075902

Noorlidah, A., Vikineswary, S., Yusoff, M. and Desjardin, D. E. 2005. Higher fungi of northeast Langkawi. *Malaysian Journal of Science* 24: 95–102.

Nur Amirah Sakinah, M.S.F., Nur Amalina, M.I., Farah Ayuni, F., Nurul Farizah, A., Hafizi, R. and Nor Azliza, I. 2023. Diversity and ecological roles of macrofungi within UiTM Jengka, Pahang, Malaysia. *Bioresources and Environment* 1(3): 1–13.

Nur Aqilah, M.B., NurJannah, S., Salleh, S., Thi, B.K., Ahmad Fitri, Z., Mohd Khairul Faizi, M., Haja Maideen, K.M. and Nizam, M.S. 2020. Elevation influence the macrofungi diversity and composition of Gunung Korbu, Perak, Malaysia. *Biodiversitas* 21: 1707–1713.

Ono, Y., Baharuddin, S. and Izumi, O. 2023. Additional records of rust fungi (Pucciniales) in Peninsular Malaysia and Penang Island. *Bulletin of the College of Education, Ibaraki University (Natural Science)* 72: 77–94.

Qu, X., Li, X., Bardgett, R.D., Kuzyakov, Y., Revillini, D., Sonne, C., Xia, C. *et al.* 2024. Deforestation impacts soil biodiversity and ecosystem services worldwide. *Proceedings of the National Academy of Sciences of the United States of America* 121(13): e2318475121. https://doi.org/10.1073/pnas.2318475121

Radu, S. and Cheah, Y.K. 2002. Preliminary screening of endophytic fungi from medicinal plants in Malaysia for antimicrobial and antitumor activity. *Malaysian Journal of Medical Science* 9(2): 23–33.

Rillig, M.C. 2026. Fungal diversity, ecology and functions in soil ecosystems. *Nature Reviews Microbiology* 2026: 01321. https://doi.org/10.1038/s41579-026-01321-y

Saccardo, P.A. 1882–1931. *Sylloge fungorum omnium hucusque cognitorum*. 25 vols. Patavii (Padua): Sumptibus auctoris.

Shahbaz, M., Chong, K.P., Abdullah, S. and Jaya Seelan, S.S. 2026a. Entomopathogenic fungi as potential biological control agents against basal stem rot in oil palm plantations of Sabah, Malaysia. *Scientific Reports* 16: 20070.

Shahbaz, M., Mohadden, F.Z., Jeremiah Sia, Y.R., Yap, J.W. & Jaya Seelan, S.S. 2026b. Taxonomy and phylogeny of *Pleurocordyceps* (Polycephalomycetaceae, Hypocreales) associated with ants and cicadas from Malaysia, including a new species and new records. *Phytotaxa* 750(4): 219–237. https://doi.org/10.11646/phytotaxa.750.4.1

Show, P.L., Oladele, K.O., Siew, Q.Y., Aziz Zakry, F.A., Lan, J.C.W. and Ling, T.C. 2015. Overview of citric acid production from *Aspergillus niger*. *Frontiers in Life Science* 8(3): 271–283. https://doi.org/10.1080/21553769.2015.1033653

Simon, E., Martina, P., Christoph, B., Werner, S. and François, A. 2006. Mushroom picking does not impair future harvests - Results of a long-term study in Switzerland. *Biological Conservation* 129: 271–276. https://doi.org/10.1016/j.biocon.2005.10.042

Tan, C.S., Ng, S.T. and Tan, J. 2013. Two new species of *Lignosus* (Polyporaceae) from Malaysia — *L. tigris* and *L. cameronensis*. *Mycotaxon* 123: 193–204.

Tang, L.P., Lee, S.S., Zeng, N.K., Cai, Q., Zhang, P. and Yang, Z.L. 2017. Notes on *Amanita* section *Caesareae* from Malaysia. *Mycologia* 109(4): 557–567. https://doi.org/10.1080/00275514.2017.1394789

Thi, B.K. 2013. Inventory of macrofungal diversity of Sungai Enam Basin at Temengor Forest Reserve, Perak. *Proceedings of the 2nd Temengor Scientific Expedition 2012*, pp. 171–178. Perak: Pulau Banding Foundation.

Thi, B.K. 2025. Macrofungal Diversity at Endau Rompin National Park. Paper presented at Johor National Park, 31 October 2025.

Thi, B.K. and Jing, Y. 2025. Preliminary findings on the study of mycorrhizal fungi community structure in *Eucalyptus* hybrid plantation forest (*E. grandis* x *E. urophylla*). Paper presented at Sino-ASEAN Network of Forestry Research Institutes (SANFRI): The fourth Early Career Academics Forum. Impiana KLCC Hotel. 3-5 December 2025.

Thi, B.K. and Lee, S.S. 2008. Survey of macrofungi at Gua Bewah and Sungai Cicir, Terengganu National Park. In Biodiversity Resources and Conservation Status in Peninsular Malaysia, E. Sivananthan, Y. Siti Hawa, A.B. Abu Kadir, Hasdi Hassan, B.L. Lim, H. Rosli, A. Noorlidah, M.N. Shukor and I. Rahman (Eds.), pp. 155–162. Kuala Lumpur: Department of Wildlife and National Park.

Thi, B.K. and Lee S.S. 2010. Macrofungi of Fraser's Hill: Part 1. *Conservation Malaysia: A Bulletin Supporting Plant and Animal Conservation in Malaysia* 11: 6–8.

Thi B.K. and Lee S.S. 2010. A survey of macrofungi at Sungai Kejar, Taman Diraja Belum, Gerik, Perak. In *Proceeding of National Biodiversity Seminar 2008*, Y. Mohd Nawayai, M.N. Shukor, I. Rahmah, S.M.K. Syarifah Khadiejah, M. Mohd Rufino Baipura and T.S. Frankie (Eds.), pp. 155–162. Cheras: Department of Wildlife and National Park.

Thi, B.K. and Lee, S.S. 2017. Diversity of macrofungi at Gunung Ledang Johor National Park. In *Gunung Ledang: Geology, Biodiversity and Socio-economic Environment*, B. Ahmad Naqiyuddin, A. Abdul Rauf, M.Y. Farida Zuraina, H.R. Singh and L. Tokiman (Eds.), pp.71–75. Shah Alam: Penerbit Press Universiti Teknologi Mara.

Thi, B.K., Ho, W.M. and Thooyavan, S. 2018. White parasol: a new fungus record for Malaysia. *Conservation Malaysia: A Bulletin Supporting Plant and Animal Conservation in Malaysia* 28: 4–5.

Thi, B.K., Lee, S.S., Zainuddin, N. and Chan, H.T. 2011. *A Guidebook to the Macrofungi of Fraser's Hill (Siri Alam dan Rimba No.14)*. Kepong: Forest Research Institute Malaysia.
Thi, B.K., Mohd Salleh, S. and Noorsiha, A. 2020. *Climacodon sanguineus* (Beeli) Maas Geest. Malaysia Biodiversity Information System (MyBIS). https://www.mybis.gov.my/art/287
Tsia, M.K. and Aqilah, M. 2019. Macrofungi of Pulau Bidong. *Universiti Malaysia Terengganu Journal of Undergraduate Research* 1(2): 26–35.
Yamashita, S., Hattori, T., Okabe, K. and Lee, S.S. 2015. Estimating the diversity of wood-decaying polypores in tropical lowland rain forests in Malaysia: the effect of sampling strategy. *Biodiversity Conservation* 24: 393–406. https://doi.org/10.1007/s10531-014-0815-2
Yazid, S.N.E., Jinap, S., Ismail, S.I., Magan, N. and Samsudin, N.I.P. 2020. Phytopathogenic organisms and mycotoxigenic fungi: Why do we control one and neglect the other? A biological control perspective in Malaysia. *Comprehensive Reviews in Food Science and Food Safety* 2020: 1–27.
Zainudin, N., Alias, S.A. and Jones, E.B.G. 2007. Frequency of occurrence of marine fungi from Malaysian mangroves. In *Innovations and Technologies in Oceanography for Sustainable Development*, S.M. Phang, V.C. Chong, A. Hussin, S.A. Alias and S.C. Ho (Eds.), pp. 269–280.
Zainuddin, N., Lee, S.S., Chan, H.T. and Thi, B.K. 2010. *A Guidebook to the Macrofungi of Tasik Bera (Siri Alam dan Rimba No.13)*. Kepong: Forest Research Institute Malaysia.
Zhao, H., Yuan, H.S., Cui, Y.J., Wang, K., Wu, F., Dai, Y.C. and Yuan, Y. 2026. Global polypore diversity and distribution patterns. *Fungal Diversity* 136: 136002. https://doi.org/10.65390/fdiv.2026.136002

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CHAPTER 2

DNA barcoding, taxonomy, and IUCN updates on Malaysian fungal biodiversity

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Abstract: The island of Borneo, renowned for its unparalleled biodiversity, is home to a vast array of mushroom species that have remained understudied, despite their ecological, economic, and medicinal significance. Fungi play crucial roles in understanding the health of forest ecosystems, from decomposing organic matter to forming symbiotic relationships with other lifeforms, while mushroom species essentially provide support for food, medicine, and bioactive compounds. However, the process to identify and catalogue Borneo's unique fungi at present is often plagued with challenges, from inadequate support towards research and development, human resources capital for mycological expertise, and compounded by the present threat of deforestation and habitat loss. To uncover the potential of Borneo's fungal diversity, a collaborative and multidisciplinary approach is presently vital, especially involving taxonomic studies for identification for species, exploring greater nuance for its ecological research, while understanding their symbiotic roles, and the optimisation towards innovative biotechnological exploration. Borneo has the potential to develop a thriving mushroom industry, contributing significantly to the wealth and prosperity of its people, benefited by its many diverse local traditional communities, as this will be a unique proposition for future generations. The journey to fully understand and harness the potential of Borneo's mushrooms is remaina journey far from complete, but with concerted effort, holds immense promise for science, society, and the environment.

INTRODUCTION

Fungi form an extremely diverse group of organisms. They occur everywhere—not only in forests, but also in urban environments, beaches, mangroves, and even inside other living organisms. Without fungi, ecosystems would function differently, and yet fungi do not receive as much research attention and funding compared to flora and fauna.

People associate fungi mainly with mushrooms—the fruiting bodies that can be seen to the naked human eye. However, most fungi occur within soil, substrates, plants, animals, and other organisms. They are able to interact with plants and animals and form highly diverse ecological networks. Other than mushrooms, fungi exist as moulds, yeasts, and many microscopic forms, only observed via specialised equipment. It is these microscopic fungi that are the most visually striking, where they may stand individually or in clusters, some with unique colouration, forms, and shapes. And yet they often go unnoticed by the public, owing to their often diminutive stature.

Many fungi are beneficial to humans, while some can be harmful. They function as important natural recyclers, contributing greatly to nutrient cycling and decomposition. Decomposition is closely linked to carbon processes, yet fungal contributions to carbon dynamics remain an area that requires more research studies. Fungi also form partnerships with plants and animals that can be beneficial, neutral, or even harmful.

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A common example of this interaction is the relationship between nitrogen-fixing microbes, fungi, and plant roots. In this relationship, atmospheric nitrogen is too stable to be utilised by plants, instead nitrogen-fixing microbes convert atmospheric nitrogen, N_2 into ammonia, NH_3, which can readily be absorbed by the plant. Fungi, on the other hand, can form minute tendrils that spread through the soil, transporting nutrients, such as phosphorus, and moisture to the plant. In return, the plant provides sugars, lipids, and amino acids, complimenting the nutritional needs of the microbes and fungi (Liu-Xu *et al.* 2024).

On the other hand, the planet's warming atmosphere and its effects in shifting weather patterns, especially due to increased rainfall may have negative implications for fungi species that are deleterious. The warmer climate enables the proliferation of various fungi species into uncharted territory, and along with it, fungal diseases that may impact previously safe species. For example, amphibians in the warming Palaearctic are facing increasing vulnerability to the fungal pathogen *Batrachochytrium salamandrivorans* (Luedtke *et al.* 2023). Closer to home, Malaysian vegetable farmers may be adversely impacted by fungal pathogens such as *Pythium* spp., *Phytophthora* spp., and *Fusarium* spp., which thrives in waterlogged soils, arising from frequent rainfall. Besides the immediate livelihood concerns, fungal pathogens in a warming climate pose risks to a nation's food sovereignty and biodiversity health as well (Abd Murad and Mohd Zainudin 2017).

Global estimates of fungal species diversity have increased substantially over time. Earlier estimates suggested approximately 1.5 million fungal species (Hawksworth 2001), while recent estimates have proposed several million species worldwide (Hawksworth and Lücking 2017). Only a relatively small proportion of this has been formally described, amounting to approximately 205,000 species (Royal Botanic Gardens, Kew 2026).

HISTORY OF MYCOLOGY RESEARCH IN SABAH

The earliest fungal documentations and collections in Borneo were made in Sarawak by Odoardo Beccari during his first expedition to this region, between 1865 and 1868 (Cesati 1879). In Sabah (formerly North Borneo), early systematic mycological work began later, primarily undertaken in the 1950s. However, the earliest collections were generally deposited in overseas herbaria rather than in local collections. Between the 1950s and 1960s, Professor E.J.H. Corner, who travelled extensively around the Mount Kinabalu region, had collected fungal specimens (Corner 1964). Some of these collections are now kept in Singapore, Edinburgh, and in the Kew Gardens. Historically, knowledge of Borneo's macrofungi was mainly recorded from Corner's studies. Later regional documentation was featured in David Pegler's *The Large Fungi of Borneo* (Pegler 1997).

Most of the earlier specimens were identified using traditional morphological taxonomy. Consequently, many organisms were classified as varieties rather than distinct species. Today, mycologists aim to revisit and revise these historical collections. Unfortunately, some specimens are missing or their locations are uncertain. Nevertheless, researchers can return to clarify the scientific descriptions and to determine what species were documented in the past, which may represent new species, and which are new records for particular regions.

In recent years, extensive survey and documentation of macrofungi were carried out during expeditions to forests and other conservation areas in Sabah, including the Taman Botanikal Sepilok Forest Reserve, Kadamaian Forest, Imbak Canyon Conservation Area, Danum Valley Conservation Area, Tawau Hills Park, Mount Kinabalu, and limestone caves in Sabah (Paul *et al.* 2019; Subari *et al.* 2020; Mohammad Hafiz Syukri *et al.* 2020; Dukit *et al.* 2024; Ibrahem *et al.* 2024, Lim and Jaya Seelan 2024), all these have significantly

expanded our understanding of Bornean fungal diversity. At present, several guidebooks have documented the macrofungal diversity of Sabah (Pegler 1997; Piakong *et al.* 2018; Jaya Seelan and Yap 2026).

DNA BARCODING AND FUNGAL RESEARCH IN SABAH

Significant knowledge gap exists for tropical fungi within the region, with many taxa awaiting molecular DNA barcoding. Recent molecular studies are increasingly relying on ribosomal DNA (rDNA) sequencing, specifically targeting the Internal Transcribed Spacer (ITS) region, which serves as the DNA barcode for fungi, and this has helped resolve species complexes. As examples, Jaya Seelan *et al.* (2015), Lim and Jaya Seelan (2024), as well as Dukit and Jaya Seelan (2024) had revised and updated the species information for some of the Bornean macrofungi, particularly Polyporaceae, Panaceae, and *Cantharellus cuticulatus* using molecular approaches.



Figure 1. *Cantharellus cuticulatus*. Scale bar = 20mm. Photo by Aderina Dukit.

The Institute for Tropical Biology and Conservation (ITBC) at Universiti Sabah Malaysia (UMS) employs an integrative taxonomic approach that combines traditional taxonomy and morphology with specimen collections. Morphological descriptions, observations, notes, and distinguishing characteristics are carefully documented and integrated with molecular identification. DNA-based approaches enable the investigation on phylogenetic and evolutionary relationships among the fungal species.

More recently, ITBC have significantly worked on developing new approaches involving chemotaxonomy, which uses chemical characteristics as additional taxonomic markers. For instance, one mushroom species may contain particular bioactive compounds that are absent from another species. Combining these morphology, molecular information, phylogeny, and chemistry gives us a much stronger basis for identifying and differentiating lineages.

One of the case studies in the long-term fungi monitoring and research in Sabah involves *Chlorogaster dipterocarpi*, a new gasteroid fungus species collected in a dipterocarp forest in Sabah (Læssøe and Jalink 2004). This species has been tracked by ITBC for almost 12 years. Characterised by its distinctive durian-like appearance and striking green colouration, the fungus is a particularly notable organism of Sabah's forest biodiversity. Based on these observations, the species appears to be endemic to Sabah. Its populations have been monitored from several locations, particularly in south-western Sabah, including key conservation areas such as Danum Valley and Tawau. This long-term monitoring provides valuable information on the species distribution, contributing to a better understanding of its ecology and informing future conservation assessments to these areas.

Another significant find in this region, is the Spongiforma squarepantsii, which was first discovered in Lambir Hills National Park in Sarawak. It gained popularity because of its resemblance to a cartoon character, SpongeBob SquarePants. The species belongs to a bolete-related group and forms an ectomycorrhizal relationship with forest trees, particularly dipterocarps. These fungi have a symbiotic or mutualistic association with their host trees. The Bornean species has distinctive characteristics and differ from similar-looking species reported from Peninsular Malaysia and Thailand. This highlights an important taxonomic significant difference: whereby the organisms that look similar may actually represent or belong to a different species.

The common cup fungi is another example which is commonly encountered in the forests. Despite their apparent abundance, these fungi harbour a surprising vast diversity. Studies have revealed cryptic species and new records. *Cookeina sinensis* is reported as a new record from Malaysia, and was collected for the first time from Sabah (Subari *et al.* 2022). Asian specimens display considerable variation in colour and morphology, while specimens from subtropical and tropical regions, such as Mexico, Suriname, and Brazil may represent other forms or species. Only a handful of species had ever been recorded in Malaysia. Morphological and phenotypic variation makes it difficult to determine whether specimens belong to the same species or a different species. Only through molecular evidence enables us to separate some of these groups into distinct lineages, and to be recommended formally as new species.

A newly described macrofungus species, *Calocybe kinabaluensis*, was collected from the Kinabalu UNESCO Global Geopark in Sabah. This species is distinguished by its deep blue to indigo-blue cap, and whitish to pale cream gills. This extraordinary species has placed the region's significance for its fungal biodiversity.

Medicinal and edible fungi

A well-known example of medicinal fungi is the tiger milk mushroom. Many people became familiar with this mushroom through its commercial use in supplements, particularly for respiratory health. It is also regarded as an important medicinal mushroom in Malaysia. In Peninsular Malaysia, some populations may be threatened because habitats where the mushroom was historically recorded have experienced deforestation and development. In Borneo, populations may still occur in relatively intact habitats, although information on their distribution has historically been limited.

Research by ITBC examined the species present in Borneo and compared them with those in Peninsular Malaysia. *Lignosus hainanensis* was also identified as an additional record related to a species previously reported from China (Chong *et al*. 2024). The phenology of these mushrooms was observed in order to better understand when they occur. Their underground structures are also important taxonomic characteristics that are difficult to

appreciate unless researchers observe the fungi directly in the field. In addition to field-based research, the laboratory has also successfully cultivated certain species using agricultural cultivation approaches. One objective is to increase the size and biomass of the cultivated fungi. Larger fruiting bodies can potentially increase their economic value.



Figure 2. *Lignosus hainanensis* collected in Sabah. Scale bar = 1 cm.

An example of an edible mushroom used by local communities in Sabah is *Pleurotus tuber-regium*. There has been taxonomic uncertainty because similar fungi occur in Africa and Asia. The African form possesses a tuber-like structure, whereas the Asian form appears to differ morphologically. This suggests that what was once regarded as a single species may actually represent a different species. Some of these mushrooms have also shown potential bioactive compounds, including possible anti-nematode properties.

Another interesting group of fungi is the *Amauroderma* spp., which have been traditionally associated with treatments for epilepsy. Orang Asli communities in Peninsular Malaysia have traditionally used these for medicinal and traditional purposes. Specifically, it is used to prevent fits, with the traditional preparation requiring the mushroom's hollow stipe (stem) to be worn around the neck (Chang and Lee 2004). To investigate these mushrooms scientifically, research is being conducted by ITBC to identify whether specimens identified as *Amauroderma* represent a single species or several species. Preliminary findings indicate substantial variation, with different forms potentially representing distinct species. Several may still require formal description.

Hericium coralloides, also known as coral tooth mushroom, was recorded for the first time in Sabah. This fungus produces bioactive compounds (e.g. hericonones, polysaccharides, erinacines) with antioxidant, immunomodulatory, cytotoxic, and neuroprotective properties, including potential therapeutic applications for age-related immune decline and Alzheimer's disease.



Figure 3. Coral-like, branched fruiting body of *Hericium coralloides*.

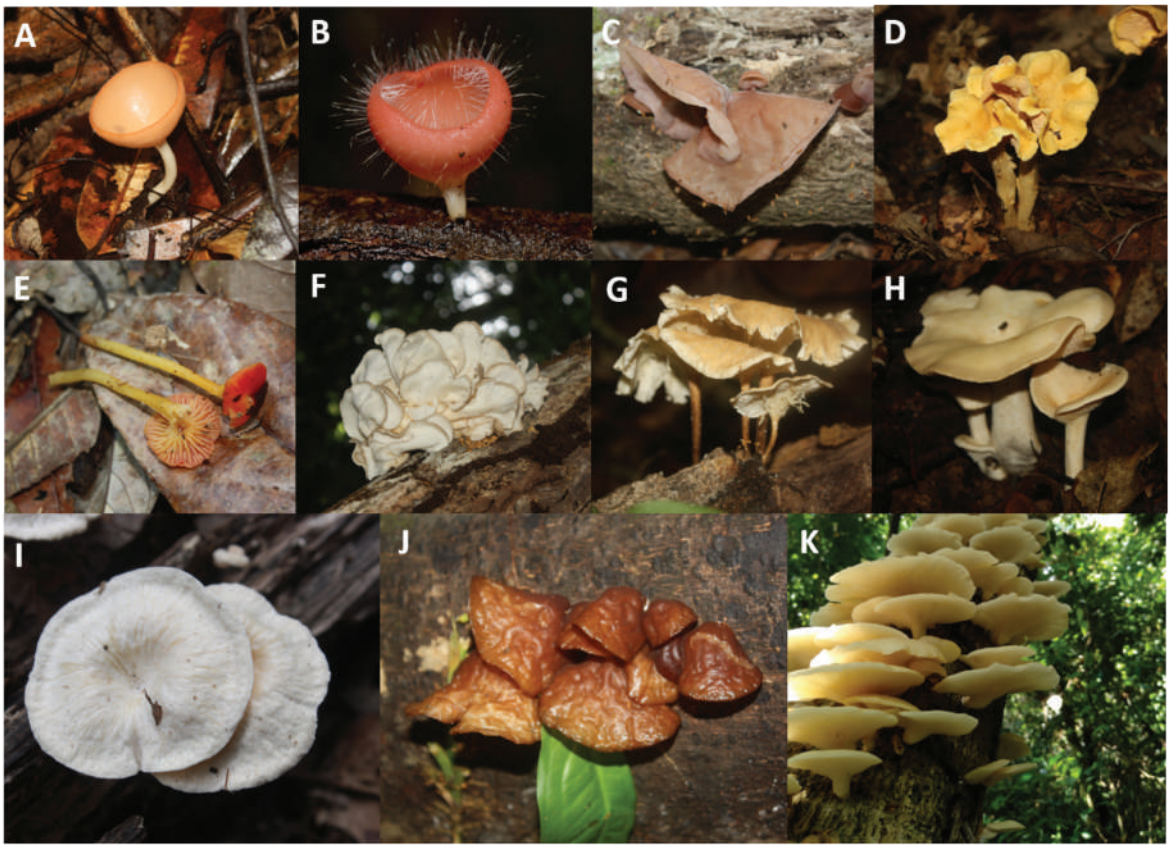

Figure 4. Wild edible mushrooms species found in Imbak Canyon Conservation Area, Sabah. **A.** *Cookeina sulcipes*; **B.** *Cookeina tricholoma*; **C.** *Auricularia polytricha*; **D.** *Chantarellus* sp.; **E.** *Hygrocybe miniata*; **F.** *Pleurotus* sp.; **G.** *Pleurotus tuberregium*; **H.** *Hydnum* sp.; **I.** *Lentinus squarrosulus*; **J.** *Auricularia delicata*; and **K.** *Favolus* sp.

"Zombie fungi"

Entomopathogenic fungi, commonly referred to as "zombie fungi", are parasitic fungi associated with insects and other arthropods. These fungi have attracted broader public attention through portrayals in popular media such as the American television serial, *The Last of Us*. In nature, they are extraordinary organisms that exhibit remarkable biological adaptation that allows them to infect, kill, and in some cases, manipulate their hosts. At the same time, they may contain compounds or ecological properties that could be useful to humans. Many entomopathogenic fungi are highly host-specific. Different ant species, for example, may be infected by different fungal species. Other fungi may specialise to target beetles, cicadas, spiders, or other hosts. These fungi potentially contain compounds with antifungal, antibacterial, and biocontrol properties.

Tropical regions harbour high entomopathogenic fungi diversity and abundance. However, there are limited studies on entomopathogenic fungi in Borneo. In Sarawak, Lavery *et al.* (2021) investigated the spatial dynamics of ants infected by *Ophiocordyceps unilateralis* in Gunung Mulu National Park, Sarawak, Borneo, and found that the height at which infected ants are located is driven by microclimatic conditions that optimise fungal growth and spore release. Moreover, recent inventories in Sabah's conservation areas, including Mount Kinabalu, Danum Valley, and Maliau Basin have established the baseline for entomopathogenic fungi diversity in Borneo.

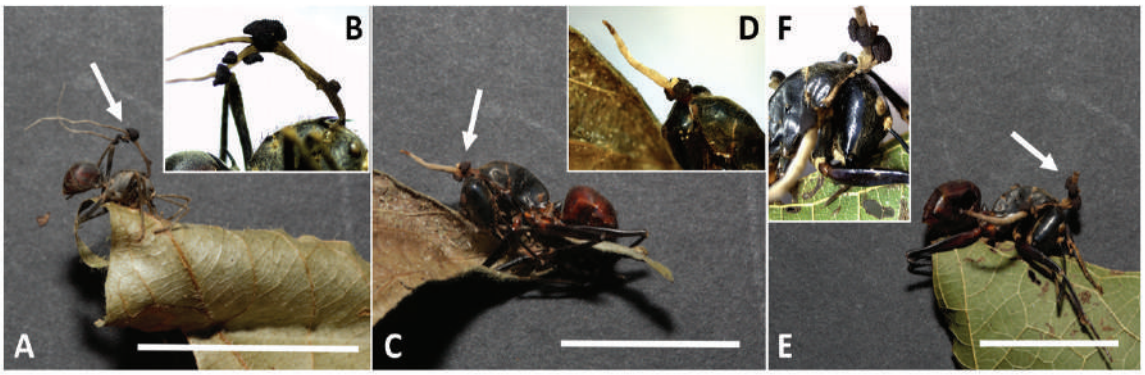

Figure 5. *Ophiocordyceps unilateralis* complex. **A.** Stroma arising anteriorly from the pronotum of ant, firmly attached on the edge of leaf; **B.** The fruiting body of fungus with a few perithecia on the stroma (white arrow); **C.** Single stroma arising anteriorly from the pronotum of ant attached on the edge of leaf; **D.** Single perithecia close to the dorsal pronotum of ant; **E.** Two stroma grew from the dorsal pronotum of the ant attached on the edge of the leaf; and **F.** Perithecia on stroma. Scale bars = 1 cm.

Recent studies in Sabah revealed several notable additions to Malaysia's fungal diversity. Shahbaz *et al*. (2026a) documented five entomopathogenic fungi species for Borneo, including *Cordyceps jakajanicola*, *C. tenuipes*, *Blackwellomyces calendulinus*, *Purpureocillium lilacinum*, and *Simplicillium formicae* in oil palm plantation of Sabah. Four new species of entomopathogenic fungi for Malaysia are Leptobacillium geminatum (Shahbaz *et al.* 2026b), *Akanthomyces infaproensis* (Shahbaz *et al.* 2026c), *Metarhizium tawauensis* (Shahbaz *et al.* 2026d), *Pleurocordyceps cornusynnemata* (Shahbaz *et al.* 2026e), were discovered in Sabah. In addition to these new species, six new records for Malaysia were reported, such as, *Simplicillium formicae* (Shahbaz *et al.* 2026a), *Leptobacillium leptobactrum*. *Leptobacillium symbiotic*, and *L. coffeanum* isolated from spiders, *Simplicillium puwenense*, isolated from a wasp (Shahbaz *et al.* 2026b) and *Pleurocordyceps aurantiaca*, isolated from Diptera (Shahbaz *et al*. 2026e) collected from Sabah. Of these, *Simplicillium formicae* (Shahbaz *et al.* 2026a), *S. puwenense* (Shahbaz *et al*. 2026b) and *Pleurocordyceps cornusynnemata* (Shahbaz *et al.* 2026e) are the hyperparasitic fungi infecting other entomopathogenic fungi.

Bioluminescent fungi

Bioluminescent fungi are well studied in Peninsular Malaysia, where approximately 20 species can be found (Chew *et al*. 2014; Thi and Siti Nuratikah 2025). However, no data are available for Borneo. Through the funding under the 12th Malaysia Plan, we were able to identify how many different groups of bioluminescent fungi are present in Borneo. Collaborations involving government agencies and the Sabah Forestry Department have enabled fungal surveys, expeditions, specimen collection, identification services, and investigations into potential bioprospecting value of mushrooms. Malaysia still has major gaps in fungal biodiversity information. There are many species proposed for assessment, but only a portion have been formally accepted and published through the IUCN process.

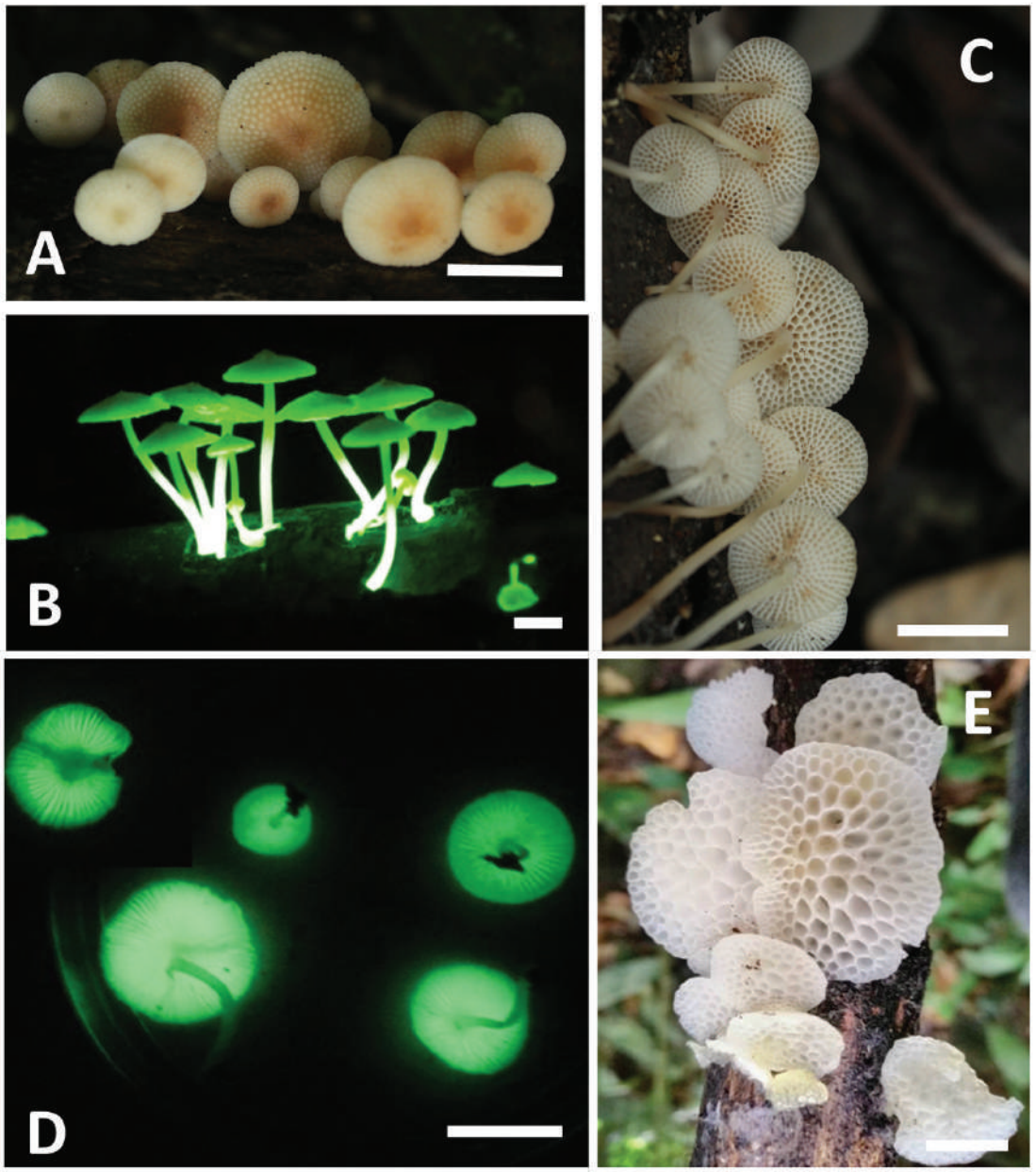

Figure 5. Bioluminescence mushrooms collected from Kadamaian Forest. **A-C**. *Filoboletus manipularis*, a convex, slightly umbonate pileus with hymenopores; **D.** *Mycena chlorophos*, pileus convex with striate margin and closed lamellae; and **E.** *Favolaschia cyatheae*. Scale bars = 1 cm.

Mycophagy

Fungi occurrence in the forest ecosystem contributes to the diets of other wildlife. For instance, the Asian brown giant tortoise (*Manouria emys*), was observed feeding on *Russula virescens* in Danum Valley Conservation Area (Jaya Seelan *et al.* 2025). Malaysian primates, such as the long-tailed macaque (*Macaca fascucularis*), Bornean Orangutan (*Pongo pygmaeus morio*), and the red langur (*Presbytis rubicunda*) includes fungi, albeit in extremely minute quantities, in their diets (Kanamori *et al.* 2010; Ruslin *et al*. 2018; Cheyne *et al.* 2019). Besides vertebrates, Malaysian insects, including beetles and grasshoppers are known to consume a variety of fungi species (Monk and Samuels 1990; Meghma Bera 2018). Mycophagy is a symbiotic relationship between the fungi and the fauna, where the fungi is able to disperse its spores through the feces of the fauna that consumes them and propagate the fungi to new territory, while the fauna is able to access nutrients that are made bioavailable through the decomposition of detritus.

FUNGI CONSERVATION IN MALAYSIA

Fungi conservation still requires continuous systemic biodiversity surveys, which not only covers monitoring of wild populations, but also broadening the existing fungi culture deposits. This will enormously build a comprehensive DNA barcode reference library (ITS and secondary markers). This improved baseline understanding of fungi in Malaysia, compliments the forest landscapes and ecological importance of the habitat in the region, factoring a zonation classification for national biodiversity and conservation plan and its policies.

At the same time, citizen science documentation of fungi can be promoted through platforms such as Malaysia Biodiversity Information System (MyBIS); especially for environmental education programmes in improving public awareness on the ecological importance of fungi. There is an urgent need to encourage inter-agency collaboration on species-specific conservation action plans for classifying rare, endemic, or threatened fungi.

Presently, the spores are in collections, and cultivated as germplasm or tissue cultures, which can be a repository for future studies and research use. However, this cryo-preservation comes with a high cost in maintaining it for a long run. An alternative method for this preservation is in urgent need to find an alternative, and as a result of the collection that has gathered approximately 2,400 cultures from edible and medicinal mushrooms, 800 cultures from limestone cave fungi, and about 1,000 cultures of entomopathogenic fungi. These samples are comprehensively studied at present, enabling future fungi researchers to explore how these mushrooms benefit human society at large.

Staff of Yayasan Sabah, Sabah Parks, Sabah Forestry, including rangers and guides have received training and knowledge on fungi. They, in turn, share their observation with the researchers, contributing to the existing knowledge bank on Bornean fungi. Borneensis Collection Centre is the primary repository for preserved fungi specimens in Sabah, serving as a major hub for fungi taxonomy and DNA studies.

Public engagement initiative via educational modules, outreach especially for children, on the importance and awareness of mushrooms has been promising. This is further incorporated into indigenous folklore and art projects, where children are able to interact closely with what they learnt about fungi, and transform that into simple and easy story narrative associating with fungi. Mushrooms Culinary of Sabah, is another project where students collect edible mushrooms, this activity was popular since during the COVID period. Fungi of Borneo Mushroom Art Exhibition was another major highlight using citizen science and drawing the public to contribute a collage of mushroom photographs. All these culminated into a book, in collaboration with Shangri-La Sabah.

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REFERENCES

Abd Murah, N.B. and Mohd Zainudin, N.A.I. 2017. Review of Fruit Rot Diseases of important tropical and some temperate fruit crops. *Pertanika Journal of Scholarly Research Reviews* 3(1): 138–156.

Bera, M. 2018. A report on the mycophagy in *Bolitotherus cornutus* (Panzer) from the tropical rain forest of Malaysia. *Ecology, Environment and Conservation* 24(3): 318–323.

Cesati, V. 1879. Mycetum in itinere Borneensi lectorum a Cl. Od. Beccari enumeratio curis Vincentii Cesati. *Atti dell' Accademia delle Scienze Fisiche e Matematiche di Napoli* 8(4): 1–28.

Chang, Y.S. and Lee, S.S. 2004. Utilisation of macrofungi species in Malaysia. *Fungal Diversity* 15(2): 15–22.

Chew, A.L.C., Desjardin, D.E., Tan, Y.S., Musa, M.Y. and Sabaratnam, V. 2015. Bioluminescent fungi from Peninsular Malaysia—a taxonomic and phylogenetic overview. *Fungal Diversity* 70(1): 149–187.

Cheyne, S.M., Adul, S., Wilcox, C.H., Cahyaningrum, E., Smith, Y.C.E., Smith, D.A.E. and Kulu, I.P. 2019. A short cut to mushrooms - Red langur (*Presbytis rubicunda*) consumption of terrestrial fungus. *Folia Primatol* 90: 190–198. https://doi.org/10.1159/000496146

Chong C., Tan Y.S. and Jaya Seelan, S.S. 2024. Discovery of a rare medicinal mushroom, *Lignosus hainanensis* (Polyporaceae, Basidiomycota) in Sabah (Northern Borneo), Malaysia. *Malayan Nature Journal* 76(3): 237–247. https://doi.org/10.62613/mnj.24763.03

Corner, E.J.H. 1964. Royal Society Expedition to North Borneo 1961. *Empire Forestry Review* 41(3, 109): 224–233.

Desjardin, D.E., Peay, K.G. and Bruns, T.D. 2011. *Spongiforma squarepantsii*, a new species of gasteroid bolete from Borneo. *Mycologia* 103(5): 1119–1123.

Dukit A. and Jaya Seelan, S.S. 2024. Taxonomic revision of *Cantharellus cuticulatus* Corner (Cantharellaceae, Basidiomycota) from Sabah (North Borneo), Malaysia. *Malayan Nature Journal* 76(3): 249–260.

Dukit, A, Subari, I.A.A.M.H, Lim J.Y. and Jaya Seelan S.S. 2024. Preliminary survey of the macrofungi of Marai Parai- Gurkha Hut, Kota Belud, Sabah. *Sabah Parks Nature Journal* 14: 87–100.

Foo, S.F., Fiffy, H.S., Julius, K. and Seelan, J.S.S. 2018. Distribution and ethnomycological knowledge of wild edible mushrooms in Sabah (Northern Borneo), Malaysia. *Journal for Tropical Biology and Conservation* 15: 203–222.

Hawksworth, D. and Lücking, R. 2017. Fungal diversity revisited: 2.2 to 3.8 million species. *Microbiology Spectrum* 5(4): 0052. https://doi.org/10.1128/microbiolspec.FUNK-0052-2016

Hawksworth, D.L. 2001. The magnitude of fungal diversity: The 1.5 million species estimate revisited. *Mycological Research* 105(12): 1422–1432.

Ibrahem, G.W., Tom, M.F, Jayaraj, V.K., Faisal, A.A.K. and Jaya Seelan S.S. 2024. Fungal community composition in arthropogenically-active and non-active northern Borneo caves. *Malayan Nature Journal* 76(3): 261–291.

Jaya Seelan, S.S. and Yap, S.W. 2026. *Fungi of Borneo: Exploring Fungal Diversity (Vol. 1)*. Kota Kinabalu: Institute for Tropical Biology and Conservation (ITBC), Universiti Malaysia Sabah.

Jaya Seelan, S.S., Alaia, I.A., Yap, S.W. and Das, I. 2025. *Manouria emys* (Asian Brown Giant Tortoise). Mycophagy. *Herpetological Review* 56(4): 431–432.

Jaya Seelan, S.S., Justo, A., Nagy, L.G., Grand, E.A., Redhead, S.A. and Hibbett, D. 2015. Phylo genetic relationships and morphological evolution in *Lentinus*, *Polyporellus* and *Neofavolus*, emphasizing southeastern Asian taxa. *Mycologia* 107(3): 460–474. https://doi.org/10.3852/14-084

Jaya Seelan, S.S., Vizzini, A., Wasti, I.G., Kasmin, J., Usimin, N.A.B. and Shahbaz, M. 2026. *Calocybe kinabaluensis* (Lyophyllaceae, Agaricales), a new species from Kinabalu UNESCO Global Geopark, Sabah, Northern Borneo, Malaysia. *Phytotaxa* 759(3): 227–244.

Kanamori, T., Kuze, N., Bernard, H., Malim, T.P. and Kohshima, S. 2010. Feeding ecology of Bornean Orangutans (*Pongo pygmaeus morio*) in Danum Valley, Sabah, Malaysia: A 3-year record including two mast fruitings. *American Journal of Primatology* 71(9): 820-840. https://doi.org/10.1002/ajp.20848

Læssøe, T. and Jalink, L.M. 2004. *Chlorogaster dipterocarpi*. A new peristomate gasteroid taxon of the Sclerodermataceae. *Persoonia* 18(3): 421–428.

Lavery, M., Murphy, C. and Bowman, E. 2021. Zombie ant graveyard dynamics in Gunung Mulu National Park. *Reinvention: an International Journal of Undergraduate Research* 14. https://doi.org/10.31273/reinvention.v14i1.704

Lim J.Y. and Jaya Seelan S.S. 2024. Revisiting Corner's *Panus* collections (Panaceae, Polyporaceae): Occurrence, taxonomic notes on *Panus similis* and the renaming of *Lentinus* to *Panus velutinus* in Malaysia. *Malayan Nature Journal* 76(3): 293–309.

Liu-Xu, L., González-Hernández, A.I., Camañes, G., Vicedo, B., Scalschi, L. and Llorens, E. 2024. Harnessing green helpers: Nitrogen-fixing bacteria and other beneficial microorganisms in plant-microbe interactions for sustainable agriculture. *Horticulturae* 10(6): 1–17. https://doi.org/10.3390/horticulturae10060621

Luedtke, J.A., Chanson, J., Neam, K., Hobin, L., Maciel, A.O., Catenazzi, A., Borzée, A. *et al.* 2023. Ongoing declines for the world's amphibians in the face of emerging threats. *Nature* 622: 304–314. https://doi.org/10.1038/s41586-023-06578-4

Mohammad Hafiz Syukri, K., Wasti, I.G., Subari, I.A.A.M.H., Ganesan, T.A., Tang, P.L., Chong, C.C., Subramaniam, N. and Jaya Seelan S.S. 2020. Macrofungi of Sungai Kangkawat Research Station, Imbak Canyon Conservation Area, Sabah, Malaysia. *Malayan Nature Journal* 72: 371–388.

Monk, K.A. and Samuels G.J. 1990. Mycophagy in grasshoppers (Orthoptera: Acrididae) in Indo-Malayan Rain forests. *Biotropica* 22(1): 16-21.

Paul, V., Tang P.L., Jocelyn, CIA, Aji, M., Chung A.Y.C. and Midin N. A preliminary checklist and notes on macrofungi from the Rainforest Discovery Centre, Sandakan, Sabah. *Sepilok Bulletin* 28: 1–17.

Pegler, D.N. 1997. *The larger fungi of Borneo*. Kota Kinabalu: Natural History Publications.

Piakong, M.T., Atong, M. and Nur Zaida Z. 2018. *Wild Fungi of Sabah: A Pictorial Documentation*. Kota Kinabalu: Universiti Malaysia Sabah.

Royal Botanic Gardens, Kew. 2026. *State of the World's Plants and Fungi 2026*. Royal Botanic Gardens, Kew. https://www.kew.org/sites/default/files/2026-06/State-of-the-World-s-Plants-and-Fungi-2026.pdf

Ruslin, F., Matsuda, I. and Md-Zain, B.M. 2018. The feeding ecology and dietary overlap in two sympatric primate species, the long-tailed macaque (*Macaca fascicularis*) and dusky langur (*Trachypithecus obscurus obscurus*), in Malaysia. *Primates* 60: 41–50. https://doi.org/10.1007/s10329-018-00705-w

Shahbaz, M., Chong, K.P, Syahriel, A., Kishneth, P. and Jaya Seelan, S.S. 2026a. Entomopathogenic fungi as potential biological control agents against basal stem rot in oil palm plantations of Sabah, Malaysia. *Scientific Reports* 16: 20070.

Shahbaz, M., Cheak, C.C., Wasti, I.G., Wai, Y.S. and Jaya Seelan, S.S. 2026c. *Akanthomyces infaproensis* sp. nov. (Cordycipitaceae, Hypocreales), a new entomopathogenic fungus from Sabah, Malaysian Borneo. *Phytotaxa* 772(2): 101–120.

Shahbaz, M., De Wint Frederik, C., Jeremiah Sia Y.R., Yap J.W, Koid Q., Fayle Tom, Tan Y.S., Abdullah S., Palaniveloo K. and Jaya Seelan S.S. 2026b. A new species of *Leptobacillium* and additional records of *Simplicillium* and *Leptobacillium* from Sabah, Malaysia. *New Zealand Journal of Botany* 64: e70107. https://doi.org/10.1002/nzb2.70107

Shahbaz, M., Mohadden, F.Z., Jeremiah Sia Y.R., Yap J.W. and Jaya Seelan, S.S. 2026e. Taxonomy and phylogeny of *Pleurocordyceps* (Polycephalomycetaceae, Hypocreales) associated with ants and cicadas from Malaysia, including a new species and new records. *Phytotaxa* 750 (4): 219–237. https://doi.org/10.11646/phytotaxa.750.4.1

Shahbaz, M., Wasti, I., Baluat, Z., Ling, E. and Jaya Seelan S.S. 2026d. *Metarhizium tawauensis* (Clavicipitaceae, Hypocreales), a new entomopathogenic fungus from Sabah, northern Borneo, Malaysia. *Phytotaxa* 763: 219–234. https://doi.org/ 10.11646/phytotaxa.763.3.2

Subari, I.A.A.M.H, Muhammad, S., Repin, R., Karim, R., Tan, Y.S. and Jaya Seelan S.S. 2025 First record of *Hericium coralloides* (Hericiaceae, Basidomycota): A coral tooth mushroom from Sabah (Northern Borneo), Malaysia. *Malayan Nature Journal* 77(4): 251–264.

Subari, I.A.A.M.H., Tang, P.L., Ibrahem, G.W., Chong, C.C., Dukit, A., Lim J.Y. and Jaya Seelan S.S. Distribution of macrofungi in Kadamaian, Kota Belud, Sabah (Malaysia). *Malayan Nature Journal* 74(4): 611–638.

Thi, B.K. and Siti Nuratikah, D. 2025, January 22. Bioluminescent fungi as a valuable natural heritage. *Dewan Kosmik*. https://dewankosmik.jendeladbp.my/2025/01/22/16162/

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CHAPTER 3

Bryophytes in Malaysia: Diversity and conservation

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Abstract: Bryophytes (mosses, liverworts, and hornworts) are a major component of tropical plant diversity, with Malaysia harbouring an estimated ca. 2,000 species and infraspecific taxa. Bryophyte research in Malaysia dates back to the 19th century and has since produced updated checklists, taxonomic revisions, and molecular studies, although many regions remain underexplored. A compilation of 196 selected bryophyte species, comprising 117 liverworts, 78 mosses and one hornwort, includes species known only from their type localities or a few collections, as well as species with restricted distributions and narrow geographical endemism. Sabah, especially Mount Kinabalu and surrounding highlands, is the main centre of this diversity and endemism, followed by Sarawak and the montane regions of Peninsular Malaysia. Despite this, formal conservation assessments are still largely lacking. Targeted field surveys and protection of key montane habitats are urgently needed to safeguard Malaysia's bryophyte diversity.

INTRODUCTION

Diversity of bryophytes in Malaysia

Bryophytes, comprising mosses (Bryophyta), liverworts (Marchantiophyta), and hornworts (Anthocerotophyta), represent the second largest lineage of land plants after the flowering plants (Magnoliophyta). Global estimates of bryophyte diversity range from about 15,000 species (Gradstein *et al.* 2001) to over 25,000 species (Crum 2001), with tropical rainforests harbouring the greatest richness. They flourish primarily in humid, mountainous forests, forming loose mats, dense cushions, or flattened patches on rocks, tree trunks, and leaves, while some species hang pendulously from branches in shaded forest canopies. Recent phylogenomic studies have shown that bryophytes form a monophyletic group, meaning they share a single common ancestor distinct from vascular plants (Harris *et al.* 2022; Bechteler *et al.* 2023; Li *et al.* 2023). This finding has reshaped our understanding of early land plant evolution, confirming that mosses, liverworts, and hornworts together represent the earliest diverging lineage of terrestrial plants.

Bryophytes in Malaysia have been collected since the 19th century, with an estimated total of 2000 species and infraspecific taxa recorded so far (Suleiman *et al.* 2006, 2024; Mohamed *et al*. 2011; Yong *et al.* 2013; Ellis *et al.* 2017 – 2025; Syazwana *et al.* 2025). Figure 1 shows the number of bryophyte species from each state in Malaysia.

The history of liverwort exploration in Malaysia was reviewed by Lee *et al*. (2018), describing its beginning in the early 19th century with the first collections from Penang Island by Nathaniel Wallich, followed by subsequent work by European botanists such as

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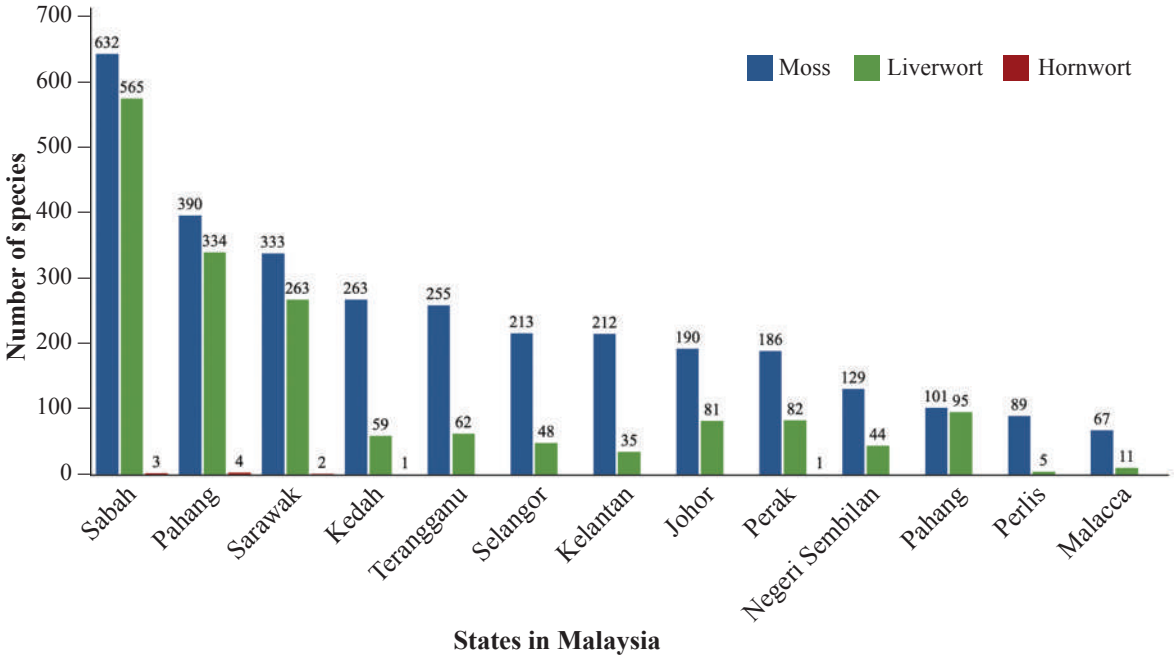

Figure 1. The number of bryophyte species reported from each state in Malaysia.

J.G.C. Lehmann and Franz Stephani. Liverwort research activity revived between 1950 and 2000, led mainly by Japanese bryologists whose extensive work, particularly on Mt. Kinabalu, resulted in many new species and genera (see references in Lee *et al*. 2018). Since 2000, local researchers have advanced the field through comprehensive checklists, taxonomic revisions, a guidebook to the genera, and molecular studies (e.g., Lee and Gradstein 2021; Lee *et al*. 2022a).

Similar to liverworts, moss exploration in Malaysia began in the 19th century, when Mitten (1859) reported early collections from Peninsular Malaysia made by Griffith and Wallich. The serious study of mosses in Peninsular Malaysia began with the English bryologist Hugh Neville Dixon (1861–1944), who examined specimens sent by collectors such as C.H. Binstead, H.N. Ridley, I.H. Burkill, and R.E. Holttum, and staff of the Singapore Botanic Gardens. Dixon described 46 new species in 18 genera and 11 families (Dixon 1924), and later listed 340 taxa in 87 genera and 28 families (Dixon 1926). Subsequent studies added many new records, leading to a comprehensive checklist of 475 taxa in 134 genera and 35 families (Mohamed and Tan 1988), later updated to 512 taxa in 158 genera and 46 families (Yong *et al.* 2013). Local bryologists, particularly A. Damanhuri made substantial contributions between 1990 and 2017, documenting numerous new records across diverse habitats in Peninsular Malaysia (e.g., Mohamad and Gidiman 1990; Damanhuri *et al.* 2017, see also Damanhuri's papers in Yong *et al*. 2013). In Malaysian Borneo, moss collections began with Hugh Low on Mount Kinabalu in 1851, followed by Odoardo Beccari in Sarawak (1865–1867) and Paul W. Richards (1932–1933). Mount Kinabalu attracted many foreign bryologists due to its wide elevational range, and Japanese expeditions between 1963 and 1969 yielded thousands of specimens and many new species. Local bryologists have been actively collecting in Borneo since the late 1980s and now play a key role in documenting moss diversity (e.g., Mohamed *et al.* 1992; Andi *et al.* 2015; Suleiman *et al.* 2024).

Distribution of bryophytes in Malaysia

Many bryophyte species in Malaysia exhibit highly restricted distributions and specific habitat requirements, highlighting their vulnerability to habitat disturbance and climate change. Based on the compiled checklist in Table 1, among 117 liverwort species, 42 are known only from their type localities, while another 28 are recorded from just 2 – 3 collections worldwide. Endemism is particularly high in Sabah, with over 30 species confined to a single mountain, mostly Mount Kinabalu (e.g., *Andrewsianthus kinabaluensis*, *Cololejeunea rosellata*, *Microlejeunea kinabaluensis*). Sarawak harbours around 15 liverworts restricted to Mount Dulit or nearby highlands, while Peninsular Malaysia supports 7 narrowly endemic species, mainly in highland forests such as Cameron Highlands, Genting Highlands, and Maxwell Hill (e.g., *Cololejeunea malayana*, *Mastigopelma latiffiana*). Several liverworts have a very limited range, confined to Malaysia, Indonesia, and Papua New Guinea (e.g., *Acrolejeunea crassicaulis*, *Cephalolejeunea parvilobula*, *Eotrichocolea furukii*).

Hornworts are extremely limited in Malaysia, with only six known species. *Dendroceros difficilis* is recorded only from its type locality in Indonesia and two highland sites in Peninsular Malaysia: Cameron Highlands and Fraser's Hill.

Among the 78 moss species (Table 1), several are known only from their type collections or have very limited records in Malaysia. These include *Cyclodictyon kinabaluense*, which is endemic to Mount Kinabalu, and *Macromitrium papillisetum*, which has not been recollected since 1927 and whose habitat has been lost. Other species have not been recorded for several decades or are known from only one or a few localities. For example, *Fissidens geminiflorus* is known from a single collection in Peninsular Malaysia, with no subsequent records since its first report in 1987.

Overall, Sabah emerges as the main hotspot for bryophyte endemism and rarity, with Mount Kinabalu, Mount Tambuyukon, and Mount Silam representing critical refugia. Sarawak (Mount Dulit) and Peninsular highlands (Genting Highlands, Cameron Highlands, Fraser's Hill, and Maxwell Hill) also support narrow endemics.

Conservation of bryophytes in Malaysia

To date, the conservation status of bryophyte species in Malaysia has not been formally assessed except for *Taxitheliella richardsii*, which is Critically Endangered (CR). Many species are known only from their original collections. Efforts to evaluate them for inclusion in the IUCN Red List of Threatened Species are currently underway. Future work should prioritise targeted field surveys to relocate historical populations, assess population sizes, and document habitat conditions. Protecting key sites such as Mount Kinabalu, Mount Silam, and Genting Highlands is crucial, as these areas represent important refugia for many rare and endemic bryophytes.

Table 1. Rare, endemic and poorly known bryophytes (liverworts, mosses and hornworts) of Malaysia, with their distribution and remarks.

No.	Species	Distribution	Remarks
LIVERWORTS			
1	*Acrolejeunea crassicaulis* (Steph.) Jian Wang bis & Gradst.	Sabah (Labuk River, type); the Philippines; Papua New Guinea	Rare, known from three localities, >1500 m
2	*Acromastigum aurescens* A.Evans	Johor (Mt Ledang, type)	Known only from type
3	*Acromastigum fimbriatum* (Steph.) A.Evans	Sarawak (Baram, type)	Known only from type
4	*Anastrophyllum fissum* Steph.	Sarawak (Mt Dulit), Sabah (Mt Kinabalu); Hawaii Islands (type)	Rare, known only from Borneo and Hawaii Islands
5	*Anastrophyllum obtusum* Herzog	Sarawak (Mt Dulit, type)	Endemic to Sarawak
6	*Anastrophyllum prionophyllum* S.Hatt.	Sabah (Mt Kinabalu); Indonesia (West Irian, type); Papua New Guinea	Rare, only in Borneo and New Guinea
7	*Andrewsianthus chimbuensis* R.M.Schust.	Sabah (Mt Kinabalu); Papua New Guinea (type)	Rare, only in Borneo and Papua New Guinea
8	*Andrewsianthus kinabaluensis* N.Kitag.	Sabah (Mt Kinabalu, type)	Endemic to Sabah
9	*Andrewsianthus mizutanii* N.Kitag.	Sabah (Mt Kinabalu, type)	Endemic to Sabah
10	*Andrewsianthus papillosus* N.Kitag.	Sabah (Mt Kinabalu, type)	Endemic to Sabah
11	*Aphanotropis saxicola* Herzog	Sarawak (Mt Dulit, type)	Endemic genus, known only from type, probable synonym of *Colura*
12	*Balantiopsis ciliaris* S.Hatt.	Sabah (Mt Kinabalu, type); Indonesia (Kalimantan); the Philippines	Only in Borneo and the Philippines
13	*Bazzania friabilis* N.Kitag. & T.Kodama	Pahang (Genting Highlands), Sabah (Mt Kinabalu, type); Vietnam	Known from three localities
14	*Bazzania diminuta* Herzog	Sarawak (Mt Dulit, type)	Known only from type
15	*Bazzania dulitensis* Herzog	Sarawak (Mt Dulit, type), Sabah (Mt Kinabalu)	Endemic to Borneo
16	*Bazzania drepanophylla* Herzog	Sarawak (Mt Dulit, type)	Known only from type
17	*Bazzania linearis* Herzog	Sarawak (Mt Dulit, type)	Known only from type
18	*Bazzania pseudovittata* N.Kitag. & T.Kodama	Pahang (Genting Highlands), Sabah (Mt Kinabalu, type)	Known only from two localities
19	*Bazzania undulata* Herzog	Sarawak (Mt Dulit, type)	Known only from type
20	*Cephalolejeunea parvilobula* Mizut.	Sabah (Mt Kinabalu, type); Kalimantan; Brunei	Rare, monotypic genus, endemic to Borneo
21	*Cephalozia acuminata* (Herzog) Váňa	Sarawak (Mt Dulit, type); the Philippines	Known only from two localities, restricted to mossy forest, >1000 m
22	*Cephalozia acutiloba* (Inoue) Váňa	Pahang (Cameron Highlands, type)	Rare, known only from type, restricted to mossy forest, >2000 m
23	*Cephalozia mollusca* (De Not.) Váňa	Sarawak (Mt Dulit), Sabah (Mt Kinabalu); Indonesia (Kalimantan)	Endemic to Borneo, 600 – 1800 m
24	*Cephalozia stolonacea* (Herzog) Váňa	Sarawak (Dulit Ridge, type); Indonesia (Amboina/Maluku Islands)	Known only from Dulit Ridge and Maluku Islands, >1000 m

25	*Cheilolejeunea loriana* (Steph.) W.Ye & R.L.Zhu	Sabah (Mt Kinabalu); New Guinea (type, specific locality unknown)	Endemic to Borneo and New Guinea
26	*Cololejeunea changlongiana* Tixier	Perak (Maxwell Hill); Thailand (type)	Known only from two collections
27	*Cololejuenea chinii* Tixier	Kelantan (Gua Musang, type), Selangor (Bukit Anak Takun); Vietnam	Rare, known only from Peninsular Malaysia and Vietnam, found only in carstic lowland rain forest on limestone ground
28	*Cololejuenea fissilobula* Herzog	Sarawak (Mt Dulit, type)	Rare, known only from type
29	*Cololejeunea georgiana* Tixier	Penang (Georgetown, type)	Rare, known only from type
30	*Cololejuenea hattoriana* Mizut. & Pócs	Sabah (Mt Silam, type)	Known only from two collections including type
31	*Cololejeunea johannis-winkleri* (Herzog) R.L.Zhu	Sabah (Tawau); Indonesia (Kalimantan, type)	Endemic to Borneo
32	*Cololejuenea malaccensis* Tixier	Johor (Mt Ledang, type)	Rare, known only from type
33	*Cololejeunea malayana* Tixier	Perak (Maxwell Hill, type), Pahang (Cameron Highlands)	Endemic to Peninsular Malaysia, known only from two collections
34	*Cololejeunea peponiformis* Mizut.	Sabah (Mt Kinabalu, type; Ulu Senagang)	Endemic to Sabah, known only from two collections
35	*Cololejeunea pseudostipulata* P.Syd.	Sabah (Mt Silam); New Guinea (type); New Caledonia	Rare; found only in carstic lowland rain forest on limestone ground
36	*Cololejunea rosellata* Mizut.	Sabah (Mt Kinabalu, Kinabalu Park)	Endemic to Sabah (Kinabalu Park), known only from two collections
37	*Cololejeunea shimizui* N.Kitagawa	Kelantan (Gua Musang, type); Thailand	Rare, known only from type and Thailand, found only in carstic lowland rain forest on limestone ground
38	*Cololejeunea stoniana* Tixier	Johor (Mt Ledang, type), Sarawak (Matang); Singapore	Known only from three localities
39	*Cololejeunea tridentata* Tixier	Johor (Mt Ledang, type), Sarawak (Semengoh)	Rare, known only from two collections including type
40	*Colura clementis* Grolle	Sabah (Mt Tambuyukon); Papua New Guinea (type)	Rare, known only from two localities
41	*Colura cymbalifera* Herzog & Jovet-Ast	Peninsular Malaysia (specific locality unknown)	Known only from type
42	*Colura galeata* Jovet-Ast	Sabah (Mt Tambuyukon, type)	Endemic to Sabah, known only from type
43	*Colura sigmoidea* Sangratt., Chantanaorr. & R.L.Zhu	Pahang (Cameron Highlands, type); Thailand	Known only from two localities
44	*Colura strophiolata* Tixier	Kedah; Cambodia (type)	Rare, known only from two localities
45	*Drepanolejuenea ciliata* Mizut.	Sabah (Mt Kinabalu, type); Papua New Guinea	Rare, known only from two localities
46	*Diplasiolejeunea longilobula* Herzog	Sarawak (Mt Dulit, type)	Rare, known only from type
47	*Diplophyllum kinabaluense* Furuki & Suleiman	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Mt Kinabalu), restricted to montane forest, 1500 – 1650 m
48	*Eotrichocolea furukii* T.Katag.	Sabah (Mt Kinabalu, type); Papua New Guinea	Rare, endemic to Borneo and New Guinea, on soil in montane forest, ~1500 m

49	*Frullania benjaminiana* Inoue	Pahang (Cameron Highlands, type)	Rare, known only from type, restricted to mossy forest, >2000 m
50	*Frullania clemensiana* Verd.	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Mt Kinabalu), only a few collections known to this area
51	*Frulllania hottana* S.Hatt.	Sarawak (Bintulu, type); Sri Lanka/Ceylon	Known only from two localities
52	*Frullania meijeri* S.Hatt.	Sabah (Mt Silam, type); Indonesia (Kalimantan)	Rare, known only from two specimens in Borneo
53	*Frullania mizutanii* Kamim. & S.Hatt.	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Mt Kinabalu)
54	*Frullania ocellata* S.Hatt. & Kamim.	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Mt Kinabalu)
55	*Frullania papillilobula* S.Hatt.	Sabah (Lahad Datu, type); Brunei	Endemic to Borneo
56	*Frullania recurvistipula* S.Hatt.	Pahang (Cameron Highlands, type)	Known only from type
57	*Frullania sabahana* S.Hatt.	Sabah (Mt Silam, type), Sarawak (Bintulu); Indonesia (Kalimantan)	Endemic to Borneo
58	*Frullania sarawakensis* S.Hatt.	Sarawak (Bintulu); Indonesia (Sulawesi)	Known only from two collections
59	*Frullania togashiana* S.Hatt.	Pahang (Cameron Highlands, type)	Known only from type
60	*Frullania venusta* S.Hatt.	Sabah (Mt Silam, type)	Rare, known only from collections from Mt Silam
61	*Hebertus pilifer* (Steph.) H.A.Mill	Sarawak (Mt Dulit); New Guinea (West Irian, Papua New Guinea)	Known only from Sarawak and New Guinea
62	*Heteroscyphus iwatsukii* (S.Hatt.) Piippo	Sabah (Mt Silam, type)	Known only from type
63	*Heteroscyphus parvulus* (Schiffn.) Schiffn.	Sabah (Mt Kinabalu); Indonesia (Java, type)	Known only from two localities
64	*Jackiella angustifolia* Herzog	Sarawak (Mt Dulit, type), Sabah (Mt Kinabalu)	Endemic to Borneo
65	*Jackiella singapurensis* Schiffn.	Penang; Singapore (type)	Endemic to Peninsular Malaysia and Singapore
66	*Kurzia abbreviata* Mizut.	Pahang (Genting Highlands), Sarawak (Mt Dulit), Sabah (Mt Kinabalu, type)	Rare, known from three localities in Peninsular Malaysia and Borneo
67	*Kurzia abietinella* (Herzog) Grolle	Pahang (Genting Highlands), Sarawak (Mt Dulit, type), Sabah (Mt Kinabalu)	Rare, known from three localities in Peninsular Malaysia and Borneo
68	*Kurzia borneensis* Mizut.	Pahang (Genting Highlands), Sabah (Mt Kinabalu, type); the Philippines	Rare, known from three localities
69	*Kurzia geniculata* Mizut.	Pahang (Genting Highlands), Sabah (Mt Kinabalu, type); the Philippines	Rare, known from three localities
70	*Kurzia lineariloba* Mizut.	Pahang (Genting Highlands), Sabah (Mt Kinabalu, type); the Philippines	Rare, known from three localities
71	*Lejeunea contracta* Mizut.	Sabah (Mt Kinabalu, type)	Rare, endemic to Sabah (Mt Kinabalu)
72	*Lejeunea gradsteinii* G.E.Lee, Damanhuri & A.Latiff	Sabah (Mt Kinabalu, type), Pahang (Cameron Highlands)	Known only from the two localities
73	*Lejeunea pectinella* Mizut.	Sabah (Mt Kinabalu, type); Indonesia (Java)	Rare, known only from the two localities
74	*Lepidozia everettii* Steph.	Sarawak (Mt Penrissen, type)	Endemic to Sarawak
75	*Lepidozia haskarliana* (Gottsche, Lindenb. & Nees) Steph.	Sabah (Mt Kinabalu); Indonesia (Java, type)	Rare, known only from two localities
76	*Lepidozia kinabaluensis* Mizut.	Sabah (Mt Kinabalu, type)	Known only from type

77	*Lepidozia lacerifolia* Steph.	Sarawak (Mt Dulit), Papua New Guinea (type)	Rare, only in Sarawak and New Guinea
78	*Lepidozia richardsii* Herzog	Sarawak (Mt Dulit, type)	Known only from type
79	*Lepidozia squamifolia* Steph.	Sabah (Mt Silam), Sarawak (type: Mt Poe/Pueh)	Endemic to Borneo
80	*Leptolejeunea borneensis* Herzog	Sabah (Mt Kinabalu, type); Indonesia (Sumatra)	Known only from the type and Sumatra, >1700 m
81	*Leptolejeunea ligulata* Herzog	Pahang (Tambeling, type), Sabah (Ulu Senagang, Crocker Range Park)	Known only from the two localities
82	*Lophocolea steetziae* De Not.	Sarawak (specific locality unknown, type)	Known only from type
83	*Lopholejeunea borneensis* (Steph.) Verd.	Sarawak (Mt Dulit); Indonesia (Kalimantan, type)	Rare, known only from two collections in Borneo
84	*Lopholejeunea magna* Mizut.	Sabah (Mt Kinabalu, type)	Rare, endemic to Sabah (Mt Kinabalu), known only from the type and paratypes
85	*Marsupella stoloniformis* N.Kitag.	Sabah (Mt Kinabalu, type); Papua New Guinea	Known only from the two localities
86	*Mastigopelma latiffiana* G.E.Lee, E.Pesiu & X.L.He	Pahang (Cameron Highlands, type)	Known only from type, mossy forest, ~1900 m
87	*Mesoptychia subcrispa* (Herzog) L.Söderstr. & Váňa	Pahang (Genting Highlands); Indonesia (Sumatra, type)	Rare, only tropical species of the genus
88	*Microlejeunea constricta* (Grolle) Grolle	Sabah (Mt Kinabalu); Solomon Islands (type)	Rare, known only from the type in Solomon Islands and Sabah
89	*Microlejeunea kinabaluensis* (Mizut.) Grolle	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Kinabalu Park)
90	*Microlejeunea mammillosa* (Mizut.) Grolle	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Kinabalu Park)
91	*Microlejeunea minutissima* (Mizut.) Grolle	Sabah (Paka Cave, type)	Endemic to Sabah (Kinabalu Park)
92	*Microlejeunea spinosa* (Mizut.) Grolle	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Mt Kinabalu)
93	*Neolepidozia longitudinalis* (Herzog) E.D.Cooper	Sarawak (Mt Dulit, type)	Endemic to Sarawak, known only from type
94	*Neolepidozia mamillosa* (Schiffn.) E.D.Cooper	Sabah (Mt Kinabalu), New Guinea (type)	Known only in Sabah and New Guinea
95	*Odontoschisma purpuratum* Herzog	Sarawak (Mt Dulit, type), Sabah (Mt Kinabalu), Pahang (Cameron Highlands)	Rare, endemic to Malaysia, known from three localities, 1500 – 2700 m
96	*Pictolejeunea mizutanii* Grolle	Sabah (Mt Kinabalu, type), Sarawak; Brunei	Endemic to Borneo
97	*Plagiochila borneensis* Steph.	Sarawak (Mt Dulit, type)	Rare, endemic to Sarawak, known only from type
98	*Plagiochila denigrata* Inoue	Sabah (Mt Kinabalu, type)	Endemic to Sabah
99	*Plagiochila dolichoblasta* Herzog	Sarawak (Mt Dulit, type)	Rare, endemic to Sarawak, known only from type
100	*Plagiochila nitens* Inoue	Sabah (Mt Kinabalu, type)	Endemic to Sabah
101	*Pseudomarsupidium borneensis* (Grolle) Váňa, L.Söderstr., A.Hagborg & von Konrat	Sabah (Paka Cave, type)	Rare, endemic to Sabah, known only from type
102	*Pycnolejeunea cavistipula* (Steph.) Mizut.	Sabah (Mt Silam)	Endemic to Borneo, type locality unknown
103	*Radula ceylanica* K.Yamada	Pahang (Cameron Highlands); Sri Lanka (type)	Known only from two localities
104	*Radula ectophylla* Promma, M.A.M.Renner & R.L.Zhu	Sarawak (Kubah National Park, type), Sabah (Lahad Datu)	Endemic to Malaysian Borneo
105	*Radula kinabaluensis* K.Yamada	Sabah (Mt Kinabalu, type)	Endemic to Sabah (Mt Kinabalu)
106	*Radula resupinatiramosa* Promma, M.A.M.Renner & R.L.Zhu	Sarawak (Mulu National Park, type); Papua New Guinea	Known only from two localities

107	*Radula tambuyukonensis* Promma, M.A.M.Renner & R.L.Zhu	Sabah (Mt Tambuyukon, type)	Endemic to Sabah
108	*Riccardia deguchii* Furuki & K.T.Yong	Pahang (Genting Highlands, type; Cameron Highlands)	Endemic to Peninsular Malaysia, mossy forest, 1000 – 2000 m
109	*Riccardia hattorii* Furuki	Sabah (Mt Kinabalu); Indonesia (Kalimantan)	Known only from two localities in Borneo
110	*Schistochila doriae* (De Not) Trevis.	Sarawak (Mt Matang, type), Sabah, Pahang (Fraser Hill, Genting Highlands); Indonesia	Little known species
111	*Schistochila rubriseta* Steph.	Sabah (Mt Kinabalu); New Guinea (type)	Rare, known only from two localities
112	*Soella spinistipula* (Mizut.) R.L.Zhu & L.Shu	Sabah (Mt Silam, type)	Endemic to Sabah (Mt Silam)
113	*Telaranea octolona* Del Ros.	Johor (Mt Belumut); the Philippines (type)	Rare, only known from two localities
114	*Thiersianthus silamensis* R.L.Zhu & L.Shu	Sabah (Mt Silam, type)	Endemic to Sabah (Mt Silam)
115	*Thysananthus gradsteinii* (Sukkharak) Sukkharak & Gradstein	Pahang (Bukit Serdam, type), Kelantan (Gua Musang)	Endemic to Peninsular Malaysia, restricted to limestone habitats
116	*Tricholepidozia trichocoleoides* (Herzog) E.D.Cooper	Sarawak (Mt Dulit, type), Sabah (Mt Kinabalu)	Rare, endemic to Borneo
117	*Tuyamaella borneensis* Tixier	Sabah (Mt Kinabalu, type)	Endemic to Sabah
MOSSES			
118	*Acanthorrhynchium subintegrum* (Broth. & Dixon) Broth.	Sarawak (type)	Known only from two localities
119	*Acroporium convolutum var. horridulum* (E.B.Bartram) B.C.Tan, T.J.Kop. & D.H.Norris	Sabah; Papua New Guinea	Locally rare
120	*Acroporium dicranoides* M.Fleisch.	Kedah, Sabah; Indonesia; Vietnam	Locally rare
121	*Acroporium ridleyi* Dixon	Kedah, Pahang, Sabah	Only one record in Sabah
122	*Barbella enervis* (Thwaites ex Mitt.) M.Fleisch.	Pahang	No subsequent collections since first report by Manuel (1981)
123	*Barbella horridula* Broth.	Sabah; China; the Philippines (Luzon); Indonesia (Sumatra)	Locally rare
124	*Benitotania elimbata* H.Akiyama, T.Yamag. & Suleiman	Sabah (Mt Alab, Mt Kinabalu, Mt Tambuyukon)	Endemic to Sabah, known only from three localities, mossy forests, 1400–1800 m
125	*Braunfelsia edentula* var. *angusta* (C.H. Wright) Wijk & Margad.	Sabah (type)	Known only from the type
126	*Braunfelsia muscicola* J. Froehl.	Sabah (Mt Kinabalu, type)	Known only from the type
127	*Breutelia arundinifolia* (Duby) M.Fleisch.	Pahang (Genting Highlands)	In Peninsular Malaysia, restricted to summit area of Genting Highlands, habitat threatened
128	*Breutelia kinabaluensis* Dixon	Sabah (Mt Kinabalu, Mt Tambuyukon)	Endemic to Sabah, known only from two localities, 2700 – 2800 m
129	*Brotherella longipes* Broth.	Sarawak (type); Indonesia (Kalimantan); the Philippines; Papua New Guinea	In Sarawak, known only from the type
130	*Bryobrothera tambuyukonensis* H.Akiyama & Suleiman	Sabah (Mt Tambuyukon, Sg Imbak, Mt Kinabalu)	Endemic to Sabah, known only from three localities, montane forests, 900 – 1670 m

131	*Callicostella papillata* var. *viridissima* Dixon	Sabah (Tenom, type); Indonesia (Sumatra)	Locally, known only from the type
132	*Calymperes beccarii* Hampe	Sarawak (type), Sabah; Papua New Guinea, Thailand	Locally rare
133	*Calymperes serratioides* L.T.Ellis	Sabah (Danum, paratype); Indonesia (Kalimantan, holotype)	Locally, known only form one locality
134	*Calyptrochaeta enervis* (Nog. & Z.Iwats.) Touw	Sabah (Mt Kinabalu, type)	Known only from the type
135	*Campylopus sericeoides* Dixon	Sabah (Mt Kinabalu, type); Indonesia (Flores)	Rare, known only from two localities, on wet rocks, 2000–3300 m
136	*Campylopus validinervis* (Dixon) B.C.Tan	Sarawak (Miri)	Known only from one locality
137	*Chaetomitrium darnaedii* H.Akiyama & Suleiman	Sabah (Mt Muruk Mio); Indonesia (Kalimantan, type)	Endemic to Borneo; known only from two localities
138	*Chaetomitrium lancifolium* Mitt.	Sabah; Indonesia	Locally rare
139	*Chaetomitrium maryatii* H.Akiyama & Suleiman	Sabah (Maliau Basin, Imbak Canyon)	Endemic to Sabah, known only from two localities, lowland forests, 300 – 500 m
140	*Chaetomitrium vrieseanum* Bosch & Sande Lac.	Sabah; Indonesia; Papua New Guinea; the Philippines	Locally rare, only one locality
141	*Chionoloma perlongifolium* (J.Froehl.) M.Alonso, M.J.Cano & J.A.Jiménez	Sabah; Puerto Rico	Locally rare
142	*Chionostomum hainanense* B.C.Tan & Y.Jia	Sabah; China; Vietnam	Locally rare, only one collection
143	*Cryptogonium phyllogonioides* (Sull.) Isov.	Kedah, Pahang, Perlis, Sabah (Mt Kinabalu)	Limestone specialist, quarrying threat
144	*Cyclodictyon kinabaluense* Nog. & Z.Iwats.	Sabah	Endemic to Sabah (Mt Kinabalu), known only from type
145	*Dicranoloma havilandii* Broth.	Sabah (Mt Kinabalu, type); Papua New Guinea	Rare, restricted to high elevation, population declining
146	*Distichophyllum angustissimum* Dixon	Sarawak (Mt Dulit, Type)	Known only from the type
147	*Distichophyllum leiopogon* Dixon	Sabah; Indonesia, the Philippines, Papua New Guinea	Locally rare, only one collection
148	*Ectropothecium erythrocaule* Dixon	Sarawak (Type)	Known only from the type
149	*Ectropothecium kinabaluense* Dixon	Sabah (Mt Kinabalu, type)	Known only from the type
150	*Ectropothecium neoperrevolutum* Suleiman, H.Akiyama & B.C.Tan	Sabah (type)	Known only from the type
151	*Ectropothecium plicatum* E.B.Bartram & Dixon	Sabah (Mt Kinabalu, type)	Known only from the type
152	*Ectropothecium striatulum* Dixon	Pahang, Sabah; the Philippines	Locally rare, only two localities
153	*Ectropothecium subhaplocladum* Broth.	Sarawak (Type)	Locally, known only from the type
154	*Ectropothecium sublaticuspis* Dixon	Sabah (Mt Kinabalu, type)	Known only from the type
155	*Ectropothecium turgidum* Dixon	Sabah (Mt Kinabalu, type)	Known only from the type
156	*Elmeriobryum philippinense* Broth.	Sabah; China; the Philippines; Japan, Papua New Guinea	Locally rare, only one locality

157	*Erpodium biseriatum* (Austin) Austin	Selangor	Urban site (Batu Caves), unprotected
158	*Erythrodontium julaceum* (Hook. ex. Schwägr.) Paris	Pahang (Taman Rimba Kenong), Selangor (Batu Caves)	In Peninsular Malaysia, known only from two localities, restricted to karst habitats
159	*Fissidens beccarii* (Hampe) Broth.	Sarawak (type); Indonesia (Kalimantan)	Endemic to Borneo, not recorded >160 years
160	*Fissidens geminiflorus* Dozy & Molk.	Selangor (Ulu Gombak); Indonesia (Java, Sumatra), Sabah (Mt Kinabalu, Mt Lumaku, Tawau); Indonesia (Java, Sumatra)	In Peninsular Malaysia, known from a single collection, no subsequent records since the first report by Iwatsuki & Mohamed (1987)
161	*Fissidens longevaginatus* Dixon	Sarawak (Mt Dulit, Type); Indonesia (Kalimantan)	Known only from two localities
162	*Fissidens pachyphyllus* Dixon	Sarawak (Ulu Koyan)	Endemic to Sarawak, known only from a single specimen
163	*Fissidens subdiscolor* Dixon	Negeri Sembilan (Gemas, type)	Endemic to Negeri Sembilan, known only from type
164	*Himantocladium submontanum* Enroth	Sarawak; Indonesia; Papua New Guinea	Locally rare, only one locality
165	*Hookeria acutifolia* Hook. & Grev.	Kelantan (Lojing Highlands), Sabah (Crocker Range)	In Peninsular Malaysia, known only from one locality
166	*Hymenostylium recurvirostrum* (Hedw.) Dixon	Pahang (Taman Rimba Kenong), Selangor (Batu Caves)	In Peninsular Malaysia, known only from two localities, restricted to karst habitats
167	*Isopterygium battakense* M.Fleisch.	Sarawak; Indonesia (Sumatra)	Only one locality in Malaysia
168	*Isopterygium fissum* Dixon	Sabah (Sandakan, type)	Known only from the type
169	*Macromitrium ochraceoides* Dixon	Sabah (Mt Kinabalu, type); the Philippines	Locally, known only from the type
170	*Macromitrium papillisetum* Dixon	Sabah (Sandakan)	Known only from type, habitat lost, no subsequent collections since 1927
171	*Mastopoma subrobustum* Dixon	Sarawak (Dulit, type); Sabah	Endemic to Borneo
172	*Neolindbergia cladomnioides* H.Akiyama	Sabah (type); Indonesia (Kalimantan); the Philippines	Locally, known only from two localities
173	*Neonoguchia auriculata* (Copp. ex Thér.) S.H.Lin	Sabah; China	Locally rare, only one locality
174	*Oxyrrhynchium bergmaniae* (E.B.Bartram) Huttunen & Ignatov	Sabah; Indonesia; Papua New Guinea	Locally rare, only one locality
175	*Pachylomidium pachyloma* (Broth.) R.H. Zander & B.H. Allen	Sarawak, Sabah; Indonesia, the Philippines; Papua New Guinea	Locally rare, on limestone rocks
176	*Polytrichadelphus archboldii* var. *kinabaluensis* H.Akiyama & T.Yamag.	Sabah (Mt Kinabalu, type)	Known only from the type
177	*Racopilum laxirete* Broth.	Sabah (Mt Kinabalu); Indonesia (Kalimantan, type)	Endemic to Borneo
178	*Rhaphidostichum dubium* Dixon	Sarawak (Mt Dulit, type)	Known only from the type
179	*Rhizohypnella sundaensis* M.Fleisch.	Sarawak	Known only from one locality
180	*Schlotheimia emarginatopilosa* Herzog	Sabah; Indonesia; Papua New Guinea	Locally rare, only one locality
181	*Schlotheimia rubiginosa* C.H.Wright	Sabah (Mt Kinabalu, Mt Tambuyukon)	Endemic to Sabah, upper montane zones

182	*Schoenobryum concavifolium* (Griff.) Gangulee	Pahang (Cameron Highlands), Sabah (Crocker Range and Imbak Canyon)	In Peninsular Malaysia, known only from one locality
183	*Sematophyllum laticuspis* (Dixon) W.R. Buck & B.C.Tan	Sarawak (Type)	Known only from the type
184	*Symphyodon ovalifolius* H.Akiyama & Suleiman	Sabah (Mt Kinabalu, type); Indonesia	Locally, known only from type locality
185	*Syrrhopodon mammillosus* Müll. Hal.	Sabah (Mt Silam), Kedah, Pahang; New Caledonia; the Philippines	Rare in Sabah
186	*Syrrhopodon meijeri* W.D.Reese	Sabah (Sipitang, type), Sarawak (Bako)	Rare, known only from two localities
187	*Syrrhopodon multipapillosus* L.T.Ellis	Sarawak (Mt Mulu, type)	Endemic to Mt Mulu, known only from type, limestone forest
188	*Syrrhopodon scalariformis* Dixon	Sarawak (Ulu Koyan, type), Sabah (Imbak Canyon)	Endemic to Borneo
189	*Syrrhopodon teniolatus* L.T.Ellis	Sabah (Danum Valley, type), Sarawak (Mt Mulu); Indonesia (Kalimantan)	Endemic to Borneo
190	*Taxitheliella richardsii* Dixon	Sarawak (Mt Dulit, Type)	Known only from the type; Critically Endangered (CR)
191	*Touwia negrosensis* (E.B.Bartram) S.Olsson, Enroth & D.Quandt	Sabah; the Philippines	Locally rare, only one locality
192	*Trichosteleum inflexifolium* Dixon	Sarawak (Mt Dulit, Type)	Known only from the type
193	*Trismegistia maliauensis* H.Akiyama & Suleiman	Sabah (Maliau Basin, type)	Endemic to Sabah (Maliau Basin), known only from type
194	*Ulota splendida* E.B.Bartram	Sabah (Mt Kinabalu, type); Papua New Guinea; New Zealand	Locally, known only from the type
195	*Warburgiella nitens* Dixon	Sarawak (Mt Dulit, Type)	Known only from the type
HORNWORT			
196	*Dendroceros difficilis* Steph.	Pahang (Cameron HighalndsHighlands, Fraser's Hill); Indonesia (Java, type)	Known only from three localities

REFERENCES

Andi, M.A.M. and Suleiman, M. 2005. Preliminary list of mosses from Meliau Range, Ulu Tungud Forest Reserve, Sabah. *Sepilok Bulletin* 3: 57–64.

Bechteler, J., Peñaloza-Bojacá, G., Bell, D., Burleigh, J.G, McDaniel, S.F., Davies, E.C., Sessa, E.B. *et al.* 2023. Comprehensive phylogenomic time tree of bryophytes reveals deep relationships and uncovers gene incongruences in the last 500 million years of diversification. *American Journal of Botany* 110(11): e16249.

Crum, H.A. 2001. *Structural diversity of bryophytes*. Ann Arbor: The University of Michigan Herbarium.

Damanhuri, A., Aishah, S., Ahmad Fitri, Z., Norhazrina, N. and Maideen, H. 2017. Mosses of Gunung Basor and its vicinity, Jeli, Kelantan. In *Gunung Basor dan Tasik Pergau, Kelantan: Kepelbagaian Biologi*, I. Zahari, A. Mohd Radhi Chu, A.R. Razali, D.A. Nur Najwa, M.N. Suryani and A. Latiff (Eds.), pp. 94–109. Kota Bharu: Jabatan Perhutanan Negeri Kelantan.

Damanhuri, A., Maideen, H., Azmi, A., Khamis, M.T. and Ibrahim, N. 2007. Flora lumut jati (Musci) di Taman Rimba Kenong. In *Taman Rimba Kenong, Pahang: Pengurusan, persekitaran fizikal dan kepelbagaian biologi*, A. Muda, A.A. Rahman, C.H. Hassan, H.L. Koh, A. Norhayati and A. Latiff (Eds.), pp 83–95. Kuala Lumpur: Jabatan Perhutanan Semenanjung Malaysia.

Dixon, H.N. 1924. New species of mosses from the Malay Peninsular. *Bulletin of the Torrey Botanical Club* 51: 225–259.

Dixon, H.N. 1926. A list of the mosses of the Malay Peninsula. *Gardens' Bulletin, Straits Settlements* 4: 1–4.

Ellis, L.T., Alataş, M., Aleffi, M., Alegro, A.L., Segota, V., Ozimec, S., Vukovic, N. *et al.* 2017. New national and regional bryophyte records, 52. *Journal of Bryology* 39(3): 285–304.

Ellis, L.T., Aleffi, M., Asthana, G., Bhagat, C., Bakalin, V.A., Barath, K., Becker, R. *et al.* 2018. New national and regional bryophyte records, 57. *Journal of Bryology* 40(4): 399–419.

Ellis, L.T., Afonina, O.M., Doroshina, G.Y., Agudelo, C., Andriamiarisoa, L.R., Asthana, A.K., Gupta, D. *et al.* 2019a. New national and regional bryophyte records, 58. *Journal of Bryology* 41(1): 63–84.

Ellis, L.T., Amélio, L.A., Peralta, D.F., Backor, M., Baisheva, E.Z., Bednarek-Ochyra, H., Burghardt, M. *et al.* 2019b. New national and regional bryophyte records, 59. *Journal of Bryology* 41(2): 177–194.

Ellis, L.T., Afonina, O.M., Atwood, J.J., Bednarek-Ochyra, H., Burghadt, M., Dragicevic, S., Vuksanovic, S. *et al.* 2020. New national and regional bryophyte records, 62. *Journal of Bryology* 42(2): 195–208.

Ellis, L.T., Ah-Peng, C., Aslan, G., Bakalin, V.A., Bergamimi, A., Callaghan, D.A., Campisi, P. *et al.* 2021. New national and regional bryophyte records, 65. *Journal of Bryology* 43(1): 67–91.

Ellis, L.T., Afonina, O.M., Alia, M.H.B., Burghardt, M., Cabezudo, B., Cano, M.J., Cottet, A.C. *et al*. 2022. New national and regional bryophyte records, 70. *Journal of Bryology* 44(2): 175–183.

Ellis, L.T., Aceñolaza, P.G., Alvarez, D., Bednarek-Ochyra, H., Brzeczek, D., Cabezudo, B., Cedres-Perdomo, R.D. *et al*. 2023a. New national and regional bryophyte records, 74. *Journal of Bryology* 45(3): 249–262.

Ellis, L.T., Alegro, A., Alvarez, D.J., Aponte Rojas, A.M., Ashouri, A., Atwood, J.J., Bednarek-Ochyra, H. *et al.* 2023b. New national and regional bryophyte records, 75. *Journal of Bryology* 45(4): 321–338.

Frahm, J.-P., Frey, W., Kürschner, H. and Menzel, M. 1990. *Mosses and Liverworts of Mount Kinabalu*. Kota Kinabalu: Natural History Publications (Borneo) Sdn. Bhd.

Gradstein, S.R., Churchill, S.P. and Salazar-Allen, N. 2001. Guide to the bryophytes of Tropical America. In *Memoirs of the New York Botanical Garden* 86, 577 pp. New York: New York Botanical Garden and Commission of the European Communities.

Iwatsuki, Z. and Mohamed, M.A.H. 1987. The genus *Fissidens* in Peninsular Malaysia and Singapore (A preliminary study). *Journal of the Hattori Botanical Laboratory* 62: 339–360.

Lee, G.E., Pócs, T., Gradstein, S.R., Damanhuri, A. and Latiff, A. 2018 Abundant but neglected past and present of liverwort (Marchantiophyta) studies in Malaysia. *Cryptogamie, Bryologie* 39: 83–91.
Lee, G.E. and Gradstein, S.R. 2021. Guide to the genera of liverworts and hornworts of Malaysia. Tokyo: Hattori Botanical Laboratory. 234 pp.
Lee, G.E., Gradstein, S.R., Pesiu, E. and Norhazrina, N. 2022a. An updated checklist of liverworts and hornworts of Malaysia. *PhytoKeys* 199: 29–111.
Lee, G.E., Bechteler. J., Pócs T, Schäfer-Verwimp, A., Tang, H.Y. and Chia, P.W. 2022b. Integrative taxonomy reveals a new species of the genus *Lejeunea* (Marchantiophyta, Lejeuneaceae) from Peninsular Malaysia. *Plants* 11: 1–12.
Lee, G.E., Pesiu, E. and He, X.L. 2024. Data to the Malaysian liverwort flora, IV: A new species of *Mastigopelma* Mitt. (Lepidoziaceae) from Cameron Highlands, Peninsular Malaysia. *Acta Botanica Hungarica* 66: 93–100.
Lee, G.E., Pócs, T. and Schäfer-Verwimp, A. 2026 (in press). Data to the Malaysian liverwort flora, VI: Two new species from the family Lejeuneaceae. *Phytotaxa* 754(2) : 217–226.
Manuel, M.G. 1981. Additions to the bryoflora of Malaya. *The Bryologist* 84: 220–221.
Mitten, W. 1859. Musci Indiae Orientalis: An Enumeration of the Mosses of the East Indies. *Journal of the Proceedings of the Linnean Society, Supplement to Botany* 1(2): 1–171.
Mohamad, A.D.H. and Gidiman, J.B. 1990. Flora lumut sejati (Bryophytina) Hutan Simpan Bangi dan kawasan sekitarnya. In *Ekologi dan Biologi Hutan Simpan Bangi*, Latiff, A. (Ed.), pp. 147–151. Bangi: Universiti Kebangsaan Malaysia.
Mohamed, H., Damanhuri, A. and Bakar, B. 1992. Three mosses new to Borneo. *Journal of Bryology* 17: 285–288.
Mohamed, H. 1995. Mosses of Sayap-Kinabalu Park, Sabah. In *A Scientific Journey through Borneo: Sayap-Kinabalu Park, Sabah*, Ismail, G. and Din, L. (Eds.), pp. 105–122. Kuching: Universiti Malaysia Sarawak.
Mohamed, H. and Tan, B.C. 1988. A checklist of mosses of Peninsular Malaya and Singapore. *Bryologist* 91(1): 24–44.
Mohamed, H., Damanhuri Mohamed, A. and Bakar, B. 1992. Three mosses new to Borneo. *Journal of Bryology* 17: 285–288.
Mohamed, H., Yong, K.T. and Gunaseelan, G. 2004. Additions to the moss flora of Peninsular Malaysia. *Journal of Bryology* 26: 47–52.
Mohamed H., Damanhuri A., Suleiman M. and Yong K.-T. 2011. Mosses of Lanjak Entimau Wildlife Sanctuary. In *Lanjak Entimau Wildlife Sanctuary: Hidden Jewel of Sarawak*, H. Mohamed, I. Ipor, K. Meekiong, S. Ahmad and A. Ampeng (Eds.), pp. 153–171. Kuching: Academy of Sciences Malaysia and Sarawak Forest Department.
Suleiman, M., Akiyama, H. and Tan, B. C. 2006. A revised catalogue of mosses reported from Borneo. *Journal of the Hattori Botanical Laboratory* 99: 107–183.
Suleiman, M., Damanhuri, A., Yong, K.T. and Rahman, M.R. 2010. Mosses of Lojing Highlands, Kelantan. In Conserving Lojing Highlands for Sustainable Development, I.C. Omar. and Z. Hamzah (Eds.), pp. 55–65. Kelantan: Penerbit Universiti Malaysia Kelantan.
Suleiman M., Andi A.M.A.M., Rimi R. and Anwar I. 2024. Mosses of Marai Parai Trail, Mount Kinabalu. *Sabah Parks Nature Journal* 13: 109–125.
Syazwana, N., Lee, G.E. and Norhazrina, N. 2025. A new species of *Fissidens* (Fissidentaceae, Bryophyta) from Peninsular Malaysia. *Malayan Nature Journal* 77(1&2): 1–7.
Yong, K.T., Tan, B.C., Ho, B.C., Ho, Q.Y. and Mohamed, H. 2013. *A Revised Moss Checklist of Peninsular Malaysia and Singapore*. Kepong: Forest Research Institute Malaysia.


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CHAPTER 4

Monilophytes and lycophytes of Malaysia: Diversity, threats and conservation priorities

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Abstract: Malaysia harbours one of the richest monilophyte and lycophyte floras in Southeast Asia, with approximately 1,165 documented taxa occupying habitats ranging from coastal and lowland forests to limestone karsts and montane cloud forests. The last national assessment of this group was provided by Aziz Bidin in *The State of Nature Conservation in Malaysia* (1991), which recognised approximately 650 species and highlighted habitat loss, limestone quarrying and development as major conservation concerns. Over the past three decades, substantial advances in floristic exploration, taxonomy and systematics have transformed understanding of Malaysia's pteridophyte diversity. Numerous surveys have expanded knowledge of species distributions and habitat associations, while molecular phylogenetic studies and modern classification systems have refined taxonomic concepts and evolutionary relationships. Continued fieldwork has also resulted in the discovery of species new to science, new national records and the rediscovery of rare, poorly-known taxa previously thought to be lost. This chapter synthesises current knowledge of Malaysia's ferns and lycophytes, examines diversity patterns across major habitats including lowland forests, limestone hills and montane ecosystems, and reviews emerging conservation challenges. While habitat conversion, forest fragmentation, and limestone quarrying remain significant threats, climate change is increasingly recognised as a major concern, particularly for moisture-dependent species restricted to montane environments. The chapter highlights the importance of continued taxonomic research, long-term monitoring, and habitat protection for safeguarding Malaysia's pteridophyte diversity. By revisiting and expanding upon Bidin's 1991 assessment, this review provides an updated national perspective and identifies priorities for research and conservation in the decades ahead.

INTRODUCTION

Revisiting Malaysia's ferns after 1991

Monilophyte and lycophytes (the "ferns and fern-allies" of older literature) are a vital part of Malaysia's natural heritage. They regulate forest moisture, stabilise soils, contribute to nutrient cycling, and act as sensitive indicators of environmental change (Lu *et al.* 2023). From coastal mangroves to the tops of the main range, fern communities are a conspicuous and dominant element of the Malaysian flora, yet they remain less documented and less protected than the flowering plants with which they share these forests.

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The last dedicated overview of this group at a national scale was written by Aziz Bidin for the Malaysian Nature Society's *State of Nature Conservation in Malaysia* (Bidin 1991). That chapter recognised about 650 species of ferns and fern-allies, described their distribution from the lowlands to the cloud forests, and flagged the most threatened settings of the day – island floras, limestone hills, and lower montane forests under pressure from logging and land development. It provided a strong foundation and reflected the taxonomic and ecological understanding available at the time.

Over the past 34 years, both Malaysia's forests and the science describing them have changed substantially. Land-use change, climate variability and habitat fragmentation have continued to reshape forest ecosystems (NRECC 2022). At the same time, sustained survey efforts, new records and rediscoveries in Malaysia—including *Diplazium velutinum* (Aliah *et al*. 2026), *Diplazium procumbens* (Maideen *et al.* 2019) and *Cornopteris* (Maideen *et al.* 2021)—and a community-derived phylogenetic classification (PPG I 2016) have considerably expanded and refined our understanding of fern diversity. Subsequent compilations and floristic studies have increased the documented Malaysian pteridophyte flora to approximately 1,165 taxa (Parris and Latiff 1997). This chapter provides an updated conservation reassessment of Malaysia's ferns since Bidin (1991), where we attempt to summarise the ferns that occur across the major forest zones in Malaysia, update the assessment of the threats they face (while illustrating these patterns with a case insight from Sabah) and recommend conservation priorities. The reassessment is organised around a simple question: What has changed in our understanding of Malaysian ferns since Bidin's 1991 account? While many of the habitats and conservation concerns identified three decades ago remain relevant today, substantial advances in taxonomy, floristic exploration and conservation science now provide a much clearer picture of the country's fern flora. Understanding these developments is essential for setting conservation priorities for the decades ahead.

Advances in knowledge since 1991

The most significant change since 1991 is not the fern flora itself, but the amount of information available about it. New surveys, taxonomic revisions, and modern analytical tools have expanded our understanding of species diversity, distribution, and conservation status across Malaysia. As a result, the picture available today is far more comprehensive than that described three decades ago. Three developments have transformed our knowledge of Malaysian ferns since Bidin wrote. First, documentation has deepened. Systematic surveys of individual forest reserves, many leading led from the cryptogamic herbarium at Universiti Kebangsaan Malaysia (UKMB), have produced published checklists for sites spanning a the full elevational range, from lowland reserves such as Kenong and Endau -Rompin (Maideen *et al*. 2004; Jaman and Latiff 2007) to montane settings such as Mount Tebu and the Cameron Highlands mossy forest (Maideen *et al.* 2012, 2025). Where Bidin could only draw on a handful of well-botanised localities, today's picture rests on a far broader base of well-recorded documentation.

Second, the taxonomy has been modernised. The classification used in 1991 has been superseded by the community-derived framework of the Pteridophyte Phylogeny Group (PPG I 2016), and molecular tools such as DNA barcoding and phylogenetics now complement classical morphology. These approaches have resolved long-standing uncertainties and made it possible to recognise taxa that earlier surveys could not separate. In parallel, comprehensive taxonomic revisions have clarified species boundaries in several groups occurring in Malaysia. For example, a revision of the Asian genus *Oleandra* reduced numerous previously recognised taxa and provided a clearer circumscription of species distributed in Peninsular Malaysia and Borneo (Hovenkamp and Ho 2012). In addition, integrative systematic studies combining molecular and anatomical evidence have improved understanding of relationships within Malaysian fern groups. A phylogenetic study of Athyriaceae in Peninsular Malaysia confirmed the monophyly of the family and clarified

relationships among *Diplazium*, *Athyrium*, *Cornopteris* and *Deparia* (Aliah *et al.* 2024). Together, these studies illustrate how modern systematic approaches continue to refine our understanding of Malaysia's fern flora.

Third, continued fieldwork and taxonomic research have yielded numerous new discoveries, rediscoveries and nomenclatural updates. Recent examples include the rediscovery and lectotypification of *Diplazium velutinum*, a rare endemic fern from Peninsular Malaysia (Aliah *et al*. 2026), the first record of the genus *Cornopteris* (Athyriaceae) for Peninsular Malaysia (Maideen *et al.* 2021), and the rediscovery of *Diplazium procumbens* after more than 70 years (Maideen *et al.* 2019). Taxonomic studies have also revealed previously unrecognised diversity, such as the description of two new species of *Phlegmariurus* (Lycopodiaceae) and a new combination from Peninsular Malaysia (Kiew and Kamin 2018). Together, these findings demonstrate that Malaysia's fern and lycophyte flora remains incompletely documented and that continued exploration, particularly in under-surveyed regions and specialised habitats, is likely to reveal additional taxa and distribution records. The net effect is a far clearer – though still incomplete – understanding of Malaysia's pteridophyte diversity than was available in 1991.

MALAYSIA'S FERNS ACROSS THE MAJOR HABITATS

Lowland forests

Lowland dipterocarp forests remain the principal centre of fern diversity in Malaysia. Their extensive environmental heterogeneity, including shaded forest floors, riparian corridors, treefall gaps and humid understories, provides a wide variety of ecological niches for terrestrial, epiphytic and climbing species. Common genera include *Stenochlaena*, *Blechnum*, *Nephrolepis*, *Lygodium*, *Asplenium* and *Pyrrosia*. Despite their importance, lowland forests continue to experience the greatest pressure from land-use change and habitat conversion, making them a priority for conservation.

Limestone hills

Limestone hills support a specialised fern flora adapted to the unique environmental conditions associated with karst landscapes. Although occupying only a small proportion of Malaysia's land area, these habitats contribute disproportionately to national biodiversity and contain numerous restricted-range species. As noted by Bidin (1991), limestone ecosystems remain among the most vulnerable habitats due to quarrying, mining and habitat fragmentation.

Many limestone-associated ferns exhibit strong habitat specialisation. *Antrophyum parvulum* Blume, for example, is closely associated with limestone substrates throughout Peninsular Malaysia and is capable of withstanding prolonged drought periods typical of exposed karst environments (Holttum 1968; Piggott 1988). Field observations from Mount Baling, Kedah, and Mount Senyum, Pahang, showed that populations occur on limestone rock surfaces ranging from shaded, moss-covered habitats to exposed cliff faces, illustrating adaptation to the diverse microhabitats found within limestone ecosystems (Kiew *et al.* 2011). Likewise, *Calciphilopteris alleniae* (R.M.Tryon) Yesilyurt & H.Schneid. is a limestone specialist typically confined to shaded crevices and moss-covered limestone outcrops and is considered conservation-dependent because of its restricted distribution and the ongoing impacts of quarrying and forest clearing on limestone habitats (Kiew *et al.* 2017).

Recent botanical exploration has further demonstrated the conservation significance of limestone habitats. The discovery of *Asplenium merapohense* Jaman & K.Imin, a limestone endemic described from karst hills in Pahang and Kelantan, highlights the continued potential for new discoveries in these habitats (Jaman *et al.* 2017). This species is currently assessed as Critically Endangered because it is known from only two localities, occupies a

highly restricted area, and faces continuing threats from quarrying and agricultural encroachment (Jaman *et al*. 2017). Restricted to steep limestone cliffs and crevices, *A. merapohense* exemplifies the vulnerability of narrowly endemic fern species dependent on intact karst ecosystems. Limestone habitats also support high levels of pteridophyte diversity. In Sarawak, surveys of the Bau Limestone area documented approximately 120 species of ferns and lycophytes representing 55 genera and 26 families, accounting for approximately 20% of Sarawak's known pteridophyte flora despite the relatively limited extent of limestone habitat (Kalu 2004). The concentration of both species richness and habitat specialists within isolated karst systems underscores the importance of limestone hills as centres of pteridophyte diversity and conservation priority in Malaysia.

Montane forests

Montane forests support distinct fern assemblages adapted to cooler temperatures, frequent cloud cover and consistently high humidity. Filmy ferns (Hymenophyllaceae), grammitid ferns and species associated with moss-covered substrates are characteristic components of these communities. Studies from Kinabalu Park have shown that montane habitats between 1,500 and 2,200 m elevation support high fern diversity, particularly within Hymenophyllaceae and Polypodiaceae, with genera such as *Hymenophyllum* and *Oreogrammitis* being especially well represented (Anthony *et al.* 2024). These taxa are closely associated with humid cloud -forest environments where persistent moisture and reduced evapotranspiration create favourable conditions for epiphytic and moisture-dependent species. Furthermore, Kinabalu Park remains one of the most important centres of fern diversity in Southeast Asia, supporting approximately 645 species of ferns and numerous endemic taxa (Parris and Latiff 1997; Anthony *et al*. 2024).

Montane forests also contribute significantly to the evolutionary diversity of Malaysia's fern flora and continue to yield important botanical discoveries. Recent studies from Borneo have documented several species new to science, including *Pteris borneensis* from the Trus Madi Forest Reserve in Sabah (Chao *et al.* 2017), and *Antrophyum hovenkampii* and *Pteris hovenkampii* from Mount Mulu National Park, Sarawak (Chen *et al.* 2021). Similar discoveries have been made in Peninsular Malaysia, where *Cornopteris opaca* was recorded for the first time from Mount Berinchang, Cameron Highlands, extending the known distribution of the genus beyond Mount Kinabalu in Sabah (Maideen *et al.* 2021). More recently, *Diplazium velutinum*, a rare endemic species originally described from Cameron Highlands, was rediscovered after more than three decades without confirmed collections, underscoring the continued value of floristic surveys in Malaysia's montane forests (Aliah *et al.* 2026). The rediscovery of *D. velutinum* also highlighted the importance of protecting upper montane habitats, where the species appears restricted to cool, humid forests above 1,400 m elevation.

Although montane forests generally contain fewer species than lowland forests, they contribute unique ecological and evolutionary elements to Malaysia's fern flora and provide important refugia for moisture-dependent taxa. Their significance is further reflected in protected areas such as Kinabalu Park and Mount Mulu National Park, both internationally recognised for their exceptional biodiversity and high levels of plant endemism (Jermy *et al.* 1984; UNESCO 2000). Mount Mulu alone supports at least 442 recorded species of pteridophytes across a wide range of montane and limestone habitats (Jermy *et al*. 1984), making it one of the richest fern localities in Borneo. Together, these findings demonstrate that Malaysia's montane forests are not only reservoirs of fern diversity but also centres of endemism, ecological specialisation and ongoing evolutionary diversification. Because many montane fern species depend on consistently cool, humid conditions and persistent cloud cover, these ecosystems may be particularly vulnerable to climate-driven changes in temperature, rainfall and cloud formation. Protecting Malaysia's montane forests, including those of the Cameron Highlands, Crocker Range (Majuakim and Anthony 2016), Mount Kinabalu and Mount Mulu, is therefore essential for safeguarding some of the country's most specialised and range-restricted fern species.

THREATS AND PRESSURES: AN UPDATED PICTURE

Many of the conservation concerns identified by Bidin (1991) remain highly relevant today. More than three decades ago, Bidin highlighted the vulnerability of lowland forests, limestone hills and island ecosystems to logging, land conversion and development. While substantial progress has been made in expanding protected areas and improving knowledge of Malaysia's fern flora, habitat loss and degradation continue to threaten many fern-rich ecosystems. Lowland dipterocarp forests remain under the greatest pressure because they coincide with areas most suitable for agriculture, infrastructure development and human settlement. As these forests support the highest fern diversity in the country, continued habitat loss poses a significant risk to many species. Limestone hills remain particularly vulnerable because their specialised fern communities are confined to isolated outcrops and cannot easily disperse when habitats are destroyed. Similarly, island floras continue to face pressures associated with tourism development and habitat modification.

The most significant new challenge since 1991 is climate change. Unlike habitat loss, which primarily affects specific locations, climate change has the potential to alter environmental conditions across entire landscapes. Montane and cloud forests are especially vulnerable because many of their fern species depend on persistently cool and humid conditions. Rising temperatures, changing rainfall patterns and shifts in cloud formation may reduce the extent of suitable habitat available to these specialised species, many of which occur in restricted high-elevation environments. Several broader challenges further complicate fern conservation in Malaysia. Habitat fragmentation reduces connectivity between forest habitats and may limit the movement and long-term persistence of some species. At the same time, large areas of Malaysia, particularly in Sabah and Sarawak, remain incompletely surveyed, making it difficult to determine the true conservation status of many taxa. Although hundreds of fern species are known from Malaysia, only a small proportion have undergone formal conservation assessment.

CONSERVATION MEASURES AND OPPORTUNITIES

Many of the conservation measures proposed by Bidin (1991) remain highly relevant today. His recommendations included the establishment of fern conservatories, the collection and storage of spores, the protection of fern-rich habitats through gazettement, and the cultivation of rare species in botanic gardens. More than three decades later, these measures continue to provide a strong foundation for fern conservation in Malaysia. However, advances in scientific knowledge and the emergence of new environmental pressures require these efforts to be expanded and updated.

Protect whole elevational gradients, not isolated patches

As each zone holds a largely distinct community and the transitions between them matter, conservation should aim to keep lowland, hill and montane habitats connected rather than protecting fragments in isolation. Particular attention should be given to lowland forests and limestone ecosystems, where biodiversity value remains high but conservation pressures continue to intensify.

Strengthen ex situ conservation

Living collections and spore banks remain essential insurance against habitat loss. There is a notable continuity here: the fern garden Bidin illustrated at Universiti Kebangsaan Malaysia in 1991 (Bidin 1991) (Figure 4; Taman Paku-pakis) has since developed into an established fernarium that supports conservation, research and education—a concrete example of the kind of ex situ facility he envisioned, now realised and expandable.

Apply modern tools to set priorities
Modern scientific tools provide new opportunities to strengthen fern conservation. DNA barcoding, phylogenetic analyses, species distribution modelling and climate-vulnerability assessments can help identify species and habitats most at risk. When combined with renewed field surveys and herbarium-based research, these approaches can improve conservation planning and support the formal assessment of Malaysian fern species, many of which remain unevaluated.

Use ferns to engage the public
Ferns are charismatic, easily recognised and present in every forest type, which makes them an accessible entry point for public awareness and education. Because they are sensitive to changes in moisture and forest structure, making them useful ecological indicators of forest condition. Advances in ecological monitoring and molecular tools now provide opportunities to strengthen their application in biodiversity assessment and conservation.

CONCLUSION: THE WAY FORWARD

More than three decades after the *State of Nature Conservation in Malaysia* 1991 assessment of Malaysia's ferns and lycophytes, our understanding of this important component of biodiversity has expanded substantially. Continued floristic surveys, taxonomic revision, herbarium research and molecular phylogenetic studies have revealed a richer and more complex flora than was previously recognised. New species, new national records and the rediscovery of rare taxa demonstrate that Malaysia's pteridophyte diversity remains incompletely documented and that further exploration continues to yield significant findings. Despite these advances, many of the conservation concerns identified in 1991 remain relevant today. Lowland forests, limestone hills and island ecosystems continue to face pressures from habitat loss, fragmentation and development, while climate change has emerged as an additional threat, particularly for moisture-dependent species confined to montane environments. Significant knowledge gaps also persist, especially in under-surveyed regions of Sabah and Sarawak, and many species have yet to undergo formal conservation assessment. The priorities for the coming decades are therefore clear: (1) strengthening habitat protection across Malaysia's diverse forest ecosystems, (2) expanding long-term inventories and monitoring programmes, (3) enhancing *ex situ* conservation initiatives, and (4) integrating modern tools such as DNA barcoding, phylogenomics and species distribution modelling into conservation planning. Greater collaboration among researchers, conservation agencies, protected-area managers and local communities will also be essential to ensure that scientific knowledge is translated into effective conservation action. By building on the foundation laid by Bidin (1991), Malaysia is well positioned to advance both the study and conservation of its fern and lycophyte flora. Conserving these ancient plant lineages is not only a matter of protecting species diversity, but also of safeguarding the ecological integrity, evolutionary heritage and resilience of Malaysia's forests for future generations.

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REFERENCES

Acebey, A.R., Krömer, T. and Kessler, M. 2017. Species richness and vertical distribution of ferns and lycophytes along an elevational gradient in Los Tuxtlas, Veracruz, Mexico. *Flora* 235: 83–91. https://doi.org/10.1016/j.flora.2017.08.003

Aliah, N., Maideen, H., Nadhirah, N. and Norhazrina, N. 2024. Systematics of Athyriaceae family in Peninsular Malaysia based on combination anatomical and molecular data. *Sains Malaysiana* 53(10): 3263–3277. https://doi.org/10.17576/jsm-2024-5310-03

Aliah, N., Nadhirah, N., Maideen, H., Norhazrina, N., Khamis, S., Mohd Yusop, S., Basir, S. *et al.* 2026. Rediscovery and lectotypification of *Diplazium velutinum* Holttum (Athyriaceae), a rare endemic fern from Peninsular Malaysia. *PhytoKeys* 276: 139–149. https://doi.org/10.3897/phytokeys.276.197738

Anthony, F., Mustapeng, A.M.A., Lanting, S., Wong, H. and Suleiman, M. 2024. A checklist of ferns and lycophytes from Marai-Parai in Kinabalu Park, Sabah. *Sabah Parks Nature Journal* 14: 1–13.

Bidin, A. 1991. Ferns and fern-allies of Peninsular Malaysia. In *The State of Nature Conservation in Malaysia*, R. Kiew (Ed.), pp. 62–66. Kuala Lumpur: Malayan Nature Society.

Chao, Y.-S., Mustapeng, A.M.A., Chen, C.-W. and Chiou, W.-L. 2017. *Pteris borneensis* (Pteridaceae), a new species from Borneo, with re-circumscription of *Pteris* decrescens and *Pteris parviloba*. *Systematic Botany* 42(4): 724–732. https://doi.org/10.1600/036364417X696609

Chen, C.-W., Chao, Y.-S., Mustapeng, A.M.A., Sapawi, N.M. and Huang, Y.-M. 2021. Two new fern species from Gunung Mulu National Park, Sarawak, Malaysian Borneo. *Systematic Botany* 46(3): 739–749. https://doi.org/10.1600/036364421X16312067913381

Holttum, R.E. 1968. *A Revised Flora of Malaya. Vol. II: Ferns of Malaya*. Singapore: Government Printing Office.

Hovenkamp, P.H. and Ho, B.-C. 2012. A revision of the fern genus *Oleandra* (Oleandraceae) in Asia. *PhytoKeys* 11: 1–37.

Jaman, A.R. and Latiff, A. 2007. Pteridophytes diversity of Taman Rimba Kenong. In *Taman Rimba Kenong, Pahang: Pengurusan Persekitaran Fizikal dan Kepelbagaian Biologi*. Siri Kepelbagaian Biologi Hutan. Kuala Lumpur: Jabatan Perhutanan Semenanjung Malaysia.

Jaman, R., Imin, K. and Kiew, R. 2017. *Asplenium merapohense* (Aspleniaceae), a new species from Peninsular Malaysia. *PhytoKeys* 89: 85–90. https://doi.org/10.3897/phytokeys.89.20875

Jermy, A.C., Parris, B.S., Camus, J.M. and Paul, A.M. 1984. The Pteridophyta of Gunung Mulu National Park. In *Studies on the Flora of Gunung Mulu National Park*. Kuching: Forest Department Sarawak.

Kalu, M. 2004. Ferns and fern-allies. In Sarawak Bau Limestone Biodiversity, H.S. Yong, F.S.P. Ng and E.E.L. Yen (Eds.). *Sarawak Museum Journal* 59(80): 187–192.

Kiew, R. and Kamin, I. 2018. Two new *Phlegmariurus* species (Lycopodiaceae) and one new combination from Peninsular Malaysia. *PhytoKeys* 96: 99–110. https://doi.org/10.3897/phytokeys.96.20878

Kiew, R., Nor-Ezzawanis, A.T., Saw, L.G. and Lau, K.H. 2011. Inside the quail trap: A botanical snapshot of Gunung Jebak Puyuh. *Malaysian Naturalist* 64(4): 32–36.

Kiew, R., Rafidah, A.R., Ong, P.T. and Ummul Nazrah, A.R. 2017. Limestone treasures: Rare plants in Peninsular Malaysia – What they are, where they grow and how to conserve them? *Malaysian Naturalist* 71(1): 32–41.

Lu, Y., Lyu, M., Xiong, X., Deng, C., Jiang, Y., Zeng, M. and Xie, J. 2023. Understory ferns promote the restoration of soil microbial diversity and function in previously degraded lands. *Science of The Total Environment* 870: 161934. https://doi.org/10.1016/j.scitotenv.2023.161934

Maideen, H., Nadia, W.H., Jaman, R., Damanhuri, A. and Latiff, A. 2004. Kepelbagaian paku-pakis di Taman Negeri Endau Rompin. In *Taman Negeri Endau Rompin: Pengurusan, Persekitaran Fizikal dan Biologi*, S.M. Ismail, M.M. Isa, W.Y.W. Ahmad, M. Rahim Ramli and A. Latiff (Eds.). Kuala Lumpur: Jabatan Perhutanan Semenanjung Malaysia.

Maideen, H., Saad, A.R., Zainal, N. and Damanhuri, A. 2012. Flora paku-pakis di Hutan Lipur Lata Belatan, Gunung Tebu, Besut, Terengganu. In *Hutan Simpan Gunung Tebu, Terengganu: Pengurusan Hutan, Persekitaran Fizikal dan Kepelbagaian Biologi*, A.R. Abd. Rahim, A. Nordin, M.N.A. Hassan, M.B. Nor Hasliza and A. Latiff (Eds.), Siri Kepelbagaian Biologi Hutan 22. Kuala Lumpur: Jabatan Perhutanan Semenanjung Malaysia.

Maideen, H., Aliah, N., Norhazrina, N. and Go, R. 2019. Rediscovery of *Diplazium procumbens* (Athyriaceae) in Peninsular Malaysia after more than 70 years, with notes on the morphology, spore ornamentation and anatomy. *Phytotaxa* 422(3): 241–247. https://doi.org/10.11646/phytotaxa.422.3.4

Maideen, H., Aliah, N. and Nadhirah, N. 2021. A new record of the fern genus *Cornopteris* (Athyriaceae) from Peninsular Malaysia. *American Fern Journal* 111(2): 63–68. https://doi.org/10.1640/0002-8444-111.2.63

Maideen, H., Nadhirah, N., Nik Muhamad Haikal, M. and Aliah, N. 2025. Flora paku-pakis di Taman Eko Rimba Mossy Forest dan kawasan sekitarnya di Cameron Highlands, Pahang. *Seminar Ekspedisi Saintifik Taman Ekorimba Mossy Forest*, pp. 1–40.

Majuakim, L. and Anthony, F. 2016. Diversity and ecology of ferns on Mount Alab, Crocker Range Park, Sabah, Malaysia. *Malayan Nature Journal* 68(1–2): 167–176.

Ministry of Natural Resources, Environment and Climate Change (NRECC). 2022. *National Policy on Biological Diversity 2022–2030. Putrajaya: Biodiversity and Forestry Management Division*. Putrajaya: Ministry of Natural Resources, Environment and Climate Change .

Parris, B.S. and Latiff, A. 1997. Towards a pteridophyte flora of Malaysia: a provisional checklist of taxa. *Malayan Nature Journal* 50: 257–329.

Piggott, A.G. 1988. *Ferns of Malaysia in Colour*. Kuala Lumpur: Tropical Press.

Pteridophyte Phylogeny Group I (PPG I). 2016. A community-derived classification for extant lycophytes and ferns. *Journal of Systematics and Evolution* 54(6): 563–603. https://doi.org/10.1111/jse.12229

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CHAPTER 5

Seagrass ecosystems in Malaysia

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Abstract: Seagrass meadows are widely distributed along the shallow coasts of Malaysia and provide important ecological functions that supports biodiversity and coastal livelihoods. Malaysia also supports 17 species of seagrass, with highest recorded species richness in southern Peninsular Malaysia and eastern Sabah (14 species), although national estimates of the extent of seagrass meadow remain uncertain due to uneven survey coverage and limited long-term monitoring efforts. Available evidence indicates permanent losses and major contractions of seagrass meadows associated primarily with coastal development, seabed filling, dredging, and declining water quality. The protection of seagrass is still mostly indirect and often incidental, with management responses being reactive and species-driven, with seagrass commonly protected indirectly through Marine Parks and broader coastal conservation frameworks rather than integrated into coastal planning and management. The Sibu-Tinggi Archipelago, Johor and Kampung Kebagu, Sabah case studies illustrated in this study highlights the contrasting conservation outcomes and importance of sustained research and preventive management.

INTRODUCTION

Seagrass meadows occur widely along Malaysia's shallow coasts, forming highly productive ecosystems that support fisheries, coastal livelihoods, and marine biodiversity. They are found in estuaries, lagoons, nearshore flats, and around islands, where they are closely linked to mangroves and coral reefs as part of connected coastal systems. These meadows provide nursery and feeding habitat for fish and invertebrates and support gleaning and small-scale fisheries on which many coastal communities depend. They also serve as critical habitat for endangered megafauna such as dugongs and green turtles.

Malaysia spans two major marine regions—the Sunda Shelf and the western edge of the Coral Triangle—contributing to relatively high seagrass diversity compared to many countries in the region. Despite this ecological importance, seagrass meadows remain unevenly documented and weakly integrated into coastal planning and management. Clear information on their distribution, condition, and trajectories is therefore essential for assessing the current state of Malaysia's coastal ecosystems and informing decisions that prevent irreversible loss.

At the national scale, assessment of seagrass remains constrained by uneven mapping and limited long-term monitoring, yet available evidence shows that permanent losses and major contractions have already occurred. Coastal development, seabed filling, dredging, and declining water quality are the most consistent pressures, while conservation responses remain largely reactive and fragmented.

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SITUATIONAL ANALYSIS

Distribution and extent

Seagrasses occur along much of Malaysia's coastline in shallow, sheltered waters with soft substrates and adequate light, and are absent from rocky or high-energy coasts (Figure 1). They form both intertidal and subtidal meadows across coastal settings including estuaries and deltas, semi-enclosed lagoons, reef-associated flats, open coastal flats, and offshore shoals (e.g. Bujang *et al.* 2006; Ooi *et al.* 2011b).

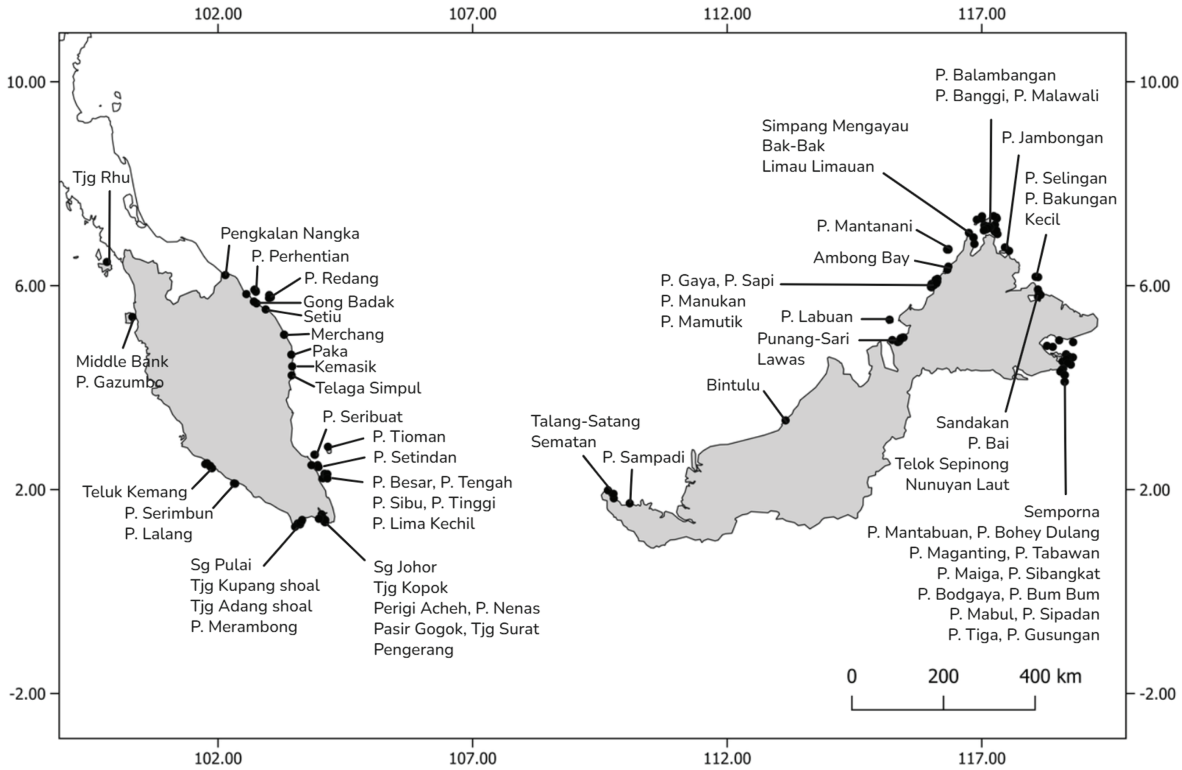

Figure 1. Map of verified seagrass occurrence records in Malaysia, showing 205 point locations compiled from 59 peer-reviewed papers and technical reports published between 2000 and 2025. Areas without points reflect gaps in survey coverage and data availability rather than confirmed absence of seagrass. "P." denotes Pulau (Malay for "island").

National-scale mapping remains incomplete. The most recent verified estimate of approximately 49 km^2 (Sudo *et al.* 2021) almost certainly underrepresents true national extent, particularly in Sarawak. In contrast, substantially larger figures reported in global datasets (e.g. 5,581 km^2 in Thorhaug *et al.* 2020) lack Malaysia-specific validation.

Seagrass meadows in Malaysia vary widely in size, with a small number of well-documented sites providing important anchors for national understanding. The largest documented meadow occurs in the Sibu Archipelago (Johor), where a continuous subtidal system covers approximately 12.88 km^2 (Heng *et al.* 2022). Among intertidal systems, the most extensive meadow is found in the Lawas region of Sarawak, estimated at around 2 – 3 km^2 (Bujang *et al.* 2006). In Sabah, significant seagrass areas have been mapped around Banggi Island, where multiple subtidal sites together support approximately 4.15 km^2 of seagrass (Rajamani and Marsh 2015). Beyond these locations, seagrass mapping

has been spatially uneven and largely focused on intertidal habitats, with subtidal meadows remaining a major knowledge gap due to the need for in-water surveys. A national intertidal seagrass mapping programme funded by Yayasan PETRONAS, initiated in 2025, is expected to substantially improve coverage and area estimates for Peninsular Malaysia and Sabah.

Species richness and diversity

Located within the Indo–West Pacific, one of the global centres of seagrass diversity, Malaysia supports a relatively high diversity of seagrass species, with 17 species recorded nationally (Table 1). Species richness varies regionally, reflecting differences in coastal geomorphology, water clarity, and survey effort. The south coast of Peninsular Malaysia and east coast of Sabah show the highest recorded richness, each supporting up to 14 species. In contrast, Sarawak exhibits lower recorded richness, reflecting limited survey coverage rather than confirmed absence.

At the site level, areas of high richness are concentrated in Johor and Sabah. The Sibu–Tinggi archipelago supports up to 12 species (Ooi *et al.* 2011b, 2017), while the Sungai Pulai estuary has recorded 10 – 12 species, but with evidence of species loss over time (Bujang and Zakaria 2014; Che Alias *et al.* 2024). In East Malaysia, Pulau Banggi and Pulau Gaya (Sabah) support around 10 species, while Lawas (Sarawak) records approximately eight species (Bujang *et al.* 2006; Ahmad-Kamil *et al.* 2013; Rajamani and Marsh 2015).

Most Malaysian seagrass species are classified as Least Concern (Table 1); however, *Halophila beccarii* is listed as Vulnerable due to habitat degradation, and emerging evidence of decline in *Enhalus acoroides* indicates growing conservation concern despite being in the Least Concern category (IUCN 2024).

Ecological Functions and Services

Seagrass meadows function as important nursery and feeding habitats for fish and invertebrates, supporting nearshore fisheries and coastal food webs. Malaysian seagrass meadows are used by commercially important demersal and nearshore fishes, including emperors (Lethrinidae) and threadfin breams (Nemipteridae), and support high densities of juvenile fishes, reinforcing their role as nursery grounds contributing to fisheries productivity (Arshad *et al.* 2006; Ho *et al.* 2018; Ho 2019).

Seagrass meadows also contribute to coastal environmental quality by reducing turbidity, stabilising sediments, and improving nearshore conditions (Japar Sidik and Bujang 2006; Lamb *et al.* 2017). Structurally large species such as tape seagrass (*Enhalus acoroides*) play an important role in sediment stabilisation in shallow systems, including in Penang (Nur Asilah 2020). Malaysian seagrass meadows further contribute to blue carbon storage, although available estimates are limited and likely conservative (Rozaimi *et al.* 2017).

In addition, seagrass meadows are key foraging habitats for endangered megafauna such as dugongs and green turtles, and support coastal livelihoods through intertidal gleaning and small-scale fisheries, particularly for women (Affendi *et al.* 2005; Ponnampalam *et al.* 2015; Heng *et al.* 2022; Nishizawa *et al.* 2023; David *et al.* 2024). Socio-economic valuation suggests substantial livelihood and non-market benefits, conservatively estimated at at least US$57,000 per hectare per year in Sungai Pulai, although such assessments remain geographically limited (Rahman and Yaakub 2020).

Table 1. Seagrass species in Malaysia by region. IUCN Red List Categories in increasing order of extinction risk - LC Least Concern, NT Near Threatened, VU Vulnerable.

No.	Family/Species	IUCN Red List Category	West Peninsular Malaysia	East Peninsular Malaysia	South Peninsular Malaysia	West Sabah	East Sabah	North Sabah	Sarawak
	Family Hydrocharitaceae								
1	*Enhalus acoroides* (Linnaeus *f.*) Royle	LC	√	√	√	√	√	√	√
2	*Thalassia hemprichii* (Ehrenb.) Aschers.	LC	√	√	√	√	√	√	√
3	*Halophila beccarii* Aschers.	VU		√	√				√
4	*Halophila decipiens* Ostenfeld	LC	√	√	√		√	√	√
5	*Halophila major* (Zoll.) Miquel	LC		√	√		√	√	
6	*Halophila minor* (Zoll.) den Hartog	LC		√	√	√	√	√	√
7	*Halophila ovalis* (R. Br.) Hook. *f.*	LC	√	√	√	√	√	√	√
8	*Halophila nipponica* J. Kuo.	NT			√				
9	*Halophila spinulosa* Aschers.	LC	√	√	√		√	√	
10	*Halophila tricostata* M.Greenway	LC					√		
	Family Cymodoceaceae								
11	*Cymodocea rotundata* Ehrenb. & Hempr. ex Aschers.	LC	√	√	√	√	√	√	√
12	**Oceana serrulata* (R. Br.) Byng & Christenh.	LC	√	√	√	√	√	√	√
13	*Halodule pinifolia* (Miki) den Hartog	LC	√	√	√	√	√	√	√
14	*Halodule uninervis* (Forssk.) Aschers.	LC	√	√	√	√	√	√	√
15	*Syringodium isoetifolium* (Ashers.) Dandy	LC	√	√	√		√	√	
16	*Thalassodendron ciliatum* (Forssk.) den Hartog	LC					√		
	Family Ruppiaceae								
17	*Ruppia maritima* Linnaues	LC	√						
	Total Species		12	13	14	8	14	12	10
	Total Species by Region			15			14		10

*Previously *Cymodocea serrulata* (R. Br.) Aschers. Magnus.

STATUS AND TRENDS

The national status of seagrass ecosystems in Malaysia remains difficult to resolve due to uneven spatial coverage and limited long-term observations. Nevertheless, there is clear evidence that seagrass meadows have been permanently lost at multiple locations. Entire meadows have been eliminated following coastal development, dredging, sand mining, and land reclamation, with documented losses in Johor, Terengganu, Kelantan, and Negeri Sembilan (Bujang *et al*. 1999, 2016; Zakaria *et al.* 2025). These records demonstrate that seagrass loss in Malaysia is real, substantial, and often irreversible.

In addition to complete losses, several large meadows have undergone substantial contraction, including reductions by half and more at Pengkalan Nangka Lagoon (Kelantan), Telaga Simpul (Terengganu), and Tanjung Adang Laut (Johor), as well as marked declines at Paka Lagoon (Terengganu) and the Punang–Sari Lawas River Estuary (Sarawak), driven by combinations of coastal development, sediment disturbance, and natural sand dynamics (Bujang and Zakaria 2014; Hossain *et al.* 2015; Zakaria *et al*. 2025).

At the same time, seagrass meadows can exhibit pronounced variability within annual cycles, particularly in monsoon-influenced systems that experience light limitation and sediment dynamics. Studies from both intertidal and subtidal environments show that meadow extent and cover can fluctuate markedly within a single year without necessarily indicating sustained decline. Seasonal contraction and partial recovery have been documented in subtidal meadows of the Sibu–Tinggi archipelago and in intertidal systems in Tanjung Kopok (Johor) and Lawas (Sarawak) (Ahmad-Kamil *et al.* 2013; Ooi and Lim 2019; Heng *et al.* 2022; Ooi *et al.* 2024a), underscoring the need to distinguish seasonal variability from persistent loss when interpreting monitoring data.

Drivers of change and pressures

In Malaysia's intertidal systems, the strongest evidence of seagrass loss is linked to human-driven drivers, particularly coastal development, dredging, and seabed infilling (Table 2). In Sungai Pulai (Johor), shoreline modification and dredging have caused long-term reductions in seagrass extent through altered sediment transport, burial, and reduced light availability (Bujang and Zakaria 2014; Hossain *et al.* 2019), processes known to constrain recovery following disturbance (Ooi *et al.* 2011a). Similar land-based pressures occur in Sabah, where catchment disturbance and infrastructure development have increased sediment inputs and reduced light availability, including within protected areas (Freeman *et al.* 2008).

Natural forcing also shapes intertidal dynamics. At Kampung Kebagu (Sabah), seagrass cover declines during the Northeast Monsoon but recovers during calmer periods, indicating short-term variability (Hassan *et al.* 2025), although episodic extreme events such as the 2015 Sabah earthquake and repeated exposure to adverse conditions have since been associated with more persistent loss in nearby systems such as Usukan Bay.

Water-quality degradation further compounds stress. Elevated nutrients, turbidity, and pollutants are associated with declining seagrass condition at Sungai Johor, Lawas (Sarawak), and parts of Sabah (Freeman *et al.* 2008; Ahmad-Kamil *et al.* 2013; Ooi *et al.* 2024a). Localised physical disturbance, particularly boat anchoring and propeller scarring, damages shoots and rhizomes and disproportionately affects large, slow-growing species such as *Enhalus acoroides*. Additional damage may occur when leaves are manually torn to prevent propeller entanglement, further reducing canopy integrity.

Subtidal meadows such as Pulau Sibu (Johor), within a marine protected area, are shaped primarily by monsoon-driven hydrodynamics, with waves and currents driving cycles of contraction and re-establishment (Ooi *et al.* 2014; Ooi and Lim 2019; Heng *et al.* 2022). In parts of Sabah, destructive fishing practices, including blast fishing, remain an additional pressure on nearshore seagrass habitats (Showen *et al.* 2018).

Table 2. Summary of major drivers of seagrass change in Malaysia, the pressures through which they act, and observed ecological effects at representative sites.

Driver	Pressure	Key Sites	Observed Effects
Coastal development & land reclamation	Dredging, infilling, direct habitat removal, altered sediment transport	Johor: Sungai Pulai (Merambong, Tanjung Adang Laut, Tanjung Adang Darat)	Long-term loss of intertidal seagrass extent
Catchment disturbance & land-use change	Sediment runoff, turbidity, reduced light availability	Johor: Sungai Pulai; Sungai Johor Sabah: Tunku Abdul Rahman Park	Seagrass loss or delayed recovery due to light limitation
Poor water quality management	Elevated nutrients and industrial pollutants	Johor: Tanjung Kopok; Perigi Acheh Sarawak: Lawas	Reduced seagrass cover, shortened canopy height, algal dominance
Boating and vessel traffic	Physical damage from anchoring and propeller scarring	Johor: Pulau Sibu (subtidal, MPA)	Localised scarring and loss of seagrass cover and biomass
Monsoon climate variability	Strong waves and currents causing physical disturbance	Johor: Pulau Sibu (subtidal, MPA)	Seasonal to multi-year contraction and re-establishment
Episodic extreme events	Acute sediment discharge and turbidity following natural disturbances	Sabah: Usukan Bay (post-2015 earthquake)	Localised seagrass loss associated with short-term sediment loading

CONSERVATION AND MANAGEMENT OVERVIEW

Seagrass conservation in Malaysia has evolved through a series of overlapping initiatives rather than a coordinated national framework. Early work focused on inventory and use, while later studies—particularly those linked to dugong research—brought seagrass into conservation discussions (Affendi *et al.* 2005; Ponnampalam *et al.* 2015; Heng *et al.* 2022) and, as recently seen in Pahang, triggered immediate restrictions on tourism (Ooi *et al.* 2024b). Despite this, translation into formal, lasting protection has been limited by legislative and governance constraints.

At present, seagrass is still mostly protected indirectly, with about 15% of mapped meadows falling within Marine Parks or Ramsar sites (Sudo *et al.* 2021). While seagrass has gained some recognition through broader ecosystem-based planning frameworks, including marine protected areas and the Important Marine and Coastal Areas programme (WWF Malaysia & MSMS 2024), protection is often incidental, and management responses tend to be reactive and species-driven rather than part of routine planning and regulation.

Notably, community-based monitoring has raised the profile of seagrass and generated useful site-level knowledge, particularly in Johor meadows since the late 2000s. However, these efforts remain weakly linked to formal management and regulatory processes, limiting their influence on planning and regulatory decisions.

Knowledge gaps

Despite growing research attention, significant knowledge gaps continue to constrain effective seagrass conservation and management in Malaysia.

1. Spatial data gaps and uneven geographic coverage

Seagrass distribution data remain spatially incomplete and geographically uneven, with major gaps in Sabah and Sarawak despite known occurrences. Existing maps are largely derived from site-specific or opportunistic surveys—mostly in Johor—limiting confidence in national-scale estimates of meadow extent, richness, and representativeness.

2. Limited long-term data to assess seagrass condition and trends

Malaysia lacks sustained, standardised data frameworks to track seagrass condition over time. Consequently, long-term trends in meadow condition, species composition, and responses to interacting pressures remain poorly understood. Most monitoring efforts have been short-lived, constraining the detection of cumulative change and comparison of trajectories across sites.

3. Limited data on ecosystem functions and services to humans

Although the ecological importance of seagrass meadows is widely recognised, empirical data on functions of direct policy relevance—such as fisheries support, coastal protection, and carbon sequestration—remain limited. Socio-ecological dimensions, including livelihood dependence, gendered use, and cultural values, are unevenly documented and rarely integrated with biophysical datasets.

4. Limited scientific evidence to guide seagrass restoration

Seagrass restoration has gained rapid momentum as a preferred response to meadow loss, often in the absence of Malaysia-specific scientific evidence to guide practice. Key uncertainties remain around site suitability, physical constraints, and long-term persistence in tropical multi-species meadows, compounded by the lack of sustained post-restoration monitoring. In this context, ad hoc restoration efforts, which commonly involve removal of plant material from existing meadows and are undertaken without ecological guidance, risk harming donor sites and adding pressure to remaining seagrass rather than supporting recovery.

Case studies

The following case studies illustrate contrasting pathways of seagrass conservation in Malaysia: one shaped by long-term research informing conservation recognition, and another documenting rapid loss in a highly exposed system.

Sibu-Tinggi Archipelago, Johor, Peninsular Malaysia

The shallow waters of the Sibu–Tinggi archipelago off Mersing support some of the largest subtidal seagrass meadows in Peninsular Malaysia. Pulau Sibu alone supports a continuous meadow of approximately 12.9 km^2, the largest recorded nationally, while Pulau Tinggi supports a second large meadow of about 3 km^2 (Ooi *et al.* 2011b; Heng *et al.* 2022). Unlike the intertidal systems more commonly studied in Malaysia, these are permanently submerged forereef meadows occurring mainly at depths of about 3 to 6 metres, close to the lower light limits for seagrass growth (Ooi 2012).

The meadows are dominated by small, fast-growing species such as *Halophila ovalis* and *Halodule uninervis*, which are preferred forage for dugongs. Long-term research has identified the archipelago as an important dugong feeding ground, with repeated use by individuals including mother-calf pairs (Affendi *et al.* 2005; Ponnampalam *et al.* 2015; Heng *et al.* 2022).

Ecological studies show that these subtidal meadows are highly sensitive to disturbance. Because they occur near their light thresholds, they undergo cycles of contraction during turbid periods and partial recovery when conditions improve, while even shallow burial of centimetres can cause rapid local loss (Ooi *et al.* 2011a, 2014; Ooi and Lim 2019). As a result, disturbance can have lasting spatial effects even when overall meadow extent appears stable.

Sustained research in the Sibu–Tinggi archipelago has directly informed conservation planning, contributing to its recognition under Malaysia's Important Marine and Coastal Area (MyIMCA) framework (Ooi and Adam 2024). This case illustrates how long-term ecological evidence can support proactive identification of nationally significant seagrass systems.

Kampung Kebagu, Sepanggar Bay, Kota Kinabalu, Sabah

Kampung Kebagu in Sepanggar Bay once supported one of the most extensive remaining intertidal seagrass meadows near Kota Kinabalu. The shallow meadow was exposed to both monsoonal forcing and coastal pressures, and earlier surveys recorded up to seven seagrass species, including *Enhalus acoroides*, *Cymodocea* spp., *Thalassia hemprichii*, *Halodule uninervis* and *Halophila* spp. (Phang 2000; Bujang *et al.* 2006; Thomas 2023).

Monitoring conducted in 2023 documented pronounced seasonal fluctuations in seagrass cover linked to monsoon cycles, alongside an overall decline in meadow condition and loss of *T. hemprichii* and *H. pinifolia* (Hassan *et al.* 2025). Cover decreased substantially during the Northeast Monsoon, recovered during calmer periods, and then declined sharply again by early 2024. Severe seabed erosion and prolonged exposure followed, and by late 2024 the meadow was largely lost. By 2025, only small, patchy remnants of *H. uninervis* and *H. ovalis* remained, with no clear signs of recovery.

At Kampung Kebagu, the combination of shallow depth, tidal exposure, and repeated extreme weather left little scope for recovery once the meadow was lost. This case highlights how exposed intertidal seagrass systems can cross irreversible thresholds when climate -driven stress interacts with local pressures.

CHALLENGES AND OPPORTUNITIES

Seagrass management in Malaysia is shaped by fragmented institutional responsibility across agencies responsible for fisheries, environment, coastal development, and marine protected areas, alongside the absence of a nationally coordinated seagrass inventory and long-term monitoring framework. As a result, national estimates of seagrass extent remain uncertain, the capacity to detect long-term change is limited, and large areas of Sabah and Sarawak remain poorly surveyed despite confirmed seagrass occurrence.

Research and monitoring efforts are largely project-based and short-term, with limited coordination among government agencies, universities, and non-governmental organisations. Monitoring conducted under Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP) requirements is not always easily accessible, reducing continuity and uptake into planning and management decisions.

Despite their ecological importance, seagrass meadows remain weakly recognised in national policy and coastal planning. They are rarely treated as priority habitats in environmental impact assessment or marine spatial planning, and where protection exists it is often incidental, leaving many meadows exposed to pressures from coastal development, seabed filling, dredging, and declining water quality.

At the same time, new opportunities are emerging. Growing interest from industry and private funders, linked to increasing recognition of seagrass as a climate-relevant ecosystem, could support longer-term monitoring and help address key data gaps if channelled through coordinated frameworks. Community-based monitoring and local ecological knowledge also offer practical ways to strengthen conservation by complementing scientific surveys, particularly where institutional capacity is limited.

Policy recommendations

In Malaysia, seagrass conservation needs to be preventive and planning-led, rather than driven by reactive, project-by-project responses. These recommendations emphasise a precautionary approach and coordinated decision-making to avoid irreversible seagrass loss:

1. Apply precautionary limits on seabed filling/land reclamation affecting seagrass

Given strong evidence of sustained seagrass loss linked to seabed filling (land reclamation) and associated dredging, particularly in estuarine and intertidal systems, states should apply time-bound or site-specific moratoria on seabed filling affecting seagrass meadows until adequate baseline data, cumulative impact assessments, and clear avoidance options are available. These measures are likely to face resistance in development-intensive states, but local evidence indicates that once seagrass is buried or fragmented, recovery at meaningful scales is unlikely.

2. Prioritise avoidance of high-value seagrass and define clear no-go areas

Where development is proposed near seagrass, planning should prioritise avoidance of high-value meadows and minimise unavoidable impacts, with restoration or offsets treated only as last-resort measures. No-go areas should include large continuous meadows, sites supporting threatened megafauna, and seagrass areas critical for ecological connectivity, sediment stabilisation, and long-term carbon storage.

3. Make seagrass explicit in coastal planning and EIA decision rules

Seagrass meadows should be explicitly recognised as priority coastal habitats in national and state coastal plans, Environmental Impact Assessment (EIA) guidance, and marine spatial planning layers, so they are considered early in development decisions rather than incidentally or after impacts occur.

4. Address water quality and sediment inputs as core seagrass pressures

Seagrass conservation should be explicitly linked to catchment and coastal water-quality management, recognising that sedimentation, turbidity, and nutrient inputs are major drivers of seagrass decline beyond the meadow itself.

5. Fund long-term, standardised monitoring and cumulative assessment

A nationally endorsed monitoring framework should be established and supported over multiple years to distinguish seasonal variability from sustained decline and to enable cumulative impact assessment in development hotspots, integrating spatially explicit seagrass data from multiple sectors using standard methods and scheduled updates so outputs are directly usable in planning and EIA processes.

REFERENCES

Affendi, Y.A., Ooi, J.L.S., Phang, S.M., Azhar, H., Faedzul, R. and Rosmadi, F. 2005. *Dugongs in Peril: The Conservation and Protection of Dugongs in Johor, Malaysia*. A Report by the University of Malaya Maritime Research Centre (UMMReC) for the United Nations Development Programme Malaysia.

Ahmad-Kamil, E.I., Ramli, R., Jaaman, S.A., Bali, J. and Al-Obaidi, J.R. 2013. The effects of water parameters on monthly seagrass percentage cover in Lawas, East Malaysia. *The Scientific World Journal* 2013: 892746. https://doi.org/10.1155/2013/892746

Arshad, A.B., Japar Sidik, B., Muta Harah, Z., Yusof, S. and Mazlan, A.G. 2006. Fish communities from seagrass bed of Merchang Lagoon, Terengganu, Peninsular Malaysia. *Coastal Marine Science* 30(1): 268–275.

Bujang, J.S., Zakaria, M.H., Pauzi, A.M. and Madhavan, S. 1999. *Halodule* species from Malaysia - distribution and morphological variation. *Aquatic Botany* 65(1-4): 33–45.

Bujang, J.S., Zakaria, M.H. and Arshad, A. 2006. Distribution and significance of seagrass ecosystems in Malaysia. *Aquatic Ecosystem Health & Management* 9: 1–12.

Bujang, J.S. and Zakaria, M.H. 2014. Seagrass shoals of Sungai Pulai Estuary, Johor. *Malayan Nature Journal* 66(1-2): 1–14.

Bujang, J.S., Zakaria, M.H. and Short, F.T. 2016. Seagrass in Malaysia: Issues and challenges ahead. In *The Wetland Book: II: Distribution, Description and Conservation*, C.M. Finlayson, G.R. Milton, R.C. Prentice and N.C. Davidson (Eds.), pp. 1–9. Netherlands: Springer Netherlands. https://doi.org/10.1007/978-94-007-6173-5_268-1

Che Alias, M.A., Zakaria, M.H., Ramaiya, S.D., Esa, Y., Ab Ghani, N.I. and Bujang, J.S. 2024. Morphological and genetic identification of *Halophila* species and a new distribution record of *Halophila nipponica* at the Tanjung Adang Laut shoal, Johor, Malaysia. *Plos One* 19(10): e0309143. https://doi.org/10.1371/journal.pone.0309143

David, A.D., Fadzil, K.S., Affendi, Y.A. and Ooi, J.L.S. 2024. Gleaners, gleaning activities, and livelihoods in Peninsular Malaysia. *JATI - Journal of Southeast Asian Studies* 29(2).: 99–142. https://doi.org/10.22452/jati.vol29no2.5

Freeman, A.S., Short, F.T., Isnain, I., Razak, F.A. and Coles, R.G. 2008. Seagrass on the edge: Land-use practices threaten coastal seagrass communities in Sabah, Malaysia. *Biological Conservation* 141(12): 2993–3005. https://doi.org/10.1016/j.biocon.2008.09.018

Hassan, M.A., Saleh, E., Tahir, R. and Madin, J. 2025. Influence of monsoon seasons on seagrass ecosystems on the coast of Kota Kinabalu (Sabah, Malaysia). *Borneo Journal of Resource Science and Technology* 15(1): 23–31. https://doi.org/10.33736/bjrst.7355.2025

Heng, H.W.K., Ooi, J.L.S., Affendi, Y.A., Kee Alfian, A.A. and Ponnampalam, L.S. 2022. Dugong feeding grounds and spatial feeding patterns in subtidal seagrass: A case study at Sibu Archipelago, Malaysia. *Estuarine, Coastal and Shelf Science* 264: 107670. https://doi.org/https://doi.org/10.1016/j.ecss.2021.107670

Ho, N.A.J., Ooi, J.L.S., Affendi, Y.A. and Chong, V.C. 2018. Influence of habitat complexity on fish density and species richness in structurally simple forereef seagrass meadows. *Botanica Marina* 61(6): 547–557. https://doi.org/10.1515/bot-2017-0115

Ho, N.A.J. 2019. Fish communities in adjacent seagrass and coral reefs in Babi Besar island and Tinggi island, Malaysia. [Masters Thesis]. Kuala Lumpur: University of Malaya.

Hossain, M.S., Bujang, J.S., Zakaria, M.H. and Hashim, M. 2015. Application of Landsat images to seagrass areal cover change analysis for Lawas, Terengganu and Kelantan of Malaysia. *Continental Shelf Research* 110: 124–148. https://doi.org/10.1016/j.csr.2015.10.009

Hossain, M.S., Hashim, M., Bujang, J.S., Zakaria, M.H. and Muslim, A.M. 2019. Assessment of the impact of coastal reclamation activities on seagrass meadows in Sungai Pulai estuary, Malaysia, using Landsat data (1994–2017). *International Journal of Remote Sensing* 40(9): 3571–3605. https://doi.org/10.1080/01431161.2018.1547931

IUCN. 2024. The IUCN Red List of Threatened Species. https://www.iucnredlist.org/

Nishizawa, H., Joseph, J., Jolis, G., Irwan, I., Hussien, M., Sofia, J. and Saleh, E. 2023. Variations in body condition of green turtles (*Chelonia mydas*)in two nearby foraging grounds indicate their sensitivity to foraging habitats. *Aquatic Conservation: Marsh, Freshwater Ecosystem* 34(1): e4038.

Nur Asilah, A. 2020. The ecological function of intertidal seagrass for sediment entrapment on middle Bank Shoal, Penang. [Masters Thesis]. Kuala Lumpur: University of Malaya.

Ooi, J.L.S., Kendrick, G.A. and Van Niel, K.P. 2011a. Effects of sediment burial on tropical ruderal seagrasses are moderated by clonal integration. *Continental Shelf Research* 31: 1945–1954. https://doi.org/10.1016/j.csr.2011.09.005

Ooi, J.L.S., Kendrick, G.A., Van Niel, K.P. and Affendi, Y.A. 2011b. Knowledge gaps in tropical Southeast Asian seagrass systems. *Estuarine, Coastal and Shelf Science* 92(1): 118–131. https://doi.org/doi:10.1016/j.ecss.2010.12.021

Ooi, J.L.S. 2012. Pattern and process in the distribution and abundance of seagrass species in Pulau Tinggi, Malaysia. [PhD Thesis]. Perth: University of Western Australia.
Ooi, J.L.S., Van Niel, K.P., Kendrick, G.A. and Holmes, K.W. 2014. Spatial structure of seagrass suggests that size-dependent plant traits have a strong influence on the distribution and maintenance of tropical multispecies meadows. *Plos One* 9(1): e86782. https://doi.org/10.1371/journal.pone.0086782
Ooi, J.L.S., Goh, H.C., Then, A.Y.H. and Affendi, Y.A. 2017. *Status Report on the Marine Environment of the Mersing Marine Park Islands, and Indicative Proposal for a Marine Protected Area (MPA) Network*. Scientific Report for the Department of Marine Park Malaysia. pp. 126.
Ooi, J.L.S. and Lim, A.C.O. 2019. Seagrasses and Syngnathid fish of Pulau Sibu, Johor. *Malayan Nature Journal* 71(3): 361-365.
Ooi, J.L.S. and Adam, S. 2024. Site 9: Kepulauan Mersing IMCA. In *Malaysian Important Marine and Coastal Areas (MyIMCA)*, WWF-Malaysia & MSMS (Eds.), pp. 66-75). Petaling Jaya: WWF-Malaysia.
Ooi, J.L.S., Affendi, Y.A., Afiqah, D.D. and Kamal Solhaimi, F. 2024a. *Seagrass Conservation Project, Sungai Johor (2022–2024): Summary of key findings*. Report prepared for Reef Check Malaysia.
Ooi, J.L.S., Affendi, Y.A., Siti Nabila, M.S., Muhaffiz, H. and Amirul Siddiq, M.A.R. 2024b. *Preliminary survey of seagrass distribution and detection of dugong presence at Pulau Seri Buat-Sembilang, Pahang*. Report prepared for the Department of Fisheries Pahang, Malaysia.
Phang, S.M. 2000. *Seagrasses of Malaysia*. Kuala Lumpur: Institute of Biological Sciences, University of Malaya.
Ponnampalam, L.S., Fairul Izmal, J.H., Adulyanukosol, K., Ooi, J.L.S. and Reynolds, J.E.I. 2015. Aligning conservation and research priorities for proactive species and habitat management: the case of dugongs *Dugong dugon* in Johor, Malaysia. *Oryx* 49(04): 743–749. https://doi.org/doi:10.1017/S0030605313001580
Rahman, S.A. and Yaakub, S.M. 2020. Socio-economic valuation of seagrass meadows in the Pulai River Estuary, Peninsular Malaysia, through a wellbeing lens [FUNCTIONS & SERVICES]. *Marine and Freshwater Research* 71: 877–891. https://doi.org/10.1071/MF19208
Rajamani, L. and Marsh, H. 2015. Mapping seagrass cost-effectively in the Coral Triangle: Sabah, Malaysia as a case study. *Pacific Conservation Biology* 21(2): 113. https://doi.org/10.1071/pc14908
Rozaimi, M., Fairoz, M., Hakimi, T.M., Hamdan, N.H., Omar, R., Ali, M.M. and Tahirin, S.A. 2017. Carbon stores from a tropical seagrass meadow in the midst of anthropogenic disturbance. *Marine Pollution Bulletin* 119(2): 253–260. https://doi.org/10.1016/j.marpolbul.2017.03.073
Showen, R., Dunson, C., Woodman, G.H., Christopher, S., Lim, T. and Wilson, S.C. 2018. Locating fish bomb blasts in real-time using a networked acoustic system. *Marine Pollution Bulletin* 128: 496–507. https://doi.org/https://doi.org/10.1016/j.marpolbul.2018.01.029
Sudo, K., Quiros, T.E.A.L., Prathep, A., Luong, C.V., Lin, H.-J., Bujang, J.S., Ooi, J.L.S. *et al.* 2021. Distribution, temporal change, and conservation status of tropical seagrass beds in Southeast Asia: 2000–2020. *Frontiers in Marine Science* 8: 637722. https://doi.org/10.3389/fmars.2021.637722
Thomas, C. 2023. Status of seagrass meadow at Kampung Kebagu Beach, Kota Kinabalu, Sabah. [Thesis]. Kota Kinabalu: Universiti Malaysia Sabah.
Thorhaug, A., Gallagher, J.B., Kiswara, W., Prathep, A., Huang, X., Yap, T.-K., Dorward, S. and Berlyn, G. 2020. Coastal and estuarine blue carbon stocks in the greater Southeast Asia region: Seagrasses and mangroves per nation and sum of total. *Marine Pollution Bulletin* 160: 111168. https://doi.org/10.1016/j.marpolbul.2020.111168
WWF Malaysia and MSMS. 2024. *Malaysia's Important Marine and Coastal Areas (MyIMCA).* Petaling Jaya: WWF Malaysia.
Zakaria, M.H., Syed, N.N.F. and Bujang, J.S. 2025. The vulnerable seagrass *Halophila beccarii* Aschers. (Hydrocharitaceae) from Malaysia. *Frontiers in Conservation Science* 6: 1648415. https://doi.org/10.3389/fcosc.2025.1648415


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CHAPTER 6

Thismia (Thismiaceae) of Malaysia and its conservation

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Abstract: The mycoheterotrophic genus *Thismia* Griff. (Thismiaceae), commonly known as fairy lanterns, comprises some of the most enigmatic flowering plants in tropical forests. Malaysia is recognised as a global centre of diversity for the genus, harbouring a remarkable assemblage of species across Peninsular Malaysia, Sabah, and Sarawak. These plants are fully mycoheterotrophic and depend on specialised fungal associations within undisturbed forest ecosystems, making them highly sensitive to habitat disturbance. This study updates the diversity of the genus in Malaysia by compiling a species list and conservation data from historical literatures, herbarium records, and recent discoveries. Currently, approximately 45 species are known from Malaysia, the majority occurring in Peninsular Malaysia. Many species are highly localised endemics restricted to single forest reserve or mountain area. A checklist of Malaysian *Thismia* species, their geographic occurrence, conservation assessments based on available IUCN evaluations, and patterns of regional endemism are presented. A discovery timeline from 1878 to 2025 highlights the dramatic increase in species discovery during the last decade. The results show that Malaysian forests support exceptional diversity of mycoheterotrophic plants and represent one of the most important centres of *Thismia* diversity globally. Continued botanical exploration, integrative taxonomic research, and targeted conservation strategies are urgently needed to safeguard this unique component of Malaysia's forest biodiversity.

INTRODUCTION

The genus *Thismia* Griff. (Thismiaceae) is one of the most unusual and morphologically distinctive groups of flowering plants in tropical forests. Species of *Thismia* are small, achlorophyllous herbs that lack functional chlorophyll and therefore do not perform photosynthesis (Garrett *et al.* 2023). Instead, they are fully mycoheterotrophic, obtaining carbon and nutrients through highly specialised symbiotic associations with soil fungi, which are themselves connected to photosynthetic plants via mycorrhizal networks (Garrett *et al*. 2023; Ogura-Tsujita *et al*. 2021). Members of the genus are typically diminutive herbs, often only a few centimetres tall, with reduced, scale-like leaves (Siti-Munirah and Nikong 2023) and delicate stems emerging from root systems. As they spend most of their life cycle underground and emerge only briefly during flowering, *Thismia* species are difficult to detect (Mar and Saunders 2015). Their ephemeral above-ground appearance, combined with their preference for shaded microhabitats beneath dense leaf litter, has contributed to the perception that they are among the rarest and most cryptic flowering plants in the tropics. The genus *Thismia* has a pantropical distribution; the native range of this genus spans tropical and subtropical Asia, northern and eastern Australia, the North Island of New Zealand, north-central U.S.A., and the tropical Americas from Costa Rica to southern Brazil (POWO 2026). However, most species are concentrated in Southeast Asia and the Malesian floristic region, especially the Malay Peninsula and Borneo,. Currently, more than 120 species have been described worldwide (Siti-Munirah *et al.* 2025), although this number continues to increase as new species are discovered.

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Malaysia occupies a unique biogeographical position within Southeast Asia, encompassing both the Sundaic flora of Peninsular Malaysia and the diverse ecosystems of Borneo. Over the past two decades, Malaysia has emerged as one of the most important centres of Thismia diversity globally. Numerous new species have been discovered in Peninsular Malaysia, particularly within protected areas in Terengganu (Siti-Munirah and Mohamad Alias 2025) and in Borneo, especially Sarawak (Dančák *et al*. 2025). Despite the increasing number of discoveries, knowledge of Thismia diversity in Malaysia remains incomplete. This paper aims to provide a baseline assessment of diversity, geographic distribution, and conservation status.

MATERIALS AND METHODS

Information on Malaysian *Thismia* species was compiled through a review of published taxonomic literatures, herbarium records, and conservation databases. Primary data sources included original species descriptions, taxonomic revisions, and recent publications describing newly discovered species. Herbarium data from the Forest Research Institute Malaysia (Herbarium Kepong, KEP) and other regional herbaria were consulted to verify their occurrences. For this study, species were categorised into three principal regions: Peninsular Malaysia, Sabah, and Sarawak. Conservation status was recorded according to IUCN categories as previously documented: Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Least Concern (LC), and Not Evaluated (NE). Endemism status was also determined based on the available data.

RESULTS

Based on the compilation, Malaysia currently hosts approximately 45 recognised species of *Thismia* (Table 1, Figure 1). Peninsular Malaysia is the primary centre of diversity, with more than half of the known Malaysian species. Sarawak is the second most diverse region, while Sabah supports a smaller but distinctive assemblage of species associated with montane habitats.

A quantitative analysis of conservation statuses (Figure 2) reveal a precarious future for Malaysia's fairy lanterns. Over 60% of the country's *Thismia* species fall into threatened categories (Critically Endangered – CR, Endangered – EN, and Vulnerable – VU). Notably, 40% of species are classified as CR. This high proportion results directly from their extreme endemism; many species are known from only a few dozen individuals in a single, localised microhabitat. For these taxa, the loss of even a few square metres of forest floor can cause immediate extinction.

Figure 2 highlights a significant gap in current knowledge, with 31.11% of species remains Not Evaluated (NE). This information gap is particularly concerning, as most newly discovered species in the modern discovery phase (2000 – 2025) are likely to be rare or threatened by default due to their cryptic nature and small known distribution ranges. As these NE species undergo formal assessment, it is highly probable that the percentage of threatened taxa will increase, shifting the chart further towards the "Critically Endangered" and "Endangered" categories. With only 2.22% of species classified as Least Concern (LC), *Thismia* is one of the most threatened plant genera in Malaysia. This data underscores the urgency of shifting conservation efforts from general forest protection to safeguarding specific "micro-hotspots" where these fragile populations persist.

Table 1. List of *Thismia* taxa recorded in Malaysia, with conservation status and endemism. (Besi *et al.* 2024; Dančák *et al.* 2020, 2025; Jonker 1948; Siti-Munirah 2018; Siti-Munirah *et al.* 2022, 2024, 2025; Siti-Munirah and Mohamad Alias 2025; Siti-Munirah and Ling 2025).

No.	Species	Peninsular Malaysia	Sabah	Sarawak	Conservation Status	Endemic
1	*T. alba*	√	–	–	NE	–
2	*T. acuminata*	–	–	√	CR	***
3	*T. aliasii*	√	–	–	CR	* +
4	*T. arachnites*	√	–	–	NE	–
5	*T. aseroe*	√	–	√	NE	–
6	*T. belumensis*	√	–	–	CR	*
7	*T. bifida*	–	–	√	NE	***+
8	*T. brunneomita*	–	√	√	EN	–
9	*T. brunneomitroides*	√	–	–	NE	–
10	*T. bryndonii*	–	√	–	NE	** +
11	*T. chrysops*	√	–	–	NE	* +
12	*T. clavigera*	√	–	√	NE	–
13	*T. clavigeroides*	√	–	–	NE	–
14	*T. crocea*	√	–	–	NE	+
15	*T. cornuta*	–	–	√	EN	***
16	*T. coronata*	–	–	√	CR	***
17	*T. dasyantha*	–	–	√	CR	***
18	*T. domei*	√	–	–	CR	*
19	*T. episcopalis*	–	–	√	NE	***+
20	*T. fumida*	√	–	–	NE	–
21	*T. goodii*	–	√	√	CR	–
22	*T. grandiflora*	√	–	–	NE	* +
23	*T. hexagona* var. *grandiflora*	–	–	√	NE	**
24	*T. javanica*	√	–	–	CR	–
25	*T. kelabitiana*	–	–	√	CR	***
26	*T. kelantanensis*	√	–	–	VU	* +
27	*T. kenyirensis*	√	–	–	LC	* +
28	*T. kinabaluensis*	–	√	–	NE	**
29	*T. laevis*	–	–	√	CR	***
30	*T. latiffiana*	√	–	–	CR	* +
31	*T. limkokthayi*	√	–	–	CR	* +
32	*T. malayana*	√	–	–	VU	*
33	*T. minutissima*	–	–	√	VU	***
34	*T. neptunis*	–	–	√	EN	***
35	*T. nigra*	–	–	√	EN	***
36	*T. ophiuris*	–	–	√	NE	***
37	*T. ornata*	√	–	√	VU	–
38	*T. perlisensis*	√	–	–	DD	–
39	*T. pallida*	–	√	√	CR	–
40	*T. racemosa*	√	–	–	NE	* +
41	*T. selangorensis*	√	–	–	CR	* +
42	*T. sitimeriamiae*	√	–	–	CR	* +
43	*T. terengganuensis*	√	–	–	CR	* +
44	*T. velaris*	–	–	√	CR	***
45	*T. viridistriata*	–	–	√	EN	***

Note:
Conservation Status: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, DD = Data Deficient, NE = Not Evaluated. Endemism Key: * = Endemic to Peninsular Malaysia; ** = Endemic to Sabah; *** = Endemic to Sarawak; +Highly localised endemic (known only from type locality).



Figure 1. Some species of *Thismia* from Malaysia. **A.** *Thismia alba*, **B.** *T. domei*, **C.** *T. kelantanensis*, **D.** *T. latiffiana*, **E.** *T. malayana*, and **F.** *T. perlisensis* (All photos by Siti-Munirah Mat Yunoh).

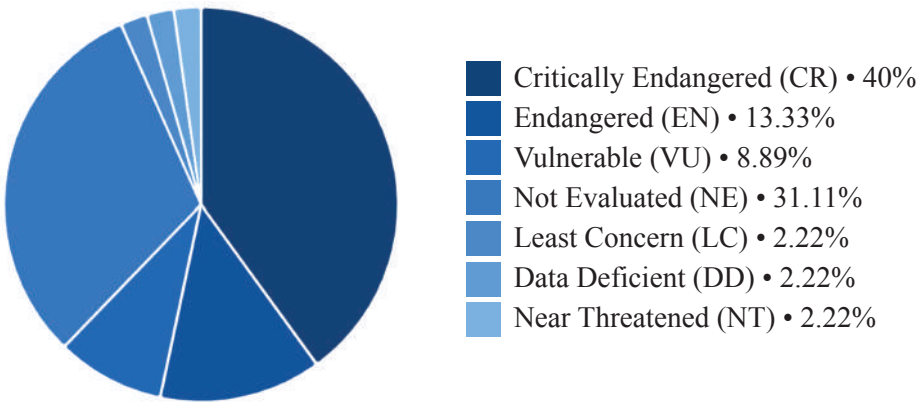

Figure 2. Conservation status of *Thismia* species in Malaysia based on IUCN Red List categories (Table 1). The data highlights that 40% of known species are Critically Endangered (CR), reflecting high habitat sensitivity and narrow endemism.

DISCUSSION

The high diversity of *Thismia* in Malaysia reflects the ecological complexity and environmental stability of Malaysian forests. These species however are threatened by habitat vulnerability. Most are known from extremely small populations and restricted geographic ranges. Even minor disturbances, such as hiking trails or selective logging, can disrupt the soil fungal networks essential for their survival. Protected areas such as Taman Negeri Kenyir thus serve as crucial refugia. The results of this synthesis confirm that Malaysia is one of the most significant global centres of diversity for the genus. With 45 recognised species, Malaysia hosts nearly 40% of the world's known species. This concentration is a result of the country's unique position within the Sundaland biogeographic region. The high species richness is driven by the long-term climatic stability of the region's rainforests, which has allowed the persistence of complex subterranean fungal networks. Unlike photosynthetic plants that compete for light, *Thismia* species occupy a specialised niche on the forest floor, relying on a stable and moist microclimate that only an intact primary forest canopy can provide. The striking level of endemism, with many species such as *T. sitimeriamiae* and *T. latiffiana* known only from a single forest reserve, suggests a pattern of localised evolutionary radiation. In states such as Terengganu, the complex topography of mountain ranges and undisturbed habitat acts as a series of forest islands. These isolated habitats facilitate speciation through geographic isolation. Furthermore, the morphological diversity of floral structures, ranging from the mitriform domes of *T. kelantanensis* to the elongated tentacles of *T. aliasii*, indicates a high degree of pollinator specialisation. Most *Thismia* species are believed to be pollinated by fungus gnats. The evolution of diverse floral traps suggests that *Thismia* has undergone rapid diversification to exploit specific local insect populations, further driving the high rates of endemism observed across Peninsular Malaysia and Borneo.

The history of *Thismia* discovery in Malaysia spans more than a century. The early discovery phase (1878 – 1930) documented pioneering taxa. After a long period of limited discovery (1930 – 2000), the modern discovery phase (2000 – 2025) has seen a dramatic resurgence. Many currently recognised taxa were discovered after 2015, particularly in Peninsular Malaysia. The modern discovery phase (2000 – 2025), highlighted in the results section, reveals a critical bias in botanical history. For decades, *Thismia* species were considered "rare" primarily because they were overlooked. Their ephemeral life cycle, with the plant remaining underground for most of the year and producing a flower for only a few days, means that traditional botanical surveys often miss them. The recent surge in discoveries is less an indication of a sudden population boom and more a reflection of improved citizen science and targeted botany of the forest floor. This suggests that many more species likely exist in the remote interior of Peninsular Malaysia, Sarawak, and Sabah, where survey intensity has historically been lower.

The most pressing concern raised by this study is the conservation status of these plants. As *Thismia* species are fully mycoheterotrophic, they are considered ultimate indicators of forest health. They require not only trees, but also a specific, undisturbed relationship between trees and soil fungi. Several factors contribute to their vulnerability. Soil compaction, even from small-scale disturbances such as the widening of hiking trails in popular locations like Genting Highlands or Taman Negeri Kenyir, can crush the delicate, shallow rhizomes of *Thismia* and destroy the mycelial mats they depend on. Microclimate sensitivity is another factor: selective logging and thinning of the canopy increase the temperature and decrease the humidity of the forest floor. *Thismia* species, which lack a protective cuticle and are prone to desiccation, cannot survive these changes. Finally, there is the "Critically Endangered" paradox: under IUCN criteria, many Malaysian *Thismia* are classified as CR because they occupy an Area of Occupancy (AOO) of less than 10 km^2. This makes them extremely susceptible to stochastic events; a single landslide or new road construction could effectively wipe out an entire species.

To safeguard the *Thismia* of Malaysia, conservation must extend beyond protecting trees and focus on microhabitats. We recommend that the Forestry Departments establish "Micro-Conservation Zones" within larger Forest Reserves. In areas where *Thismia* hotspots are identified, human foot traffic should be strictly diverted and the removal of leaf litter prohibited. Furthermore, Thismia should serve as a flagship species for hidden biodiversity to increase public awareness of the importance of soil health and fungal conservation in tropical ecosystems.

CONCLUSION

The study of *Thismia* in Malaysia highlights the hidden richness of tropical forest ecosystems. With 45 species and high endemism, the country plays a central role in global conservation of mycoheterotrophic plants. Protecting the habitats that sustain these species is essential not only for *Thismia* but also for the overall health of forest biodiversity. The comprehensive synthesis presented in the paper underscores the country's status as a global epicentre for mycoheterotrophic biodiversity. With 45 recognised species, many described only in the last decade, it is clear that we are in the midst of a golden age of discovery for the genus Thismia. The high degree of regional endemism identified in this study highlights the unique evolutionary history of the Sundaic and Bornean floras, where local ecological niches have fostered a remarkable radiation of floral forms and specialised pollination syndromes.

However, the findings of this research also provide a sobering assessment of the survival prospects for these enigmatic plants. The overwhelming majority of Malaysian *Thismia* species are currently classified as Critically Endangered (CR), Endangered (EN), or Not Evaluated (NE) due to their extreme rarity and cryptic life cycles. As these plants are inextricably linked to the health of subterranean fungal networks, their presence serves as a living barometer for the ecological integrity of Malaysia's primary forests. The loss of a single forest patch in a hotspot such as Terengganu or Sarawak does not merely represent the loss of individual plants, it signifies the collapse of complex, millions of years old symbiotic relationships that are largely invisible to the naked eye.

Looking ahead, the study of Malaysian *Thismia* requires a shift from opportunistic discovery to systematic, integrative research. Future efforts should prioritise the use of molecular phylogenetics to resolve the evolutionary relationships between the Peninsular and Bornean lineages. In addition, ecological studies focusing on the specific fungal partners of *Thismia* are essential. If the specific fungi these plants rely on can be identified, their occurrence can be better predicted and forest management practices can be tailored to protect the mycorrhizal networks that sustain them. Ultimately, conserving *Thismia* in Malaysia requires a shift in national conservation paradigms. Protecting the charismatic megaflora of the canopy, such as the dipterocarps, is necessary but insufficient if the delicate, ephemeral flora of the forest floor is neglected. We recommend that *Thismia* species be formally recognised as flagship organisms for hidden biodiversity. By integrating *Thismia* hotspots into the management plans of the Central Forest Spine and the Heart of Borneo, Malaysia can lead the way in holistic tropical conservation. This paper serves as both a baseline and a challenge to the scientific community. While we have documented 45 species, the vast, unexplored interior of Sabah and Sarawak likely holds many more fairy lanterns yet to be discovered, even in Peninsular Malaysia. With sustained botanical exploration, strengthened legal protection for microhabitats, and a commitment to understanding the below-ground world, Malaysia can ensure that these extraordinary plants continue to thrive in the shadows of its majestic rainforests for generations to come.

REFERENCES

Besi, E.E., Qistina Anis, M.J., Syamil, A.R., Mohd Zulkifly, S., Ag. Shaffie, A.A. and Go, R. 2024. *Thismia perlisensis* (Thismiaceae), a new red-annulus *Thismia* species from Peninsular Malaysia. *Phytotaxa* 675(1): 1–10. https://doi.org/10.11646/phytotaxa.675.1.1

Dančák, M., Hroneš, M. and Sochor, M. 2020. Thismia: The rarest of the rare? Ranges of some Bornean species are much larger than previously believed. *Phytotaxa* 455(4): 245–261. https://doi.org/10.11646/phytotaxa.455.4.2

Dančák, M., Hroneš, M., Sochor, M., Uvírová, A., Blažek, V.T., Siti-Munirah, M.Y. and Yiing L.C. 2025. *Thismia velaris* and *T. dasyantha*, two new species of *Thismia* section *Thismia* subsect. *Odoardoa* (Thismiaceae) from Sarawak, Malaysia. *Phytotaxa* 715(2): 117–128. https://doi.org/10.11646/phytotaxa.715.2.2

Garrett, N., Viruel, J., Klimpert, N., Soto Gomez, M., Lam, V.K.Y., Merckx, V.S.F.T. and Graham, S.W. 2023. Plastid phylogenomics and molecular evolution of Thismiaceae (Dioscoreales). *American Journal of Botany* 110(4): e16141. https://doi.org/10.1002/ajb2.16141

Jonker, F.P. 1948. Burmanniaceae. *Flora Malesiana* 1(4): 13–26.

Mar, S.S. and Saunders, R.M.K. 2015. *Thismia hongkongensis* (Thismiaceae): a new mycoheterotrophic species from Hong Kong, China, with observations on floral visitors and seed dispersal. *PhytoKeys* 46: 21–33. https://doi.org/10.3897/phytokeys.46.8963

Ogura-Tsujita, Y., Yukawa, T. and Kinoshita, A. 2021. Evolutionary histories and mycorrhizal associations of mycoheterotrophic plants dependent on saprotrophic fungi. *Journal of Plant Research* 134: 19–41. https://doi.org/10.1007/s10265-020-01244-6

POWO. 2026. Plants of the World Online. *Royal Botanic Gardens, Kew*. https://powo.science.kew.org/

Siti-Munirah, M.Y. 2018. *Thismia kelantanensis* (Thismiaceae), a new species from Kelantan, Peninsular Malaysia. *Kew Bulletin* 73(3): e42. https://doi.org/10.1007/s12225-018-9767-0

Siti-Munirah, M.Y., Suhaida, M. and Eddie, C. 2022. *Thismia limkokthayi* (Thismiaceae): A new mycoheterotrophic species from Genting Highlands in Pahang, Malaysia. *PhytoKeys* 211: 1–11. https://doi.org/10.3897/phytokeys.211.89453

Siti-Munirah, M.Y. and D. Nikong. 2023. *Thismia kenyirensis* (Thismiaceae), a new species from Taman Negeri Kenyir, Terengganu, Peninsular Malaysia. *PhytoKeys* 221: 61–72. https://doi.org/10.3897/phytokeys.221.98571

Siti-Munirah, M.Y., Chin, H.-A., Mohamad-Shafiq, S., Irwan-Syah, Z. and Hamidi, A.H. 2024. *Thismia malayana* (Thismiaceae), a new mycoheterotrophic species from Peninsular Malaysia. *PhytoKeys* 242: 229–239. https://doi.org/10.3897/phytokeys.242.120967

Siti-Munirah, M.Y. and Ling, C.Y. 2025. Distribution of *Thismia* species (Thismiaceae) mycoheterotrophic herbs in Sarawak with a new record species from Long Mekaba. In *Proceedings of The Heart of Borneo (HoB) Sarawak Seminar 2023 on The Scientific Expedition to Gerenai-Long Mekaba, Sarawak*, S.P. Teo, A. Kho, A.D. Chung, J. Sang, H. Salleh, and H.M. Mohamad (Eds.), pp. 90–97. Kuching: Forest Department Sarawak.

Siti-Munirah, M.Y. and Mohamad Alias, S. 2025. *Thismia aliasii* (Thismiaceae), a new species from Terengganu, Peninsular Malaysia. *PhytoKeys* 254: 175–188. https://doi.org/10.3897/phytokeys.254.136085

Siti-Munirah, M.Y., Gim, S.T., Mat-Tahir, M.F. and Azhar, A. 2025. *Thismia selangorensis* (Thismiaceae): a new mitriform fairy lantern species from Selangor, Malaysia. *PhytoKeys* 267: 9–21. https://doi.org/10.3897/phytokeys.267.157968


PERSATUAN PENCINTA ALAM MALAYSIA
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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.

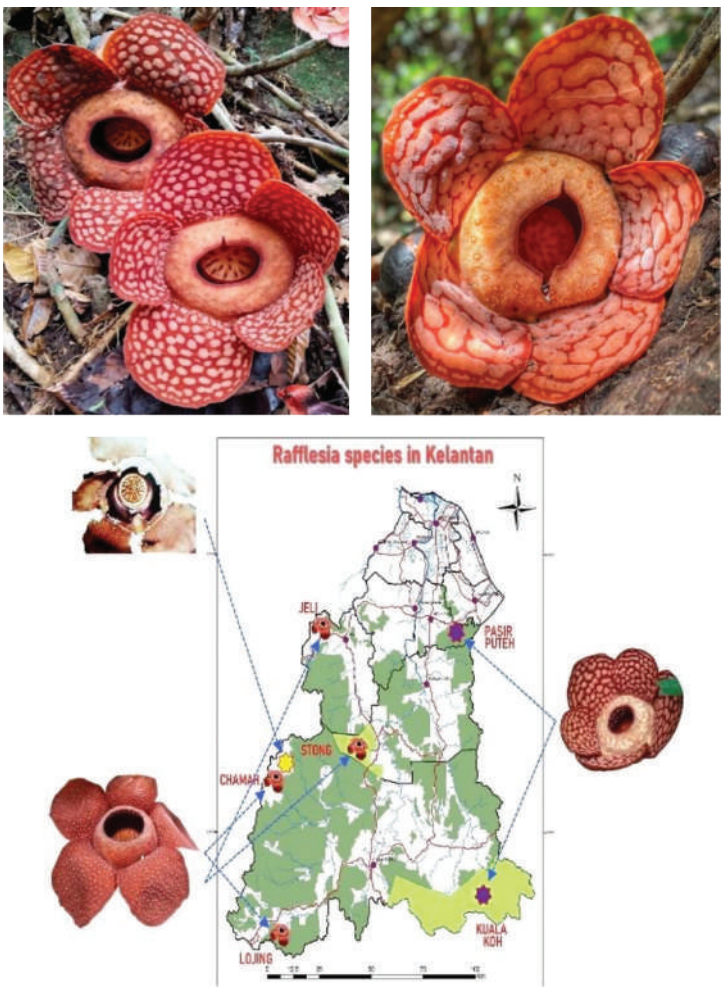

Figure 1. ***(Top left)*** The twin flower of *Rafflesia cantleyi*, ***(top right)*** The flower of *R. azlanii*, and ***(bottom)*** the distribution of *Rafflesia* in Kelantan.

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.

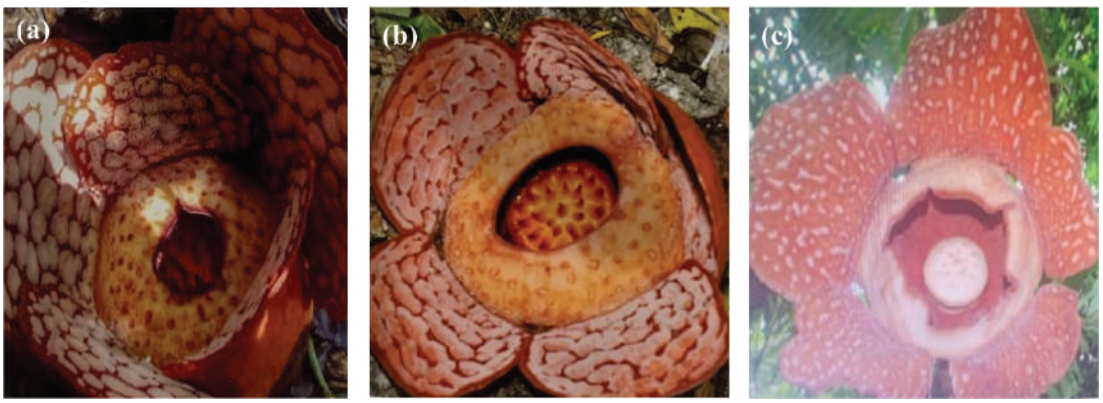

Figure 3. (a) *Rafflesia sharifah-hafsahiae*, **(b)** *R. tuanku-halimii*, and **(c)** *R. tiomanensis.*

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.

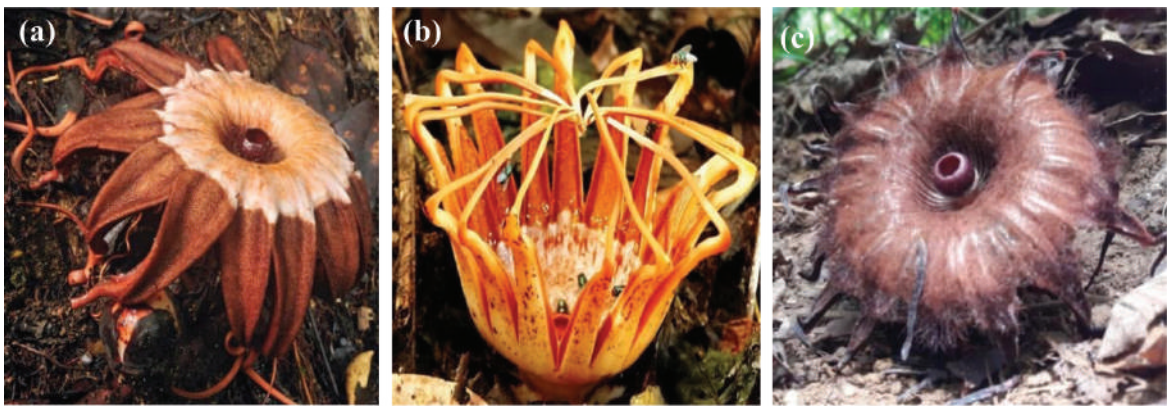

Figure 6. (a) *Rhizanthes lowii* of Sabah and Sarawak, opened flower, note the white coloured base of perianth lobes, *(b)* the flower was about to open with the appendages forming like a crown before they reflexed downwards, and **(c)** *R. infanticida* of Peninsular Malaysia.

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.

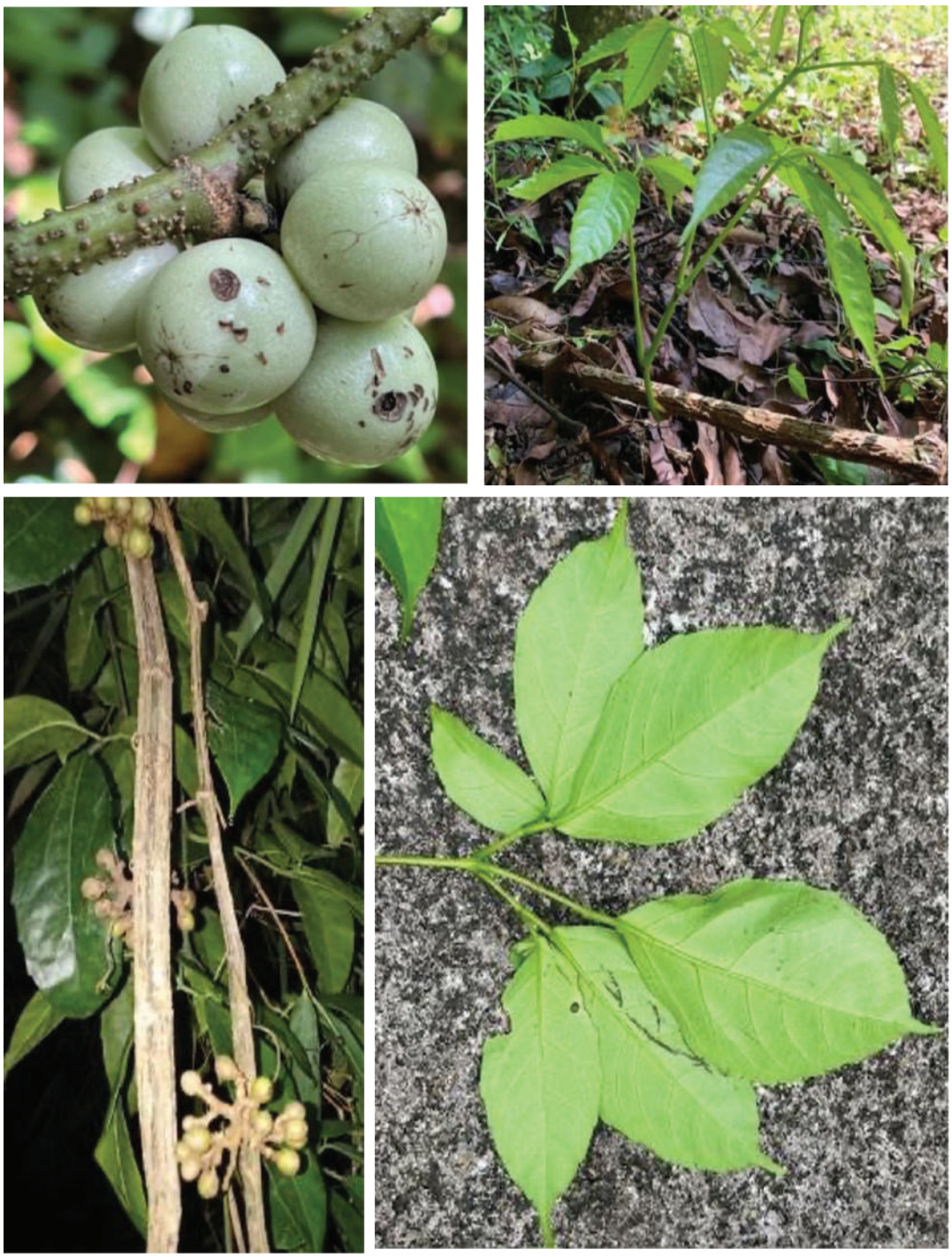

Figure 6. (a) the large, cream and succulent berries of *Tetrastigma hookeri*, note the pustules on the peduncle; **(b)** the most common 5-foliolate leaves of *T. hookeri*, **(c)** strap-like stem of *T. hookeri* with immature berries and **(d)** the rarely 6-foliolate leaves of *T. rafflesiae*.

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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REFERENCES

Adam, J., Mohamad,R., Nik Ariff, N.N.F. and Wan, K.L. 2013. *Rafflesia sharifah-hafsahiae* (Rafflesiaceae), a new species from Peninsular Malaysia. *Turkish Journal of Botany* 37: 1038–1044.

Adam, J., Juhari, M.A.A., Mohamad, R., Wahab, N.A.A., Arshad, S., Kamaruzaman, M.P. and Wan, K.L. 2016. *Rafflesia tuanku-halimii* (Rafflesiaceae), a new species from Peninsular Malaysia. *Sains Malaysiana* 45(11): 1589–1595.

Adam, J.H., Aizat-Juhari, M.A., Ariff, N.N-F.N., Khamis, S., Yasin, M.H.M. and Wan, K-L. 2022. *Rafflesia tunku-azizahiae* (Rafflesiaceae), a new species from Pahang, Malaysia. *Sains Malaysiana* 51(11): 3843–3855.

Ahmad Puad, A.S., Wan Zakaria, W. N. F., Geri, C., Zainudin, R. and Latiff, A. 2020. Notes on *Rafflesia hasseltii* Suring. (Rafflesiaceae), a new record for Sarawak, Malaysia. *Malayan Nature Journal* 72(1): 19–25.

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

Banzinger, H. 1995. Ecological, morphological and taxonomic studies on Thailand's fifth species of Rafflesiaceae: *Rhizanthes zippelii* (Blume) Spach. *Natural History Bulletin of Siam Society* 43: 337–365.

Banziger, H. 2004. Studies on hitherto unknown fruits and seeds of some Rafflesiaceae, and a method to manually pollinate their flowers for research and conservation. *Linzer Biologische Beitraege. Linz*. 36(2): 1175–1196.

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

Bänziger, H., Lamb, A. and Kocyan, A. 2007. Bisexual *Rhizanthes lowii* (Beccari) Harms (Rafflesiaceae) from Borneo: first description of flowers, fruits and seeds. *Natural History Bulletin of the Siam Society* 55(2): 341–352.

Beaman, R., Decker, P.J. and Beaman, J.H. 1988. Pollination of *Rafflesia*. *American Journal of Botany* 75(8): 1148–1162.

Bidin, A. 1991. Two notable jungle plants of the jungle of Pulau Tioman. *Nature Malaysiana* 16: 8–9.

Brown, R. 1821. An account of a new genus of plant named *Rafflesia*. *Transaction of the Linnean Society of London* 13: 201–234.

Emmons, L.H., Nais, J. and Biun, A. 1991. The fruits and consumers of *Rafflesia keithii* (Rafflesiaceae). *Biotropica* 23: 197–199.

Fatimah Mohamad and Nor Nafizah Mohd. Noor. 2016. A preliminary note on the growth rate of male *Rafflesia azlanii* Latiff and Wong (Rafflesiaceae). *Malayan Nature Journal* 68(1 & 2): 217–223.

Gan, F. 1993. A new record of *Rafflesia* in Peninsular Malaysia. *Malayan Naturalist* 47(1 & 2): 8–9.

Ghazally, I. 1991. Conservation of the giant *Rafflesia* in Sabah, Malaysia. *Trends in Ecology & Evolution* 3(12): 316–317.

Ghazally, I., Mat-Salleh, K., Lamri, A. and Adlin, D.T.Z. 1988. *Rafflesia* in Sabah: A case for conservation. *Sabah Society Journal* 8(4): 437–456.

Hor, P.L., Norhazlini, M.Z., Nasihah, M. and Zulhazman, H. 2021. Diurnal insect pollinators of *Rafflesia kerri* Meijer at Lojing Highlands, Kelantan, Peninsular Malaysia. *Malaysian Forester* 84(1): 7–15.

Jelani, N.S. 2020. Reproductive characteristics of two holoparasitic species of Rafflesiaceae in Sarawak, Malaysia. Master's Thesis). Nagoya: Nagoya University. [Unpublished].

Latiff, A. 1983. Studies in Malesian Vitaceae VII. The genus *Tetrastigma* in Peninsular Malaysia. *Gardens' Bulletin Singapore* 36: 213–228.
Latiff, A. 2001. Notes on the discovery of *R. hasseltii* Suringar (Rafflesiaceae) in Taman Negara (National Park), Malaysia. *Flora Malesiana Bulletin* 12 (7/8): 393–395.
Latiff, A. 2021. Studies in Malesian Vitaceae XVII. A Revision of *Tetrastigma* (Miq.) Planch. *Malayan Nature Journal* 73(2): 237–269.
Latiff, A. and Mat-Salleh, K. 1991. *Rafflesia*. In *The State of Nature Conservation in Malaysia*, R. Kiew (Ed.). Kuala Lumpur: Malayan Nature Society.
Latiff, A. and Wong, M. 2003. A new species of *Rafflesia* from Belum in Upper Perak. *Folia Malaysiana* 4 (374): 135–146.
Latiff, A., Faridah-Hanum, I. and Ozturk, M. 2025. *Rafflesia* - The World's largest flower : A centennial anniversary. *Azerbaijan Journal of Botany* 1(1): 16–34.
Linton, J., Lamb, A. and Lim, H.K.L. 2005. A breakthrough in the vegetative propagation of *Rafflesia keithii* Meijer. *Sabah Agricultural Research Journal* 2: 7–13.
Mat-Salleh, K. 1991. *Rafflesia: Magnificient Flower of Sabah*. Kota Kinabalu: Borneo Publishing Company.
Mat-Salleh, K. 1996. *Rafflesia*. In *Kinabalu: Summit of Borneo*, K.M. Wong and A. Phillipps (Eds.). Kota Kinabalu: The Sabah Society and Sabah Parks.
Mat-Salleh, K. and Latiff, A. 1989. A new species of *Rafflesia* and notes on other species from Trus Madi Range, Sabah (Borneo). *Blumea* 34: 111–116.
Mat-Salleh, K., Jackson, D. and Siti Munirah, M.Y. 2006. Whither the *Rafflesias*. *Malaysian Naturalist* 59(4): 36–38.
Mat-Salleh, K., Mohd-Ros, A.H. and Donna, J. 2006. *The role of protected areas in the conservation of Rafflesia in Malaysia*. Cheras: Department of Wildlife and National Parks Peninsular Malaysia. pp. 141–154.
Mazlan Mohd. Som, Mohd Husin, S., Md Shukor, A., Effendi, A.F., Abdul Rani, N.I., Khamis, S., Abdul Karim, N.H. and Shukor, M.N. 2019. *Rafflesia Conservation and Management at Royal Belum State Park*. Kajang: TNB Research Sdn. Bhd.
Meekiong, K., Jackson, D., Ampeng, A., AlBukharey, M.R. and Latiff, A. 2020. *Rhizanthes lowii* (Becc.) Harms. (Rafflesiaceae), a new record from Lanjak Entimau Wildlife Sanctuary, Sarawak, Malaysia. *Malayan Nature Journal* 72(3): 365–370.
Meijer, W. 1984. New species of *Rafflesia*. *Blumea* 30: 209–215.
Meijer, W. 1985. Saving the world's largest flower. *National Geographic Magazine* 168: 136–140.
Meijer, W. 1997. Rafflesiaceae. *Flora Malesiana Series 1, Spermatophyta* 13(1): 1–42.
Meijer, W. and Veldkamp, J.F. 1988. A revision of *Rhizanthes* (Rafflesiaceae). *Blumea* 33: 329–342.
Meijer, W. and 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.
Mohd. Hizamri Mohd. Yasin, Sulaiman, N. and Khamis, S. 2023. *Rafflesia of Pahang*. Pahang: Department of Forestry Pahang.
Mokhtar, N., Zulhazman, H., Siti Munirah, M.Y., Wan Ariffin, W.N.N. and Latiff, A. 2016. *Tetrastigma hookeri* (Laws.) Planch. (Vitaceae), a host plant for *Rafflesia kerrii* Meijer in Peninsular Malaysia. *Malayan Nature Journal* 68(1&2): 33–39.
Nais, J. 1997. Distribution, reproductive ecology and conservation of *Rafflesia* in Sabah, Malaysia. PhD Dissertation. Scotland: University of Aberdeen. [Unpublished].
Nais, J. 2001. *Rafflesia of the World*. Kota Kinabalu: Sabah Parks.
Nais, J. and Wilcock, C.C. 1998. The *Rafflesia* conservation incentive scheme in Sabah, Malaysian Borneo. *Sabah Park Nature Journal* 2: 9–17.
Nais, J. and Wilcock, C.C. 1999. The propagation of *Rafflesia* and its host plant: prospects for *ex situ* conservation. *Sabah Parks Nature Journal* 2: 111–120.
Ng, F.S.P. 2019. Is *Rafflesia* an angiosperm? *Journal of Tropical Forest Science* 31(3): 286–297.
Ng, F.S.P. 2023. *Rafflesia* as a hapaxanthic plant and implications for *Rafflesia* conservation and management. *Journal of Tropical Forest Science* 35(4): 489–495.
Ng, F.S.P. 2024. *Rafflesia* realities and fantasies. *Journal of Tropical Forest Science* 36(4): 461–472.
Nikolov, L.A., Endress, P.K., Sugumaran, M., Sasirat, S., Vessabutr, S., Kramer, E.M. and Davis, C.C. 2013. Developmental origins of the world's largest flowers, Rafflesiaceae. *Proceedings of the National Academy of Sciences of the United States of America* 110(46): 18578–18583.
Niyomdham, C. and Kubat, R. 1987. Balonophoraceae and Rafflesiaceae of Thailand. In *Proceedings of the 4th International Symposium on Parasitic Flowering Plants*, H.C. Weber and W. Forstreuter (Eds.), pp. 493–496. Marburg: Philipps-Universität Marburg.

Ong, L.P. 2004. Biologi *Rafflesia hasseltii* di Tanjung Datu, Sarawak. B.Sc. Hons. dissertation. Bangi: Universiti Kebangsaan Malaysia, Bangi. [Unpubllished].
Piereira, J.T., Sugau, J.B., Jeisin, J., Joel, D., Suis, J.A.F., Nilus, R. and Ong, R.C. 2022. Notes on the new distribution record of *Rafflesia keithii* Meijer (Rafflesiaceae) in Sabah. *Sepilok Bulletin* 31: 71–74.
Qayyum, N.W.A., Siti-Munirah, M.Y., Norhazlini, M.Z. and Zulhazman, H. 2023. Evaluating the mortality rate of *Rafflesia kerrii* in Lojing Highlands, Peninsular Malaysia. *Malayan Nature Journal* 75(4): 1–8.
Sheikh Kamal, S.H., Suratman, M.N., Khamis, S., Nik Hassan, A.N. and Mohammad, M.S. 2021. Host-parasitic relationship between *Tetrastigma rafflesiae* and *Rafflesia azlanii* and *Rafflesia cantleyi* in Belum-Temengor Forest Complex, Perak, Malaysia. *Pertanika Journal of Tropical Agricultural Science* 44(4): 755–771.
Sheikh Kamal. S.H., Suratman, M.N., Khamis, S., Ahmad Najmi, N.H. and Mohammad, S. 2022. Growth rate, mortality rate and life cycle of *Rafflesia azlanii* and *R. cantleyi* in Belum-Temenggor Forest Complex, Perak, Malaysia. *Sains Malaysiana* 51(4): 943–957.
Siti Munirah, M.Y. 2011. *Rafflesia* of the peninsula. *Malayan Naturalist* 65(2): 30–31.
Siti Munirah, M.Y. 2012. *Rafflesia* blooms in Royal Belum. *Conservation Malaysia* 16: 6–10.
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. and Razelan, M.S. 2020. On the morphological variation of *R. cantleyi* (Rafflesiaceae) on Pulau Tioman, Pahang, Peninsular Malaysia. *Blumea* 65: 75–82.
Siti-Munirah, M.Y., Salamah, A. and Razelan, M.S. 2021. *Rafflesia tiomanensis* (Rafflesiaceae), a new species from Pulau Tioman, Pahang, Malaysia. *Malayan Nature Journal* 73(1): 19–26.
Sofiyanti, N. and Choong, C.Y. 2012. Morphology of ovule, seed and pollen grain of *Rafflesia* R. Br. (Rafflesiaceae). *Bangladesh Journal of Plant Taxonomy* 19(2): 109–117.
Sofiyanti, N., Mat-Salleh, K., Purwanto, D. and Shahputra, E. 2007. The note on morphology of *Rafflesia hasseltii* Surigar from Bukit Tiga Puluh National Park, Riau. *Biodiversitas* 3 :257–261.
Sofiyanti, N., Mat-Salleh, K., Mahmood, K., Mazlan, N.Z., AlBukharey Hasein, M.R. and Burselem, D.F.P. 2016. *Rafflesia parvimaculata* (Rafflesiaceae), a new species of *Rafflesia* from Peninsular Malaysia. *Phytotaxa* 255(2): 207–213.
Solm-Laubach, H.G.Z. 1910. Uber eine neue species der gattung *Rafflesia*. *Annales du Jardin Botanique de Buitenzorg* 20: 1–7.
Veldkamp, J.F. 2007. Some notes on the cultivation of *Rafflesia*. *Flora Malesiana Bulletin* 14: 50–53.
Wan Zakaria, W.N.F., Ahmad Puad, A.S., Geri, C., Zainudin, R. and Latiff, A. 2016. *Tetrastigma diepenhorstii* (Miq.) Latiff (Vitaceae), a new host for *Rafflesia tuan-mudae* Becc. (Rafflesiaceae) in Borneo. *Journal of Botany* 2016(2): 1–6.
Wee, S.L., Tan, S.B. and Jurgens, A. 2018. Pollination specialisation in the enigmatic *Rafflesia cantleyi* : A true carrion flower with species-specific and sex-based blow fly pollination. *Phytochemistry* 153: 120–128.
Wong, M. 1990. *Rafflesia hasseltii*. *Nature Malaysiana* 15: 56–59.
Wong, M. 1992. Kerr's *Rafflesia*, a rare botanical gem. *Nature Malaysiana* 17(4): 124–129.
Wong, M. and Latiff, A. 1990. *Rafflesia hasseltii*. *Nature Malaysiana* 15 : 26
Wong, M. and Latiff, A. 1994. *Rafflesia* of Peninsular Malaysia. *Nature Malaysiana* 19: 84–88
Wong, M. and Latiff, A. 2001. A fragrant *Rafflesia cantleyi* discovered. *Folia Malaysiana* 2(4): 211–218.
Wong, M. and Gan, F. 2002. *Rafflesia* No. 19 : A new species of *Rafflesia* found in Peninsular Malaysia. *Malayan Naturalist* 56(1): 14–17.
Wong, M. and Gan, F. 2003. The elegant *Rafflesia kerrii* of Kelantan. *Folia Malaysiana* 4(1): 53–62.
Wong, M. and Gan, F. 2008. Lima lidah, a potentially new species of *Rafflesia*. *Malaysian Naturalist* 62(2): 40–42.
Wong, N., Nais, J. and Gan, F. 2009. *Rafflesia su-meiae* (Rafflesiaceae), a new species from Kelantan, Peninsular Malaysia. *Folia Malaysiana* 10(2): 89–98.
Wyatt-Smith, J. 1940. *Rafflesia hasseltii*. *Malayan Foresters* 9: 71–73.
Zulhazman, H., Maryati, M., Cornelius, P. and Mohd, M. 2010. Spatial distribution and conservation of *Rafflesia kerrii* in Lojing Highlands, Kelantan. In *Conserving Lojing Highlands for Sustainable Development*. Kelantan: Universiti Malaysia Kelantan. pp. 44–54.


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CHAPTER 8

Safeguarding *Rafflesia* in Kelantan: Conservation initiatives and the strategic role of Universiti Malaysia Kelantan

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Abstract: *Rafflesia* plants are one of the most extraordinary plants worldwide, and have gained prominence in Southeast Asia as both a flagship species for ecotourism and a focal point for conservation advocacy. In Kelantan, its distribution is largely restricted to the southern highland regions, where populations occur within forest reserves, protected areas and stateland landscapes, including Lojing Highlands, Gunung Chamah and Gunung Stong. In response to growing conservation concerns, Universiti Malaysia Kelantan (UMK) has emerged as a key institutional actor over the past decade, leading a range of initiatives encompassing scientific efforts. These coordinated efforts contributed directly to the gazettement of a 400-ha Rafflesia Conservation Area in the Lojing Highlands in 2011 and the subsequent designation of several High Conservation Value Forests (HCVFs). Nevertheless, *Rafflesia* populations in Kelantan continue to experience mounting pressures arising from agricultural expansion, habitat fragmentation, unmanaged tourism and climate-related variability. As a holoparasitic genus with highly specific host and habitat requirements, Rafflesia is particularly sensitive to environmental disturbance, underscoring the complexity of its conservation. The case of UMK's involvement demonstrates the importance of science-driven management, institutional leadership, and multi-stakeholder collaboration in addressing species-level conservation challenges. Sustaining and strengthening these approaches will be critical not only for the long-term survival of *Rafflesia* in Kelantan, but also for advancing broader biodiversity conservation and sustainability objectives at regional and global scales.

INTRODUCTION

Malaysia forms an integral part of the West Malesian tropical rainforest belt and is globally recognised for its exceptional biological richness. The country supports an extraordinarily diverse flora and fauna, with plant diversity alone estimated to exceed 25,000 species (van Steenis 1971; Whitmore 1984). Beyond their biological value, Malaysian rainforests underpin national and local economies through the provision of timber and a wide range of non-timber forest products, including rattan, medicinal plants, resins, food resources, and fertilisers. These forest ecosystems also deliver vital ecological functions, such as safeguarding freshwater resources, stabilising soils, regulating microclimatic conditions, and sequestering atmospheric carbon. Increasingly, they serve as important destinations for nature-based tourism. Owing to this combination of high species richness and accelerating land-use pressures, Malaysia has been identified as one of the world's twelve megadiverse nations and a global biodiversity hotspot requiring urgent conservation attention (Myers 1988).

Within this national context, the state of Kelantan, particularly its southern region, stands out as an area of outstanding ecological significance. Large tracts of hill dipterocarp and submontane forests remain relatively intact, supporting diverse plant assemblages. Botanical surveys have demonstrated that this region harbours one of the highest known populations of *Rafflesia kerrii* (Zulhazman *et al.* 2010), elevating its importance for both

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conservation and scientific research. The Lojing Highlands, in particular, are renowned for their botanical diversity, encompassing a wide array of mosses, ferns, wild orchids, gingers, pitcher plants, bamboos, wildflowers, and numerous ethnobotanically valuable species. This remarkable floristic richness has also contributed to the area's growing appeal as an international ecotourism destination.

Faunal diversity in the region further reinforces its conservation value. A broad range of insect taxa has been documented, including representatives of Reduviidae, Vespidae, Asilidae, Coreidae, Lycaenidae and Mantidae, reflecting the structural complexity of the forest habitats. Avifaunal diversity is similarly notable, with species such as swallows, grey-throated babblers, magpie-robins and white-chested babblers commonly recorded. Mammalian fauna, including monkeys, slow lorises and bats, also form an integral component of these forest ecosystems (Ibrahim and Zulhazman 2010).

Universiti Malaysia Kelantan (UMK) has played a sustained role in supporting forest conservation initiatives, particularly in the Lojing Highlands and across Kelantan more broadly. These efforts align closely with the objectives of the National Forestry Policy (1978), which emphasises sustainable forest management, biodiversity conservation and community well-being. At the state level, forest conservation remains a central management priority. Under the stewardship of the Kelantan State Forestry Department (KFD), approximately 800,986.60 ha, representing 53.3% of the state's land area, remain under forest cover. Of this total, 623,848 ha have been gazetted as Permanent Forest Reserve (PFR), comprising both production forests (477,508 ha) and protection forests (146,341 ha). In addition, a network of protected forest areas has been established to support conservation, research and education, including High Conservation Value Forests (HCVF). Areas characterised by elevations above 1,000 m, slopes exceeding 40º, or high susceptibility to erosion, landslides, flash floods and nutrient loss are designated as Land Protection Areas, which emphasise the strategic importance of forest conservation in safeguarding environmental stability in Kelantan.

STATUS AND SPATIAL DISTRIBUTION OF *RAFFLESIA* POPULATIONS IN KELANTAN

Globally, the genus *Rafflesia* comprises 43 recognised species, reflecting a narrow but highly specialised evolutionary lineage. Malaysia represents a major centre of diversity for the genus, harbouring 15 species. Of these, ten species are distributed in Peninsular Malaysia, namely *Rafflesia azlanii*, *R. cantleyi*, *R. kerrii*, *R. perakensis*, *R. sharifah-hapsahiae*, *R. su-meiae*, *R. parvimaculata*, *R. tuanku-halimii*, *R. tiomanensis*, and *R. tunku-azizahiae*. The remaining five species, *R. hasseltii*, *R. pricei*, *R. keithii*, *R. tengku-adlinii*, and *R. tuan-mudae* are confined to the forests of Sabah and Sarawak (Wong and Latiff 1994; Wong and Gan 2003; Mat Salleh *et al*. 2006; Wong *et al*. 2009; Ahmad-Puad *et al.* 2020; Siti-Munirah *et al.* 2021; Adam *et al*. 2022; Siti-Munirah 2026).

Within Peninsular Malaysia, Kelantan plays a particularly important role in sustaining *Rafflesia* diversity. Three species have been recorded in the state, with distributions largely concentrated in the southern highlands: *R. cantleyi*, *R. kerrii*, and *R. su-meiae*. *Rafflesia cantleyi* occurs in limited localities, primarily within and surrounding Kuala Koh National Park, with more recent records from the Ulu Sat and Chabang Tongkat Forest Reserves in the districts of Pasir Puteh and Machang. *Rafflesia su-meiae* is known exclusively from Mount Chamah and is considered likely endemic to this area. In contrast, *R. kerrii* exhibits a broader distribution along the Main Range of Kelantan, making it the most widespread species in the state.

The exceptional abundance of *R. kerrii* in the Lojing Highlands has elevated the region's profile as a major ecotourism destination, particularly for international visitors. Biogeographically, this species is restricted to tropical rainforest zones extending from southern Thailand into the border regions of Perak, Kelantan and Pahang. In Malaysia, *R. kerrii* was first recorded in 2002, followed by the discovery of a new population in the Lojing Highlands in 2003 (Wong and Gan 2003). These findings prompted further investigation, culminating in the Lojing Scientific Expedition in 2008, during which a UMK-led research team documented 26 distinct *Rafflesia* populations (Zulhazman *et al.* 2010).

Notably, all populations identified during the 2008 expedition were located on stateland. Subsequent surveys, however, revealed additional populations within neighbouring forest reserves, including the Sungai Berok and Lojing Forest Reserves. This expanding knowledge base directly informed policy and management decisions, leading to the gazettement of a 400-hae *Rafflesia* Conservation Area in the Lojing Highlands by the Kelantan State Government in 2011.

Conservation measures were further reinforced in 2015 when the Kelantan State Forestry Department designated a 50-hectare High Conservation Value Forest within Compartment 1 of the Lojing Forest Reserve, specifically to safeguard *Rafflesia* habitats (Kelantan State Forestry Department 2015). More recently, in 2024, with technical support from UMK, an additional 20-ha area was proposed for gazettement as a HCVF to protect *R. cantleyi* populations in the Ulu Sat and Chabang Tongkat Forest Reserves. Collectively, these initiatives reflect an evolving, science-informed approach to Rafflesia conservation in Kelantan, underpinned by sustained research, institutional collaboration and adaptive forest management.

BUILDING A SCIENCE-BASED FRAMEWORK FOR *RAFFLESIA* CONSERVATION IN KELANTAN

Systematic research on *Rafflesia* in Kelantan was initiated by UMK in 2008, in parallel with the establishment of the Faculty of Earth Sciences. Since then, UMK has developed a sustained research programme addressing multiple dimensions of *Rafflesia* biology, ecology, and conservation. Core research themes include host-parasite relationships, growth dynamics and mortality patterns, pollination biology, seed dispersal mechanisms, floral scent chemistry, microbial associations, and the ecological impacts of ecotourism. This integrated research agenda has been supported by competitive funding from the Ministry of Higher Education and the Ministry of Natural Resources and Environmental Sustainability, reflecting national recognition of the scientific and conservation value of *Rafflesia*.

Funded projects have examined both species- and ecosystem-level processes, ranging from assessments of *Rafflesia* population status and community-based conservation strategies to advanced molecular and chemical analyses of plant-microbe-pollinator interactions. Long-term field monitoring has generated critical baseline data on population size, spatial distributions, and demographic trends, while experimental and laboratory -based studies have provided insights into the biochemical and microbial drivers of floral scent and pollinator attraction, strengthening the scientific foundation for evidence-based management of *Rafflesia* habitats in Kelantan and beyond.

Research outputs from UMK have been disseminated widely through peer-reviewed journals, monographs, conference proceedings, and public-oriented publications. Key findings have substantially advanced understanding of *Rafflesia* ecology. Extensive field surveys identified 26 populations of *Rafflesia kerrii* across the Lojing Highlands, with the

highest concentration recorded near Kampung Jedip, where population density and bud abundance were notably high (Zulhazman *et al.* 2010). Detailed phenological monitoring further revealed exceptionally high bud mortality, with more than half of observed buds failing to reach anthesis, primarily due to termite infestation and seasonal moisture stress, underscoring the species' vulnerability during early developmental stages (Qayyum *et al.* 2013, 2014, 2023).

UMK research has also contributed to taxonomic and ecological discoveries. The identification of *Tetrastigma hookeri* as a previously unrecorded host for *R. kerrii* in Peninsular Malaysia expanded understanding of host specificity and habitat requirements (Nasihah *et al.* 2016). Pollination studies documented a diverse assemblage of insect visitors and confirmed carrion-associated calliphorid flies as the primary pollinators, reinforcing the importance of olfactory cues in reproductive success (Hor *et al*. 2021). Chemical and phytochemical analyses revealed complex mixtures of secondary metabolites and floral volatile constituents, supporting the hypothesis that scent "cocktails" play a central role in attracting pollinators (Norhazlini *et al.* 2020).

More recent investigations have highlighted the role of microbial communities in *Rafflesia* ecology. Diverse bacterial assemblages dominated by Proteobacteria, Bacteroidetes, Firmicutes, Actinobacteria and Cyanobacteria were detected in *R. kerrii*, suggesting potential microbial contributions to scent production and pollinator attraction (Norhazlini 2022). These findings open new avenues for understanding plant-microbe-insect interactions in holoparasitic species.

Beyond biological research, UMK studies have documented the growing pressures of ecotourism on *Rafflesia* habitats. The site near Kampung Jedip has emerged as the most frequently visited location in the Lojing Highlands, with daily visitation by international tourists and active promotion by tour operators based in Cameron Highlands. Unregulated trampling has resulted in habitat degradation at several sites, highlighting the urgent need for improved visitor management and conservation-aware tourism practices (Zulhazman 2012). Together, UMK's research efforts provide a comprehensive knowledge base that informs both conservation planning and sustainable ecotourism management for *Rafflesia* in Kelantan.

PROTECTING *RAFFLESIA* THROUGH GOVERNANCE AND COLLABORATION IN KELANTAN

The establishment of the *Rafflesia* Conservation Area (RCA) in the Lojing Highlands represents a landmark achievement in habitat-level conservation in Kelantan and stands as one of UMK's most significant contributions to biodiversity protection. By positioning conservation as a central pillar of sustainable highland development, UMK has played a strategic role in ensuring that ecological integrity remains integral to land-use planning in the Lojing Highlands.

The foundation for this conservation initiative was laid during the Lojing Scientific Expedition in 2008, jointly organised by UMK in collaboration with Universiti Malaysia Sabah, the Kelantan State Forestry Department and the South Kelantan Development Authority. This expedition documented 26 *Rafflesia* populations, all of which were located in stateland areas lacking formal legal protection. The findings highlighted an urgent conservation gap, as these biologically significant sites were highly exposed to land conversion and human disturbance. During the post-expedition seminar held in Kota Bharu, researchers and stakeholders raised critical concerns regarding the absence of

comprehensive protection for the Lojing Highlands, particularly in the context of expanding agriculture, uncontrolled development and poorly managed tourism activities. A key outcome of the plenary discussions was a consensus recommendation to formally designate the area as a *Rafflesia* Conservation Area.

Building on this consensus, UMK submitted a formal proposal in 2010 to the Kelantan State Government and relevant agencies, advocating for the legal gazettement of the Lojing Highlands as a conservation area. This proposal emphasised that safeguarding *Rafflesia* populations required immediate and decisive action, and that conservation should be viewed as a collective responsibility to ensure the long-term ecological and socio-economic sustainability of the region.

In 2011, the Kelantan State Government officially gazetted a 400-hectare area in the Lojing Highlands as the *Rafflesia* Conservation Area, declaring it a site reserved for public interest and dedicated to the preservation of *Rafflesia*. Management and coordination responsibilities were assigned to the Lojing Sub-District Office, providing an institutional framework for oversight and enforcement. The gazettement marked a critical turning point, as legal protection enabled regulatory control over activities that could degrade habitats, including land clearing and unsustainable tourism practices. This intervention was particularly timely given the increasing pressures from agricultural expansion, which have contributed to soil erosion, landslides and environmental degradation, with direct implications for the livelihoods and well-being of the local Temiar community.

Recognising that effective conservation extends beyond legal designation, UMK further strengthened its commitment through strategic partnerships. In November 2014, a Memorandum of Understanding was formalised between UMK, the Kelantan State Government, the Tropical Rainforest Conservation and Research Centre and the East Coast Economic Region Development Council. This multi-institutional agreement established a long-term, 20-year framework for collaborative action aimed at protecting the ecological integrity of the Lojing Highlands while enhancing community resilience and sustainable development outcomes.

KEY CHALLENGES AND STRATEGIC GAPS IN *RAFFLESIA* CONSERVATION IN KELANTAN

Despite notable progress in research and habitat protection, the effective conservation of *Rafflesia* in Kelantan continues to face multiple, interrelated challenges. These challenges arise from ecological sensitivity, land-use pressures, governance gaps and resource constraints, all of which require coordinated and strategic responses. One of the most pressing threats is large-scale agricultural expansion surrounding *Rafflesia* habitats, particularly in the southern region of Kelantan. Many populations occur in landscapes where conservation areas are directly adjacent to plantations, with little or no buffer zone to mitigate edge effects. This proximity exposes *Rafflesia* habitats to habitat degradation, changes in microclimate and disruption of ecological interactions. Given the species' reliance on specific insect pollinators and small mammals for seed dispersal, any disturbance to the surrounding ecosystem can have cascading effects on reproductive success and long-term population viability.

A further constraint lies in the absence of a comprehensive and coordinated management plan for *Rafflesia* conservation in the Lojing Highlands. At present, there are no standardised guidelines governing habitat protection, ecotourism activities, community participation or visitor management. As a result, several *Rafflesia* sites have experienced

physical disturbance due to unregulated tourism and other human activities. Without a clearly articulated management framework, conservation efforts remain fragmented and reactive rather than proactive and sustainable.

Scientific uncertainty also presents a major challenge. As one of the most biologically unusual flowering plants, *Rafflesia* remains poorly understood across many fundamental aspects, including its evolutionary origins, co-evolution with host plants, reproductive biology, physiological processes, genetic diversity and potential medicinal properties. These knowledge gaps limit the development of targeted conservation strategies. The establishment of the *Rafflesia* Conservation Area offers a unique platform to address these challenges by facilitating long-term, interdisciplinary research and fostering collaboration among local and international scientists.

Ecotourism represents both an opportunity and a risk. The presence of *Rafflesia* in the Lojing Highlands has strong appeal for nature-based tourism, with visitors willing to travel considerable distances to observe the world's largest flower in situ. However, without a well-designed tourism management plan, increased visitation risks accelerating habitat degradation through trampling, soil compaction and disturbance to host plants. Sustainable ecotourism development must therefore be carefully planned, balancing visitor access with strict conservation safeguards.

The role of local communities is equally critical to the success of conservation initiatives. *Rafflesia* conservation has the potential to provide alternative and sustainable sources of income through guided tourism and conservation-related employment. However, this requires active community engagement and capacity building. Empowering local residents, particularly those involved in tourism, as informed stewards of *Rafflesia* habitats through training, workshops and awareness programmes can foster a sense of ownership and reinforce the long-term benefits of conservation over short-term exploitation.

Finally, financial sustainability remains a key challenge. While *Rafflesia* holds strong symbolic value as an international icon of nature conservation, dedicated funding for its protection remains limited. Strengthening conservation efforts will require diversified funding sources, including partnerships with government agencies, universities, non-governmental organisations and the private sector. Strategic engagement with major Malaysian corporations, alongside the development of comprehensive conservation proposals targeting international funding bodies such as WWF, UNDP and JICA, would significantly enhance the capacity to implement long-term conservation programmes.

Addressing these interconnected challenges demands an integrated, multi-stakeholder approach that combines sound science, effective governance, community participation and sustained financial support; only through such a coordinated strategy can *Rafflesia* conservation in Kelantan be secured for future generations.

A STRATEGIC ROADMAP FOR STRENGTHENING *RAFFLESIA* CONSERVATION IN KELANTAN

Looking ahead, the long-term conservation of *Rafflesia* in Kelantan requires a coordinated and adaptive strategy that integrates sound science, effective governance, and inclusive community participation. Future efforts should move beyond site-based protection toward a landscape-level approach that recognises the ecological sensitivity of *Rafflesia* and the socio-economic realities of the surrounding region. A fundamental priority is the strengthening of legal protection and land-use planning within and around the *Rafflesia* Conservation Area. While gazettement provides a critical legal foundation, its effectiveness depends on the

establishment of clear zoning systems, functional buffer zones and consistent enforcement. Close collaboration with the Kelantan State Forestry Department and other state agencies is essential to ensure that agricultural expansion, infrastructure development and tourism activities are aligned with conservation objectives and do not undermine habitat integrity.

Scientific research must remain central to conservation planning. Addressing existing knowledge gaps will require sustained, long-term ecological monitoring that tracks population trends, host–parasite dynamics, pollination processes, genetic diversity and climate-related stressors. As an institution with long-standing expertise in *Rafflesia* research, UMK is well positioned to lead and coordinate interdisciplinary research initiatives, while fostering regional and international scientific collaboration to enhance knowledge exchange and methodological innovation.

Equally important is the development of a comprehensive management framework that integrates conservation with responsible ecotourism. Carefully designed tourism plans should be guided by carrying capacity assessments, supported by low-impact infrastructure and reinforced through effective visitor management. The training of local guides and the provision of high-quality interpretative materials will not only reduce ecological disturbance but also enrich visitor experiences and strengthen conservation awareness. When properly managed, ecotourism can serve as a sustainable economic driver without compromising the ecological requirements of *Rafflesia*.

Meaningful engagement of local communities, particularly the Temiar and other residents of the Lojing Highlands, is critical to the durability of conservation outcomes. Community empowerment through education, skills training and participation in conservation -based tourism can foster stewardship and shared responsibility for protecting the *Rafflesia Conservation Area*. Ensuring that conservation initiatives generate tangible socio-economic benefits will help align local livelihoods with long-term environmental sustainability.

Sustained conservation action also depends on robust institutional partnerships and reliable funding mechanisms. Strengthening collaboration among UMK, government agencies, non-governmental organisations, the private sector and international bodies will enhance technical capacity and resource mobilisation. The establishment of a dedicated conservation fund, supported through corporate social responsibility programmes and international grants from organisations such as WWF, UNDP and JICA, would provide the financial continuity needed to support long-term initiatives.

Ultimately, with strategic planning and coordinated implementation, the *Rafflesia* Conservation Area in the Lojing Highlands has the potential to evolve into an internationally recognised centre of excellence. Such a transformation would position Kelantan as a leader in *Rafflesia* conservation, tropical biodiversity research and sustainable ecotourism, while contributing meaningfully to national conservation priorities and global biodiversity goals.

CONCLUSION

The conservation of *Rafflesia* in Kelantan represents a compelling example of how science, policy and community engagement can converge to safeguard a highly specialised and vulnerable species. As one of the world's most extraordinary flowering plants, *Rafflesia* serves not only as a biological marvel but also as a flagship species whose protection supports wider ecosystem integrity, biodiversity conservation and sustainable landscape management. The forests that sustain *Rafflesia* also underpin essential ecosystem services, cultural values and livelihoods, highlighting the broader ecological and socio-economic significance of conservation efforts.

Over the past decade, UMK has played a central and sustained role in advancing *Rafflesia* conservation through rigorous scientific research, long-term ecological monitoring, policy advocacy and multi-stakeholder collaboration. These efforts have translated scientific knowledge into tangible conservation outcomes, most notably the gazettement of the *Rafflesia* Conservation Area in the Lojing Highlands and the establishment of complementary High Conservation Value Forests. Such milestones demonstrate the effectiveness of evidence -based decision-making and institutional leadership in addressing complex conservation challenges.

Despite these achievements, *Rafflesia* conservation in Kelantan continues to face pressures from land-use change, agricultural expansion, unmanaged tourism and climate variability. Addressing these challenges requires an integrated and adaptive approach that strengthens legal protection, enhances research capacity, empowers local communities and secures long-term funding. The *Rafflesia* Conservation Area provides a critical platform for implementing these strategies and for positioning conservation as a driver of sustainable development rather than a competing land-use priority.

Looking forward, Kelantan has the opportunity to emerge as an international reference point for *Rafflesia* conservation and tropical forest stewardship. By consolidating partnerships among academic institutions, government agencies, local communities and international organisations, the state can transform the *Rafflesia* Conservation Area into a centre of excellence for biodiversity research, conservation innovation and responsible ecotourism. Ultimately, conserving *Rafflesia* transcends the protection of a single species; it embodies a broader commitment to preserving entire ecosystems, sustaining cultural and ecological heritage, and fulfilling our shared responsibility to protect nature for future generations.

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REFERENCES

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

Ahmad-Puad, A.S., Wan-Zakaria, W.N.F., Geri, C., Ramlah, Z. and A., Latiff. 2020. Notes on *Rafflesia hasseltii* Suring. (Rafflesiaceae), a new record for Sarawak, Malaysia. *Malayan Nature Journal* 72(1): 19–25.

Hor, P.L., Norhazlini, M.Z., Nasihah, M. and Zulhazman, H. 2021. Diurnal insect pollinators of *Rafflesia kerri* Meijer at Lojing Highlands, Kelantan, Peninsular Malaysia. *Malaysian Forester* 84(1): 7–15.

Ibrahim, C.O. and Zulhazman, H. 2010. *Conserving Lojing Highlands for sustainable development*. Kota Bharu, Malaysia: Universiti Malaysia Kelantan Press.

Kelantan State Forestry Department. 2015. *Rancangan pengurusan kawasan Hutan Mempunyai Nilai Pemeliharaan yang Tinggi (HCVF) untuk spesies Rafflesia kerri (bunga pakma) di kawasan Hutan Simpan Lojing, Kelantan*. Kelantan: Kelantan State Forestry Department.

Mat-Salleh, K., Mohd-Ros, A.H. and Donna, J. 2006. The role of protected areas in the conservation of *Rafflesia* in Malaysia. In *Management and status of resources in protected areas of Peninsular Malaysia*, S. Othman, S.H. Yatim, S. Ellagupillay, S.M. Nor, N. Ahmad and S.A.M. Sah (Eds.), pp. 141–154. Kuala Lumpur: Department of Wildlife and National Parks.

Myers, N. 1988. Threatened biotas: 'Hot spots' in tropical forests. *Environmentalist* 8: 187–208.
Nasihah, M., Zulhazman, H., Siti-Munirah, M.Y., Qayyum, N.W.A. and Latiff, A. 2016. *Tetrastigma hookeri* (Laws.) Planch. (Vitaceae), a host plant for *Rafflesia kerri* Meijer in Peninsular Malaysia. *Malayan Nature Journal* 68(1&2): 33–39.
Norhazlini, M.Z. 2022. Assessing the bacterial community associated with *Rafflesia kerri* Meijer related to pollinator activity. Kelantan: Universiti Malaysia Kelantan. [Unpublished].
Norhazlini, M.Z., Mailina, J., Markandan, S., Nor-Azah, M.A. and Zulhazman, H. 2020. Assessing the floral volatile constituents of male and female Rafflesia kerri Meijer from Lojing Highlands, Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science* 549: 012068.
Qayyum, N.W.A., Siti-Munirah, M.Y. and Zulhazman, H. 2013. Bud development and flowering phenology of *Rafflesia kerri* in Lojing Highlands, Kelantan, Peninsular Malaysia. In *Proceedings of the 9th International Flora Malesiana Symposium*, 27th-31st August 2013, Bogor, Indonesia. Jakarta: Indonesian Institute of Sciences.
Qayyum, N.W.A., Siti-Munirah, M.Y., Aainaa, S.A.H., Razak, W. and Zulhazman, H. 2014. A preliminary survey on population, mortality and anthesis of *Rafflesia kerri* in Lojing Highlands, Gua Musang, Kelantan. *Jurnal Teknologi* 56: 1–13.
Qayyum, N.W.A., Siti-Munirah, M.Y., Norhazlini, M.Z. and Zulhazman, H. 2023. Evaluating the mortality rate of *Rafflesia kerrii* in Lojing Highlands, Peninsular Malaysia. *Malayan Nature Journal* 75(4): 1–8.
Siti-Munirah, M.Y., Salamah, A. and Razelan, M. S. 2021. *Rafflesia tiomanensis* (Rafflesiaceae), a new species from Pulau Tioman, Pahang, Malaysia. *Malayan Nature Journal* 73(1): 19–26.
Siti-Munirah, M.Y. 2026. *Rafflesia perakensis* (Rafflesiaceae), a new species from Perak, Peninsular Malaysia. *Malayan Nature Journal* 78(3): 219–230.
van Steenis, C.G.G. 1971. Plant conservation in Malaysia. *Bulletin du Jardin Botanique National Belge* 41: 189–202.
Whitmore, T.C. 1984. *Tropical rainforests of the Far East*. Oxford: Clarendon Press.
Wong, M. and Gan, F. 2003. The elegant *Rafflesia kerrii* of Kelantan. *Folia Malaysiana* 4(1): 53–62.
Wong, M and Latiff, A. 1994. Rafflesias of Peninsular Malaysia. *Nature Malaysiana* 19(3): 84–88.
Wong, M., Nais, J. and Gan, F. 2009. *Rafflesia su-meiae* (Rafflesiaceae): A new species from Kelantan, Peninsular Malaysia. *Folia Malaysiana* 10(2): 89–98.
Zulhazman, H. 2012. Assessing and mapping of Rafflesia distribution hotspots for nature conservation in Kelantan, Malaysia. In *Proceedings of the 3rd International Seminar on Regional Network on Poverty Eradication (RENPER)*, C.O. Ibrahim and Z. Muktamar (Eds.). Kota Bharu: Universiti Malaysia Kelantan Press.
Zulhazman, H., Maryati, M., Cornelius, P. and Mohd, M. 2010. Spatial distribution and conservation of *Rafflesia kerrii* in Lojing Highlands, Kelantan. In *Conserving Lojing Highlands for sustainable development*, C.O. Ibrahim and H. Zulhazman (Eds.), pp. 44–54. Kota Bharu: Universiti Malaysia Kelantan Press.


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CHAPTER 9

Wild *Durio* (Malvaceae) of Malaysia: Diversity and conservation priorities

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Abstract: Malaysia is one of the centres of diversity for the genus *Durio* (Malvaceae), which comprises 31 species distributed throughout Southeast Asia. While *Durio zibethinus* dominates global durian cultivation and trade, Malaysian forests harbour critical assemblage of wild *Durio* species occupying ecological niches from lowland dipterocarp forests to lower montane systems. These wild species represent critical crop wild relatives with potential value for durian improvement, climate resilience, and disease resistance. Despite this, many wild *Durio* species remain taxonomically unresolved and have received little attention in conservation planning. This review synthesises the current status on wild *Durio* in Malaysia, covering their taxonomy, distribution, ecology, reproductive biology, and conservation status. To date, wild *Durio* species have been documented across Peninsular Malaysia, Sabah, and Sarawak, including edible species such as *D. oxleyanus*, *D. graveolens*, *D. kutejensis*, *D. dulcis*, *D. kinabaluensis* and *D. malaccensis*. Major threats include habitat loss, fragmentation, restricted endemism, and limited *ex situ* conservation efforts. Significant research gaps were identified in pollination ecology, climate vulnerability assessment, and long term population monitoring. Strengthening integrative taxonomy and coordinated conservation strategies is urgently required to safeguard Malaysia's wild durian diversity.

INTRODUCTION

The genus *Durio* is among the most distinctive tree genera of Southeast Asian tropical forests (Kostermans 1958). While Durio is best known for the cultivated durian, *Durio zibethinus*, the genus encompasses a far broader diversity of wild species distributed across Thailand, Peninsular Malaysia, Sumatera, Borneo, and the Philippines (Alponsin *et al.* 2026). Malaysia represents a major centre of species richness and endemism within the distributional range (Salma 2011, 2015; Ghazalli *et al*. 2022). Numerous species occur exclusively in Borneo, underscoring the island's importance as a hotspot of diversification within the Sundaic region (Kostermans 1958; Soepadmo 1995).

Wild *Durio* species are ecologically significant canopy or emergent trees that contribute seasonally to forest food source (Brown 1997). Their large, often nocturnally anthesing flowers are adapted to vertebrate pollination, particularly by bats, reflecting specialised reproductive strategies characteristic of Malesian rainforests (Nawa 1990) (Figure 1). The production of sizeable, fleshy-aril fruits provides food resources for a diversity of frugivorous vertebrates and facilitates seed dispersal, thereby contributing to forest regeneration (Soepadmo 1995) (Figure 2). These ecological roles position wild *Durio* as important structural and functional components of lowland and hill dipterocarp forest ecosystems (Primack 2005).

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Figure 1. Variation in floral morphology. **A.** *Durio griffithii*; **B.** *Durio oxleyanus*; **C.** *Durio singaporensis* var. *singaporensis*; **D.** *Durio lowianus*; **E.** *Durio kutejensis*; and **F.** *Durio malaccencis*

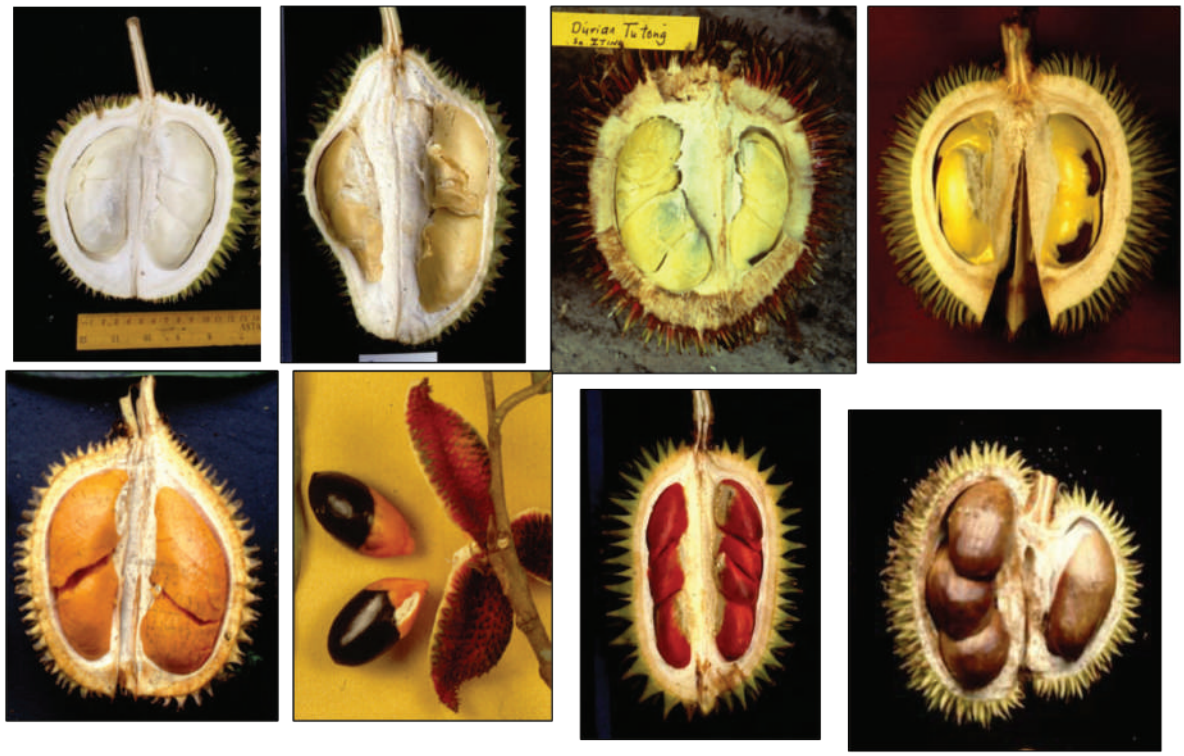

Figure 3. Variation in aril appearance. **A.** *Durio lowianus*; **B.** *Durio zibethinus*; **C.** *Durio dulcis*; **D.** *Durio graveolens*; **E.** *Durio kutejensis*; **F.** *Durio griffithii*; **G.** *Durio carinatus*; and **H.** *Durio singaporensis* var. *singaporensis*

From an agricultural perspective, wild species constitute an underutilised reservoir of genetic diversity. Traits such as resistance to soil-borne pathogens, tolerance to abiotic stress, variation in fruit morphology and flavour, and adaptation to environmentally-challenging conditions are of potential value for crop improvement. Incorporating genetic resources from wild relatives into breeding programmes for *Durio zibethinus* could strengthen their resilience in the face of emerging diseases and climatic variability, while also broadening the commercial fruit portfolio beyond existing cultivars (Salma *et al.* 2011) (Figure 3).

Despite their ecological and agronomic relevance, wild *Durio* species remain under-studied compared cultivated durian varieties. Taxonomic ambiguities persist, particularly among Bornean species where morphological variation is high and herbarium representation is uneven. Not just that, population-level genetic data remain sparse, thereby limiting the understanding of gene flow, demographic history, and conservation status of this genus. Comprehensive conservation assessments are incomplete, with several species yet to undergo formal risk evaluation. Hence, this review consolidates the state of knowledge up to 2026 and identifies priority directions for future research, systematics, and conservation planning for *Durio*.

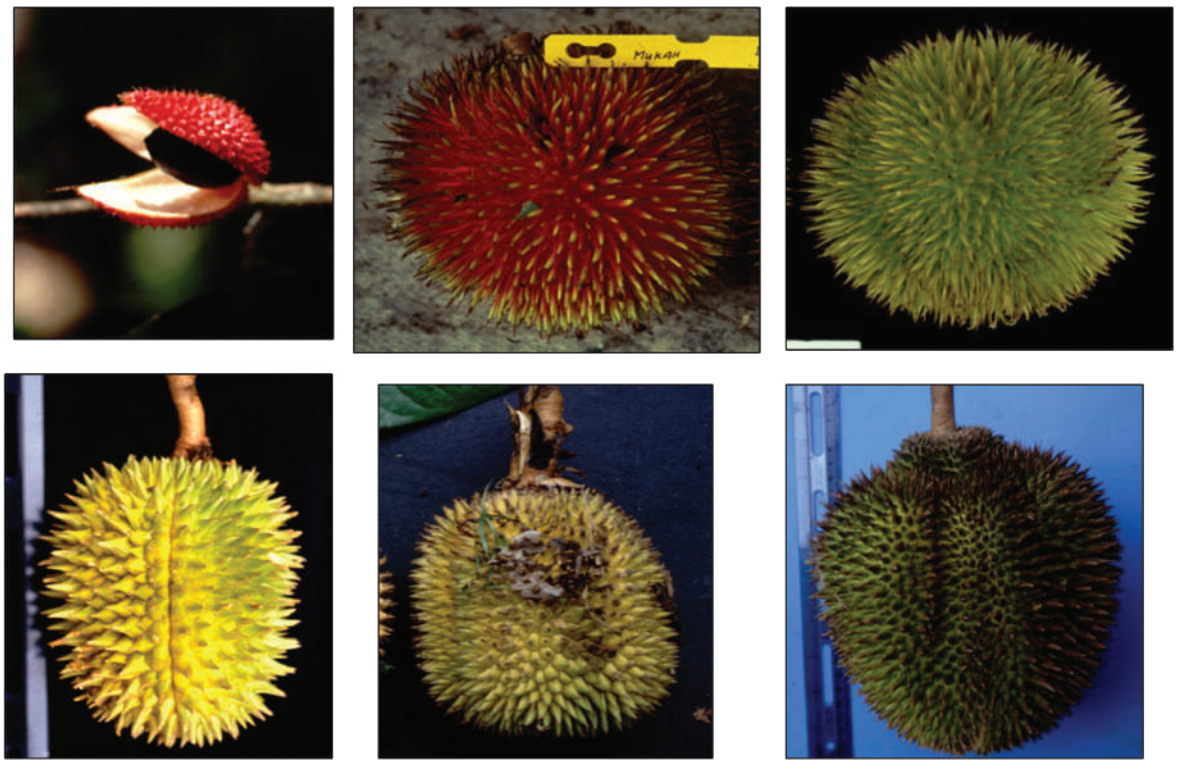

Figure 3. Variation in fruit morphology. **A.** *Durio griffithii*; **B.** *Durio dulcis*; **C.** *Durio lowianus*; **D.** *Durio carinatus*; **E.** *Durio malaccencis*; and **F.** *Durio zibethinus*

TAXONOMIC HISTORY AND SYSTEMATICS

The genus *Durio* was first described in the 18th century with its early taxonomic treatment based primarily on cultivated materials of *D. zibethinus* (Kostermans 1958; Brown 1997). Subsequent taxonomic revisions, particularly those undertaken in the mid-20th century, established much of the current taxonomic framework. Species delimitation relied on floral morphology, fruit spine structure, indumentum characteristics, and leaf venation patterns. However, several challenges complicate taxonomic resolution including overlapping

vegetative characters among sympatric species and incomplete type material (Kostermans 1958; Soepadmo 1995). Integrative taxonomy combining morphology, palynology, wood anatomy, and phylogenomics is increasingly recognised as necessary for resolving species boundaries. As of 2026, Malaysia recorded 25 species of wild *Durio*. Species richness of *Durio* is particularly higher in Sabah and Sarawak than in Peninsular Malaysia.

In Peninsular Malaysia, 14 species recorded include *D. malaccensis*, *D. oxleyanus*, *D. griffithii* and *D. wyatt-smithii*. These species typically inhabit lowland and hill dipterocarp forests, with some population extending into riparian and alluvial habitats (Salma 2011). In Sabah and Sarawak, 13 and 16 species were recorded, respectively, including *D. graveolens*, *D. kutejensis*, *D. dulcis*, *D. kinabaluensis*, and *D. crassipes*.

Several species exhibit restricted distributions, particularly montane endemics associated with the Crocker Range and Kinabalu region (Parris 1992; Soepadmo 1995; Salma, 2011). Endemism is especially pronounced in Sabah, where elevational gradients and geological heterogeneity may have promoted speciation.

Wild *Durio* species are typically large trees (20 – 50 m) with buttressed trunks and dense canopies. Diagnostic features include alternate, entire, often with scaly or lepidote undersurfaces ranging from silvery to golden-brown. Venation density and indumentum are taxonomically informative; cauliflorous or ramiflorous; large, fleshy petals; abundant nectar; nocturnal anthesis in many species and fruits with considerable interspecific variation in size, rind thickness, spine morphology, aril colour, and dehiscence pattern. Variation also observed in aril pigmentation ranges from white and pale yellow to deep orange and red.

CONSERVATION STATUS AND THREATS

Major threats to wild *Durio* populations in Malaysia are primarily driven by habitat loss and landscape modification. Infrastructure development including highways, hydroelectric projects, and urban expansion further accelerates habitat conversion and ecological isolation (FAO 2020). The cumulative effect of these pressures is increasing forest fragmentation, which disrupts pollinator movement, reduces gene flow, and limits natural regeneration processes (Corlett 2016). Restricted-range and endemic species are especially vulnerable under these conditions. Many wild *Durio* species are confined to specific ecological niches, such as riverine forests, limestone outcrops, or hill dipterocarp zones in Peninsular Malaysia, Sabah, and Sarawak (Sodhi *et al.* 2010). Habitat contraction in these specialised environments will rapidly translate into population decline. Regeneration outside intact forest is often poor, as seedlings require shaded microhabitats and stable soil moisture conditions.

Ex situ conservation efforts remain disproportionately focused on cultivated durian varieties, particularly *Durio zibethinus*, while wild species still in limited representation in field gene banks and seed repositories. Existing germplasm collections, including those maintained by institutions such as Malaysian Agricultural Research and Development Institute, prioritise agronomically valuable cultivars. As a result, the genetic diversity of wild relatives critical for breeding resilience traits such as disease resistance, abiotic stress tolerance, and novel fruit characteristics remains under-secured.

To address these challenges, several conservation measures are recommended. First, wild *Durio* species should be formally integrated into protected area management plans to ensure that habitat conservation strategies explicitly recognise their ecological and genetic importance. Then, comprehensive national Red List assessments aligned with International Union for Conservation of Nature (IUCN) criteria are also needed to evaluate extinction

risk and guide prioritisation. The establishment of dedicated field gene banks and living collections will strengthen *ex situ* safeguarding of threatened wild *Durio* species. Complementary research on seed biology including storage behaviour and cryopreservation potential is essential, given that many *Durio* species exhibit recalcitrant seed traits (Lah *et al*. 2023). Finally, community-based stewardship initiatives that engage Indigenous Peoples and local communities in monitoring, sustainable utilisation, and habitat protection can enhance long-term conservation outcomes while aligning biodiversity goals with rural livelihoods.

Table 1. The species in Malaysia, their distribution and the IUCN conservation categories.

Species	Distribution	IUCN Conservation Category*
Durio affinis	Peninsular Malaysia and Borneo	Not Evaluated (NE) / Data unavailable
D. carinatus	Peninsular Malaysia, Sumatera and Borneo	Not Evaluated (NE) / Data unavailable
D. crassipes	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. dulcis	Borneo, endemic	Vulnerable (VU) (Wikipedia)
D. excelsus	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. grandiflorus	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. graveolens	Peninsular Malaysia and Borneo	Vulnerable (VU)
D. gerikensis	Peninsular Malaysia, endemic	Not Evaluated (NE) (recently described species)
D. griffithii	Peninsular Malaysia, Sumatera and Borneo	Not Evaluated (NE) / Data unavailable
D. kinabaluensis	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. kutejensis	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. lanceolatus	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. lowianus	Peninsular Malaysia and Sumatera	Not Evaluated (NE) / Data unavailable
D. macrophyllus	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. perakensis	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. macrolepis	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. malaccensis	Peninsular Malaysia and Sumatera	Not Evaluated (NE) / Data unavailable
D. johoricus	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. oblongus	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. oxleyanus	Peninsular Malaysia, Sumatera and Borneo	Not Evaluated (NE) / Data unavailable
D. pinangianus	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. singaporensis	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. testudinarius	Borneo, endemic	Not Evaluated (NE) / Data unavailable
D. wyatt-smithii	Peninsular Malaysia, endemic	Not Evaluated (NE) / Data unavailable
D. zibethinus	Peninsular Malaysia, Myanmar, Thailand, Sumatera and Borneo	Data Deficient (DD) / widely cultivated taxon

RESEARCH PRIORITIES

Priority research areas for advancing knowledge and conservation of wild *Durio* in Malaysia begin with integrative taxonomic revision. Many species remain poorly delimited due to overlapping morphological characters, limited type material, and uneven sampling across Peninsular Malaysia, Sabah, and Sarawak. A comprehensive revision that synthesises classical morphology, micromorphology including pollen and trichome characters, herbarium studies, ecological data, and genomic evidence is essential to resolve species boundaries, clarify synonymies, and stabilise nomenclature. Such integrative approaches will reduce taxonomic ambiguity and provide a robust baseline for conservation prioritisation.

Population-level genetic assessments are also critical, particularly in landscapes increasingly fragmented by agricultural expansion and infrastructure development. Analyses of genetic diversity, population structure, gene flow, and demographic history using SNP-based markers or whole-genome resequencing can reveal levels of inbreeding, bottlenecks, and connectivity among remnant populations. Such information is indispensable for designing in situ conservation strategies, identifying priority populations for *ex situ* germplasm banking, and guiding assisted gene flow or restoration programmes.

Pollination network studies represent another key important character, especially given the predominantly bat-involvement pollination observed in many *Durio* species. Detailed investigations of floral phenology, nectar production, visitor assemblages, and plant pollinator interaction networks will illuminate the ecological characters that sustain reproductive success. Understanding how habitat fragmentation and declines in pollinator populations will affect fruit set and genetic diversity will further strengthen ecosystem -based conservation planning.

Climate vulnerability modelling should also be prioritised to anticipate the impacts of future climatic shifts on species distributions. Species distribution models integrating current occurrence data with downscaled climate projections can identify potential refugia, range contractions and areas of climatic suitability under different emissions scenarios. These projections can help inform long-term conservation zoning and assisted migration strategies, particularly for narrow endemics or montane species with limited adaptive capacity.

Finally, it is also essential to systematically integrate wild *Durio* genetic resources into national agrobiodiversity and food security frameworks. Aligning research outputs with national policies on plant genetic resources, sustainable agriculture, and food security will ensure that wild relatives are recognised as strategic assets for crop improvement and resilience breeding. Strengthening linkages between academic and research institutions, forest management authorities, and germplasm repositories will facilitate the conservation, characterisation, and sustainable utilisation of wild *Durio* for future agricultural innovation.

EX SITU CONSERVATION EFFORTS

MARDI Serdang, Serdang

MARDI Serdang, Selangor maintains an important *ex situ* conservation collection of wild and cultivated *Durio* species, comprising 139 accessions representing 12 species. The collection includes both the economically important and underutilised durian relatives, such as *Durio zibethinus*, *D. lowianus*, *D. graveolens*, *D. oxleyanus*, *D. pahangensis*, *D. singaporensis*, *D. malaccensis*, *D. kutejensis*, *D. dulcis*, *D. testudinarius*, *D. gerikensis* and *D. acutifolius*. The largest holdings are *D. zibethinus* and *D. lowianus*, with 40 accessions each, followed by *D. graveolens* (23 accessions) and *D. oxleyanus* (13 accessions). These living collections serve as a valuable genetic reservoir for conservation, research, characterisation, and future

breeding programmes. The collection also safeguards several rare and endemic taxa represented by limited accessions, highlighting the importance of continued germplasm exploration and enrichment to enhance genetic representation and ensure the long-term conservation of Malaysia's native durian diversity.

MARDI Jerangau, Terengganu

The *Durio ex situ* germplasm collection at MARDI Jerangau, Terengganu comprises 84 accessions representing at least eight species and several locally named landraces or unidentified accessions. The collection is dominated by *Durio zibethinus* (24 accessions) and *D. lowianus* (18 accessions), followed by *D. graveolens* (12 accessions), *D. dulcis* (7 accessions), and *D. oxleyanus* (11 accessions, including accessions recorded under the local name *Isu*). Other species conserved include *D. oblongus* (2 accessions), *D. testudinarius* (2 accessions), and *D. kutejensis* (2 accessions, including accessions recorded under the local name *Nyekak*). In addition, several accessions are maintained under local names such as *Sempa* and *Sangka*, which require further taxonomic verification. This living collection serves as an important genetic resource for the conservation of wild durian diversity, supporting taxonomic research, genetic studies, crop improvement programmes, and the long-term safeguarding of valuable germplasm that may possess traits for disease resistance, climate resilience, and fruit quality improvement.

In addition to *ex situ* conservation, MARDI also contributes to the *in situ* conservation of durian diversity through the protection of naturally occurring populations within its research stations. A notable example is *Durio singaporensis* var. *jerangauensis*, a recently described variety that is currently known only from MARDI Jerangau, Terengganu. This variety is considered endemic to the station and represents a unique component of Malaysia's durian biodiversity. The conservation of its natural habitat within MARDI Jerangau ensures the continued survival of this taxon in its native ecological setting, allowing natural evolutionary and ecological processes to continue. Together, these *ex situ* and *in situ* conservation efforts strengthen MARDI's role as a national custodian of *Durio* genetic resources and support the long-term conservation and sustainable utilization of Malaysia's rich durian diversity.

Private *Durio* orchard of Dr. Abdul Aziz Zakaria

Apart from institutional conservation efforts, significant contributions have also been made through individual initiatives. Dr. Abdul Aziz Zakaria has established and maintained a private conservation orchard in Ketereh, Kota Bharu, Kelantan, using his own resources to protect several wild *Durio* species. The collection includes *Durio graveolens*, *D. testudinarium*, *D. dulcis*, *D. kutejensis*, *D. lowianus* and *D. oxleyanus*. This initiative serves as an important *ex situ* conservation effort for wild durian genetic resources, particularly for species that are uncommon, geographically restricted, or increasingly threatened by habitat loss. The orchard functions as a living repository for the preservation of genetic diversity and provides valuable material for future research, breeding, and conservation programmes. Such individual-led conservation efforts complement national germplasm conservation activities and highlight the importance of collaborative approaches involving researchers, institutions, and private stakeholders in safeguarding Malaysia's rich *Durio* biodiversity.

CONCLUSION

Malaysia represents a global hotspot of wild *Durio* diversity. These species are ecologically integral components of tropical forests and valuable genetic resources for future durian improvement. Despite increasing research attention, substantial systematic and conservation gaps remain. Coordinated national strategies integrating taxonomy, genomics, ecology, and conservation planning are essential to secure the long-term persistence of Malaysia's wild durians.

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REFERENCES

lponsin, Nurainas and Taufiq, A. 2026. Distribution, conservation status and list of *Durio* Adans (Malvaceae) in Southeast Asia: A review. *Sainstek: Jurnal Sains dan Teknologi* 18(1): 18–31.

Beaman, J.H. and Beaman, R.S. 1990. *The plants of Mount Kinabalu (Vol. 1: Ferns and fern allies)*. Kew: Royal Botanic Gardens.

Brown, M.J. 1997. *Durio*: A bibliographic review. R.K. Arora, V. Ramanatha Rao and A.N. Rao (Eds.). New Delhi: International Plant Genetic Resources Institute Office for South Asia.

Corlett, R.T. 2016. Plant diversity in a changing world: Status, trends, and conservation needs. *Plant Diversity* 38(1): 10–16.

Food and Agriculture Organization (FAO). 2020. *Global Forest Resources Assessment 2020: Main report*. Rome: FAO.

Ghazalli, M.N., Hashim, M.H., Besi, E.E., Mat-Esa, M.I., Zaini, A.Z., Saranum, M.M., Salleh, S. *et al*. 2022. *Durio gerikensis* (Malvaceae), a new Arilless *Durio* from Hulu Perak, Malaysia. *Phytotaxa* 543(1): 21–30.

Kostermans, A.J.G.H. 1958. The genus *Durio* Adans. (Bombac.). *Reinwardtia* 4(3): 47–153.

Lah, N.H.C., El Enshasy, H.A., Mediani, A., Azizan, K.A., Aizat, W.M., Tan, J.K., Afzan, A., Noor, N.M. and Rohani, E.R. 2023. An insight into the behaviour of recalcitrant seeds by understanding their molecular changes upon desiccation and low temperature. *Agronomy* 13(8): 2099. https://doi.org/10.3390/agronomy13082099

Primack, R.B. and Corlett, R. 2005. *Tropical Rain Forests: An Ecological and Biogeographical Comparison*. Oxford: Blackwell Publishing.

Salma, I. 2011. *Durio of Malaysia*. Serdang: Penerbit MARDI.

Salma, I. 2015. A new species and a new variety of *Durio* Adans. (Malvaceae) from Peninsular Malaysia. *Malayan Nature Journal* 67(4) : 412–418.

Soepadmo, E. 1995. *Durio* Adans. In *Tree Flora of Sabah and Sarawak* Vol. 1, E. Soepadmo and K.M. Wong (Eds.), pp.120–145. Kuala Lumpur: Forest Research Institute Malaysia.

Sodhi, N.S., Posa, M.R.C., Lee, T.M., Bickford, D., Koh, L.P. and Brook, B.W. 2010. The state and conservation of Southeast Asian biodiversity. *Biodiversity and Conservation* 19: 317–328.

Wong, K.M. 1998. Patterns in plant endemism and rarity in Borneo and the Malay Peninsula. In *Rare, threatened and endangered floras of Asia and the Pacific Rim: Proceedings of the International Symposium on Rare, Threatened, and Endangered Floras of Asia and the Pacific Rim*, April 30 - May 4, Taipei, 1996, C.-I. Peng and P. P. Lowry II (Eds.), zpp. 139–169. Taipei: Institute of Botany, Academia Sinica.

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CHAPTER 10

Gingers of Malaysia: Their taxonomy and conservation

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Abstract: Malaysia is a global centre of biodiversity for the Zingiberaceae, harbouring ca. 750 species in 31 genera. This chapter examines the taxonomic composition, ecological roles, and conservation status of gingers in Malaysia. In Peninsular Malaysia, the flora is characterised by high niche specialisation, including unique limestone endemics and recently described state-specific genera such as *Johoralia*, *Perakalia*, and *Kedhalia*. Conversely, the Bornean states of Sabah and Sarawak exhibit distinct evolutionary trajectories driven by insular isolation and diverse geological substrates, resulting in high rates of endemism (40 – 50%) and the presence of specialised genus such as *Burbidgea*. Beyond their ecological significance as nutrient cyclers and food sources for pollinators, these plants hold deep ethnobotanical value for Malaysian indigenous and local communities. However, the family faces critical threats from habitat fragmentation and land-use change, particularly for species restricted to micro-habitats like ultramafic soils or sky island montane systems. The study highlights the Wallacean shortfall, the gap between known and actual diversity, and emphasises the necessity of integrating traditional morphological taxonomy with molecular phylogenetics to inform nationwide conservation strategies and protect Malaysia's botanical heritage.

INTRODUCTION

Malaysia is recognised as one of the world's megadiverse countries, and within its tropical rainforests, the family Zingiberaceae stands as one of the most significant groups of monocotyledonous herbs. Distributed across both Peninsular Malaysia and the states of Sabah and Sarawak, the family comprises ca. 750 species and approximately 31 genera (Govaerts *et al.* 2022). These plants are not merely structural components of the forest understorey; they are ecologically pivotal, serving as primary food sources for specialised pollinators, ranging from halictid bees to spiderhunters, and playing a critical role in the nutrient cycling of the humid tropical floor (Larsen *et al.* 1999).

Members of the family typically occupy humid, shaded environments with organic-rich soils, although they may also persist in disturbed habitats, secondary forests, and limestone formations, reflecting a degree of ecological plasticity across taxa. At the genus level, species of *Zingiber* shows distribution patterns closely governed by environmental variables, with species distribution modelling that indicates climatic factors strongly shape habitat suitability and thereby influence their occurrence and spatial distribution (Huang *et al.* 2024). This ecological dependence suggests an association with relatively stable forest conditions, where deviations in occurrence may reflect changes in habitat quality or microclimatic stability. Such sensitivity highlights their potential role as bioindicators in tropical forest ecosystems, as vascular plants are increasingly used in forest health biomonitoring to assess ecosystem integrity and environmental change (Abas 2023).

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The diversity of Malaysian gingers is deeply influenced by the country's complex biogeographical history (Burtt and Smith 1972). While the Peninsula shares many floral elements with the Asian mainland (the Indo-China influence) (Zhu and Tan 2022), the states of Sabah and Sarawak on the island of Borneo exhibit a distinct evolutionary trajectory. This insular isolation, combined with varied geological substrates such as the karst limestones of Sarawak and the ultramafic soils of Sabah, has fostered an extraordinary rate of endemism. In fact, while genera like *Alpinia*, *Amomum* and *Zingiber* are found nationwide, the species composition often shifts dramatically across the South China Sea, with Borneo hosting an endemic genus like *Burbidgea* (now extended to the Philippines) (Mazo *et al.* 2022).

Beyond their ecological contributions, the Zingiberaceae hold immense ethnobotanical and economic importance across all Malaysian cultures. From the ubiquitous use of *Etlingera elatior* (locally known as Bunga Kantan) in culinary traditions to the medicinal application of *Curcuma* and *Zingiber* species by indigenous communities like the Orang Asli in the Peninsula as well as the Dayak and Kadazan-Dusun in Borneo, gingers are woven into the country's heritage. Despite this, many species remain under-documented and are highly vulnerable to localised disturbances, particularly those driven by anthropogenic activities such as rapid land-use change, deforestation and urbanisation as documented across multiple regions (Akram *et al.* 2023; Sedek 2026). A comprehensive understanding of the taxonomic landscape in Sabah and Sarawak is therefore essential to complete the picture of Malaysia's botanical heritage and to inform nationwide conservation strategies.

THE ZINGIBERACEAE OF PENINSULAR MALAYSIA

Taxonomic composition, diversity patterns and major genera

The study of Zingiberaceae in Peninsular Malaysia reveals a botanical landscape of immense complexity and historical significance. As a core component of the Sundaic flora, the Peninsula serves as a critical bridge between the seasonal ginger floras of Indochina and the ever-wet, hyper-diverse assemblages of Borneo. With over 165 species recorded across approximately 26 genera, the Peninsular Malaysian gingers are characterised by a high degree of niche specialisation, particularly within the shaded understorey of lowland dipterocarp forests and the unique microclimates of limestone karsts.

Historically, the family was classified into four principal tribes: Alpinieae, Hedychieae, Globbeae, and Zingibereae. However, advances in molecular phylogenetics especially analyses based on internal transcribed spacer (ITS) and *matK* sequences have refined this into four subfamilies: Siphonochiloideae, Tamijioideae, Alpinioideae and Zingiberoideae (Kress *et al.* 2002). The taxonomic framework of Peninsular Malaysian gingers is dominated by the latter two subfamilies, Alpinioideae and Zingiberoideae, which together encompass most native taxa.

There are several key genera that define the structure of the forest floor in this region. Members of Alpinioideae, particularly within the tribe Alpinieae, such as *Alpinia*, *Amomum* (including recently segregated genera like *Meistera*, *Wurfbainia*, *Conamomum*) (De Boer *et al.* 2018), and *Etlingera* represent the larger, more robust members of the family, often reaching several meters, and frequently co-dominates understory vegetation in open areas and along stream banks.

In contrast, the smaller-statured taxa belonging to Zingiberoideae especially within the tribe Zingibereae (e.g., *Zingiber* and *Boesenbergia*), exhibit a range of morphological and phenological adaptations to shaded forest floor environments. This includes the development of underground rhizomes, seasonal dormancy, and rapid regeneration under favourable conditions reflecting their specialisation to seasonally dynamic tropical forests (Kress 2011).

Members of the tribe Globbeae, represented by *Globba* specifically in Peninsular Malaysia, are delicate understorey herbs distinguished by distinctive inflorescences morphology and strong reliance on vegetative reproduction through bulbils. Although vegetative propagation via bulbils is relatively uncommon among tropical angiosperms, *Globba* is notable for its substantial investment in this reproductive strategy, which facilitates rapid establishment and clonal spread (Box and Rudall 2006).

Of particular ecological and taxonomic interest is *Scaphochlamys*, a genus notable for its species richness and endemism in Peninsular Malaysia (Sam *et al.* 2015). The genus continues to yield new taxa through on-going taxonomic works, highlighting its diversity and the likelihood of further undiscovered species in the region (Sam and Ibrahim 2018). Many species are associated with specific forest habitats and microenvironments, making the genus a useful indicator of local ecological conditions and habitat integrity.

Another noteworthy taxon is *Camptandra*, a relatively small genus comprising four recognised species (POWO 2025), three of which occur in Peninsular Malaysia, with a fourth species recently described from Cambodia (Tanaka *et al*. 2025). The occurrence of such narrowly distributed and recently described taxa underscores the Peninsula's role as a centre of ginger diversity and highlights the incompletely documented nature of its flora.

Habitat heterogeneity and limestone endemism

Lowland forest up to altitudes of 600 m is the principal habitat for Zingiberaceae, and species richness drops at higher altitude. A defining feature of the Peninsular Malaysian ginger flora is its intrinsic link with the region's complex geological formations, which facilitate a diverse range of ecological niches. Species of Zingiberaceae occupy varied environments, including lowland primary and secondary forests, on karst formations, stream banks, plateaus, ravines, and even roadside habitats (Mohamad and Kalu 2019; Setiawan *et al.* 2022). Majority of Zingiberaceae species are adapted to shaded, low-light understory environments, particularly smaller and medium-sized gingers such as species of *Boesenbergia*, *Scaphochlamys*, *Conamomum*, *Meistera*, and *Zingiber*. In contrast, some species exhibit significant tolerance to more open, sunlit habitats, including those with more robust and taller leafy shoots (approximately 3 – 4 m), such as *Etlingera* and *Hornstedtia*, which are frequently encountered along roadsides and tourist trails.

The ecological diversity is further reflected in substrate preferences. Most species thrive in deep leaf litter with well-drained soils including sandy loam, clay loam, and alluvial soils, with a pH range of 5.0 – 6.5, and are scarce at limestone, heath, ultramafic and other non-fertile soils (Larsen *et al.* 1998). Nevertheless, some species demonstrate high ecological specialisation for calcium-rich limestone and ultramafic substrates (Sam 2015). Limestone formations in states such as Perak, Kelantan, and Pahang host a distinctive assemblage of calcicolous (lime-adapted) gingers, however, their diversity remains poorly documented. Appalasamy *et al.* (2022a) reported a relatively high representation of *Zingiber* species in Kelantan suggested that limestone-associated gingers remain underexplored. This indicates that limestone ecosystem are still under-sampled and may harbour additional undescribed taxa.

Pronounced patterns of narrow endemism are evident across several genera. For example, *Boesenbergia basispicata* is often restricted to a single limestone massif in Perak (Sam 2015; Abd Karim *et al*. 2025), while *Camptandra* are frequently found on rocky substrates or in boulder-rich environments (Syahida-Emiza *et al.* 2021). The genus *Geostachys* is comparatively rare and is generally associated with cooler, higher-elevation habitats, with several species regarded as highly endemic (Lau 2014). In addition, although *Geocharis* is more widely distributed in Sumatera and Borneo, the presence of two species endemic to Peninsular Malaysia (*G. aurantiaca* and *G. secundiflora*) highlights the region's importance

as a centre of diversity for many genera within the family (Nurainas *et al.* 2024). The edaphic conditions of limestone substrates, including high calcium content and low nutrient availability, together with the insular nature of karst outcrops, likely promote ecological specialisation and restricted gene flow, thereby driving high levels of local endemism (Clements *et al.* 2006; Meng *et al.* 2023). These highly localised distributions also make many limestone-associated species particularly vulnerable to habitat disturbance, especially from quarrying and land-use change (Clements *et al.* 2006).

The State-Named Endemics

In addition to the broadly recognised genera, Peninsular Malaysia is home to a unique group of endemic or nearly endemic genera that have been described or re-circumscribed in recent decades. These genera, often named after the states where they were first discovered, represent micro-endemic lineages that are frequently restricted to very specific river systems or forest reserves. These genera were established by the Malaysian botanist C.K. Lim and highlight the extreme localisation of certain ginger species (Table 1).

Table 1. State-named endemic genera of Zingiberaceae in Peninsular Malaysia: distribution, habitat, and endemism status.

Genus	Primary location	Forest type	Status
Johoralia	Johor	Lowland MDF	Rare/Narrow Endemic
Perakalia	Perak	Hill MDF	Localised Endemic
Kedhalia	Kedah	Seasonal Forest	Localised Endemic
Scaphochlamys	Peninsula-wide	Varied (Limestone/Clay)	High Endemism (> 80%)

- *Johoralia*: This is a monotypic genus (consists only one species, *J. lada* C.K. Lim; Figure 1). It is currently known only from the southern tip of the Peninsula, specifically within the lowland wet forests of Johor, such as the Panti and Labis Forest Reserves. Its discovery underscored the importance of the southern Malay Peninsula as a distinct floristic province (Lim 2015).
- *Perakalia*: Named after the state of Perak, this genus represents another localised lineage. Its species are often found in the shaded, humid understories of central and northern Perak. Like *Johoralia*, it is distinguished by specific floral architectures, particularly the shape of the labellum and anther, that do not fit into the broader definitions of *Amomum* or *Alpinia*. [*P. perakensis* C.K. Lim; Figure 2] (Lim 2016).
- *Kedhalia*: Found in the northern state of Kedah, this genus further illustrates the state-level endemism that characterizes Malaysian gingers. These plants are often adapted to the slightly more seasonal climates of the north, bridging the gap between the ever-wet rainforests of the south and the deciduous forests of Thailand. [*K. flaviflora* C.K. Lim; Figure 3] (Lim 2009).

The recognition of these genera is part of a larger trend in Southeast Asian botany to split large, polyphyletic genera (like *Amomum* or *Elettaria*) into smaller, more natural groups that reflect their true evolutionary history. These genera are often separated based on subtle but consistent differences in their inflorescence structure (whether they flower from the base or the tip) and the presence of specialised anther appendages. Because these plants often look identical to more common gingers when not in flower, they remained hidden in herbaria for decades. Their formal description requires precise timing to catch them in their brief flowering windows.



Figure 1. *Johoralia lada* C.K. Lim.



Figure 2. *Perakalia perakensis* C.K. Lim.



Figure 3. *Kedhalia flaviflora* C.K. Lim.

Ethnobotanical significance and heritage

In Peninsular Malaysia, the Zingiberaceae is deeply embedded in the cultural and medicinal practices of the Malay, Chinese, and Indian communities, as well as the indigenous Orang Asli. Beyond globally recognised *Zingiber officinale* (Ginger), *Curcuma longa* (Turmeric), and *Elettaria cardamomum* (Buah Pelaga), the Malayan native taxa *Etlingera elatior* (*Bunga Kantan*), serves as culinary staples in many parts of the region. The main uses of Zingiberaceae in this region include their use as food and vegetables, condiments and flavourings in the daily diet, medicines for treating gastrointestinal issues, general health and skin care, as well as as spices and in cultural rituals (Ibrahim *et al.* 2000; Appalasamy *et al.* 2022b; Ramli *et al.* 2021; Tan *et al.* 2025). An ethnobotanical documentation conducted in 14 selected villages in the states of Kelantan, Selangor and Wilayah Persekutuan recorded at least 16 ginger species used for various purposes. These include the native species such as *Alpinia conchigera* (Lengkuas genting), *Alpinia galanga* (Lengkuas), *Curcuma zanthorrhiza* (Temulawak), *Elettariopsis curtisii* (Pepijat), *Kaempferia galanga* (Cekur), and *Zingiber zerumbet* (Lempoyang).

Within the Peranakan Chinese community, ginger holds notable ethnobotanical significance due to its carminative properties, especially in relation to women's health practices. This functional importance is reflected in its pervasive use across Peranakan cuisine, where it is incorporated into steamed dishes, soups, stir-fries, and stews (Nik Halman *et al.* 2022). The Orang Asli possesses a profound depth of knowledge regarding the wild gingers, utilising species of *Boesenbergia* and *Zingiber* from postpartum care to the treatment of digestive ailments (Ibrahim *et al.* 2007). This biocultural heritage highlights the importance of conserving not just the plants themselves, but the traditional knowledge associated with them. Likewise, in Kota Tinggi, Johor, the ethnobotanical knowledge of wild gingers among indigenous communities, particularly the Orang Kanaq and Orang Jakun, is centred on their use in traditional medicine, daily sustenance, and cultural rituals. The table below provides examples of ethnobotanical records from Johor.

Table 2. List of ginger species associated with traditional uses among Orang Asli in Johor.

Species	Vernacular names	Communities	Traditional uses	References
Amomum curtisii	Semomok (Orang Kanaq), Cawak (Jakun)	Jakun	Used as an amulet to ward off disease. The whole plant is used by the healer during medication sessions.	Perbadanan Bioteknologi dan Biodiversiti Negeri Johor (2008)
Etlingera elatior	Kantan	Jakun	Used in cooking.	Tan *et al*. (2025)
		Orang Kanaq	Used in cooking. The stem is also used as a symbolic marker during house construction to signify the site is safe for habitation.	
Etlingera megalocheilos	Tepus gunung	Orang Kanaq	Used to treat coughs, sore throats, fevers, and general vitality – The rhizome is cleaned, sliced and boiled before consumption.	

Globba leucantha Miq.	Meroyan Berok, Bunga Putih, Merian darah (Temuan)	Jakun	Used for postnatal care by consuming a decoction made from the roots.	Ong *et al*. (2011)
Scaphochlamys aff. *klossii*	Kunyit landak, Tepus landak Orang Kanaq)	Jakun	Used for heartburn (dyspepsia) - The fresh rhizome is consumed raw.	Perbadanan Bioteknologi dan Biodiversiti Negeri Johor (2008)
		Orang Kanaq	Treatment for stomachache. The leaves are warmed and applied externally.	Ab. Hadi and Mohamad (2026)
Scaphochlamys aff. *lanceolata*	Kunyit landak	Jakun	Used for heartburn (dyspepsia). The fresh rhizome is consumed raw.	Ab. Hadi and Mohamad (2026)
		Orang Kanaq	Treatment for stomach-ache. The leaves are warmed and applied externally.	

Conservation challenges of Zingiberaceae in Peninsular Malaysia

Despite a long history of botanical documentation, dating back to the seminal works of Ridley and Holttum, the gingers of Peninsular Malaysia face modern pressures from habitat fragmentation and land-use conversion. Many species are low-density plants, meaning they occur in small, scattered populations that are easily wiped out by localised disturbances (Sedek *et al.* 2024). These patterns highlight the importance of safeguarding primary forest reserves and the remaining limestone karsts, which serves as critical habitats for these understorey taxa. Addressing these challenges requires an integrated approach that combines traditional herbarium-based taxonomy with modern molecular techniques to better identify and protect the most evolutionarily significant lineages.

Within genera such as *Geostachys*, the assumption that high-altitude habitats provide natural protection is increasingly questionable. Although these species are typically associated with montane environments, they face conservation pressures similar to those affecting lowland forest taxa. In areas such as Cameron Highlands and Genting Highlands, expanding ecotourism and related land-use changes have contributed to habitat encroachment and environmental degradation (Lau 2014), indicating that highland ecosystems are not as secure as often assumed. A similar situation is observed in *Zingiber*, where taxa such as *Z. multibracteatum* var. *viride* are frequently found near main trails and popular hiking routes. Their proximity to these areas increases their exposure to trampling, habitat disturbance, and long-term ecological stress. In addition, *Z. longibracteatum* has been recorded in sites cleared for camping, demonstrating direct human modification of its habitat and highlighting the extent of ongoing disturbance (Sedek 2026).

At the same time, the limited documentation of Zingiberaceae in limestone ecosystems points to a significant gap in current knowledge. Limestone habitats function as specialised microenvironments that often support unique and endemic plant species. However, these systems are increasingly threatened by quarrying and other forms of habitat destruction. The combination of ecological specialisation and insufficient research in Peninsular Malaysia suggests that the conservation risks facing these taxa may be substantially underestimated (Kiew *et al.* 2019).

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THE ZINGIBERACEAE OF SABAH AND SARAWAK

The taxonomic landscape of Zingiberaceae in Sabah and Sarawak is characterised by a high degree of complexity and a significant rate of species discovery. As research into the Bornean understorey continues, the traditional morphological classifications are increasingly being supplemented by molecular phylogenetics, revealing a richness that places these two states among the most significant centres of ginger diversity globally. Current records indicate that Borneo harbours approximately 25 – 28 genera and over 300 named taxa within the family. Sarawak, in particular, is noted for its exceptional diversity, with a checklist that currently includes roughly 210 species (Meekiong and Teo 2022), many of which are exclusive to the state. Sabah mirrors this richness, particularly in high-biodiversity areas like the Crocker Range and Mount Kinabalu. While some genera like *Alpinia* and *Etlingera* are widespread across both states, the distribution of specific species often follows strict geographical boundaries or specialised geological substrates. For instance, the silver-leaved group of *Zingiber* was long thought to be a Bornean endemic before recent records appeared in Peninsular Malaysia (Tan *et al.* 2024).

The classification of gingers in Malaysian Borneo has transitioned from the classic four-tribe system (Alpinieae, Hedychieae, Globbeae and Zingibereae) to a more nuanced molecular framework.

- Alpinioideae: This is the most species-rich subfamily in the region, encompassing major genera such as *Alpinia*, *Amomum*, *Etlingera*, *Hornstedtia*, and *Plagiostachys*. These are often larger herbs characterised by terminal or radical inflorescences.
- Zingiberoideae: Represented heavily by the tribes Zingibereae (including *Zingiber*, *Boesenbergia*, and *Scaphochlamys*) and Globbeae (primarily the genus *Globba*).
- Endemic genera: Borneo is home to several endemic or near-endemic genera that underscore its evolutionary isolation, such as *Tamijia*, *Burbidgea*, *Haplochorema* (recently being reduced to *Boesenbergia* by Mood *et al.* 2020), and the recently described *Borneocola* (Sam *et al*. 2016 – need further clarification).

A defining feature of the ginger flora in Sabah and Sarawak is the high level of local endemism. Many species are restricted to specific forest types:

- Limestone specialists: In areas like Bau (Sarawak) and the karst regions of Sabah, specialised species of *Boesenbergia* and *Scaphochlamys* have evolved to thrive in nutrient-poor, alkaline environments.
- Ultramafic endemics: Sabah's unique ultramafic soils, particularly around Mount Kinabalu, support distinct taxa such as *Zingiber lambii*, which are physiologically adapted to high metal concentrations.
- Peat swamp resilience: In the fragmented peat swamps of Sarawak, species from genera like *Amomum* and *Zingiber* show remarkable resilience, although they are highly sensitive to hydrological changes.

The taxonomy of Bornean gingers remains in a state of flux. Large genera like *Etlingera*, with over 42 species in Borneo (Poulsen 2006) and *Boesenbergia* (ca. 100 species across Asia) frequently see the addition of new species, such as the recently described *Sulettaria*, a genus segregated from *Elettaria* (Poulsen *et al.* 2018). The primary challenge for researchers in Sabah and Sarawak remains cryptic morphology; many species look nearly identical in their vegetative state and can only be accurately identified during their brief flowering windows. This highlights the ongoing necessity for integrated taxonomic approaches that combine traditional field botany with DNA barcoding to ensure accurate conservation assessments.

The species richness and endemism of Zingiberaceae in Sabah and Sarawak reflect the high biodiversity of the Sundaland region, with each state boasting unique botanical assemblages driven by their distinct geological and topographical features. While exact numbers fluctuate as new species are discovered and genera are re-circumscribed (such as the recent creation of *Sulettaria* (Poulsen *et al.* 2018) and *Borneocola* (Sam *et al.* 2016)), the following overview summarises the diversity patterns based on current botanical records.

Sarawak generally exhibits a slightly higher documented species richness compared to Sabah, partly due to its larger landmass and extensive history of botanical exploration in areas like the Dered Krian National Park (Bau Limestone) and the Lambir Hills National Park (Sakai and Nagamasu 2003) (Table 2).

Table 3. The distribution of genera across the two states reveals fascinating patterns of localised evolution.

State	Total Estimated Species	Approx. Endemism	Key High-Diversity Genera
Sabah	ca. 150 – 180	35 – 45%	*Etlingera*, *Alpinia*, *Globba*, *Burbidgea*
Sarawak	ca. 200 – 220	40 – 50%	*Alpinia*, *Etlingera*, Zingiber, *Boesenbergia*, *Burbidgea*, *Scaphochlamys*, *Sundamomum*, *Sulettaria*

Subfamily Alpinioideae (The large gingers)

- *Etlingera*: This genus is hyper-diverse in Borneo. Sabah is particularly famous for its spectacular Etlingera species, including several endemics found in the Crocker Range. Sarawak holds significant diversity in the earth ginger types that flower at ground level.
- *Amomum sensu lato* : Historically the largest genus in Sarawak (often cited with 30+ species). Recent taxonomic splits have moved many species into *Meistera*, *Wurfbainia*, and *Sundamomum* (de Boer *et al.* 2018).
- *Alpinia*: Widespread in both states, with many species being common understorey components. Endemism is lower compared to smaller-statured genera but still significant in montane regions.
- *Plagiostachys*: A Bornean specialty with a high concentration of endemic species in Sarawak's lowland dipterocarp forests (e.g., Lambir Hills National Park).

Subfamily Zingiberoideae (The understorey herbs)

- *Zingiber*: Sarawak has seen a surge in descriptions recently, with roughly 18 – 20 species now recorded, many being narrow endemics to limestone or kerangas forests. Sabah hosts unique silvery-leaved endemics like *Z. lambii*.
- *Boesenbergia*: This genus shows extreme micro-endemism. A single hill in Sarawak or a specific valley in Sabah may harbour a species found nowhere else on Earth.
- *Burbidgea*: Previously known as a Bornean endemic genus (recently was also recorded from Zamboanga region of Mindanao in the Philippines (Mazo *et al.* 2022)). While found in both states, species like *B. stenantha* are iconic representatives of the damp, shaded rocks of Sarawak and Sabah's highland forests.
- *Globba*: Highly diverse in the seasonal and moist forests of both states, often exhibiting complex bulbils for asexual reproduction.

Overview of the diversity and distribution of endemic and geographically restricted Zingiberaceae genera in Malaysia, emphasising the high level of hyper-endemism in Peninsular Malaysia alongside more regionally confined distributions spanning Peninsular Malaysia and Borneo (Table 4.).

Table 4. Endemic and restricted genera of Zingiberaceae in Malaysia.

Genus	Species count (approx..)	Region	Endemism status
Johoralia	1	Peninsular Malaysia	Hyper endemic (*J. lada*)
Perakalia	1	Peninsular Malaysia	Hyper endemic (*P. perakensis*)
Kedhalia	1	Peninsular Malaysia	Hyper endemic (*K. flaviflora*)
Burbidgea	5 – 6	Borneo (Sabah & Sarawak)	Endemic (except *B. nitida* – also recorded in the Philippines)
Scaphochlamys	ca. 40 – 50	Peninsular Malaysia & Sarawak	80% endemic (with many localised species)
Haniffia	ca. 3 – 4	Peninsular Malaysia & Sarawak	Species distribution not overlapped (*H. albiflora*, *H. cyanescens*, *H. flavescens*, *H. santubongensis*)
Tamijia	2	Borneo (Brunei & Sarawak)	Endemic to Borneo (*T. flagellaris* – Brunei and Sarawak) Hyper endemic (*T. eractifolia*)

*Not including *Borneocola*, *Conamomum*, *Epiamomum*, *Meistera*, *Sulettaria*, *Sundamomum* and *Wurfbainia*



Figure 2. A. *Burbidgea schizocheila* Hackett, **B.** *Hornstedtia merahjambu* Angela, Tawan & Meekiong, **C.** *Sulettaria meekiongii* Ripen & Teo, and **D.** *Epiamomum epiphyticum* (R.M.Sm.) A.D. Poulsen & Škorničk.

Endemic to the island of Borneo, the genus *Tamijia* represents a fascinating and highly specialised lineage within the Zingiberaceae, currently comprising two recognised species: *T. flagellaris* (distributed across Brunei and Sarawak) and the hyper-endemic *T. erectifolia*, which is restricted to Sarawak. Originally established as a distinct genus to accommodate unique morphological variations not captured within broader classification schemes (Sakai and Nagamasu 2000), *Tamijia* highlights the evolutionary isolation driven by Borneo's complex insular landscapes.

Taxonomically, *Tamijia* is distinguished by specialised structural features that separate it from other understorey Bornean gingers, reflecting a high degree of evolutionary adaptation to local forest conditions. Its confinement to specific micro-locations in Sarawak and Brunei underscores the broader biogeographical pattern observed across Sabah and Sarawak, where specialised geological substrates and localised habitats foster narrow endemism. Because these populations are often small and restricted to fragile forest pockets, ongoing taxonomic and ecological documentation of genera like *Tamijia* is crucial for understanding the full spectrum of Bornean plant evolution and implementing targeted conservation strategies against habitat loss.

Phytogeographical significance and the island effect
The high levels of endemism in Sarawak and Sabah, often exceeding 40% at the species level, can be attributed to the fragmented nature of the Bornean landscape. In Sarawak, the isolated limestone karsts of Bau and Padawan act as terrestrial islands, where restricted gene flow has led to the evolution of site-specific taxa, particularly within the genera *Boesenbergia* and *Scaphochlamys*. Similarly, the extreme altitudinal gradients of the Crocker Range and Mount Kinabalu in Sabah have created sky islands. These high-elevation habitats host specialised species that are physiologically distinct from their lowland counterparts, emphasising that topography is a primary driver of taxonomic separation in the region.

Edaphic specialisation and ecological niches
A critical point of discussion is the role of soil chemistry in shaping ginger distribution. The preference of certain Zingiberaceae for specific substrates, such as the nutrient-poor *kerangas* forests of Sabal (Sarawak) or the ultramafic soils of central Sabah, indicates a high degree of evolutionary adaptation. In Sarawak's peat swamp ecosystems, the presence of resilient monocot understory species demonstrates the family's ability to occupy niches that are often too acidic or waterlogged for other flora. This niche specialisation suggests that Zingiberaceae are excellent bio-indicators for identifying High Conservation Value Areas (HCVA), as the presence of certain endemic gingers often signals a unique or undisturbed habitat.

Taxonomic flux and the Wallacean shortfall
The difference between the number of known species and the actual diversity in the field (the Wallacean shortfall) remains a significant hurdle. Recent taxonomic revisions, such as the segregation of *Sulettaria* from *Elettaria* (Poulsen *et al.* 2018); separation of Sarawak's *Scaphochlamys* to *Borneocola* (Sam *et al.* 2016), illustrate that much of Borneo's ginger diversity has been historically hidden under broadly defined genera (authors believed that these molecular works need more evidences before accepted). The frequent discovery of new species in relatively well-explored areas like the Lambir Hills National Park or the Kinabalu foothills suggests that the current species counts for Sarawak and Sabah are likely underestimates. Integrating molecular phylogenetics with traditional morphological analysis is no longer optional; it is a necessity for resolving cryptic species complexes that look identical in their vegetative states.

Conservation implications in fragmented landscapes
The discussion must address the vulnerability of these plants to land-use changes. Because many ginger species in Sabah and Sarawak are narrow endemics, found only in a single valley or on a specific hillside, they are disproportionately affected by forest fragmentation and logging. The loss of a relatively small patch of forest could result in the total extinction of a localised species. Furthermore, as many gingers rely on specific pollinators like halictid bees or spiderhunters, the degradation of the surrounding forest canopy can disrupt reproductive cycles even if the gingers themselves are not cleared. Conservation strategies must therefore move toward protecting entire micro-habitats rather than just broad forest tracts.

Ethnobotanical value and future research
The cultural importance of Zingiberaceae to the indigenous communities of Borneo adds a layer of biocultural significance to their conservation. The documented use of various species for food, medicine, and ritual purposes across Sarawak and Sabah highlights a deep reservoir of traditional ecological knowledge. Future research should prioritise gap-filling expeditions in under-surveyed regions, such as the interior highlands of the Sarawak-Kalimantan border, and focus on the reproductive biology of these plants to better understand how they will respond to a changing climate.

CONCLUSION

The Zingiberaceae of Malaysia represent a pinnacle of tropical plant evolution, characterised by a sophisticated array of morphological adaptations and complex ecological interdependencies. Across the diverse landscapes of Peninsular Malaysia, Sarawak, and Sabah, Zingiberaceae exhibits a dual nature: a broad presence of common, widespread genera such as *Alpinia* and *Etlingera*, juxtaposed against the extreme micro-endemism of localised genera like *Johoralia*, *Perakalia*, and *Kedhalia*. The discovery and subsequent description of these state-specific taxa in the Peninsula, alongside the unique Bornean lineages like *Burbidgea*, underscore the fact that Malaysia's botanical inventory is far from complete. These plants are more than taxonomic curiosities; they are vital components of the forest understory, driving nutrient cycles and supporting specialised pollination networks that maintain the health of the rainforest. However, the survival of this rich taxonomic heritage faces unprecedented challenges. As understory specialists, many Malaysian gingers, particularly those restricted to fragmented peat swamps, limestone karsts, or sky island montane systems, possess narrow environmental tolerances. The loss of even a small forest fragment can result in the irrevocable extinction of a species found nowhere else on Earth. Moving forward, conservation strategies must shift from broad-scale forest management to the protection of specific micro-habitats and the integration of modern molecular phylogenetics with traditional morphological studies. By prioritising the documentation and protection of these hidden lineages, Malaysia can continue to lead in the study of tropical biodiversity, ensuring that the aromatic and functional wealth of its ginger flora remains a permanent feature of the Southeast Asian landscape.

REFERENCES

Ab. Hadi, A. and Mohamad, S. 2025. Ethnobotanical documentation of medicinal plants from Panti Forest Reserve, Johor. Undergraduate thesis. Johor: Universiti Tun Hussein Onn Malaysia. [Unpublished].

Abd. Karim, H.A., Usman, N.A.H., Ishak, I.S., Rahman, N.A., Ideris, S. and Osman, C.P. 2025. Exploring the metabolites of *Boesenbergia plicata* from Pulau Tuba: A dereplication approach. *Malaysian Journal of Chemistry* 27(1): 74–83.

Akram, S., Khamis, S., Zulkifly, S., Talib, R. and Nurul Izza, A.G. 2023. Phylogeny study of 20 selected species of Zingiberaceae from *ex situ* collections in Peninsular Malaysia. *Pertanika, Journal of Tropical Agricultural Science* 46(1): 329–345.

Appalasamy, S., Arumugam, N., Ahmad Zamri, N.S., Fadhlina, A., Kumaran, J.V. and Subramaniam, S. 2022a. First report on wild ginger (family: Zingiberaceae) species composition with new records in limestone forests of Kelantan, Peninsular Malaysia. *Tropical Life Sciences Research* 33(3): 33–46.

Appalasamy, S., Ahmad Zamri, N.S., Arumugam, N., Mohamad Nor, M., Zakaria, S. and Subramaniam, S. 2022b. Conservation of indigenous knowledge on the consumption of medicinal Zingiberaceae by locals in Kelantan, Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science* 1102(1): 012064. https://doi.org/10.1088/1755-1315/1102/1/012064

Burtt, B.L. and Smith, R.M. 1972. Key species in the taxonomic history of Zingiberaceae. *Notes from the Royal Botanic Graden Edinburgh* 31: 177–227.

Box, M.S. and Rudall, P.J. 2006. Floral structure and ontogeny in *Globba* (Zingiberaceae). *Plant Systematics and Evolution* 25: 107–122.

Clements, R., Sodhi, N.S., Schilthuizen, M. and Ng, P.K.L. 2006. Limestone karsts of Southeast Asia: Imperiled arks of biodiversity. *BioScience* 56(9): 733–742.

de Boer, H., Newman, M., Poulsen, A.D., Droop, A.J., Fér, T., Hiền, L.T.T., Hlavatá, K., Lamxay, V., Richardson, J.E., Steffen, K. and Leong-Škorničková, J. 2018. Convergent morphology in Alpinieae (Zingiberaceae): Recircumscribing *Amomum* as a monophyletic genus. *Taxon* 67(1): 6–36

Govaerts, R., Newman, M.F. and Lock, J.M. 2022. World Checklist of Zingiberaceae. *Plants of the World Online*. https://checklistbuilder.science.kew.org/reportbuilder.do
Holttum, R.E. 1950. The Zingiberaceae of the Malay Peninsula. *Gardens' Bulletin Singapore* 13: 1–249.
Ibrahim, H., Ong, H.C. and Hassan, R. 2000. Ethnobotanical survey of the ginger family in selected Malay villages in Peninsular Malaysia. *Malaysian Journal of Science* 19: 93–99.
Ibrahim, H., Khalid, N. and Hussin, K. 2007. Cultivated gingers of Peninsular Malaysia: Utilization, profiles and micropropagation. *Gardens' Bulletin, Singapore* 59(1–2): 71–88.
Kiew, R., Ummul-Nazrah, A.R., Ong, P.T., Imin, K., Aliaa-Athirah, A.M. and Rafidah, A.R. 2019. Distribution and conservation implications of limestone plant species in FELDA Chiku limestone flora, Kelantan, Malaysia. *Journal of Tropical Forest Science* 31(1): 19–36.
Kress, W.J. 2011. The evolution and ecology of dry tropical forest gingers (Zingiberaceae) in Southeast Asia. In *The Ecology and Conservation of Seasonally Dry Forests in Asia*, W.J. McShea, S.J. Davies and N. Bhumpakphan (Eds.), pp. 115–130. Washington, D.C.: Smithsonian Institution Scholarly Press.
Larsen, K., Ibrahim, H., Khaw, S.H. and Mood, J.D. 1999. *Gingers of Peninsular Malaysia and Singapore*. Kota Kinabalu: Natural History Publications (Borneo).
Lau, K.H. 2014. The conservation of Peninsular Malaysian *Geostachys* (Zingiberaceae). *Gardens' Bulletin Singapore* 66(1): 3–14.
Lim, C.K. 2009. A new Zingiberaceae genus from Kedah, Peninsular Malaysia. *Folia Malaysiana* 10(1): 1–10.
Lim, C.K. 2015. A new monotypic Zingiberaceae Genus from Johor, Peninsular Malaysia. *Folia Malaysiana* 16(1): 1–8.
Lim, C.K. 2016. Another new monotypic Zingiberaceae genus from Peninsular Malaysia. *Folia Malaysiana* 17(2): 69–76.
Mazo, K.R.F, Docot, R.V.A. and Poulsen, A.D. 2022. The ginger genus *Burbidgea* confirmed in the Flora of the Philippines. *Webbia* 77(2): 321–325.
Meekiong, K. and Teo, S.P. 2022. *Zingiberaceae of Sarawak*. Kuching: Walinga.
Meekiong, K. 201). *Tamijia erectifolia*, a second species (Zingiberaceae) from Sarawak, Malaysia. *Folia Malaysiana* 17(2): 29 – 34.
Meng, W., Ran, J., Dai, Q., Tu, N., Leng, T. and Ren, Q. 2023. Morphological and physiological adaptation characteristics of lithophytic bryophytes to karst high calcium environment. *BMC Plant Biology* 23: 160. https://doi.org/10.1186/s12870-022-03980-4
Mood, J.D., Ardiyani, M., Veldkamp, J.F., Mandakova, T., Prince, L.M. and de Boer, H.J. 2020. Nomenclatural changes in Zingiberaceae: *Haplochorema* is reduced to *Boesenbergia*. *Gardens' Bulletin Singapore* 72(1): 77–95.
Mohamad, S. and Kalu, M. 2019. Assessment of Zingiberaceae (Tribe Alpinieae) from North East Sarawak, Malaysia. *IOP Conference Series: Earth and Environmental Science* 269(1): 012032. https://doi. org/10.1088/1755-1315/269/1/012032
Nik Halman, N.N.A., Abdullah, A. and Lyndon, N. 2022. Ethnobotanical study and benefits of Malaysian Peranakan Chinese medicinal plants. *Mathematical Statistician and Engineering Applications* 71(3): 735–741.
Nurainas, N., Zulaspita, W., Febriamansyah, T.A., Syamsuardi, S. and Poulsen, A.D. 2024. A recircumscription of *Geocharis* (Zingiberaceae) as a result of the discovery of a new species in Sumatra, Indonesia. *PhytoKeys* 244: 15–22.
Ong, H.C., Chua, S. and Millow, P. 2011b. Ethno-medicinal plants used by the Temuan villagers in Kampung Jeram Kedah, Negeri Sembilan, Malaysia. *EthnoMed* 5(2): 95–100.
Perbadanan Bioteknologi dan Biodiversiti Negeri Johor. 2008. *Khazanah Endau Rompin Herba, Edisi Kedua*. Johor: Perbadanan Bioteknologi dan Biodiversiti Negeri Johor. pp.177.
Poulsen, A.D. 2006. *Etlingera of Borneo*. Kota Kinabalu: Natural History Publications (Borneo) in association with the Royal Botanic Garden Edinburgh.
Poulsen, A.D., Mathisen, H.B., Newman, M.F., Ardiyani, M., Lofthus, O. and Bjora, C.S. 2018. *Sulettaria*: A new disjunct from *Elettaria cardamomum*. *Taxon* 67(4): 725–738.
Sakai, S. and Nagamasu, H. 2000. Systematic Studies of Bornean Zingiberaceae: III. *Tamijia*: A new genus. *Edinburgh Journal of Botany* 57(2): 245 – 255.
Sakai, S. and Nagamasu, H. 2003. Systematic studies of Bornean Zingiberaceae. IV. Alpinioideae of Lambir Hills, Sarawak. *Edinburgh Journal of Botany* 60: 181–216.

Sam, Y.Y., Ibrahim, H. and Saw, L.G. 2015. Four new species of *Scaphochlamys* (Zingiberaceae) from Peninsular Malaysia. *Phytotaxa* 221(1): 21–34.
Sam, Y.Y., Takano, A., Ibrahim, H., Zaveska, E. and Aziz, F. 2016. *Borneocola* (Zingiberaceae), a new genus from Borneo. *Phytokeys* 75: 31–55.
Sam, Y.Y. and Ibrahim, H. 2018. *Scaphochlamys disticha* (Zingiberaceae), a new species with distichous inflorescence from Peninsular Malaysia. *PhytoKeys* 99: 85–92.
Sedek, A.S., Mohamad, S., Nazrin, A.A., Mohd Nadzreen, H.S., Hadzuha, N.H. and Abd Hakim, A.M. 2024. Diversity of wild gingers (Zingiberaceae) in Southern Peninsular Malaysia: Panti Forest Reserve and Labis Forest Reserve. *Pertanika, Journal of Tropical Agricultural Science* 47(1): 11–24.
Sedek, A.S. 2026. Taxonomic revision, palynology and phylogeny of genus *Zingiber* Mill. (Zingiberaceae) in Peninsular Malaysia. PhD thesis. Johor: Universiti Tun Hussein Onn Malaysia. [Unpublished].
Setiawan, E., Ardiyani, M., Miftahudin, M., Poulsen, A.D. and Chikmawati, T. 2022. The diversity and distribution of *Alpinia zerumbet* clade in West Malesia. *Journal of Biological Diversity* 23(4): 1734–1744.
Smith, R.M. 1984. Zingiberaceae of Gunung Mulu National Park. In *Studies on the Flora of Gunung Mulu National Park Sarawak*, A.C. Jermy (Ed.), pp. 85–96. Kuching: Forest Department Sarawak.
Syahida-Emiza, S., Sam, Y.Y., Alia-Athirah, A.M., Imni K., Siti-Munirah, M.Y., Nor-Ezzawanis, A.W., Wan Syafiq, W.P. and Angan, A. 2021. Botanical discoveries of Gunung Sarut, Terengganu. *Conservation Malaysia* 33: 1–3.
Tan, S.H., Sandin, D., Ghazalli, M.N., Rani, R., Yong, C.Y.S., Besi, E.E. and Go, R. 2024. A new species of *Zingiber* (Zingiberaceae) from Taman Negeri Rompin, Pahang, Malaysia. *Malayan Nature Journal* 76(3) : 221–227.
Tan, A.L., Kamarulzaman, F., Sharuddin, M.F. and Amir, M. 2025. Diversity of the medicinal plants species utilised by the Orang Kanaq community In Panti Forest Reserve, Kota Tinggi, Johor. *Malaysian Forester* 88 (2): 265–294.
Tanaka, N., Ohi-Toma, T., Hun, S., Ith, S., Peou, Y., Sam, Y.Y. and Funakoshi, H. 2025. *Camptandra kampucheaensis* (Zingiberaceae): A new addition to the genus after a 120-year hiatus and the first generic record from Indo-China. *Journal of Japanese Botany* 100(1): 31–39.
Zhu, H. and Tan, Y. 2022. Flora and vegetation of Yunnan, southwestern China: Diversity, origin and evolution. *Diversity* 14(5): 340.


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CHAPTER 11

Nepenthes (Nepenthaceae) of Peninsular Malaysia: Taxonomy and conservation

MOHD. NORFAIZAL, G.[1]*, EDWARD, E.B.[2] and A. LATIFF[3]

Abstract: Peninsular Malaysia represents a critical centre of diversity for *Nepenthes* (Nepenthaceae), commonly known as pitcher plants. These carnivorous plants are ecologically significant, thriving in nutrient-poor soils by supplementing nutrition through insect catch. At least 18 species are currently recognised in the Peninsula, ranging from widespread lowland species such as *N. mirabilis*, *N. gracilis* and *N. ampullaria* to montane endemics including *N. macfarlanei*, *N. ramispina* and *N. alba*. Taxonomic research has revealed considerable morphological variation and frequent natural hybridisation, complicating species delimitation. Molecular phylogenetic studies support the existence of distinct lowland and highland clades, reflecting adaptive radiation along ecological gradients. Despite their ecological and cultural importance, many *Nepenthes* species face significant threats from deforestation, habitat fragmentation, illegal collection for horticultural trade, and climate change impacts on montane ecosystems. Conservation measures include the establishment of protected areas, *ex situ* cultivation, and public awareness initiatives, yet enforcement and long-term monitoring remain limited. This review synthesises current taxonomic and phylogenetic knowledge, evaluates conservation status, and highlights future directions for research and management. Integrated strategies combining taxonomy, molecular ecology, habitat protection, and community engagement are essential to ensure the persistence of Nepenthes diversity in Peninsular Malaysia.

INTRODUCTION

Nepenthes (Nepenthaceae), commonly known as pitcher plants, are among the most iconic representatives of Southeast Asia's flora (Cheek 2001). These plants are characterised by their modified leaf structures forming pitfall traps, which enable them to supplement nutrient intake in nutrient-poor habitats through insect digestion. To date, *Nepenthes* comprises over 120 described species distributed across Southeast Asia, Madagascar, and northern Australia, with the highest diversity concentrated in the Sundaland region (Borneo, Sumatera, Jawa, and Peninsular Malaysia) (MacPherson 2009).

Peninsular Malaysia harbours a significant assemblage of *Nepenthes* species. Early botanical records documented 11 species, including *N. alba*, *N. albomarginata*, *N. gracillima*, *N. ampullaria*, *N. benstonei*, *N. gracilis*, *N. macfarlanei*, *N. rafflesiana*, *N. mirabilis*, *N. ramispina* and *N. sanguinea*. However, recent field surveys and taxonomic studies have expanded this number to at least 18 species, with discoveries between 2019 and 2022 adding new taxa and natural variations such as *N. domei*, *N. latiffiana*, *N. malayensis*, *N. ridzaiana*, *N. rafflesiana* var. *zabawiana*, *N.* × *langkawiensis*, and hybrids (Tamizi *et al.* 2021; Ghazalli *et al.* 2022). These findings underscore the dynamic nature of *Nepenthes* taxonomy in the region, where hybridisation and morphological plasticity complicate species delimitation.

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The ecological significance of *Nepenthes* extends beyond their carnivory. Their pitchers serve as microhabitats for specialised infauna, including mosquito larvae, mites, and symbiotic ants, contributing to broader ecosystem processes such as nutrient cycling. Locally, *Nepenthes* are known as *periuk kera* (monkey cups), reflecting their cultural presence in Malay folklore and traditional practices. Despite their ecological and cultural importance, *Nepenthes* species in Peninsular Malaysia face increasing threats. Habitat loss due to deforestation, agricultural expansion, and urbanisation has reduced suitable habitats, particularly for montane endemics. Illegal collection for horticultural trade further exacerbates population declines, while climate change poses long-term risks to montane ecosystems. Conservation efforts, including protected area designation, *ex situ* cultivation, and public education, have been initiated, but enforcement and monitoring remain limited.

This review aims to synthesise current knowledge on the taxonomy, phylogenetic relationships, and conservation status of *Nepenthes* in Peninsular Malaysia. By integrating recent discoveries, molecular insights, and conservation frameworks, we highlight both the richness and fragility of these carnivorous plants and propose strategies for their long-term preservation.

TAXONOMIC HISTORY AND SYSTEMATICS

The taxonomic history of *Nepenthes* in Peninsular Malaysia reflects more than a century of botanical exploration, beginning with early colonial records in the late nineteenth and early twentieth centuries. Botanists such as Ridley (1901, 1923); Holttum (1940); Kiew (1990); Clarke (1997, 2001, 2002); Rohana (1988); Shivas (1989); Turner (1995); Adam *et al.* (2005); Adam *et al*. (2007); and Latiff *et al.* (2011, 2016) documented various *Nepenthes* species and hybrids in lowland forests and montane areas, relying primarily on morphological descriptions of pitcher shape, coloration, and lid structure. These early works provided the foundation for subsequent studies but were often limited by the high degree of morphological variation within populations and the frequent occurrence of natural hybrids, which blurred species boundaries.

By the mid-twentieth century, herbarium collections and field surveys expanded knowledge of montane taxa, leading to the recognition of species such as *N. macfarlanei* and *N. ramispina*. However, taxonomic confusion persisted, with overlapping traits resulting in misidentifications. For example, *N. gracillima* was long considered a distinct montane species until later revisions clarified its affinities with *N. alba*. These challenges highlighted the need for more rigorous approaches to species delimitation.

Clarke's monograph (2001) consolidated knowledge of 11 Peninsular Malaysian taxa through extensive fieldwork and herbarium studies. Clarke's work provided detailed species accounts, ecological notes, and illustrations, and also validated the description of *N. benstonei* as a distinct endemic species (Clarke 1999). Subsequent revisions continued to refine the taxonomy with some proposed species such as *N. sharifah-hapsahii*, later reclassified as natural hybrids rather than valid taxa. Recent years have seen a surge in discoveries, with recent surveys documenting six additional taxa, bringing the total to at least 18 species. Among these, *N. malayensis* was described from montane forests in Terengganu, distinguished from *N. sanguinea* by both molecular and morphological traits (Tamizi *et al.* 2020). Systematics has advanced significantly with the integration of molecular phylogenetics. Studies using chloroplast (trnL intron) and nuclear (ITS) markers have revealed two major clades: a lowland group comprising species such as *N. ampullaria*, *N. mirabilis*, *N. gracilis*, and *N. rafflesiana*, and a highland group including *N. macfarlanei*, *N. ramispina*, *N. alba*, and *N. sanguinea* (Bunawan *et al*. 2017). These clades reflect ecological

adaptation along altitudinal gradients and support hypotheses of adaptive radiation within Peninsular Malaysia. Modern systematics now integrates morphology, molecular data, and ecological distribution, providing a more robust framework for species delimitation and highlighting the evolutionary processes shaping *Nepenthes* diversity.



Figure 1. *Nepenthes* of Peninsular Malaysia. **A.** *Nepenthes alba*, **B.** *N. albomarginata*, **C.** *N. ampullaria*, **D.** *N. benstonei*, **E.** *N. gracilis*, **F.** *N. ramispina*, **G.** *N. macfarlanei*, **H.** *N. mirabilis*, **I.** *N. sanguinea*, **J.** *N. rafflesiana*. (Photos: Mohd. Norfaizal Ghazalli).



Figure 2. *Nepenthes latiffiana* is endemic to Terengganu, Peninsular Malaysia. It thrives in high-altitude, understorey, typically growing as a terrestrial climber on shaded, rocky hill slopes.

THE PENINSULAR MALAYSIAN TAXA

A summary of Peninsular Malaysian taxa with their known distribution and IUCN conservation categories are given in Table 1.

Table 1. *Nepenthes* species in Peninsular Malaysia.

Species	Distribution	IUCN Conservation Category
Nepenthes gracilis	Lowlands, Peninsular Malaysia, Singapore, Sulawesi, Sumatera and Borneo	Least Concern (LC)
N. mirabilis	Lowlands, Peninsular Malaysia, Indochina, Thailand, Borneo, Southern China, the Philippines and New Guinea	Least Concern (LC)
N. ampullaria	Lowlands, Peninsular Malaysia, Singapore, Thailand, Borneo, New Guinea and Sumatera	Least Concern (LC)
N. albomarginata	Hills, Peninsular Malaysia, Borneo and Sumatera	Least Concern (LC)
N. macfarlanei	Highlands, Peninsular Malaysia, endemic	Vulnerable (VU)
N. rafflesiana	Lowlands and hills, Peninsular Malaysia, Sumatera and Borneo	Least Concern (LC)
N. rafflesiana var. *zabawiana*	Lowlands and hills, Peninsular Malaysia, endemic	Not Evaluated (NE)
N. ramispinosa	Highlands, Peninsular Malaysia, endemic	Least Concern (LC)
N. alba	Highlands, Peninsular Malaysia, endemic	Vulnerable (VU)
N. gracillima	Highlands, Peninsular Malaysia, endemic	Least Concern (LC)
N. sanguinea	Highlands, Peninsular Malaysia, endemic	Least Concern (LC)
N. benstonei	Highlands, Peninsular Malaysia, endemic	Not Evaluated (NE)
N. domei	Lowlands, Peninsular Malaysia, endemic	Not Evaluated (NE)
N. malayensis	Highlands, Peninsular Malaysia, endemic	Not Evaluated (NE)
N. latiffiana	Highlands, Peninsular Malaysia, endemic	Not Evaluated (NE)
N. limiana	Highlands, Peninsular Malaysia, endemic	Not Evaluated (NE)
N. ridzaina	Highlands, Peninsular Malaysia, endemic	Not Evaluated (NE)

CONSERVATION STATUS AND THREATS

The conservation of *Nepenthes* in Peninsular Malaysia has become a major concern as these carnivorous plants face increasing pressures from human activities and environmental changes. While widespread species such as *N. mirabilis* and *N. ampullaria* are currently assessed as Least Concern (LC) due to their broad distribution and tolerance of disturbed habitats, many montane and limestone-associated species are far more vulnerable. Endemic species including *N. macfarlanei*, *N. ramispina*, and *N. alba* are restricted to narrow ecological niches within the Banjaran Titiwangsa and other highland forests, making them particularly susceptible to habitat loss and climate fluctuations. Their limited distribution and specialized habitat requirements mean that even small-scale disturbances can have disproportionate impacts on population viability (Clarke 2001; Bunawan *et al*. 2017).

Habitat loss and fragmentation remain the most significant threats to *Nepenthes* populations. Lowland dipterocarp forests, once extensive across Peninsular Malaysia, have been reduced to isolated fragments due to logging, agricultural expansion, and urban development

Species such as *N. rafflesiana* and *N. gracilis*, which thrive in lowland habitats, have experienced notable declines in population density as a result of this fragmentation. Montane habitats, although less disturbed historically, are increasingly affected by infrastructure development, including road construction and tourism facilities. Fragmentation not only reduces available habitat but also limits genetic exchange between populations, increasing the risk of inbreeding and local extinctions.

Illegal collection for horticultural trade represents another major conservation challenge. Large, colourful species such as *N. rafflesiana* and rare endemics like *N. macfarlanei* are particularly targeted by collectors. Despite regulations under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), enforcement remains inconsistent, and wild populations continue to be depleted by unsustainable harvesting practices (McPherson 2009). The popularity of Nepenthes in international horticulture has created strong economic incentives for illegal trade, further exacerbating conservation difficulties.

Climate change adds a long-term dimension to conservation threats. Montane species such as *N. sanguinea* and *N. alba* are adapted to cooler, humid conditions, and even slight increases in temperature or shifts in rainfall patterns can disrupt their ecological balance. Rising temperatures are expected to reduce suitable habitat ranges for highland taxa, forcing populations into increasingly restricted conservation areas. Conservation measures have been initiated at both national and local levels. Malaysia's Central Forest Spine initiative and the establishment of national parks such as Taman Negara and Cameron Highlands Forest Reserves provide legal protection for key habitats. *Ex situ* conservation efforts, including tissue culture propagation and cultivation in botanical gardens, have created alternative sources for horticultural demand, thereby reducing pressure on wild populations. Public awareness campaigns, such as the publication *Trappers in Nature: The Nepenthes of Peninsular Malaysia* (Ghazalli *et al.* 2023), have also played an important role in promoting appreciation of these plants.

Despite these efforts, significant challenges remain. Enforcement of conservation laws is often limited, and monitoring programs are insufficient to track population trends across fragmented landscapes. Many limestone and montane habitats remain underexplored, leaving gaps in knowledge about species distributions and conservation needs. Furthermore, community engagement in conservation is still developing, with local stewardship programmes requiring greater support and integration into national biodiversity strategies. Addressing these challenges will require a combination of scientific research, stronger policy enforcement, and inclusive conservation approaches that involve local communities as active stakeholders in protecting *Nepenthes* diversity.

RESEARCH PRIORITIES

Critical priority lies in refining species delimitation through integrative taxonomy. Morphological plasticity and frequent natural hybridisation complicate traditional classification, underscoring the need for molecular approaches. Phylogenetic studies using chloroplast and nuclear markers have already revealed distinct lowland and highland clades, but broader genomic analyses could provide deeper insights into evolutionary relationships, hybridisation dynamics, and adaptive radiation. Linking molecular data with ecological traits would strengthen systematics and improve conservation planning. Ecological research also requires expansion, particularly in understanding the role of *Nepenthes* within broader forest ecosystems. Their pitchers host diverse infaunal communities, including insects, mites, and symbiotic organisms, yet the ecological interactions and nutrient cycling processes remain under-investigated. Studies on mutualistic relationships, such as ant-plant interactions, could reveal important ecosystem functions and resilience mechanisms.

From a conservation perspective, research should prioritise long-term population monitoring under climate change scenarios. Montane species such as *N. macfarlanei* and *N. alba* are highly sensitive to temperature and humidity shifts, and predictive models could identify future refugia and guide conservation strategies. Socio-economic studies on the horticultural trade and community perceptions of *Nepenthes* would also inform policy interventions, ensuring that conservation measures are both scientifically sound and socially sustainable.

Finally, *ex situ* conservation research, including tissue culture propagation and genetic banking, should be expanded to safeguard genetic diversity. Developing standardised protocols for cultivation and reintroduction could provide insurance against wild population declines. Collaborative research involving local universities, conservation agencies, and international partners will be vital to address these priorities and secure the long-term survival of Nepenthes in Peninsular Malaysia.

IN SITU CONSERVATION

Ayer Hitam Utara Forest Reserve, Johor, represents an important in situ conservation site for the *Nepenthes* species and other peat swamp flora. As the largest remaining peat swamp forest in Johor, the reserve provides critical habitat for pitcher plants and supports the maintenance of natural ecological and evolutionary processes. An on-going biodiversity assessment and habitat protection efforts have strengthened the conservation value of the area, although further research is needed to comprehensively document *Nepenthes* diversity and population status within the reserve. Ayer Hitam Utara Forest Reserve is known to provide suitable ecological conditions for several lowland *Nepenthes* species. The species that occur in the Ayer Hitam Forest Reserve include *N. ampullaria*, *N. gracilis*, *N. mirabilis*, and *N. rafflesiana*, and their hybrids. These species are commonly associated with acidic soils, peat swamp forests, heath (*kerangas*) forests, and other lowland habitats throughout Peninsular Malaysia. The presence of these habitats highlights the importance of Ayer Hitam Utara as a potential refuge for lowland *Nepenthes* diversity and underscores its value for *in situ* conservation.

EX SITU CONSERVATION

Bukit Bendera, Pulau Pinang

There is a private nursery and conservatory at Bukit Bendera, Pulau Pinang, which cultivated and conserved both the lowland and highland species for public awareness and education. A total of six species, namely *N. albomarginata*, *N. rafflesiana*, *N. macfarlanei*, *N. ampullaria*, *N. gracilis* and *N. mirabilis* and their hybrids especially *N.* × *hookeriana* are propagated and conserved there.

Nepenthes Conservatory, Kledang Saiong, Ipoh, Perak

The Department of Forestry Perak established a *Nepenthes* Conservatory in 2021 at Kledang Saiong Forest Reserve. Both the Malaysian and non-Malaysian species are introduced and cultivated in the conservatory for public education and awareness. The non-Malaysian species introduced are from northern Australia, Indonesia, the Philippines, Thailand, India and Madagascar. We assumed they were imported from those countries.

Sungai Menyala Forest Reserve, Port Dickson, Negeri Sembilan

The Department of Forestry Negeri Sembilan also established an *ex situ* conservation garden at PDForest, Sungai Menyala in 2024. Only the lowland species namely, *N. rafflesiana*, *N. ampullaria*, *N. gracilis* and *N. mirabilis* are introduced in this garden.

Private nursery
A notable private-sector initiative is Four Z E Plant Nursery in Ampang, Selangor, which is operated by Mr. Mohd. Fauzi Abu Bakar. The nursery maintains an extensive living collection of *Nepenthes* species and horticultural hybrids, serving both commercial and conservation purposes. Through propagation, hybridisation, and public engagement, the nursery contributes to the *ex situ* conservation and sustainable utilisation of *Nepenthes* genetic resources in Malaysia.

Dome Nikong Plant Conservatory
There is a private conservatory of plants established by Mr. Dome Nikong at Sungai Tong, Setiu, Terengganu which contains several lowland (*N. gracilis*, *N. mirabilis*, *N. rafflesiana*, *N. ampullaria*) and highland (*N. domei*, *N. latiffiana*, *N. sanguinea*, *N. ramispina*, *N. malayensis*) species and their hybrids.

CONCLUSION

The *Nepenthes* of Peninsular Malaysia embody both extraordinary biodiversity and pressing conservation challenges. Taxonomic research over the past century has revealed a rich assemblage of species, ranging from widespread lowland taxa such as *N. mirabilis* and *N. ampullaria* to highly localised montane endemics like *N. macfarlanei* and *N. alba*. Advances in molecular systematics have clarified evolutionary relationships, highlighting distinct lowland and highland clades and underscoring the adaptive radiation of these plants across ecological gradients. Yet, despite these scientific achievements, the persistence of Nepenthes populations is increasingly threatened by deforestation, habitat fragmentation, illegal collection, and the looming impacts of climate change.

Conservation initiatives, including protected area designation, *ex situ* cultivation, and public awareness programs, have provided important safeguards, but enforcement and long-term monitoring remain limited. The survival of these species will depend on integrated strategies that combine rigorous taxonomy, ecological research, and conservation policy with active community engagement. Future research priorities must focus on documenting undescribed taxa, refining species delimitation through genomic approaches, and modeling habitat responses to climate change. Equally important is the need to strengthen socio-economic studies on horticultural trade and to expand ex-situ conservation protocols to preserve genetic diversity.

Ultimately, *Nepenthes* serve not only as botanical curiosities, but also as flagship species for biodiversity conservation in Peninsular Malaysia. Their unique ecological roles, cultural significance, and vulnerability make them powerful symbols of the broader challenges facing tropical ecosystems. Protecting these plants is therefore not only a matter of preserving taxonomic diversity but also of safeguarding ecological integrity and cultural heritage. A coordinated effort that bridges science, policy, and community stewardship will be essential to ensure that the remarkable pitcher plants of Peninsular Malaysia continue to thrive for generations to come.

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REFERENCES

Adam, J.H. and Hamid, H.A.. 2007. Pitcher plants (*Nepenthes*) recorded from Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia. *International Journal of Botany* 3(1): 71–77. https://doi.org/10.3923/ijb.2007.71.77

Adam, J.H., Nurulhuda, E.M., Abdul Halim, H., Abdul Rahim, O., Hafiza, A.H., Gopir, G.K., Lydia, M.P. *et al.* 2005. Pitcher plants recorded from Bris forest in Jambu Bongkok, Kuala Terengganu, Malaysia. *Wetland Science* 3: 183–189.

Bunawan, H., Yen, C.C., Yaakop, S. and Noor, N.M. 2017. Phylogenetic inferences of *Nepenthes* species in Peninsular Malaysia revealed by chloroplast (trnL intron) and nuclear (ITS) DNA sequences. *BMC Research Notes* 10(1): 67. https://doi.org/10.1186/s13104-017-2379-1

Cheek, M. and Jebb, M. 2001. Nepenthaceae. *Flora Malesiana* 15: 1–157.

Clarke, C.M. 1997. *Nepenthes benstonei* (Nepenthaceae), a new pitcher plant from Peninsular Malaysia. *Sandakania* 13: 79–87.

Clarke, C.M. 2001. *Nepenthes of Sumatra & Peninsular Malaysia*. Kota Kinabalu: Natural History Publications (Borneo).

Clarke, C. 2002. *A guide to the pitcher plants of Peninsular Malaysia*. Kota Kinabalu: Natural History Publications (Borneo).

Clarke, C. and Lee, C.C. 2012. A revision of *Nepenthes* (Nepenthaceae) from Gunung Tahan, Peninsular Malaysia. *Gardens' Bulletin Singapore* 64(1): 33–49.

Ghazalli, M.N., Tamizi, A.A., Nikong, D., Besi, E.E., Mat Esa, M.I., Mohd Nordin, A.R., Latiff, A., Zaini, A.Z. and Shakri, M.A. 2020. *Nepenthes latiffiana* and *N. domei* (Nepenthaceae), two new species of pitcher plants from Terengganu, Peninsular Malaysia. *Webbia* 75(1): 5–28. https://doi.org/10.36253/jopt-7950

Ghazalli, M.N., Latiff, A., Nikong, D., Besi, E.E., Muhamad Ikhwanuddin, M.E., Saranum, M.M., Noraini, T., Salleh, S. and Mohamad Alias, S. 2023. *Trappers in Nature – The Nepenthes of Peninsular Malaysia*. Putrajaya: Ministry of Natural Resources, Environment and Climate Change.

Holttum, R.E. 1940. Malayan pitcher plants. *Malayan Nature Journal* 1: 35–44.

Jebb, M. and Cheek, M. 1997. A skeletal revision of *Nepenthes* (Nepenthaceae). *Blumea* 42(1): 1–106.

Kiew, R. 1990. Pitcher plants of Gunung Tahan. *Journal of Wildlife and Parks* 10 : 34–37.

Latiff, A., Ishak, K.I.K., Ong C.G. and Che Aziz Ali. 2011. *Porpax elwisii* (Orchidaceae) and *Nepenthes sanguinea* (Nepenthaceae), two new records for Gunung Matchinchang, Langkawi, P. Langkawi. *Folia Malaysiana* 12(1): 43–46.

Latiff, A. and Bahari, N. 2016. An elegant *Nepenthes* x *hookeriana* from Padang Tujuh, Endau Rompin State Park, Pahang. *Folia Malaysiana* 17(1) : 55-59

McPherson, S. 2009. *Pitcher plants of the Old World. Vol. 1*. Poole: Redfern Natural History Publications.

Ridley, H.N. 1923. Nepentheaceae. In *The Flora of the Malay Peninsula* Volume 3, pp. 21–25. London: L. Reeve & Co. Ltd.

Rohana, M.S. 1988. Systematic studies on *Nepenthes* species and hybrids of the Malay Peninsula. [PhD Thesis]. Bangi: Universiti Kebangsaan Malaysia.

Shivas, R.G. 1984. *Pitcher plants of Peninsular Malaysia and Singapore*. Singapore: Maruzen Asia.

Tamizi, A.A., Ghazalli, M.N., Nikong, D., Besi, E.E., Mat Esa, M.I., Mohd Nordin, A.R., Latiff, A. and Shakri, M.A. 2020. *Nepenthes malayensis* (Nepenthaceae), a new species of carnivorous pitcher plant from Peninsular Malaysia. *Kew Bulletin* 75(4): 63. https://doi.org/10.1007/s12225-020-09918-z

Turner, I.M. 1995. A catalogue of the vascular plants of Malaya. *Gardens' Bulletin Singapore* 47: 389–390.

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CHAPTER 12

Dipterocarps and their conservation

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Abstract: Dipterocarps, members of the family Dipterocarpaceae, serve as the "sentinels of the rainforest" and the primary architectural and ecological keystones of Southeast Asian forests. This chapter explores the biological characteristics, immense diversity, and conservation status of these colossal trees in Malaysia, which is identified as the global epicentre for the family. Notable biological traits include a unique winged seed dispersal mechanism and the phenomenon of mass fruiting, a synchronised reproductive strategy occurring every 3 to 7 years that drives entire ecosystem cycles. Malaysia is home to ca. 360 species, with Sarawak and Sabah on Borneo hosting the highest concentrations and levels of endemism. Despite their dominance, dipterocarps face severe threats from habitat conversion to agricultural plantations (primarily oil palm and rubber) and intensive selective logging. Currently, 211 species in Malaysia are classified as globally threatened. The chapter highlights the critical ecological roles of dipterocarps as carbon sinks and essential habitats for endangered wildlife like the Bornean orangutan. Conservation strategies discussed include the expansion of Totally Protected Areas (TPAs), sustainable forest management (SFM), and restoration initiatives such as the Greening Malaysia program. The future of these rainforest giants depends on balancing economic development with a commitment to long-term environmental preservation.

INTRODUCTION

The tropical rainforests of Malaysia are globally renowned for their exceptional biodiversity and ancient character. Dominating this landscape are the colossal trees of the family Dipterocarpaceae, commonly known as dipterocarps. These "sentinels of the rainforest" are not merely large trees; they are the architectural and ecological keystones of Southeast Asian forests. Their name, derived from Greek for two-winged fruit, hints at a remarkable reproductive strategy, a signature of their importance. For centuries, they have stood as a symbol of Malaysia's natural heritage and have played a central role in both its economy and its ecological balance. This chapter explores the fascinating world of dipterocarps in Malaysia, from their unique biological traits and immense diversity to the critical conservation challenges they face in a rapidly changing world.

BIOLOGICAL CHARACTERISTICS: LIFE OF THE WINGED SEEDS FRUITS

The life of a dipterocarp begins with its distinctive winged fruits, which allows the seeds to be dispersed by wind, often spiraling like miniature helicopters as they fall from the towering canopy. Despite the dense, five-layered canopy of the Malaysian rainforest restricting air movement within the lower strata, the spiralling, wind-mediated dispersal of dipterocarp fruits remains vital because these trees are emergent that top the main canopy, reaching heights of 60 to 80 meters (Smith *et al*. 2015). At these extreme heights, unimpeded wind currents catch the winged seeds as they detach. The aerodynamic, helicopter-like autorotation

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slows their descent, allowing ambient crosswinds to transport them away from the parent tree's shade (Comita *et al.* 2014). This lateral movement is crucial for seedling survival, as it lowers mortality rates from species-specific soil pathogens and heavy root competition near the parent tree (Comita *et al*. 2014), while increasing the statistical likelihood that seeds land in bright canopy gaps created by natural treefalls. This dispersal mechanism is vital for the colonisation of new areas (Song *et al.* 2014).

The effectiveness of this mechanism as a colonising force relies heavily on scale and strategic timing rather than individual distance. Dipterocarps participate in synchronised masting events, flooding the ecosystem with millions of seeds at once every few years (de Weduwen and Ruxton 2019). While dense interior foliage blocks many seeds from traveling far, this sheer volume ensures that a percentage catches stronger gusts to reach forest margins, buffer zones, and newly disturbed clearings. By bypassing the need for animal dispersers and exploiting atmospheric winds above the canopy, dipterocarps secure both local patch regeneration within the forest matrix and opportunistic long-distance colonisation along landscape edges (Comita *et al*. 2014; Song *et al.* 2014).

These trees are typically large to gigantic, with many species reaching heights of over 60 metres, and some, like *Richetia faguetiana* (F. Heim.) P.S. Ashton & J. Heck., holding the record for the tallest tropical trees in the world. The tree's height (named *Menara* from Sabah) was measured from the top of the crown to the lowest part of the buttress, measuring an astonishing 100.8 metres tall. The dipterocarps' trunks are often straight and cylindrical, with large buttress roots providing stability in the shallow, nutrient -poor soils of the rainforest (Ganesan 2025).

The most extraordinary biological event associated with dipterocarps is mass fruiting. This is a synchronised reproductive event where a high percentage of dipterocarp species, and other tree families, flower and fruit simultaneously over vast geographical areas. This phenomenon is a response to specific climatic triggers, often a prolonged dry spell or a drop in minimum temperature, and occurs at irregular intervals, typically every 3 to 7 years (Appanah 1985; Ashton *et al.* 1988). The phenomenon of mass masting exerts a profound ecosystem-wide impact: synchronised mass flowering provides an ephemeral glut of nectar and pollen that fuels rapid population increases in invertebrate pollinators and their associated predators, while subsequent mass fruiting supplies a vital resource for granivorous vertebrates, such as wild boars and rodents, driving both seed predation and regeneration dynamics (Ghazoul 2005; Winarni *et al.* 2016).

DIVERSITY AND DISTRIBUTION IN MALAYSIA: A GLOBAL HOTSPOT

Malaysia, encompassing Peninsular Malaysia and the territories of Sabah and Sarawak in Borneo, is the global epicenter of dipterocarp diversity. The country is home to an estimated 360 species, representing a significant portion of the family's total species count worldwide. The forests of Borneo are particularly rich, boasting the highest concentration of dipterocarp species on the planet (Whitmore 1984; MacKinnon *et al.* 1996; Slik *et al.* 2003; Ashton 2005). Genera found in Malaysia include:

- ***Anisoptera***: A small genus with 10 species registered. Eight species found in Malaysia, e.g., *A. costata* Korth., *A. grossivenia* Slooten (endemic to Borneo), *A. laevis* Ridl.
- ***Dipterocarpus***: Known for their large, distinctive fruits and valuable timber (*keruing*). The second largest genus with approx. 70 species occuring in South Asia and Southeast Asia, from Sri Lanka, India to the Philippines. The greatest diversity of *Dipterocarpus* species occurs in Malaysia with 41 species, and 18 species of them are endemic to Malaysia, e.g., *D. applanatus* Slooten, *D. caudiferus* Merr., *D. confertus* Slooten, *D. perakensis* P.S. Ashton, *D. rotundifolius* Foxw.

- ***Dryobalanops***: Famous for the camphor-producing tree. The genus has seven species, confined to Sumatra, Peninsular Malaysia and Borneo. Example of species are, *D. aromatica* C.F. Gaertn., *D. beccarii* Dyer, *D. fusca* Slooten (endemic to Borneo).
- ***Cotylelobium***: A small genus, with five species, three species recorded in Malaysia. Species recorded in Malaysia, *C. burckii* (F. Heim.) F. Heim., *C. lanceolatum* Craib, *C. melanoxylon* (Hook. *f*.) Pierre
- ***Hopea***: The largest and most diverse genus with approx. 114 species distributed from Sri Lanka to Southern China, throughout Malesia to New Guinea. The greatest diversity is in Malaysia with 71 species recorded. Out of the total number, there are 10 distinct species (plus one variety) of *Hopea* that are 100% unique to the Peninsular, and about 22 species are endemic to Borneo. Example of species in Malaysia, *H. andersonii* P.S. Ashton, *H. beccariana* Burck, *H. johorensis* Symington, *H. odorata* Roxb., and *H. vesquei* F. Heim.
- ***Neobalanocarpus***: The genus of the highly prized and durable timber tree, a monotypic genus and recorded in Peninsular Malaysia, Peninsular Thailand and Singapore with *N. heimii* (King) P.S. Ashton (*cengal*) is the only species.
- ***Parashorea***: A small genus contains about 14 species distributed from South Myanmar, Thailand, Indo-China, Peninsular Malaysia, Sumatra, Borneo and the Philippines. *Parashorea densiflora* Slooten & Symington is a massive tree that strictly endemic to the southern half of Peninsular Malaysia. *Parashorea tomentella* (Symington) Meijer is endemic to eastern Borneo (Sabah and East Kalimantan). Other *Parashorea* recorded in Malaysia are, such as *P. macrophylla* Wyatt-Smith *ex* P.S. Ashton, *P. lucida* (Miq.) Kurz and *P. malaanonan* (Blanco) Merr.
- ***Shorea***: Previously was the largest genus (before separation) and most economically important genus, encompassing species known as *meranti*, *balau*, and *damar hitam*. *Shorea curtisii* (*seraya*) and *S. leprosula* (*meranti tembaga*) are common in Peninsular Malaysia. Recent taxonomic have segregated this genus into several based on the molecular works (Ashton and Heckenhauer 2022; Cvetkovic *et al*. 2022).
  - ***Anthoshorea***: This genus corresponds to the "white meranti group" in the Dipterocarp Timber Classification. It includes about 23 species. Example of species occurs in Malaysia, *A. agami* (P.S. Ashton) P.S. Ashton & J. Heck., *A. bentongensis* (Foxw.) P.S. Ashton & J. Heck., *A. lamellata* (Foxw.) P.S. Ashton & J. Heck., and *A. ochracea* (Symington) P.S. Ashton & J. Heck.
  - ***Richetia***: This genus corresponds to the "yellow meranti group" in the Dipterocarp Timber Classification. It includes 33 species. Example of species occurs in Malaysia, *R. bakoensis* (P.S. Ashton) P.S. Ashton & J. Heck., *R. blumutensis* (Foxw.) P.S. Ashton & J. Heck., *R. chaiana* (P.S. Ashton) P.S. Ashton & J. Heck., and *R. kuantanensis* (P.S. Ashton) P.S. Ashton & J. Heck.
  - ***Rubroshorea***: This genus corresponds to the "red meranti" in the Dipterocarp Timber Classification. It includes 71 species. E.g., *R. acuta* (P.S. Ashton) P.S. Ashton & J. Heck., *R. almon* (Foxw.) P.S. Ashton & J. Heck., *R. amplexicaulis* (P.S. Ashton) P.S. Ashton & J. Heck., *R. johorensis* (Foxw.) P.S. Ashton & J. Heck., and *R. leprosula* (Miq.) P.S. Ashton & J. Heck.
  - ***Shorea***: Now the genus includes 47 species. Examples of species occurs in Malaysia, *S. atrinervosa* Symington, *S. calcicola* P.S. Ashton, *S. crassa* P.S. Ashton, *S. lumutensis* Symington, *S. lunduensis* P.S. Ashton, *S. scrobiculata* Burck, and *S. superba* Symington.

Table 1. Number of endemic species for *Shorea* and related genera.

Genus	Common group /section	Peninsular Malaysia (endemic)	Borneo (natively spanning Sabah/Sarawak)
Anthoshorea	White Meranti	2 species	6 species
Richetia	Yellow Meranti	4 species	23 species
Rubroshorea	Red Meranti	12 species	38 species
Shorea	Selangan Batu	6 species	24 species

- ***Upuna***: A monotypic genus – *Upuna borneensis* Symington (*penyau*, *resak* or *upun batu*). A large tree with low stout buttress that endemic to Borneo. This species frequently found in Mixed Dipterocarp Forests (MDF) and *kerangas* forests of Borneo, and currently listed as endangered (EN) on the IUCN Redlist. The wood is commonly used in heavy construction (FRIM 2013).
- ***Vatica***: Currently is the second largest genus in the family with approx. 81 species worldwide. Distributed from India, Sri Langka toward Asia-temperate (Southern China, Hainan, Tibet) down to Indo-China, whole Malesia and Papua New Guinea. The greatest diversity is in Malaysia with approx. 65 species recorded, with many new species being described recently (e.g. *V. abang-zoharii* Meekiong, Latiff & Yahud, *V. abdulrahmaniana* Chua, *V. adenanii* Meekiong, Nizam, Latiff, Tawan & Yahud, *V. kanthanensis* Saw, *V. latiffii* Meekiong, *V. mizaniana* Chua, *V. najibiana* Ummul-Nazrah) (El-Taguri and Latiff 2012; Tan *et al.* 2014; Meekiong 2015; Ummul-Nazrah *et al.* 2018; Meekiong and Latiff 2021). Out of 65 species recorded for Malaysia, 15 species are endemic to Peninsular Malaysia, and 23 species are strictly endemic to Borneo.

The hyperdiversity and dominance of the family Dipterocarpaceae in the lowland rainforests of Malaysian Borneo (Sarawak and Sabah) are driven by an intricate mosaic of edaphic (soil) properties and topographic landforms below 300 metres. The lowland landscape is heavily dissected into diverse micro-environments, where sharp micro-topographic shifts, ranging from narrow valley floors and alluvial terraces to steep, well-drained low ridges, create varied hydrological and drainage regimes. Dipterocarps have evolved fine-scale physiological specialisation to these micro-habitats; for instance, drought-tolerant species occupy ridge crests while fast-growing generalist taxa colonise moister lower slopes (Paoli *et al.* 2006; Ashton 2014). This micro-scale topographic heterogeneity is tightly coupled with extreme variation in soil geology. Lowland soils in Sarawak and Sabah span a complex continuum from highly leached, acidic, nutrient-impoverished podzols and quartz sands (*kerangas*) to deep, fertile alluvial clays, latosols, and the heavy-metal-rich ultramafic soils of Sabah (Baillie *et al.* 1987; Potts *et al.* 2002). The wide chemical variation in available plant nutrients, specifically phosphorus, magnesium, and calcium, acts as a primary driver of niche partitioning, enabling closely related dipterocarp species to co-exist without outcompeting one another (John *et al.* 2007; Russo *et al.* 2005).

From a macro-evolutionary and biogeographical perspective, this soil-driven habitat heterogeneity intersects with the long-term geomorphological stability of Sundaland, turning Malaysian Borneo into a global hotspot for dipterocarp speciation. Because dipterocarps form obligatory mutualisms with ectomycorrhizal (ECM) fungi to extract poorly accessible soil nutrients, they hold a distinct competitive edge over other tree families in the deeply weathered, nutrient-poor tropical soils characteristic of low-altitude Borneo (Brearley *et al.* 2017). Furthermore, historical geomorphology played a major role: during Cenozoic and Pleistocene sea-level fluctuations, the dissected river networks, mountain folds, and stable moist refugia of northern Borneo isolated plant populations, promoting vicariant speciation (Slik *et al.* 2003; Wilf *et al.* 2022). Combined with mass-synchronised masting events that flood local habitats with seeds, this tight evolutionary alignment with diverse soil chemistry and topographically fragmented lowlands allows dozens of sympatric dipterocarp species to occupy distinct edaphic niches within a single square kilometre of forest (Ashton 2014).

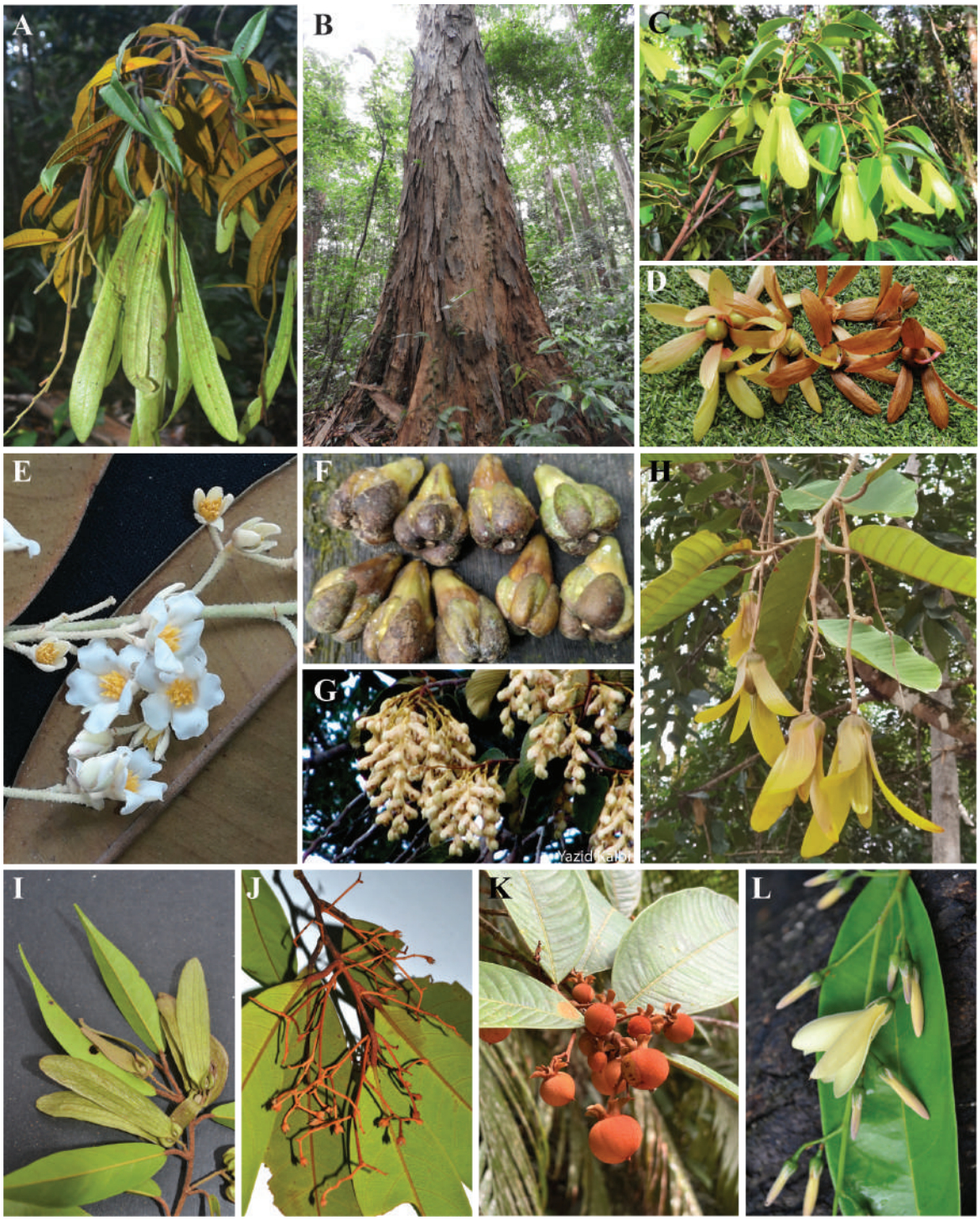

Figure 1. A. *Anisoptera grossivenia* Slooten , **B.** *Dryobalanops beccarii* Dyer, **C.** *D. aromatica* C.F. Gaertn., **D.** *D. fusca* Slooten, **E.** *Cotylelobium burckii* (F. Heim.) F. Heim., **F.** *Hopea pachycarpa* (Heim) Symington, **G.** *Anthoshorea ochracea* (Symington) P.S. Ashton & J. Heck., **H.** *Rubroshorea macrophylla* (De Vriese) P.S. Ashton & J. Heck., **I.** *Vatica abang-zoharii* Meekiong, Latiff & Yahud, **J.** *V. latiffi* Meekiong, **K.** *V. oblongifolia* spp. *crassilobata*, and **L.** *V. rynocarpa*.

ECOLOGICAL IMPORTANCE: THE BACKBONE OF MALAYSIAN RAINFOREST

The ecological role of dipterocarps extends far beyond their sheer size. As the dominant canopy and emergent trees, they are the structural foundation of the forest, providing a layered habitat for an incredible number of species. Dipterocarps are among the most effective natural carbon sinks on the planet (Saner *et al.* 2012). Their immense size and long lifespan allow them to store vast amounts of carbon in their wood and roots over centuries. A single mature dipterocarp can contain a significant percentage of the total biomass of a hectare of forest (Chave *et al*. 2005; Slik *et al.* 2013). This carbon is locked away from the atmosphere, where it would otherwise contribute to global warming. In fact, studies in Malaysian forests have shown that dipterocarp-dominated areas can hold several hundred tons of carbon per hectare (Niiyama *et al*. 2010; Hamdan *et al*. 2014; Matthew *et al*. 2018). By preserving these forests, Malaysia plays a crucial role in mitigating climate change, effectively acting as a carbon storehouse for the world.

The dipterocarp forests of Malaysia are recognised as global biodiversity hotspots. The high concentration of dipterocarps and other tree families (e.g., Annonaceae, Burseraceae, Calophyllaceae, Fabaceae, Myrtaceae, Sapotaceae) creates a complex, multi-layered habitat that supports a wide variety of flora and fauna. These trees provide food, shelter, and breeding grounds for a diverse range of wildlife, including critically endangered species like the Bornean orangutan, hornbills, and Asian elephants (Khoo *et al.* 2023). Dipterocarp ecology is fundamentally shaped by supra-annual mass masting events, during which synchronised flowering and fruiting flood the forest with an ephemeral superabundance of seeds. This reproductive strategy operates primarily via predator satiation, temporarily swamping host-specific insect larvae and vertebrate seed predators (e.g., wild boars and rodents) to ensure high per-capita seed germination. By saturating local seed predators across vast spatial scales, mass masting enables dipterocarps to overcome the severe host-specific, density-dependent seed and seedling mortality predicted by the Janzen–Connell hypothesis (Janzen 1970; Connell 1971; Curran and Webb 2000).

Another fascinating ecological aspect of dipterocarps is their symbiotic relationship with ectomycorrhizal fungi. Unlike most tropical trees that form arbuscular mycorrhizal associations, dipterocarps partner with specific fungi that form a sheath around their roots (Alexander and Lee 1992). This obligate mycorrhizal symbiosis represents a mutually beneficial trade-off: dipterocarps allocate photosynthetic carbohydrates to their fungal partners, which in turn use their extensive hyphal networks to mobilize and transport poorly soluble soil nutrients, primarily phosphorus and nitrogen, and water directly back to the host trees (Brearley 2012). This is especially crucial in the nutrient-poor, highly leached soils of tropical rainforests. This underground network of fungi and roots is essential for the survival and regeneration of dipterocarp seedlings, influencing forest health and resilience from the ground up (Alexander and Lee 1992).

DIPTEROCARPS OF PENINSULAR MALAYSIA

The family Dipterocarpaceae represents the most significant group of timber trees in the lowland forests of Peninsular Malaysia, often comprising over 30% of the forest's basal area and up to 40% of the emergent trees (Saw and Sam 2000; Richard *et al*. 2023). Beyond their high economic value, contributing nearly 40% of total log production in the late 1990s, these trees serve as the primary ecological framework for the complex rainforest ecosystem.

While dipterocarps are the most dominant trees in Malaysian lowlands, they are not evenly distributed across the country. Research indicates that over 57% of the 157 species found in Peninsular Malaysia have distribution patterns restricted to specific geographical zones. These patterns are largely dictated by climatic factors, such as rainfall and elevation, and edaphic (soil) influences like peat swamps and limestone hills. Notably, 33 species are endemic only to Peninsular Malaysia (Saw and Sam 2000; Chua *et al*. 2010) and 11 species each for Sabah and Sarawak (Julia *et al.* 2014, Kho *et al.* 2022), meaning they are found nowhere else in the world.

Table 2. Dipterocarps in Peninsular Malaysia indicating endemic and rare species (amended from Saw and Sam 2000).

Genus	No. of species	Endemic species	Endemic and rare	Rare non-endemic	Endemic and rare non-endemic
Anisoptera	6	0	0	0	0
Anthoshorea	11	2	1	7	8
Cotylelobium	2	0	2	1	1
Dipterocarpus	31	3	2	6	9
Dryobalanops	2	0	0	0	0
Hopea	32	10	4	6	15
Neobalanocarpus	1	1	0	0	1
Parashorea	3	1	0	1	2
Richetia	10	4	2	2	4
Rubroshorea	21	12	1	5	6
Shorea	19	6	1	6	10
Vatica	24	15	5	2	14
TOTAL	**162**	**54**	**16**	**36**	**70**

A primary driver of dipterocarp population decline across Malaysian Borneo has been the expansion of commercial agriculture, particularly rubber and oil palm. Between 1990 and 2018, forest cover declined by 16.3% in Sabah and 12.6% in Sarawak, largely driven by agricultural conversion. While rubber expansion predominated from the 1960s onward, oil palm replaced it as the primary agent of land conversion, expanding at annual rates exceeding 10% in key lowland and peat swamp zones during peak development periods (Bryan *et al.* 2013). This shift has pushed forestry activities into more fragile hill areas where natural regeneration is often poor and harvesting damage is more severe. Furthermore, rising timber demand and expanding market acceptance of secondary timber grades have broadened the exploitation of major commercial trade groups, principally canopy-emergent taxa of *Shorea s.l*., *Dipterocarpus*, and *Dryobalanops*, further depleting residual timber stocks in logged-over forests. Conversely, smaller-statured genera such as *Vatica* and certain understorey *Hopea* remain largely unexploited for international export, seeing only localised extraction for heavy structural posts (Appanah and Weinland 1993; Soerianegara and Lemmens 1993).

To ensure the survival of this family, a holistic conservation strategy is required, beginning with the allocation of protected Virgin Jungle Reserves (VJR) and conservation areas in every state (Saw and Sam 2000). Strategies should include targeted recovery plans for Critically Endangered and Endangered taxa through integrated habitat restoration and *ex situ* living collections in botanical gardens. Rather than relying on *ad hoc* assessments, long-term population viability requires institutionalising continuous forest monitoring within state forestry departments and research institutes. This involves establishing permanent sample plot (PSP) networks, enforcing mandatory pre-harvest inventory and post-harvest diagnostic sampling (SILVER/RIL protocols), and maintaining dedicated long-term ecological research units to ensure logging intensity stays within sustainable yield thresholds.

DIPTEROCARPS OF SARAWAK

Sarawak, the largest state in Malaysia, lies at the heart of the diversity center for the Dipterocarpaceae family. In the state's Mixed Dipterocarp Forests, these trees are not just ecologically dominant, but forming the core structural framework of the rainforest, and are also the backbone of the state's timber economy. Sarawak is home to approximately 247 species of dipterocarps, representing nearly half of all species found worldwide. Despite their ecological dominance, current IUCN Red List assessments classify approximately 67% (165 species) of these taxa as Threatened (Critically Endangered, Endangered, or Vulnerable), necessitating a policy shift from treating dipterocarps primarily as commercial timber to prioritising them for state-wide conservation and habitat protection (Julia *et al.* 2014).

The distribution of dipterocarps in Sarawak is highly specialised, primarily influenced by soil properties and topographical gradients. Unlike the Peninsular, where climate zones are the major drivers, Sarawak's species often vary based on whether they inhabit nutrient-poor sandstone ridges, fertile alluvial plains, or coastal peat swamps. Endemism is exceptionally high on the island of Borneo; out of the 267 species found on the island 174 are endemic. In Sarawak specifically, hotspots of high species density and endemism are concentrated in the Central Region and the Northwest (near the border with Brunei), where unique soil conditions have allowed for intense speciation.

The most significant threat to Sarawak's dipterocarps is the historical and ongoing conversion of lowland forests into industrial agricultural plantations, particularly oil palm and fast-growing timber trees. This land-use change leads to permanent habitat loss, which is especially devastating for species with restricted ranges. Additionally, intensive selective timber extraction removes a massive share of mature emergent dipterocarps (often over 50% of the basal area), drastically altering canopy cover, microclimate, and the physical forest matrix (Sukri *et al.* 2012). Recent data suggests that while dipterocarps remain dominant, 60% to 75% of Sarawak endemic species are currently listed as Threatened on the IUCN Red List. Details of their status as stated in the Sarawak Plant Red List Series I & II (Julia *et al*. 2014, Julia and Vilma 2016).

Table 3. Dipterocarps in Sarawak indicating endemic and rare species.

Genus	No. of species	Endemic species	Endemic and rare	Rare non-endemic	Endemic and rare non-endemic
Anisoptera	5	0	0	0	1
Anthoshorea	12	1	1	5	6
Cotylelobium	2	0	0	1	1
Dipterocarpus	35	2	2	15	17
Dryobalanops	5	1	1	1	2
Hopea	38	2	2	11	13
Upuna	1	1	0	0	1
Parashorea	5	0	0	2	2
Richetia	14	1	1	4	5
Rubroshorea	35	2	2	16	18
Shorea	27	1	1	11	12
Vatica	47	1	1	8	9
TOTAL	**226**	**12**	**11**	**75**	**87**

Conservation in Sarawak focuses on expanding the network of Totally Protected Areas (TPAs) to encompass biodiversity hotspots outside existing park boundaries. Because many dipterocarps are dispersal-limited, relying primarily on gravity and short-distance gyration that restricts seed fall to the immediate parent canopy, natural recolonisation in isolated logging gaps remains slow (Seidler and Plotkin 2006). To accelerate recovery, enrichment planting in logged-over forests has long been deployed; however, its operational success remains debated due to high seedling mortality, variable shade tolerance, and intensive maintenance requirements (Adjers *et al.* 1995). Furthermore, there is an increasing emphasis on *ex situ* conservation, such as the work done at the Semenggoh Arboretum, Sabal Forest Plantation Model and other botanical research centers to maintain genetic diversity. Sustainable Forest Management (SFM) certification is also vital to ensure that logging in production forests maintains the structural integrity and reproductive capacity of the dipterocarp populations (Hamden *et al*. 2024)

DIPTEROCARPS OF SABAH

Sabah, often referred to as the Land Below the Wind, possesses some of the most structurally impressive dipterocarp forests in the world. As of 2022, approximately 183 species of Dipterocarpaceae have been recorded in the state, making it a critical hub for biodiversity on the island of Borneo. These forests are not only iconic for their massive trees, including *Richetia faguetiana*, the world's tallest tropical tree, but also for their economic significance, historically providing the bulk of the state's timber revenue. However, with over 50% of Sabah's dipterocarp species now categorised as Threatened due to habitat loss (Kho *et al.* 2022), the focus is rapidly shifting from timber production to urgent conservation oversight.

Table 4. Dipterocarps in Sabah indicating endemic and rare species.

Genus	No. of species	Endemic species	Endemic and rare	Rare non-endemic	Endemic and rare non-endemic
Anisoptera	4	0	0	1	1
Anthoshorea	10	1	1	4	5
Cotylelobium	2	0	0	1	1
Dipterocarpus	28	1	1	8	9
Dryobalanops	4	0	0	1	1
Hopea	28	2	2	7	9
Parashorea	5	0	0	2	2
Richetia	11	2	1	3	4
Rubroshorea	26	3	2	6	8
Shorea	21	1	1	5	6
Vatica	44	1	1	6	7
TOTAL	**183**	**11**	**10**	**44**	**54**

The distribution of dipterocarps in Sabah is famously diverse, driven by a complex interplay of topography and unique soil chemistry. While lowland mixed dipterocarp forests remain the most common vegetation type, Sabah is uniquely defined by its extensive ultramafic outcrops, soils high in heavy metals, which cover roughly 4.6% of the state (van der Ent *et al.* 2015). These areas, such as Mount Tawai and the foothills of Mount Kinabalu, are hotspots for specialised species such as *Richetia tenuiramulosa* (P.S. Ashton) P.S. Ashton and J. Heck., that have evolved to survive in these harsh conditions. While some species like *Dryobalanops aromatica* are relatively widespread, others such as *Anthoshorea symingtonii* (G.H.S. Wood) P.S. Ashton and J. Heck, *Dipterocarpus condorensis* ssp. *penangianus* (Foxw.) P.S. Ashton and Luu, *Shorea biawak* P.S. Ashton, are spatially restricted to specific forest reserves like Siaungau and Mesapol.

Table 5. Conservation status, key habitats, and dipterocarp refugia in Sabah (adapted from Wong *et al.* 2025).

Site / Ecosystem Category	Key Characteristics & Associated Taxa	Conservation Status, Threats & Significance
Forest Types & Habitats		
Lowland Mixed Dipterocarp Forest (MDF)	Dominated by species of *Shorea* (including subgenus *Rubroshorea*) and *Dipterocarpus*.	Highest alpha diversity; most severely threatened by agricultural conversion and past logging.
Hill Mixed Dipterocarp Forest (MDF)	Occurs on steeper terrain, typically above 500 m a.s.l.	Lower risk of agricultural conversion, but historically vulnerable to logging and slope erosion.
Ultramafic Soils & Outcrops	Nutrient-poor, heavy-metal-rich soils (e.g., Mt. Tawai, Bidu-Bidu Hills, Mt. Silam).	High level of localised endemism; hosts specialised metallophytes and nickel-hyperaccumulators (e.g., *Richetia tenuiramulosa*).
Key Dipterocarp Refugia		
Kabili-Sepilok Forest Reserve	Lowland dipterocarp forest remnant near Sandakan.	Critical lowland sanctuary; holds the highest recorded concentration of threatened dipterocarp records (>173 species).
Siaungau & Mesapol Forest Reserves	Interconnected reserve complex in southwestern Sabah (Sipitang District).	Refuge for rare, site-restricted species; protects the highest concentration of Critically Endangered (CR) dipterocarps (e.g., *Anthoshorea symingtonii*, *Dryobalanops rappa*).
Protection Framework		
Totally Protected Area (TPA) Network	Includes National Parks, Wildlife Sanctuaries, and Class I Protection Forest Reserves.	Covers ~91% of Sabah's total dipterocarp species within its current boundaries, though coverage for hyper-localised CR taxa remains uneven.

The most severe threat to dipterocarp populations in Sabah has been the permanent loss of habitat through forest conversion. During the late 20th century, vast tracts of lowland forest were cleared for agro-industrial plantations, primarily oil palm and fast-growing timber (McMorrow and Talip 2001; Gaveau *et al.* 2014). This historical deforestation has left many species with highly fragmented populations, increasing their vulnerability to climate change and fires. For the species remaining in production forests, intensive selective logging poses a risk to genetic diversity, as the removal of large mother trees can significantly reduce the potential for natural regeneration during the infrequent mast-fruiting years.

In response to these threats, Sabah has made significant strides in expanding its network of TPAs, which now cover approximately 26% of the state's land area. A landmark conservation effort is the Sabah Red List of Dipterocarpaceae, which provides the first comprehensive documentation of the conservation status of every species in the state. Current strategies emphasise *in situ* protection within Permanent Forest Estates and the establishment of Genetic Resource Areas. Furthermore, restoration projects such as the Innoprise-IKEA Tropical Forest Rehabilitation Project (INIKEA) and Innoprise-Face Foundation Rainforest Rehabilitation Project (INFAPRO) initiatives are leading the way in active forest rehabilitation, using dipterocarp seedlings to restore biodiversity to degraded landscapes (Axelsson *et al.* 2024).

ECONOMIC VALUE AND THREATS: A LEGACY OF TIMBER AND THE CHALLENGE FOR SURVIVAL

For centuries, Dipterocarps have been the lifeblood of Malaysia's timber industry. The hardwoods from genera like *Shorea s.l.*, *Dipterocarpus*, *Dryobalanops*, *Upuna* and *Neobalanocarpus* are highly valued for their strength, durability, and beauty, and are used in everything from construction and furniture to traditional crafts. This economic value, however, led to a history of intensive logging, specifically, the large-scale, mechanised harvesting of mature canopy trees that inflicted widespread collateral damage on forest soils and surrounding stands. While small-scale logging dates back to the late 19th century, extraction shifted to an intensive industrial scale from the 1950s through the late 20th century. This timber boom proved to be a double-edged sword: while it drove Malaysia's modern economic development, decades of heavy extraction severely depleted natural dipterocarp populations.

Today, the primary threat to dipterocarps is habitat conversion, especially for the expansion of oil palm and rubber plantations. This is particularly prevalent in the lowland forests where dipterocarps thrive, lea`ding to the fragmentation and outright destruction of their native habitat. Changes in rainfall patterns and temperature may also disrupt the delicate timing of mass fruiting events, impacting the long-term regeneration of these species. As a result, 37 dipterocarp species are now listed as Critically Endangered and 122 species listed as Endangered on the IUCN Red List. For example, *Dipterocarpus coriaceus* Slooten (*keruing paya*), *Dr yobalanops fusca* Slooten (*kapur empedu*), *Richetia iliasii* (P.S. Ashton) P.S. Ashton & J. Heck., *Shorea lumutensis* Symington (*balau bukit*), *Vatica adenanii* Meekiong *et al*. (*resak denan*), and several others.

MALAYSIAN DIPTEROCARP CONSERVATION STATUS

Beyond timber, these trees provide essential non-timber products; for example, fruits from the *Section Pachycarpae* are harvested to produce illipe butter, which serves as a cocoa butter substitute or a local dietary fat. Despite their value, dipterocarps face significant survival pressures, with 360 species in Malaysia currently classified as globally threatened (Table 6). The primary drivers of this decline are agricultural land-use change, especially for industrial plantations, alongside logging and infrastructure expansion like roads. In specific regions like Peninsular Malaysia, freshwater swamp dipterocarps are particularly vulnerable, with several species now categorised as Critically Endangered due to habitat loss.

Conservation efforts in Malaysia are multi-faceted, involving large-scale restoration initiatives (Kettle 2010) and the protection of species in situ within forest reserves and nature reserves. National restoration frameworks, such as the Greening Malaysia 100 Million Trees Campaign (2021–2025), targeted large-scale forest landscape restoration across the country. While native dipterocarps (e.g., *Dryobalanops aromatica* and high-value *Shorea* species) were utilised in targeted enrichment zones, official campaign metrics primarily track initial planting tallies rather than long-term seedling establishment. Field-level survival rates for planted dipterocarps remain variable, as successful establishment in degraded or secondary canopies depends heavily on sustained post-planting liberation thinning and long-term maintenance rather than initial sapling distribution. Ongoing research also focuses on DNA barcoding, climate change impacts, and the establishment of *ex situ* collections to ensure the long-term persistence of these tropical giants.

Table 6. Status of Dipterocarps in Malaysia (Amended from Khoo *et al.* 2023).

Category	Peninsular Malaysia	Sabah	Sarawak	Malaysia
Critically Endangered (CR)	11	8	18	37
Endangered (EN)	39	32	51	122
Vulnerable (VU)	53	59	79	191
Near Threatened (NT)	26	39	50	115
Least Concern (LC)	25	41	49	115
Data Deficient (DD)	6	4	3	13
TOTAL	**160**	**183**	**250**	**593**

CONSERVATION AND FUTURE OUTLOOK: A PATH TO SUSTAINABILITY

Recognising the urgent need to protect these ecological and economic assets, Malaysia has initiated several conservation efforts. Building upon a century-long tradition of site protection, beginning with early 20th-century reserves like Chior and Krau and expanding through landmark sites like Bako National Park, Malaysia has progressively expanded its in-situ conservation network, with ongoing government initiatives continually establishing new TPAs to safeguard remaining dipterocarp ecosystems like Taman Negara, Pueh, and Danum Valley. The Malaysian government and forestry institutions, like the Sabah Forestry Department, Forest Department of Sarawak and Forest Research Institute Malaysia (FRIM), are promoting sustainable forestry practices (i.e., Sustainable Forest Management – SFM). This includes selective logging, which aims to harvest timber while ensuring the long-term health of the forest, and enrichment planting to restore degraded areas with native dipterocarp seedlings. Lastly, the botanic gardens and research institutions are maintaining *ex situ* collections of seeds and saplings, which is particularly challenging given the recalcitrant nature of dipterocarp seeds that cannot be stored for long periods.

CONCLUSION

The story of dipterocarps in Malaysia is a microcosm of the global challenge of balancing economic development with environmental preservation. As the dominant trees of Malaysia's rainforests, their fate is intrinsically linked to the fate of the entire ecosystem. The future of these magnificent giants depends on a continued commitment to sustainable management, effective law enforcement against illegal logging, and a collective recognition of their immense biological, cultural, and economic value. By safeguarding the dipterocarps, Malaysia not only protects its natural heritage but also plays a vital role in the global effort to conserve tropical biodiversity and combat climate change.

REFERENCES

Ådjers, G., Niku, S., Kuusipalo, J. and Otsamo, A. 1995. Enrichment planting of dipterocarps in logged-over dipterocarp forest. *Forest Ecology and Management* 73(1-3): 259–270.

Alexander, I.J. and Lee, S.S. 1992. The importance of ectomycorrhizas for the growth of dipterocarps and the efficacy of ectomycorrhizal inoculation schemes. *Mycorrhiza* 1(4): 159–167.

Appanah, S. 1985. General flowering in the South-East Asian rain forest. *Journal of Tropical Ecology* 1(3): 225–240.

Appanah, S. and Weinland, G. 1993. *Experience: Planting Dipterocarps in Peninsular Malaysia* (FRIM Research Pamphlet No. 113). Kepong: Forest Research Institute Malaysia.

Ashton, P.S., Givnish, T.J. and Appanah, S. 1988. Staggered flowering in the Dipterocarpaceae: New insights into floral biology and the evolutionary origin of mass fruiting. *The American Naturalist* 132(1): 44–66.

Ashton, P.S. 2005. Dipterocarpaceae. In *Tree Flora of Sabah and Sarawak*, *Volume 5*, E. Soepadmo, L.G. Saw and R.C.K. Chung (Eds.), pp. 63–288. Kepong: Forest Research Institute Malaysia.

Ashton, P.S. 2014. *On the origin of tropical rain forest tree diversity: Dipterocarpaceae*. Chicago: University of Chicago Press.

Ashton, P.S. and Heckenhauer, J. 2022. Tribe Shoreae (Dipterocarpaceae subfamily Dipterocarpoideae) finally dissected. *Kew Bulletin* 77(4): 885–903.

Axelsson, E.P., Grady, K.C., Alloysius, D., Flack, J., Lussetti, D., Vairappan, C.S., Wai, Y.S. *et al.* 2024. Lesson learned from 25 years of operational large-scale restoration: The Sow-A-Seed Project, Sabah, Borneo. *Ecological Engineering* 206: e107282.

Baillie, I.C., Ashton, P.S., Court, M.N., Anderson, J.A.R., Fitzpatrick, E.A. and Tinsley, J. 1987. Site characteristics and the distribution of tree species in Mixed Dipterocarp Forest on tertiary sediments in central Sarawak, Malaysia. *Journal of Tropical Ecology* 3(3): 201–220.

Bryan, J.E., Shearman, P.L., Asner, G.P., Knapp. D.E., Aoro, G. and Lokes, B. 2013. Extreme differences in forest degradation in Borneo: Comparing practices in Sarawak, Sabah and Brunei. *Plos One* 8(7): e69679. https://doi.org/10.1371/journal.pone.0069679

Brearley, F.Q. 2012. Ectomycorrhizal fungi and nutrient cycling in East Asian dipterocarp forests. *Journal of Tropical Ecology* 28(2): 119–131.

Brearley, F.Q., Banin, L.F. and Razi, M.F. 2017. The ecology of the Asian dipterocarps. *Plant Ecology & Diversity* 10(5–6): 429–433.

Chave, J., Andalo, C., Brown, S., Cairns, M., Chamber, J., Eamus, D. Folster, H. *et al.* 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87 – 99.

Chua, L.S.L., Suhaida, M. and Saw, L.G. 2010. *Malaysia Plant Red List Peninsular Malaysia Dipterocarpaceae. Research Pamphlet No. 129*. Kepong: Forest Research Institute Malaysia.

Comita, L.S., Queenborough, S.A., Murphy, S.J., Eck, J.L., Xu, K., Krishnadas, M., Beckman, N.G. and Bourke, B.P. 2014. Testing predictions of the Janzen-Connell hypothesis: a meta-analysis of conspecific negative density dependence in tropical forests. *Journal of Ecology* 102(4): 845–856.

Connell, J.H. 1971. On the role of natural enemies in preventing competitive exclusion in some marine animals and in rain forest trees. In *Dynamics of Populations*, P.J. den Boer and G.R. Gradwell (Eds.), pp. 298–312. Wageningen: Centre for Agricultural Publishing and Documentation.

Curran, L.M. and Webb, C.O. 2000. Experimental tests of response to dipterocarp seed consumption and pre-dispersal predation in Borneo. *Ecological Monographs* 70(1): 129–148.
Cvetkovic, T., Hinsinger, D.D., Thomas, D.C., Wieringa, J.J., Velautham, E. and Strijk, J.S. 2022. Phylogenomic and a revised tribal classification of subfamily Dipterocarpoideae (Dipterocarpaceae). *Taxon* 71(1): 85–102.
de Weduwen, D. and Ruxton, G.D. 2019. Secondary dispersal of wind-dispersed seeds: a review. *Biological Reviews* 94(6): 2013–2026.
El-Taguri, H.M.A. and Latiff, A. 2012. Two new species and two new records of *Vatica* L. (Dipterocarpaceae) for Peninsular Malaysia. *Malayan Forester* 75(2): 127–134.
Forest Research Institute Malaysia (FRIM). 2013.*Upuna borneensis*: An Endangered Monotypic Plant. https://www.frim.gov.my.
Ganesan, S.K. 2025. The tallest tropical trees in the world are restricted to Sabah biogeographically and phylogenetically to a clade within Dipterocarpaceae. *Sandakania* 27: 285–301.
Gaveau, D.L.A., Sloan, S., Molidena, E., Yaen, H., Sheil, D., Abram, N.K., Ancrenaz, M., Unnasch, R. and Meijaard, E. 2014. Four decades of forest persistence, clearance and logging on Borneo. *PLoS ONE* 9(7): e101654.
Ghazoul, J. 2005. Pollen and seed dispersal among dispersed trees and stand-level response to dipterocarp masting. *Forest Ecology and Management* 209(1): 103–115.
Hamdan, O., Norsheila, M.J.C., Ismail, P., Abdul Khalim, A.S. and Samsudin, M. 2014. Assessing carbon pools in dipterocarp forests of Peninsular Malaysia. *Conference on Tropical Resources and Sustainable Sciences*, Kota Bharu, Kelantan.
Hamden, M., Ripot, S., Alek, R.J., Cluny, W. and Kader, W.A. 2024 Sustainable forest management: Sarawak's perspective. *Malaysian Forestry Conference 2022: Harmonizing Forestry Towards Sustainability*, 29–30 October, Kota Kinabalu. Paper No.2.
Janzen, D.H. 1970. Herbivores and the number of tree species in tropical forests. *The American Naturalist* 104(940): 501–528.
John, R., Dalling, J.W., Harms, K.E., Yavitt, J.B., Stallard, R.F., Mirabello, M., Hubbell, S.P. *et al.* 2007. Soil nutrients influence spatial distributions of tropical tree species. *Proceedings of the National Academy of Sciences* 104(3): 864–869.
Julia, S., Chong, L., Vilma, B. and Esther, S. 2014. *Sarawak Plant Red List Dipterocarpaceae: Series 1: Dipterocarpus, Dryobalanops & Shorea*. Kuching: Sarawak Forestry Corporation Sdn. Bhd.
Julia, S. and Vilma, B. 2016. *Sarawak Plant Red List Dipterocarpaceae: Series II: Anisoptera, Hopea, Parashorea, Upuna & Vatica*. Kuching: Sarawak Forestry Corporation Sdn. Bhd.
Kettle, C.J. 2010. Ecological consideration for using dipterocarps for restoration of lowland rainforest in Southeast Asia. *Biodiversity Conservation* 19: 1137–1152.
Khoo, E., Lee, Y.F., Majapun, P., Tsen, S. and Nilus, R. 2022. *The Sabah Plant Red List of Dipterocarpaceae*. Kota Kinabalu: Sabah Forestry Department.
Khoo, E., Barstow, M., Maycock, C., Bodos, V., Chong, K.Y., Chua, L.S.L., Cicuzza, D. *et al.* 2023. *The Red List of Dipterocarpaceae*. London: Botanic Gardens Conservation International (BGCI) and The IUCN/SSC Global Tree Specialist Group (GTSG).
MacKinnon, K., Hatta, G., Halim, H. and Mangalik, A. 1996. *The Ecology of Kalimantan. The Ecology of Indonesia Series, III*. Singapore: Periplus Edition (HK) Ltd.
Matthew, N.K., Ahmad Shuib, Ismail, M., Mud Ekhzarizal, M.E., Ramachandran, S., Syamsul Herman, M.A. and Samdin, Z. 2018. Carbon stock and sequestration valuation in a Mixed Dipterocarp Forest of Malaysia. *Sains Malaysiana* 47(3): 447 – 455.
McMorrow, J. and Talip, M.A. 2001. Decline of forest cover in Sabah, Malaysia: Analysis of spatial and temporal trends, 1975–1995. *Global Environmental Change* 11(3): 217–230.
Meekiong, K. 2015. A new species of *Vatica* L. (Dipterocarpaceae) from Sarawak, Malaysia. *Malayan Nature Journal* 67(1) : 53–58.
Meekiong, K. and Latiff, A. 2021. A revision of genus *Vatica* L. (Dipterocarpaceae) in Borneo I: Taxa in Sabah and Sarawak. *Malayan Nature Journal* 73(1): 113–136.
Niiyama, K., Kajimoto, T., Matsuura, Y., Yamashita, T., Matsuo, N., Yashiro, Y., Ripin, A., Kassim, A.R. and Noor, N.S. 2010. Estimation of root biomass based on excavation of individual root systems in a primary dipterocarp forest in Pasoh Forest Reserve, Peninsular Malaysia. *Journal of Tropical Ecology* 26(3): 271 – 284.
Paoli, G.D., Curran, L.M. and Zak, D.R. 2006. Soil nutrients and beta diversity in the Bornean Dipterocarpaceae: Evidence for niche partitioning by tropical rain forest trees. *Journal of Ecology* 94(1): 157–170.

Potts, M.D., Ashton, P.S., Kaufman, L.S. and Plotkin, J.B. 2002. Habitat partitioning in a Bornean sand forest. *Journal of Ecology* 90(5): 850–857.
Richard, A., Mohamad Kassim, M.R., Abd. Kudus, K. and Saleh, M.N. 2023. Tropical forests stand recovery 30-year after selective logged in Peninsular Malaysia. *Pertanika Journal of Tropical Agricultural Science* 46(3): 1027–1046.
Russo, S.E., Davies, S.J., King, D.A. and Tan, S. 2005. Soil-related performance variation and distributions of tree species in a Bornean rain forest. *Journal of Ecology* 93(5): 879–889.
Saner, P., Loh, Y.Y., Ong, R.C. and Hector, A. 2012. Carbon stocks and fluxes in tropical lowland dipterocarp rainforests in Sabah, Malaysian Borneo. *PLOS One* 7(1): e29642.
Saw, L. and Sam, Y.Y. 2000. Conservation of Dipterocarpaceae in Peninsular Malaysia. *Journal of Tropical Forest Science* 12(3): 593–615.
Seidler, T.G. and Plotkin, J.B. 2006. Seed dispersal & spatial pattern in tropical trees. *PLoS Biology* 4(11): e344.
Slik, J.W.F, Poulsen, A.D., Ashton, P.S., Cannon, C.H., Eichhorn, K.A.O, Kartawinata, K., Lanniari, I. et al. 2003. A floristic analysis of the lowland dipterocarp forests of Borneo. *Journal of Biogeography* 30: 1517–1531.
Slik, J.W.F., Paoli, G., McGuire, K., Amaral, I, Barroso, J., Bastian, M., Blanc, L. *et al.* 2013. Large trees drive forests aboveground biomass variation in moist lowland forests across the tropics. *Global Ecology and Biogeography* 22: 1261–1271.
Smith, J.R., Tamme, R. and Pärtel, M. 2015. Upper canopy air dynamics and wind-dispersal efficiency in tropical emergent species. *Biotropica* 47(3): 312–320.
Soerianegara, I. and Lemmens, R.H.M.J. 1993. *Timber trees: Major commercial timbers*. *Plant Resources of South-East Asia No. 5(1).* Wageningen: Pudoc Scientific Publishers / PROSEA.
Song, Y.-B., Shen-Tu, X.-L. and Dong, M. 2020. Intraspecific variation of samara dispersal traits in the endangered tropical tree *Hopea hainanensis* (Dipterocarpaceae). *Frontiers in Plant Science* 11: 599764.
Sukri, R.S., Wahab, R.A., Salim, K.A. and Burslem, D.F.R.P. 2011. Habitat associations and community structure of dipterocarps in response to environment and soil conditions in Brunei Darussalam, Northwest Borneo. *BioTropica* 44(5): 595 – 605.
Tan, J.P.C., Kiew, R., Saw, L.G. and Ummul-Nazrah, A.R. 2014. Three new species from Gunung Kanthan, a limestone tower karst in Perak, Malaysia. *Phytotaxa* 177(3): 146–154.
Ummul-Nazrah, A.R., Mohd Amin, M.H., Kamin, I., Kiew, R. and Ong, P.T. 2018. *Vatica najibiana* (Dipterocarpaceae), a new species from limestone in Peninsular Malaysia. *PhytoKeys* 98: 99–106.
van der Ent, A., van Welzen, P.C., Sumail, S. and Sugau, J.B. 2015. Plant diversity and ecology of ultramafic outcrops in Sabah (Malaysia). *Australian Journal of Botany* 63(4): 204–215.
Whitmore, T.C. 1984. *Tropical Rain Forests of the Far East*. Oxford: Clarendon Press.
Wilf, P., Zou, X., Donovan, M.P., Kocsis, L., Briguglio, A., Shaw, D., Slik, J.W.F. and Lambiase, J.J. 2022. First fossil-leaf floras from Brunei Darussalam show dipterocarp dominance in Borneo by the Pliocene. *PeerJ* 10: e12949.
Winarni, N.I., Kurniasari, D.R., Hartiningtias, D., Nusalawo, M. and Sakuntaladewi, N. 2016. Phenology, climate, and adaptation: How does dipterocarps responds to climate? *Indonesian Journal of Forestry Research* 3(2): 129–141.
Wong, K.M., Pereire, J.T., Neo, L., Hoo, P.K. and van der Ent, A. 2025. Where are Sabah's plant biodiveristy hotspots and what are our remaining conservation options? *Sandakania* 26: 129–151.


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CHAPTER 13

Tree diversity, conservation status and management of Malaysian trees

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Abstract: Malaysia harbours one of the richest tropical tree floras in the world, yet comprehensive knowledge of its tree diversity and conservation status remains incomplete. Drawing upon the *Tree Flora of Malaya*, *Tree Flora of Sabah and Sarawak*, the *Flora of Peninsular Malaysia* project, and recent taxonomic studies, the Malaysian tree flora is estimated to comprise approximately 5,300 indigenous species. Peninsular Malaysia currently records 2,867 tree species, while the tree flora of Sabah and Sarawak is projected to exceed 4,100 species upon completion of ongoing taxonomic treatments. The continuing discovery of new species and ongoing taxonomic revisions demonstrate that Malaysia's tree flora remains incompletely documented, highlighting the critical role of systematic research in revealing previously unrecognised biodiversity. Taxonomic knowledge provides the foundation for conservation assessment by improving species delimitation, distributional data and extinction-risk evaluation. Recent assessments indicate that approximately 1,273 Malaysian tree species are globally threatened, including 151 Critically Endangered species, while endemic taxa account for more than half of all threatened trees and nearly 85% of Critically Endangered species. Habitat loss, forest degradation, fragmentation and climate change remain the principal threats, particularly for narrowly distributed endemic species associated with specialised habitats. Effective conservation therefore depends on integrating taxonomic research, floristic inventories, conservation assessments, habitat protection, sustainable forest management, ecological restoration and ex situ conservation. Strengthening the connection between botanical research and conservation practice will be essential for safeguarding Malaysia's globally significant tree diversity.

INTRODUCTION

Malaysia is recognised as one of the world's major centres of tropical plant diversity, yet the total number of tree species occurring within the country remains only an estimate despite decades of botanical research. This uncertainty reflects both the exceptional richness of Malaysia's flora and the complexity of its tropical forest ecosystems. Although these floristic works have significantly advanced our understanding of tree diversity, comprehensive taxonomic revisions remain incomplete for several families (Saw 2007; Saw and Chung 2007, 2015; Middleton *et al.* 2019). Furthermore, new species continue to be discovered, particularly in poorly explored habitats such as limestone karsts, montane forests and ultramafic areas. Accurate documentation of tree diversity is essential not only for floristic purposes but also for conservation planning, extinction-risk assessment and sustainable forest management.

This paper aims to (1) provide an updated estimate of tree species diversity in Malaysia based on current floristic knowledge, (2) evaluate the conservation status of Malaysian tree species using available national and global assessments, and (3) discuss the implications of taxonomic knowledge for conservation planning, species recovery and

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sustainable management. By integrating floristic, taxonomic and conservation information, the paper highlights the central role of botanical research in guiding evidence-based conservation actions for Malaysia's tree flora.

ESTIMATES OF TREE SPECIES DIVERSITY ACROSS MALAYSIA

Tree species diversity in Peninsular Malaysia

The *Tree Flora of Malaya*, published between 1972 and 1989, recognised 2,830 tree species in 100 families (Whitmore 1972, 1973; Ng 1978, 1989; Ng *et al.* 1990). Subsequent taxonomic and floristic studies have added a further 37 tree species to the flora of Peninsular Malaysia (Table 1), increasing the total to 2,867 species. These newly recorded species include seven members of Dipterocarpaceae, six of Lecythidaceae, and three species each of Achariaceae, Annonaceae, Lauraceae, and Malvaceae, among other families.

Table 1. Additional tree species recorded in Peninsular Malaysia since the publication of the *Tree Flora of Malaya*.

Family	Species	Publication
Achariaceae	*Hydnocarpus perakensis* Pannell	Pannell (2022)
	Ryparosa reticulata Pannell	Pannell (2022)
	Ryparosa subopposititifolia Pannell	Pannell (2022)
Alangiaceae	*Alangium pallens* W.J.de Wilde & Duyfjes	de Wilde and Duyfjes (2017)
Araliaceae	*Brassaiopsis malayana* de Kok	de Kok (2022)
Annonaceae	*Goniothalamus tomentosus* R.M.K.Saunders	Saunders (2003)
	Meiogyne kanthanensis Ummul-Nazrah & J.P.C.Tan	Tan *et al.* (2014)
	Monoon malayanum I.M.Turner & Utteridge	Turner and Utteridge (2015)
Dipterocarpaceae	*Vatica abdulrahmaniana* Chuat	Chua *et al*. (2015)
	Vatica cuneata El-Taguri & Latiff	El-Taguri and Latiff (2012)
	Vatica kanthanensis Saw	Tan *et al.* (2014)
	Vatica mizaniana Chua	Chua *et al.* (2015)
	Vatica najibiana Ummul-Nazrah	Ummul-Nazrah *et al.* (2018)
	Vatica spatulata El-Taguri & Latiff	El-Taguri and Latiff (2012)
	Vatica yeechongii L.G.Saw	Saw (2002)
Elaeocarpaceae	*Elaeocarpus ngii* Coode	Coode (2014)
	Elaeocarpus obtusus Blume (subsp. *apiculatus* (Mast.) Coode & subsp. *krukovii* Weibel ex Coode)	Coode *et al.* (1996) and Coode (2014)
Escalloniaceae	*Polyosma collina* Saw	Saw (2020)
Fagaceae	*Castanopsis corallocarpus* W.H.Tan & Strijk	Tan *et al.* (2023)
Icacinaceae	*Platea malayana* Utteridge	Utteridge (2010)
Malvaceae	*Brownlowia latifiana* R.C.K.Chung	Chung and Soepadmo (2017)
	Durio gerikensis M.N.Faizal, Besi, Latiff & Hadrul	Ghazalli *et al.* (2022)
	Microcos malayana R.C.K.Chung	Chung (2003)
Melastomataceae	*Memecylon pseudomegacarpum* M.Hughes	Hughes (2013)
Lauraceae	*Beilschmiedia atra* Kosterm. ex de Kok	de Kok (2016a)
	Beilschmiedia kochummenii de Kok	de Kok (2016a)
	Cryptocarya malayana de Kok	de Kok (2016b)
Lecythidaceae	*Barringtonia badia* Prance (= *Barringtonia schmidtii* Warb. ex Craib)	Prance (2010)
	Barringtonia fitriana Latiff	Latiff and Fitri (2018)

	Barringtonia glomerata Prance	Prance (2010)
	Barringtonia norshamiae Prance	Prance (2010)
	Barringtonia sanimiranii Rohana & Latiff	Rohana and Latiff (2012)
	Barringtonia terengganuensis Chantar.	Chantaranothai (1998)
Olacaceae	*Strombosia ceylanica* Gardner (var. *macrophylla* Phoon)	Phoon (2012)
Rubiaceae	*Timonius pasohensis* P.K.Hoo	Hoo (2024)
Sapotaceae	*Madhuca khoonmengii* N.Omar & Latiff	Omar and Latiff (2014)
	Madhuca pasohensis N.Omar & Latiff	Omar and Latiff (2014)

The *Flora of Peninsular Malaysia* project, initiated in 2005, represents a continuation of efforts to document and revise the vascular plant diversity of Peninsular Malaysia (Saw and Chung 2007, 2015). Since its inception, numerous family treatments have been published, incorporating taxonomic revisions, nomenclatural updates, new species discoveries, and additional distributional records. A notable feature of the project is the inclusion of conservation assessments based on the IUCN Red List Categories and Criteria, providing an authoritative framework for evaluating the conservation significance of the flora. While encompassing all vascular plant groups rather than trees alone, the project has substantially improved current knowledge of the taxonomy, diversity, and conservation status of Peninsular Malaysian plants, and has led to the recognition of additional tree species beyond those documented in the *Tree Flora of Malaya*.

To date, 14 volumes have been published under two series. Series I, covering ferns and lycophytes, comprises three volumes documenting 27 families, 79 genera, and 322 species (Parris *et al.* 2010, 2013, 2020). Series II, devoted to gymnosperms and angiosperms, consists of 11 volumes treating 92 families, 375 genera, and 1,309 species (Kiew *et al.* 2010, 2011, 2012, 2013, 2015, 2017, 2018, 2021, 2023, 2025; Bramley *et al.* 2022). Collectively, these published accounts have significantly advanced the documentation of Peninsular Malaysia's plant diversity and provide an essential taxonomic and conservation framework for future floristic, ecological, and biodiversity studies.

Tree species diversity in Sabah and Sarawak

Whereas tree diversity in Peninsular Malaysia is relatively well documented through the *Tree Flora of Malaya* and subsequent Flora projects, estimating the total tree diversity of Sabah and Sarawak remains more challenging because substantial taxonomic work is still in progress.

The *Tree Flora of Sabah and Sarawak* project, initiated in 1991, has thus far produced nine published volumes (Soepadmo and Wong 1995; Soepadmo and Saw 2000; Soepadmo *et al.* 1996, 2002, 2004, 2007, 2011, 2014; Chung *et al*. 2025). Collectively, these volumes document 2,331 tree species in 82 families, highlighting the remarkable diversity of the Bornean tree flora (Table 2). However, because the published volumes cover only selected families, these figures represent a partial assessment rather than a comprehensive estimate of the total tree flora of Sabah and Sarawak.

Substantial taxonomic work nevertheless remains to be completed. A further 1,309 species belonging to 28 families have yet to be revised and incorporated into the series. The largest outstanding families are Euphorbiaceae (280 species), Lauraceae (206), Rubiaceae (150), Guttiferae (100), and Tiliaceae (98). Other families awaiting revision include Actinidiaceae (30 species), Araliaceae (21), Bombacaceae (30), Combretaceae (20), Convolvulaceae (4), Dichapetalaceae (6), Dilleniaceae (10), Ericaceae (13), Flacourtiaceae (43), Gnetaceae (1), Icacinaceae (15), Leguminosae (subfamily Mimosoideae, 49 species; subfamily Papilionoideae, 24), Magnoliaceae (25), Melastomataceae (40), Myrsinaceae (34),

Podocarpaceae (8), Rosaceae (36), Sabiaceae (7), Scrophulariaceae (1), Theaceae (40), Urticaceae (11), and Violaceae (7). Together, these families constitute a significant proportion of the remaining tree flora and will be critical to achieving a comprehensive account of the forest trees of Sabah and Sarawak.

Table 2. Revisions to family circumscription and species numbers in the *Tree Flora of Sabah and Sarawak* relative to the *Tree Flora of Malaya*. Figures for the *Tree Flora of Sabah and Sarawak* were derived from Volumes 1–9 and include two monotypic families and one two-species family not represented in the *Tree Flora of Malaya*. Figures for the *Tree Flora of Malaya* were derived from Volumes 1–4 and updated according to Turner (1997).

TFSS Volumes	*Tree Flora of Sabah and Sarawak*			*Tree Flora of Malaya*			Species common to both regions
	Families	Genera	Species	Families	Genera	Species	
1	31	99	312	31	91	227	152
2	23	75	247	21	63	186	116
3	4	29	358	4	27	246	139
4	6	21	292	6	21	202	106
5	4	25	361	4	27	225	132
6	4	18	189	4	18	117	82
7	3	32	311	3	28	275	111
8	3	32	165	3	31	135	51
9	4	5	96	3	4	47	19
Total	**82**	**336**	**2,331**	**79**	**310**	**1,660**	**908**

Malaysian tree species diversity

Table 2 compares the family composition and species richness of the *Tree Flora of Sabah and Sarawak* and the *Tree Flora of Malaya*. Based on the families treated in both works, the *Tree Flora of Sabah and Sarawak* contains approximately 40.4% more species than the *Tree Flora of Malaya*. If this proportion remains broadly consistent across the remaining tree flora, and given that the *Tree Flora of Malaya* and its subsequent additions comprise 2,867 species (Ng *et al.* 1990; Table 1), the total number of tree species in Sabah and Sarawak is estimated to be approximately 4,100.

Of the species enumerated in Table 2, 908 are shared between Sabah and Sarawak and Peninsular Malaysia, representing a floristic overlap of 54.7% with Peninsular Malaysia. Using this overlap and the estimated species totals for the two regions, the overall tree flora of Malaysia is estimated to comprise approximately 5,300 species.

This estimate is based on currently available floristic data and should be regarded as a provisional estimate. It will require revision as regional floras are completed, taxonomic treatments are updated, and additional species are discovered and documented. For comparison, the Botanic Gardens Conservation International (BGCI) estimated that Malaysia contained 5,422 tree species in 2021 (BGCI 2021), whereas the BGCI Global Tree Portal listed approximately 5,300 tree species for Malaysia in 2026 (BGCI 2026).

CONSERVATION AND MANAGEMENT OF TREE SPECIES IN MALAYSIA

Malaysia harbours one of the world's richest tropical tree floras, with approximately 5,300 indigenous tree species currently recognised. Of these, about 1,300 species are endemic, occurring nowhere else in the world (BGCI 2026). Recent conservation assessments undertaken through the Global Tree Assessment and the IUCN Red List have revealed that

at least 128 Malaysian endemic tree species are classified as Critically Endangered (CR), highlighting the exceptionally high extinction risk faced by a significant component of the country's unique tree diversity (Chua *et al.* 2010; Julia *et al.* 2014; Julia and Vilma 2016; Yong *et al.* 2021; Khoo *et al.* 2022; Pereira *et al.* 2023; BGCI 2026; IUCN 2026).

The conservation of tree species has become an increasingly important component of biodiversity management in Malaysia. Trees form the structural and functional foundation of forest ecosystems, supporting ecological processes such as carbon sequestration, nutrient cycling, hydrological regulation, and the provision of habitat for diverse assemblages of flora and fauna. The loss of tree species therefore has far-reaching consequences, extending beyond the species themselves to the integrity and resilience of entire forest ecosystems.

Conservation status for Malaysian tree species

Despite substantial advances in floristic exploration and taxonomic documentation, the conservation status of many Malaysian tree species remains poorly understood. Numerous taxa are represented by only a few herbarium collections, and some have not been recollected for several decades. Consequently, it is often difficult to determine whether their apparent rarity reflects naturally small populations, insufficient botanical sampling, or genuine population decline. Continued botanical exploration, taxonomic revision, and long-term ecological monitoring are therefore essential for improving extinction-risk assessments and supporting evidence-based conservation planning (Saw *et al.* 2007, 2010).

Major taxonomic initiatives, including the *Tree Flora of Malaya*, *Tree Flora of Sabah and Sarawak*, and the ongoing *Flora of Peninsular Malaysia* project, provide the fundamental scientific framework for conservation assessments by documenting species identities, distributions, ecological requirements, and habitat preferences (Saw and Chung 2015). Accurate taxonomic knowledge remains indispensable for conservation planning because species cannot be effectively assessed, monitored, prioritised, or protected unless their identities, distributions, and ecological requirements are clearly understood.

Recent data from the BGCI Global Tree Portal (BGCI 2026; IUCN 2026) indicate that Malaysia supports approximately 5,300 indigenous tree species, of which about 1,300 are endemic. Among the indigenous tree flora, 1,273 species are currently recognised as globally threatened under the IUCN Red List Categories and Criteria, comprising 151 Critically Endangered (CR), 342 Endangered (EN), and 768 Vulnerable (VU) species. Of the endemic tree flora, 676 species are threatened, including 128 CR, 178 EN, and 370 VU species. These figures underscore the global conservation significance of Malaysia's tree diversity and demonstrate that endemic species constitute a particularly vulnerable component of the national flora.

A regional assessment conducted by Yong *et al.* (2021) for Peninsular Malaysia evaluated 1,293 indigenous plant taxa and identified 96 threatened endemic taxa, comprising 29 CR, 31 EN, and 36 VU taxa. The study additionally reported *Oreogrammitis crispatula* and *O. kunstleri* (Polypodiaceae) as Extinct (EX) in Peninsular Malaysia, while *Pisonia grandis* (Nyctaginaceae) was assessed as Regionally Extinct (RE). Although these assessments encompass all vascular plant groups rather than trees alone, they highlight the elevated extinction risk faced by narrowly distributed endemic species within the Malaysian flora.

The substantially larger number of threatened species reported by the BGCI Global Tree Portal reflects both the broader geographical scope of assessment, encompassing Peninsular Malaysia, Sabah and Sarawak, and the considerable advances in taxonomic and conservation knowledge generated through the Global Tree Assessment. Collectively, these assessments reaffirm Malaysia's status as a global centre of tree diversity and endemism while highlighting the urgent need for continued habitat protection, species recovery programmes, and periodic reassessment of threatened taxa.

Notably, endemic species account for approximately 53.1% of all threatened tree species recorded in Malaysia (676 of 1,273 species), while 84.8% of all Critically Endangered tree species are endemic (128 of 151 species). This concentration of extinction risk within the endemic flora underscores Malaysia's global responsibility for safeguarding unique evolutionary lineages found nowhere else on Earth. It further suggests that conservation initiatives targeting centres of plant endemism and habitats with high concentrations of endemic species will generate disproportionately large benefits for national biodiversity conservation.

The high proportion of threatened endemic species demonstrates that Malaysia's global importance for tree conservation extends beyond species richness alone. As many endemic taxa occur in geographically restricted and environmentally specialised habitats, their persistence depends upon the effective integration of taxonomic research, conservation assessment, habitat protection, and long-term management. Consequently, the conservation of Malaysian trees represents both a national responsibility and a contribution to global biodiversity conservation.

Major threats to threatened tree species

Habitat loss and forest degradation remain the principal threats to Malaysian tree species, particularly those with restricted distributions, specialised habitat requirements, or small population sizes. Species confined to limestone hills, peat swamp forests, ultramafic substrates, or montane ecosystems are especially vulnerable because of their limited geographic ranges and high habitat specificity. The continuing fragmentation and degradation of these ecosystems place many species at heightened risk of extinction.

Several recently described tree species from Peninsular Malaysia exemplify this vulnerability. Species such as *Vatica abdulrahmaniana*, *V. kanthanensis*, *V. najibiana*, *Durio gerikensis*, *Brownlowia latifiana*, and *Castanopsis corallocarpus* are known from a single locality or possess extremely restricted distributions. Such narrowly endemic taxa are inherently susceptible to stochastic events, habitat disturbance, quarrying activities, infrastructure development, and climate-induced environmental change. Under the IUCN Red List Criteria, species with very small areas of occupancy and limited population sizes frequently qualify for the threatened categories of Vulnerable (VU), Endangered (EN), or Critically Endangered (CR) (IUCN 2024).

The discovery of numerous narrowly endemic species during recent taxonomic revisions has demonstrated that species discovery and conservation assessment are intrinsically linked. Newly described taxa are frequently known from a single locality, small populations, or highly specialised habitats, resulting in immediate recognition as threatened under the IUCN Red List Categories and Criteria (IUCN 2024). Consequently, taxonomic research not only increases estimates of biodiversity but also directly identifies previously unrecognised conservation priorities.

The conservation of these species depends on the implementation of site-specific management interventions, including habitat protection, regular population monitoring, ecological restoration, and periodic reassessment of conservation status. Given that the extinction of a single-site endemic species may result in the global loss of an entire evolutionary lineage, the protection of key habitats should remain a high conservation priority.

Policy and legislative framework

Malaysia has established an extensive policy and legislative framework to support biodiversity conservation and sustainable forest management. In Peninsular Malaysia, the National Forestry Act 1984 provides the principal legal framework governing forest administration, management, and utilisation. Complementary legislation at both federal and state levels provides additional protection for wildlife, biodiversity, protected areas, and environmentally sensitive habitats.

The National Policy on Biological Diversity 2022–2030 serves as the overarching strategic framework for biodiversity conservation in Malaysia. The policy includes specific targets aimed at preventing species extinctions, improving the conservation status of threatened species, strengthening ecosystem resilience, and integrating biodiversity considerations into national development planning. These objectives are closely aligned with global biodiversity targets and reinforce the importance of conserving Malaysia's unique biological heritage, promoting its sustainable use, and ensuring fair and equitable sharing of its benefits in the face of increasingly complex challenges now and in the future.

Landscape-level conservation initiatives also play an important role in maintaining ecological connectivity. One of the most significant examples is the Central Forest Spine (CFS) initiative, which seeks to reconnect fragmented forest landscapes across Peninsular Malaysia through the establishment and management of ecological corridors. Such connectivity is increasingly important for maintaining gene flow among plant populations, facilitating species migration, and enhancing ecosystem resilience under changing climatic conditions.

Malaysia is also an active participant in a range of international environmental agreements, including the Convention on Biological Diversity (CBD), the Kunming-Montreal Global Biodiversity Framework (GBF), the United Nations Sustainable Development Goals (SDGs), and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). These international commitments provide strategic direction for national conservation programmes and reinforce the country's responsibilities for protecting globally significant biodiversity resources.

Collectively, these policies, legislative instruments and international commitments provide the institutional framework through which scientific information generated from taxonomic and conservation research can be translated into practical conservation actions.

Current conservation and management approaches

In situ conservation remains the most effective strategy for maintaining viable populations of threatened tree species because it preserves not only the species themselves but also the ecological interactions and evolutionary processes necessary for their long-term persistence. In Malaysia, protected areas such as Permanent Reserved Forests, national parks, wildlife sanctuaries, totally protected areas, and state parks provide the principal framework for conserving indigenous tree diversity. These areas encompass many of the country's most important centres of plant diversity and endemism, including lowland dipterocarp forests, montane ecosystems, limestone karsts, peat swamp forests, and ultramafic habitats.

However, legal protection alone is often insufficient to ensure long-term species survival. Effective conservation requires regular population assessments, habitat monitoring, threat mitigation, and the maintenance of ecological connectivity among forest fragments. Such measures are particularly important for species confined to specialised habitats where localised disturbance may threaten entire global populations. Long-term monitoring programmes further provide the data necessary to evaluate population trends and to guide adaptive management interventions (Saw 2007; Saw *et al.* 2007, 2010; BGCI 2021).

Malaysia has also progressively incorporated sustainable forest management (SFM) principles into national forestry policy. Key components include reduced-impact logging, extended harvesting cycles, forest certification schemes, identification of High Conservation Value Forests (HCVFs), protection of riparian reserves, and the maintenance of landscape connectivity. These measures seek to balance biodiversity conservation with the sustainable utilisation of forest resources, while reducing adverse impacts on threatened and endemic species.

Ex situ conservation provides an important complementary safeguard against extinction, particularly for species facing severe threats in the wild. Living collections maintained in arboreta, botanic gardens, and research institutions, together with seed banking, tissue culture, and propagation programmes, can serve as insurance populations for highly threatened taxa (BGCI 2021). The publication *Forest Research Institute Malaysia: A Sanctuary for Threatened Trees* documented living collections of 73 threatened tree species conserved at the Forest Research Institute Malaysia (FRIM) (Yong *et al.* 2011). Such collections may also support restoration programmes, population reinforcement, and research into seed biology, reproductive ecology, and propagation techniques (Chan and Chua 2020; Suhaida and Chua 2021; Tan *et al.* 2023).

Recognition of the increasing conservation challenges facing Malaysian trees has stimulated the development of targeted conservation initiatives. In 2024, a national conservation planning exercise focused specifically on Critically Endangered endemic tree species and brought together major conservation agencies from Peninsular Malaysia, Sabah, and Sarawak (BGCI 2024). Similarly, the *Malaysian Threatened and Rare Tree Identification and Landscape Guideline* identified 74 nationally threatened and rare tree species based on IUCN assessments and national conservation priorities (SDPB 2017). Many of these species belong to Dipterocarpaceae, the dominant tree family of Malaysian lowland forests and one of the most ecologically and economically important groups in Southeast Asia.

Conservation efforts should also extend beyond natural forests into human-modified landscapes. Urban parks, institutional campuses, roadside plantings, botanical gardens, and community green spaces have increasing potential to contribute to the conservation of indigenous tree diversity when a broader range of indigenous species is incorporated into planting programmes. Such initiatives not only safeguard genetic resources but also enhance ecosystem services, improve urban environmental quality, and provide habitats for indigenous wildlife.

The success of long-term tree conservation ultimately depends upon an integrated approach that combines taxonomic research, conservation assessment, habitat protection, ecological restoration, sustainable forest management, ex situ conservation, and public participation. By effectively linking scientific knowledge with conservation practice, Malaysia can significantly improve the long-term prospects for its threatened tree flora.

Remaining challenges

Despite substantial progress in biodiversity conservation, several challenges continue to constrain the effective conservation and management of Malaysia's tree flora.

- **Incomplete conservation assessments.** A significant proportion of indigenous tree species have yet to be formally assessed under the IUCN Red List Categories and Criteria. This situation is particularly evident among newly described species and taxa occurring in botanically underexplored regions. Consequently, many species may face conservation threats that remain unrecognised.
- **Taxonomic uncertainty.** Ongoing taxonomic research continues to refine species circumscriptions, nomenclature, and distributional knowledge. While such advances improve scientific understanding, taxonomic revisions may alter conservation priorities and affect the interpretation of species-level threat assessments.
- **Limited long-term monitoring.** Population trends remain unknown for many threatened tree species because comprehensive monitoring programmes are lacking. Without robust demographic data, it is often difficult to evaluate population declines, identify emerging threats, or assess the effectiveness of conservation interventions.

- **Resource limitations.** Conservation initiatives frequently face constraints in funding, technical expertise, infrastructure, and human resources. These limitations can restrict the implementation of field surveys, conservation assessments, habitat restoration, and recovery programmes.
- **Climate change.** Climate change is likely to become an increasingly important driver of biodiversity loss and may exacerbate existing conservation challenges facing Malaysian tree species. Changes in temperature regimes, precipitation patterns, and the frequency of extreme climatic events may alter species distributions, habitat suitability, reproductive success, and ecological interactions. Future conservation strategies must therefore incorporate adaptive approaches that anticipate environmental change rather than relying solely on present-day species distributions.

Future directions and recommendations

The conservation of Malaysia's tree flora will require continued investment in both scientific research and practical conservation action. Several priorities warrant particular attention.

- **Comprehensive conservation assessments.** Priority should be given to completing conservation assessments for all indigenous tree species and to regularly updating existing assessments as new information becomes available. Comprehensive Red List evaluations are fundamental for identifying conservation priorities and guiding resource allocation.
- **Integration of conservation genetics.** Genetic information should be incorporated more systematically into conservation planning. Population genetic studies can identify evolutionarily significant units, detect genetic bottlenecks, assess levels of genetic diversity, and inform the management of fragmented populations. Such information is especially important for narrowly endemic and highly threatened species.
- **Development of national seed banking programmes.** Expanding seed conservation capacity would strengthen Malaysia's long-term biodiversity security. A coordinated national seed banking programme for orthodox seeds would provide an important safeguard against extinction and support future restoration and species recovery initiatives.
- **Enhancement of landscape connectivity.** Maintaining and restoring ecological connectivity should remain a central component of conservation planning. Ecological corridors facilitate dispersal, promote gene flow among populations, increase ecosystem resilience, and may allow species to respond more effectively to environmental change.
- **Strengthening the taxonomic foundation for conservation**. A comprehensive understanding of species diversity remains the foundation of all conservation activities. Continued support for taxonomic research, floristic inventories, herbarium development, and Flora projects is therefore essential. Newly discovered species, revised distribution records, and improved species delimitations frequently have direct implications for extinction-risk assessments and conservation planning. Investments in taxonomy should consequently be recognised as investments in biodiversity conservation.

CONCLUSION

Malaysia possesses one of the world's richest tropical tree floras, with an estimated 5,300 indigenous tree species, including approximately 1,300 endemic taxa. Ongoing *Flora and Tree Flora* projects continue to reveal previously undocumented diversity and demonstrate that the country's tree flora is still incompletely known. The continued discovery of previously undocumented species underscores the importance of sustained investment in botanical exploration, herbarium-based research, and taxonomic revision. The conservation of Malaysian trees is fundamentally dependent upon accurate taxonomy. Reliable species delimitation, distributional data and ecological information provide the basis for extinction -risk assessments and the identification of conservation priorities. Recent assessments indicate that more than 1,200 Malaysian tree species are threatened, with endemic species

accounting for a disproportionately high proportion of extinction risk. Many of these taxa are restricted to specialised habitats such as limestone karsts, montane forests, peat swamps and ultramafic ecosystems, where habitat disturbance may rapidly lead to population decline.

Effective conservation therefore requires a continuum of actions extending from taxonomic discovery and conservation assessment to habitat protection, sustainable forest management, ecological restoration, *ex situ* conservation and long-term monitoring. Strengthening the integration between botanical research and conservation practice will be critical for achieving national biodiversity targets and fulfilling Malaysia's global responsibility for the protection of tropical tree diversity. Ultimately, investment in taxonomy should be recognised not merely as a scientific endeavour but as an essential component of evidence-based conservation and sustainable management of Malaysia's forest resources.

REFERENCES

BGCI. 2021. *State of the World's Trees*. Richmond: Botanic Gardens Conservation International.

BGCI. 2024. *Conservation planning for critically endangered trees of Malaysia*. Richmond: Botanic Gardens Conservation International. https://www.bgci.org/news-events/conservation-planning-for-critically-endangered-trees-of-malaysia/

BGCI. 2026. *Global Tree Portal: Malaysia country search*. Richmond: Botanic Gardens Conservation International. https://www.bgci.org/resources/bgci-databases/globaltree-portal/

Bramley, G.L.C., Atkins, S., Kiew, R., Chung, R.C.K., Cheah, Y.H. and Saw, L.G. 2022. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 9*. Kepong: Forest Research Institute Malaysia.

Chan, Y.M. and Chua, L.S.L. 2020. *Conservation action plan for Begonia herveyana*. Kepong: Forest Research Institute Malaysia.

Chantaranothai, P. 1998 (‘1996’). A new species of *Barringtonia* (Lecythidaceae) from Peninsular Malaysia. *Gardens’ Bulletin Singapore* 48(1&2): 201–202.

Chua, L.S.L., Nor-Ezzawanis, A.T., Yong, W.S.Y. and Hamidah, M. 2015. Two new species of *Vatica* (Dipterocarpaceae) from Peninsular Malaysia. *Phytotaxa* 222(3): 229–237.

Chua, L.S.L., Suhaida, M., Hamidah, M. and Saw, L.G. 2010. *Malaysia Plant Red List: Peninsular Malaysian Dipterocarpaceae. Research Pamphlet No. 129*. Kepong: Forest Research Institute Malaysia.

Chung, R.C.K. 2003. New taxa and new combinations of *Microcos* (Tiliaceae) from Peninsular Malaysia and Borneo. *Kew Bulletin* 58: 329–349.

Chung, R.C.K. and Soepadmo, E. 2017. *Brownlowia latifiana* (Malvaceae-Brownlowioideae), a new species from Terengganu, Peninsular Malaysia. *Phytotaxa* 298(2): 134–146.

Chung, R.C.K., Kiew, R., Saw, L.G., Cheah, Y.H. and Soepadmo, E. 2025. *Tree Flora of Sabah and Sarawak, Volume 9*. Kepong: Forest Research Institute Malaysia.

Coode, M.J.E. 2014. *Elaeocarpus* for Flora Malesiana: The Monocera group in West Malesia. *Kew Bulletin* 69(1)-9487: 1–25.

Coode, M.J.E., Dransfield, J., Forman, L.L., Kirkup, D.W. and Said, I.M. 1996. *A Checklist of the Flowering Plants and Gymnosperms of Brunei Darussalam*. Bandar Seri Begawan/ Richmond: Forestry Department Brunei Darussalam and Royal Botanic Gardens, Kew.

de Kok, R.P.J. 2016a. A revision of *Beilschmiedia* (Lauraceae) of Peninsular Malaysia. *Blumea* 61(2): 147–164.

de Kok, R.P.J. 2016b. A revision of *Cryptocarya* R.Br. (Lauraceae) of Peninsular Malaysia. *Kew Bulletin* 71(1): 1–26. https://doi.org/10.1007/s12225-016-9613-1

de Kok, R.P.J. 2022. The Araliaceae of Peninsular Malaysia: five new species, two neotypifications and twenty-two lectotypifications in several genera. *Gardens’ Bulletin Singapore* 74(1): 69–94.

de Wilde, W.J.J.O. and Duyfjes, B.E.E. 2017. Taxonomy of *Alangium* section *Conostigma* (Alangiaceae). *Blumea* 62(1): 29–46.

El-Taguri, H.M.A. and Latiff, A. 2012. Two new species and two new records of *Vatica* L. (Dipterocarpaceae) for Peninsular Malaysia. *The Malaysian Forester* 75(2): 127–134.

Ghazalli, M.N., Hashim, M.H., Besi, E.E., Mat-Esa, M.I., Zaini, A.Z., Saranum, M.M., Salleh, S. *et al.* 2022. *Durio gerikensis* (Malvaceae), a new arilless *Durio* from Hulu Perak, Malaysia. *Phytotaxa* 543(1): 22–30.
Hoo, P.K., Musalmah, N., Cheah, Y.H., Wong, K.M. and Sugumaran, M. 2024. *Timonius pasohensis* (Rubiaceae), a rare new species from Pasoh Forest, Malaysia, and its population characteristics in the 50-ha forest dynamics plot. *Journal of Tropical Forest Science* 36(3): 327–337.
Hughes, M. 2013. *Memecylon pseudomegacarpum* M.Hughes (Melastomataceae), a new species of tree from Peninsular Malaysia. *European Journal of Taxonomy* 56: 1–9.
IUCN. 2024. *Guidelines for Using the IUCN Red List Categories and Criteria*. Version 16. Gland: IUCN Standards and Petitions Committee.
IUCN. 2026. *The IUCN Red List of Threatened Species*. Version 2026-1. https://www.iucnredlist.org
Julia, S. and Vilma, B. 2016. *Sarawak Plant Red List: Dipterocarpaceae. Series II: Anisoptera, Cotylelobium, Hopea, Parashorea, Upuna and Vatica*. Kuching: Sarawak Forestry Corporation Sdn. Bhd.
Julia, S., Chong, L., Vilma, B., Esther, S. and Pearce, K.G. 2014. *Sarawak Plant Red List Dipterocarpaceae: Series I: Dipterocarpus, Dryobalanops and Shorea*. Kuching: Sarawak Forestry Corporation Sdn. Bhd.
Khoo, E., Tsen, S.T.L., Lee, Y.L., Sugau, J.B., Pereira, J.T., Nilus, R. and Maycock, C.R. 2022. *The Sabah Plant Red List of Dipterocarpaceae*. Sandakan: Sabah Forestry Department.
Kiew, R., Chung, R.C.K. and Saw, L.G. 2023. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 10. Malayan Forest Records No. 49*. Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Cheah, Y.H. 2025. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 11. Malayan Forest Records No. 49.* Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2012. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 3. Malayan Forest Records No 49*. Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2013. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 4. Malayan Forest Records No 49*. Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2015. *Flora of Peninsular Malaysia Series II: Seed Plants. Volume 5. Malayan Forest Records No. 49.* Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2017. *Flora of Peninsular Malaysia Series II: Seed Plants. Volume 6. Malayan Forest Records No. 49*. Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2018. *Flora of Peninsular Malaysia Series II: Seed Plants. Volume 7. Malayan Forest Records No. 49*.Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2021. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 8. Malayan Forest Records No. 49*. Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G., Soepadmo, E. and Boyce, P.C. 2010. *Flora of Peninsular Malaysia. Series II: Seed Plants. Voume. 1. Malayan Forest Records No 49.* Kepong: Forest Research Institute Malaysia.
Kiew, R., Chung, R.C.K., Saw, L.G; Soepadmo, E. and Boyce P.C. 2011. *Flora of Peninsular Malaysia. Series II: Seed Plants. Volume 2. Malayan Forest Records No. 49.* Kepong: Forest Research Institute Malaysia.
Latiff, A. and Ahmad Fitri, Z. 2018. A new species of *Barringtonia* (Lecythidaceae) from Terengganu, Peninsular Malaysia. *Malayan Nature Journal* 70(3): 279–284.
Middleton, D.J. (and 21 co-authors). 2019. Progress on Southeast Asia's Flora projects. *Gardens' Bulletin Singapore* 71(2): 267–319. https://doi/org/10.26492/gbs71(2).2019-02
Ng, F.S.P. 1978. *Tree Flora of Malaya. Volume 3*. Kuala Lumpur: Longman Malaysia.
Ng, F.S.P. 1989. *Tree Flora of Malaya. Volume 4*. Kuala Lumpur: Longman Malaysia.
Ng, F.S.P., Low, C.M. and Mat Asri, N.S. 1990. *Endemic trees of the Malay Peninsula. FRIM Research Pamphlet No. 106.* Kepong: Forest Research Institute Malaysia.
Omar, N. and Latiff, A. 2014. Two new species and a new record of *Madhuca* Buch.-Ham. ex J.F.Gmel. (Sapotaceae) from Peninsular Malaysia. *The Malaysian Forester* 77(1): 31–38.

Pannell, C.M. 2022. Three new species in the Achariaceae from Peninsular Malaysia. *Gardens' Bulletin Singapore* 74(2): 183–189.
Parris, B.S., Kiew, R., Chung, R.C.K. and Cheah, Y.H. 2020. *Flora of Peninsular Malaysia. Series I: Ferns and Lycophytes. Volume 3. Malayan Forest Records No. 48*. Kepong: Forest Research Institute Malaysia.
Parris, B.S., Kiew, R., Chung, R.C.K. and Saw, L.G. 2013. *Flora of Peninsular Malaysia. Series I: Ferns and Lycophytes. Volume. 2. Malayan Forest Records No 48*. Kepong: Forest Research Institute Malaysia.
Parris, B.S., Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2010. *Flora of Peninsular Malaysia. Series I: Ferns and Lycophytes. Volume 1. Malayan Forest Records No 48.* Kepong: Forest Research Institute Malaysia.
Pereira, J.T., Damit, A., Tsen, S.T.L., Nilus, R. and Sugau, J.B. 2023. *The Red List of Sabah Endemic Trees*. Sandakan: Sabah Forestry Department.
Phoon, S.N. 2012. A new variety of *Strombosia ceylanica* (Olacaceae) from Malaysia. *Kew Bulletin* 67(2): 191–203. https://doi.org/10.1007/s12225-012-9319-y
Prance, G.T. 2010. Notes on the Lecythidaceae of Peninsular Malaysia. *Blumea* 55(1): 14–17. https://doi.org/10.3767/000651910x499123
Rohana, K.A. and Latiff, A. 2012. *Barringtonia sanimiranii* (Lecythidaceae), a new species from Terengganu, Peninsular Malaysia and notes on two other species. *The Malaysian Forester* 75(2): 177–184.
Saunders, R.M.K. 2003. A synopsis of *Goniothalamus* species (Annonaceae) in Peninsular Malaysia, with a description of a new species. *Botanical Journal of the Linnean Society* 142(3): 321–339.
Saw, L.G. 2002. A new species of *Vatica* (Dipterocarpaceae) from Peninsular Malaysia. *Gardens' Bulletin Singapore* 54(2): 247–251.
Saw, L.G. 2007. Plant conservation in Malaysia – Meeting the challenges of the twenty-first century. Third Global Botanic Gardens Congress, 16–20 April 2007 at Wuhan, China.
Saw, L.G. 2020. A new species of *Polyosma* Blume (Escalloniaceae) and notes on a revision of the genus in Peninsular Malaysia and Singapore. *Gardens' Bulletin Singapore* 72(2): 215–231.
Saw, L.G. and Chung, R.C.K. 2007. Towards the Flora of Malaysia. In *Proceedings of Seminar and Workshop on the Status of Biological Diversity in Malaysia and Threat Assessment of Plant Species in Malaysia*, L.S.L. Chua, L.G. Kirton and L.G. Saw (Eds.), pp. 203–219. Kepong: Forest Research Institute Malaysia.
Saw, L.G. and Chung, R.C.K. 2015. The flora of Malaysia projects. *Rodriguésia* 66(4): 947–960. https://doi.org/10.1590/2175-7860201566415
Saw, L.G., Chua L.S.L., Hamidah, M., Chan, Y.M., Yong, W.S.Y., Suhaida, M., Chan Y.C., Damanhuri, S. and Koh, H.L. 2007. Conservation and management of threatened plants in Malaysia. In *Proceedings of the National Conference on the Management and Conservation of Forest Biodiversity in Malaysia – Forest Biodiversity for Better Life*, Z. Mohd. Yunus, N.K. Nazir Khan and B. Mohd. Yusoff (Eds.), pp. 535–562. Kuala Lumpur: Forestry Department of Peninsular Malaysia.
Saw, L.G., Chua, L.S.L., Suhaida, M., Yong, W.S.Y. and Hamidah, M. 2010. Conservation of some rare and endangered plants from Peninsular Malaysia. *Kew Bulletin* 65(4): 681–689. https://doi.org/10.1007/s12225-011-9251-6
SDPB. 2017. *Malaysian Threatened and Rare Tree: Identification and Landscape Guideline*. Petaling Jaya: Sime Darby Property Berhad.
Soepadmo, E. and Saw, L.G. 2000. *Tree Flora of Sabah and Sarawak, Volume 3*. Kepong/Sandakan/Kuching: Forest Research Institute Malaysia, Sabah Forestry Department, and Sarawak Forestry Department.
Soepadmo, E. and Wong, K.M. 1995. *Tree Flora of Sabah and Sarawak, Volume 1*. Kepong/Sandakan/Kuching: Forest Research Institute Malaysia, Sabah Forestry Department, and Sarawak Forestry Department.
Soepadmo, E., Saw, L.G. and Chung, R.C.K. 2002. *Tree Flora of Sabah and Sarawak, Volume 4*. Kepong/Sandakan/Kuching: Forest Research Institute Malaysia, Sabah Forestry Department, and Sarawak Forestry Department.
Soepadmo, E., Saw, L.G. and Chung, R.C.K. 2004. *Tree Flora of Sabah and Sarawak, Volume 5*. Kepong/Sandakan/Kuching: Forest Research Institute Malaysia, Sabah Forestry Department, and Sarawak Forestry Department.

Soepadmo, E., Saw, L.G., Chung, R.C.K. and Kiew, R. 2007. *Tree Flora of Sabah and Sarawak, Volume 6.* Kepong/Sandakan/Kuching: Forest Research Institute Malaysia, Sabah Forestry Department, and Sarawak Forestry Department.
Soepadmo, E., Saw, L.G., Chung, R.C.K. and Kiew, R. 2011. *Tree Flora of Sabah and Sarawak, Volume 7*. Kepong: Forest Research Institute Malaysia.
Soepadmo, E., Saw, L.G., Chung, R.C.K. and Kiew, R. 2014. *Tree Flora of Sabah and Sarawak, Volume 8*. Kepong: Forest Research Institute Malaysia.
Soepadmo, E., Wong, K.M. and Saw, L.G. 1996. *Tree Flora of Sabah and Sarawak, Volume 2.* Kepong/Sandakan/Kuching: Forest Research Institute Malaysia, Sabah Forestry Department, and Sarawak Forestry Department.
Suhaida, M. and Chua, L.S.L. 2021. *Conservation Action Plan for Vatica yeechongii*. Kepong: Forest Research Institute Malaysia.
Tan, J.P.C., Kiew, R., Saw, L.G. and Ummul-Nazrah, A.R. 2014. Three new species from Gunung Kanthan, a limestone tower karst in Perak, Malaysia. *Phytotaxa* 177(3): 146–154.
Tan, K.K., Siti Fariezza, K.T., Ikman, S. and Chan, Y.M. 2023. *Guide to propagating selected Begonia through leaf cuttings*. Kepong: Forest Research Institute Malaysia.
Tan, W.H., Ong, L. and Strijk, J.S. 2023. *Castanopsis corallocarpus* (Fagaceae), a new species from Royal Belum (Perak) in Peninsular Malaysia. *PhytoKeys* 219: 1–10.
Turner, I.M. 1997 ('1995'). A catalogue of the vascular plants of Malaya. *Gardens' Bulletin Singapore* 47: 1–757.
Turner, I.M. and Utteridge, T.M.A. 2015. A new species of *Monoon* (Annonaceae) from Peninsular Malaysia. *Webbia* 70(1): 99–102.
Ummul-Nazrah, A.R., Mohd Hairul, M.A., Imin, K., Kiew, R. and Ong, P.T. 2018. *Vatica najibiana* (Dipterocarpaceae), a new species from limestone in Peninsular Malaysia. *PhytoKeys* 98: 99–106.
Utteridge, T.M.A. 2010. A new species of *Platea* (Icacinaceae) from Peninsular Malaysia: *Platea malayana*. *Kew Bulletin* 65(2): 345–348.
Whitmore, T.C. 1972. *Tree Flora of Malaya Volume 1*. Kuala Lumpur: Longman Malaysia.
Whitmore, T.C. 1973. *Tree Flora of Malaya Volume 2.* Kuala Lumpur: Longman Malaysia.
Yong, W.S.Y., Chua, L.S.L., Suhaida, M. and Aslina, B. 2011. *Forest Research Institute Malaysia: A Sanctuary for Threatened Trees*. Kepong: Forest Research Institute Malaysia.
Yong, W.S.Y., Chua, L.S.L., Lau, K.H., Siti-Nur Fatinah, K., Cheah, Y.H., Yao, T.L., Rafidah, A.R. *et al.* 2021. *Malaysia Red List: Plants of Peninsular Malaysia. Volume 1, Part 1. Research Pamphlet No. 151*. Kepong: Forest Research Institute Malaysia.


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CHAPTER 14

Conservation planning and initiatives for endemic and threatened plant species in Malaysia

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Abstract: This article presents the partial state of knowledge for endemic and threatened plants in Malaysia after 1995, several years after the first State of Nature Conservation was published. Malaysia has a prodigious diversity of Dipterocarpaceae where 72% of the world's species reside; 12.2% of the country's dipterocarps (360 species) is endemic. At least 15 new genera and 580 taxa have been described for Sabah and Sarawak while for Peninsular Malaysia, one genera and at least 122 plants have been discovered. Non-tree families with high endemism are Begoniaceae and Orchidaceae. About 38% of plant species in Malaysia has been assessed for extinction risk, of which 27.3% are threatened. The assessment rate for tree families is much higher compared to other families. In Malaysia, plant population extinctions are driven by forest loss and enhanced forest degradation arising from continued harmful anthropogenic activities, particularly mining. Additionally, inadequate mainstreaming across extractive-based sectors and timely access to sustained funding compound the predicament. To supplement the protected areas network, existing frameworks and action plans such as the Central Forest Spine (CFS) Peninsular Malaysia, Heart of Borneo (HoB), IUCN Green List of Protected and Conserved Areas, and Other Effective Area-based Conservation Measures (OECM) should be explored strategically, together with stricter enforcement of Environmental Impact Assessment (EIA) regulations. The risk assessment for families with high levels of endemism should be prioritised. Conservation initiatives for selected species are shared for in-depth awareness.

INTRODUCTION

Plant species richness, its interactions and inter-dependencies in community level assemblages are integral to ecosystem functions. In Malaysia, the vascular plant diversity is estimated at 15,300 species (Saw and Chung 2005) dispersed across a large array of habitat associations. Of this figure, about 35% are trees (BGCI 2021). Peninsular Malaysia has ca. 7,900 species of seed plants (Kiew *et al.* 2010) and no reliable estimate is available for Sabah and Sarawak although both states are known to have ca. 12,000 plant species (Saw and Chung 2005).

PARTIAL SUMMARY FOR MALAYSIAN PLANT DIVERSITY

Floristic accounts for many plant families in Malaysia are either lacking or outdated and efforts to revise and improve knowledge of poorly known families remain a significant challenge due to the paucity of taxonomists and weak support resources. The following provides data for selected families dating from 1995.

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The country has an overwhelming diversity of Dipterocarpaceae, harbouring ca. 72% of the world's species (360 species) according to the *World Checklist of Vascular Plants* (Royal Botanic Gardens, Kew 2025) dispersed across distinct geographical provinces defined by edaphic factors (Potts *et al.* 2002; Ashton 2004; Russo *et al*. 2005; Baldeck *et al*. 2013). Sarawak has the highest diversity (290 taxa; 28 endemic), followed by Sabah (182 taxa; 6 endemic; Khoo *et al.* 2022) and Peninsular Malaysia (166 taxa; 30 endemic). Apart from dipterocarps, Sabah and Sarawak are the world's hotspots for *Knema* (47%), *Horsfieldia* (~39%) (Myristicaceae; de Wilde 2000), *Madhuca* (50%), *Payena* (63%) *Palaquium* (~37%) (Sapotaceae; Chai and Yii 2002), *Polyalthia* (31%) (Annonaceae; Turner *et al.* 2014), among others. Peninsular Malaysia is a hotspot for *Barringtonia* (35%) (Lecythidaceae; Prance 2012). Sarawak has 13 hyper-endemic genera, many from the family Araceae while Sabah has six hyper-endemic genera, of which two are Orchidaceae. Peninsular Malaysia has 15 endemic genera, of which five are hyper-endemic.

Numerous new plant genera and taxa has been described from Malaysia since 1995. The number of species described for Sabah, Sarawak and Borneo in general is notably higher compared to Peninsular Malaysia. At least two new orchid genera, i.e., *Jejewoodia* (Orchidaceae; Szlach. 1995) and *Kipandiorchis* (Orchidaceae; P.O'Byrne and Gokusing 2015) are hyper-endemic to Sabah. More than twelve genera of Araceae (Wong and Boyce 2010; Low *et al.* 2018) and *Sleumeria* (Icacinaceae; Utteridge *et al.* 2005) were ascertained for Borneo. A partial list of new species endemic to Sabah and Sarawak are 212 species of orchids (Royal Botanic Gardens, Kew 2025), 168 species of *Begonia* (Begoniaceae; Kiew *et al*. 2015, 2016; Rimi *et al*. 2015; Royal Botanic Gardens, Kew 2025), 49 species of *Timonius* (Chen and Wong (2023) and ten species of *Polyosma* (Escalloniaceae; Saw 2020). Nineteen and 12 new species of Anacardiaceae (Kochummen 1996) and Burseraceae (Kochummen 1994), respectively, have been discovered for Sabah and Sarawak. More than a hundred species of Araceae (Low *et al.* 2018; IPNI 2025), 48 species of *Bulbophyllum* (Orchidaceae; Royal Botanic Gardens, Kew 2025), 25 species of *Dendrobium* (Orchidaceae; Royal Botanic Gardens, Kew 2025), 15 species of *Coelogyne* (Orchidaceae; Chase *et al.* 2021) and 12 species of *Calamus* (Palmae; Baker 2015; Henderson 2020) have since been added to Borneo's diversity. Genera whose species number have increased in significant proportion include *Lithocarpus* (Fagaceae; Sang and Soepadmo 1998) and *Thottea* (Aristolochiaceae; Yao 2013). Given Borneo's immense diversity, many new species remain to be discovered, as anticipated by Joppa *et al.* (2011) and Gatti *et al.* (2022).

As for Peninsular Malaysia, since 1995, at least one genera *Bayabusua* (Cucurbitaceae; de Wilde and Duyfjes 1999) and more than 122 seed plant species have been discovered. Of these, 47 and 14 are orchids and *Begonias,* respectively (Royal Botanic Gardens, Kew 2025). In due time, when the projects "*Tree Flora of Sabah & Sarawak*" and "*Flora of Peninsular Malaysia*" and floristic accounts of herbaceous families such as Araceae and Zingiberaceae and other poorly known families are near completion, the often-quoted estimate of Malaysia's plant diversity may need to be revised to provide a more accurate figure.

In terms of endemism, Borneo and the Malay Peninsula (comprising Peninsular Thailand, Peninsular Malaysia and Singapore) have 65 and 12 endemic plant genera, respectively (Neo *et al.* 2020; IPNI 2025). Malaysia has 9.2% (5,422 species) of the world's tree diversity—of this number, 1,616 (29.8%) are endemic (BGCI 2021). Sabah and Sarawak has a much higher level of endemism compared to Peninsular Malaysia. For example, 69.3% of the Malaysian Begoniaceae and 32% of Malaysian Orchidaceae are endemic to both states. The high level of endemism, especially for Sarawak (Ashton 1972), is related to a high diversity of geological and geomorphological formations that had occurred since early Paleozoic (Raes 2009; Wong 2011; de Bruyn *et al.* 2014) and exemplified by a lack of adequate inventories, sampling and recent floristic accounts for Kalimantan and Brunei.

To date, an estimated 38% of the plant species in Malaysia has been assessed for extinction risk according to the IUCN Red List of Threatened Species. Of the 5,922 taxa assessed, 3.6% are Critically Endangered (CR), 7.7% are Endangered (EN) and 16% are Vulnerable (VU), bringing the total of threatened species to 27.3%. The assessment rate in Malaysia varies between families and genera and the rate is higher for trees compared with non-trees. The most complete is undoubtedly the Dipterocarpaceae. Nationwide, this family has 64.9% threatened taxa—11.5% are CR, 24.1% are EN and the remaining 29.3% are VU, with only 1.4% being Data Deficient (DD). The genus with the highest number of CR taxa is *Rubroshorea* (13 taxa) and *Vatica* (eight taxa).

For the native tree flora as a whole, 52.5% of the species has been assessed (BGCI 2021)—of this percentage, 24% is currently threatened. For herbaceous groups, the country's current estimate for Zingiberaceae is 400 taxa (Sam Y.Y., pers. comm.), where 75.5% has been assessed—of this, 49% are threatened and all the CR taxa, with the exception of one taxa, occur in a single locality. In Orchidaceae, 47.3% of *Paphiopedilum* species are CR—all are hyper-endemic to Sabah and Sarawak. By phytogeographical region, Sabah and Sarawak consistently outnumbered Peninsular Malaysia in each of the threatened category.

CHALLENGES

The main threat causing plant and population extinction in Malaysia is the loss of forest cover and enhanced regression of forest degradation arising from continued harmful anthropogenic activities. Between 1973 and 2015, Sabah and Sarawak lost 31.9% and 25.9% of its forest cover respectively. Based on 2015 data, these states had only 28.2% and 19% of intact forest, respectively, while the remaining forests had been selectively logged (Gaveau *et al.* 2016). As for the protected areas in Sabah and Sarawak, 92% and 97% of the land, respectively, had experienced various degrees of degradation by 2009 (Bryan *et al.* 2013). During the same period, Peninsular Malaysia had lost 30.5% of the natural forest cover (FAO 1973; FDPM 2016). Undisputed, the major factor that caused deforestation during that period was land conversion for industrial plantations; currently although deforestation continues to occur sporadically, the rate has reduced substantially (FAO 2025) after the country imposes in 2019 a limit of 6.5 million ha of oil palm areas under cultivation (Bernama 2019). As for forest plantations, the increasing extant replacing natural forests is a growing concern but verified data for the attributes of increment is not publicly available.

At present, in Peninsular Malaysia, fragmented forests are being further isolated and degraded by mining for underground and limestone minerals (Ministry of Natural Resources and Environment 2009, Ministry of Energy and Natural Resources 2021, Ministry of Natural Resources and Environmental Sustainability 2024; Lamb *et al.* 2024). Hughes (2017) reported Malaysia as being one of the top five global exporters of cement, which is derived from limestone quarrying. Although mining, with the exception of limestone quarrying, generally occur in areas that are degraded, several locations were in forest reserves that had to be degazetted for the purpose. The disperse distribution of potential mining sites (Ministry of Energy and Natural Resources 2021) poses substantial risks and challenges to forest and biodiversity conservation as it obstructs ecological connectivity that enables natural forest dynamics to rebound. Mining sites are notoriously slow to recover back to its productive ecological capacity (Cristescu *et al.* 2012; Majer 2014). Because of harsher and extended exposure to edge effects (Garate-Quispe *et al.* 2023), and the detrimental impacts accumulated from facilities such as roads and processing plants, adjacent forest fragments tend to suffer among others from increased tree death, death of canopy-dependent species, loss of above-ground biomass (Garate-Quispe *et al.* 2024, Yang *et al.* 2025), invasion of pioneer

plant species including climbers (Chambi-Legoas *et al.* 2021) that overwhelm and suppress the establishment of native species. How continued degradation influences the disturbances, stresses, resilience and potential recovery of natural forest fragments is not understood due to the lack of temporal-refined monitoring activities.

One of Malaysia's key challenges to ecosystem, species and genetic conservation is the lack of adequate mainstreaming across the various sectors that use the components of biodiversity (IPBES 2018, 2022) such as agriculture, fisheries and extractive-based industries, and the weak accounting of externalities, and the potential trade-offs and opportunity costs that a particular sectoral plan may have on existing plans. Timely access to sustained funds by local conservation actors is another key implementation challenge whereby fund disbursement process is bureaucratic and lengthy and projects often face unrealistic time-bound limitations.

IPBES (2022) has succinctly described how the loss of biodiversity rapidly degrades ecological services such as climate regulations, livelihood dependence, food security and human well-being. In Malaysia, we do not adequately understand the impacts to resilience of plant community assemblages due to the lack of adequately-timed monitoring programmes. When ecological damage is not addressed quickly with effective mainstreaming across sectors, such as specifically designed restoration or rehabilitation initiatives that are long-term in approach, the potential ecosystem recovery from the damage and consequently, the measure of success of the initiatives are placed at high risk.

OPPORTUNITIES AND RECOMMENDATIONS

Malaysia's vast diversity is a natural heritage we are proud of and an invaluable asset that we are bound responsibly to protect, especially so when the diversity intricately determines the quality of ecosystem services that are critical to the country's socioeconomic prosperity and public well-being.

Conservation planning begins with species risk assessment that appraises the risks, drivers of threats and extinction proximity (Rodrigues *et al.* 2006). Following the IUCN Red List Categories and Criteria guidelines, inferences from landscape-level data, evidence -based species data and expert knowledge (Rodríguez *et al.* 2007) are widely used in Malaysia since the spatial and species-level data for a large number of native plant species are scarce. Approximately 64% that were assessed are tree species, indicating a pronounced tree-biased taxonomic research. The neglect faced by herbaceous families such as Begoniaceae, Orchidaceae, Palmae and Zingiberacae should be addressed since all have record high levels of diversity and endemism. Initiatives that copy the framework of the "*Tree Flora of Sabah and Sarawak*" and "*Flora of Peninsular Malaysia*" projects can be undertaken at smaller scales for non-trees plant families. Families having high endemism such as Begoniaceae are in urgent need of risk assessment, as the first step towards conservation planning and implementation.

Conservation planning for threatened species and ecosystems is guided by three national policies on biological diversity, i.e., National Policy on Biological Diversity 1998, National Policy on Biological Diversity 2016–2025 and National Policy on Biological Diversity 2022–2030, in addition to the Kunming-Montreal Global Biodiversity Framework under the Convention on Biological Diversity (CBD 2022) and Sarawak Biodiversity Master Plan 2023–2030. Since 1998, more than 900,000 ha of forested areas in Sabah, 300,000 ha in Sarawak and over one million ha in Peninsular Malaysia have been declared as Protected Areas (PAs) (UNEP-WCMC and IUCN 2021). Currently, approximately 12.6% of the country is conserved in the network of 472 PAs. There are several other strategic frameworks and action plans available for in-situ conservation—among the most important are the

Central Forest Spine Peninsular Malaysia 2022 (PLANMalaysia 2022; Ministry of Natural Resources, Environment and Climate Change 2022), Heart of Borneo (HoB) (Forest Department Sarawak 2025), IUCN Green List of Protected and Conserved Areas (IUCN 2025a), Other Effective Area-based Conservation Measures OECMs (IUCN 2025b). At present, CFS, Green Lists and OECMs sites such as Important Bird Areas (IBAs), Key Biodiversity Areas (KBAs), UNESCO GeoParks, and Indigenous and Community Conserved Areas (ICCAs) contribute a very small percentage. These frameworks are major complements to PAs and consolidated implementation of these frameworks, as well as stricter enforcement of Environmental Impact Assessment (EIA) regulations, can be further strengthened by Malaysia, recognising that these approaches ultimately reduce population loss, conserve species richness and habitat diversity, and directly reduce the number of threatened plant species.

A SELECTION OF SPECIES-BASED CONSERVATION INITIATIVES IN MALAYSIA

I. Peninsular Malaysia

Dipterocarps (*Vatica flavida*, *Shorea macrantha*, *S. hemsleyana*) and agarwood (*Aquilaria malaccensis*).

Assess. These species were discovered in the forest of Universiti Teknologi PETRONAS (UTP) in Perak between 2006 – 2011. *Vatica flavida* is CR because it is a very rare species endemic confined to a single location in Perak. *Shorea macrantha* is also CR due to the conversion of its mixed peat swamp habitats. *Shorea hemsleyana* and *Aquilaria malaccensis* are VU threatened by habitat conversion and illegal harvesting respectively.

Plan and Act. A report on the "*Zonation of forest areas at UTP for the purpose of conservation based on the density of rare tree species*" was produced through an MoU and conservation grant generously provided by UTP. The aims were to conserve forested habitats and populations of threatened species and assist in maintaining ecosystem services to meet UTP's vision and mission. Priority areas for conservation were identified and zoned with explicit details of population demographics and spatial features.

Network and Communicate. Numerous dialogues and knowledge sharing sessions were held between UTP and the Forest Research Institute Malaysia (FRIM). In 2024, a 950-m Warisan Hijau Nature Trail featuring the freshwater swamp forest and these species is opened to the public to educate and inspire environmental conservation and strengthening environmental education.



Figure 1. Freshwater swamp forest in UTP. Photo courtesy of Siti Fariezza bt Thaw.

II. Sarawak

Rubroshorea praestans (Dipterocarpaceae)

Assess. *Rubroshorea praestans* is CR A4cd because it is endemic, occurs in four small populations in highly fragmented forests outside Totally Protected Areas, severely threatened by forest conversion, illegal encroachment and unauthorised harvesting.

Plan and Act. Population demography have been sampled for Sungai Sebatang and Bukit Tiban in Bintulu, Kenyana in Mukah and Ulu Bawan in 2011 – 2013. Phenological observations in Kenyana, Sungai Sebatang and Ulu Bawan are on-going. Fruits from several sites were collected between 2012 and 2013, grown in the nursery of the Botanical Research Centre (BRC) and subsequently planted and conserved at Landeh in Semengoh Nature Reserve, a Totally Protected Area. Efforts by Sarawak Forestry Corporation (SFC) to list *R. praestans* in the Wild Life Protection Ordinance, 1998 is on-going as part of the overall attempt to include endemic CR species into the list of Protected Plants of Sarawak.

Network and Communicate. Various engagements and dialogues with relevant stakeholders (e.g., Forest Management Units, Sarawak Timber Association) on threatened dipterocarps were carried out. In 2024, a series of workshops and training was organised with stakeholders from the relevant agencies. At present, SFC is working with the State Attorney-General's office on the proposed amendment, and this will be followed with a proposal for consideration at *Majlis Kerajaan Negeri*.

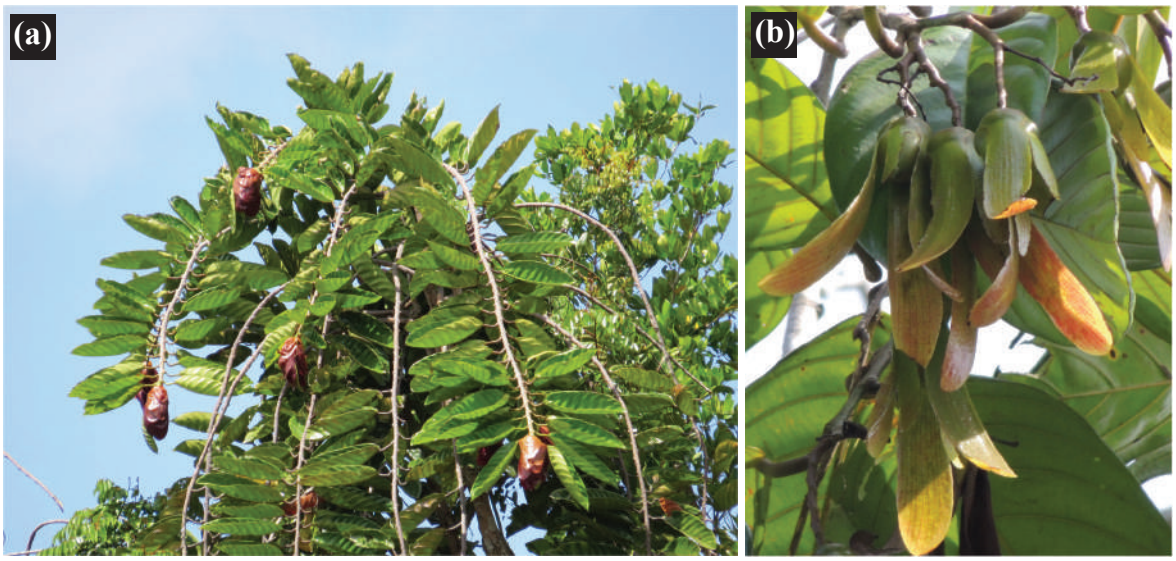

Figure 3. (a) Branches and **(b)** developing fruits of *Rubroshorea praestans*. Photos courtesy of Julia S.

Begonia belagaensis, *B. bengohensis* (Begoniaceae)

Assess. Only selected species have been provisionally assessed using the IUCN Red List of Categories & Criteria although approximately 80% are known to be hyper-endemic or restricted to a single locality (Julia and Kiew 2014). Current efforts are focused at describing numerous new species.

Plan and Act. The species are grown in BRC Garden and Murum Conservation Garden. Native Begonias are generally very difficult to grow and maintain under *ex situ* conditions and the lack of long-term commitment and sustained funding compound the struggle to sustain living collections.

Communicate. *A Guide to Begonia of Borneo* (Kiew *et al.* 2015) seeks to address the challenges associated with the identification of Bornean Begonias. It provides brief morphological descriptions, habitat information, geographical distribution, as well as notes on the potential ethnobotanical and horticultural uses. Species images constitute a major component of the book, with 134 known species represented to facilitate accurate recognition and comparison. Since then, 71 new species have been described from Sabah and Sarawak (Peng *et al.* 2015; Ling and Julia 2023).



Figure 4. (a) Begonias propagated at Botanical Research Centre (BRC) and **(b)** *B. bengohensis* rescued from Bengoh Dam and planted at BRC Garden. Photos courtesy of Julia S.

III. Sabah

Elaeocarpus pinosukii and *E. inopinatus* (Elaeocarpaceae), *Ilex mesilauensis* (Aquifoliaceae), *Melastoma maraiparaiense* (Melastomataceae), *Phyllanthus rufuschaneyi* (Phyllanthaceae), *Saurauia leopoldii* (Actinidiaceae), *Timonius clementis* (Rubiaceae), *Urophyllum lineatum* (Rubiaceae), *Symplocos trichomarginalis* (Symplocaceae), *Hedyotis protrusa* (Rubiaceae) and *Nepenthes pongoides* (Nepenthaceae)

Assess. *Elaeocarpus pinosukii* is CR and known only from a single collection from Pinosuk Plateau, outside of PA. *Elaeocarpus inopinatus* is VU; *Ilex mesilauensis* is DD; *Melastoma maraiparaiense* is VU; *Phyllanthus rufuschaneyi* is EN; *Saurauia leopoldii* is VU; *Timonius clementis* is VU and *Urophyllum lineatum* is VU.

Plan and Act. *In situ* monitoring and *ex situ* collections are established for *Phyllanthus rufuschaneyi*. Search efforts for the critically endangered *Elaeocarpus pinosukii* and data deficient *Ilex mesilauensis*, both present in single localities which have undergone significant habitat degradation, were unsuccessful, potentially heightening their extinction risks. Population surveys have been conducted for seven hyper-endemic species at Marai Parai, western Kinabalu Park and the hyper-endemic *Nepenthes pongoides* in Meliau Range.



Figure 5. (a) Vegetation at Marai Parai and **(b)** *ex situ* collection of *Phyllanthus rufuschaneyi* in the nursery at Kinabalu Park. Photos courtesy of A. Damit.

Rhododendron monkoboense and *R. tuhanense* (Ericaceae)

Assess. *Rhododendron monkoboense* is VU and restricted to the lower montane ultramafic forest. *Rhododendron tuhanensis* is also VU and restricted to the upper montane vegetation at Lipson, Mount Kinabalu, on exposed steep slope. Risks of climate change, forest fires and landslide are serious threats to both species, although their habitats are protected.

Plan and Act. The management and protection for *R. monkoboense* is outlined in the *Rhododendron monkoboense* Conservation Plan (2022–2031). Population demography and spatial distribution for both species are now known while wildings and cuttings established at the Park's nursery have been planted out at the Mount Kinabalu Botanical Garden.

Network and Communicate. This initiative was a collaboration between Sabah Forestry Department and Sabah Parks.

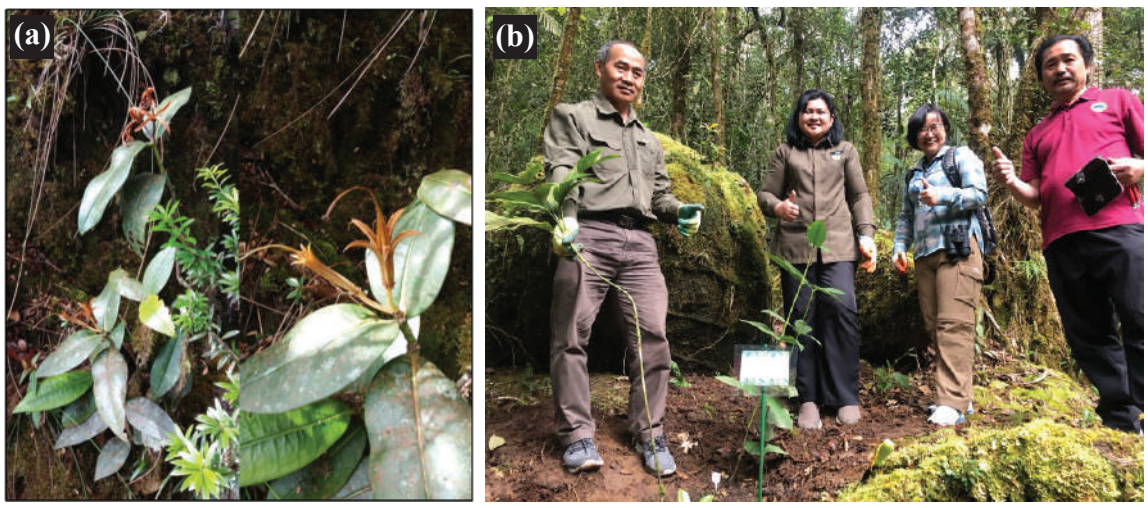

Figure 6. (a) *Rhododendron monkoboense* and **(b)** saplings planted at the Mount Kinabalu Botanical Garden. Photos courtesy of A. Damit.

REFERENCES

Ashton, P.S. 1972. The Quaternary geomorphological history of western Malesia and lowland forest phytogeography. In *The Quaternary Era in Malesia, Miscellaneous Series No. 13*. P.S. Ashton and M. Ashton (Eds), pp. 35–49. Aberdeen: Department of Geography, University of Hull.

Ashton, P.S. 2004. Dipterocarpaceae. In *Tree Flora of Sabah & Sarawak. Vol. 5*, E. Soepadmo, L.G. Saw, and R.C.K. Chung (Eds.), pp. 63–388. Kepong: Forest Research Institute Malaysia, Sabah Forestry Department & Sarawak Forestry Department.

Baker, W.J. 2015. A revised delimitation of the rattan genus *Calamus* (Arecaceae). *Phytotaxa* 197(2): 139–152. https://doi.org/10.11646/phytotaxa.197.2.7

Baldeck, C.A., Harms, K.E., Yavitt, J.B., John R., Turner, B.L., Valencia, R., Navarette, H. et al. 2013. Soil resources and topography shape local tree community structure in tropical forests. *Proceedings of the Royal Society B: Biological Sciences* 280 (1753): 20122532. https://doi.org/10.1098/rspb.2012.2532

Bernama. 2019, September 23. Malaysia adopts policies to ensure sustainable oil palm cultivation. *The Edge Malaysia*. https://theedgemalaysia.com/article/malaysia-adopts-policies-ensure-sustainable-oil-palm-cultivation

Botanic Garden Conservation International (BGCI). 2021. *State of the World's Trees*. Richmond: BGCI. 52 pp.

Bryan, J.E., Shearman, P.L., Asner, G.P., Knapp, D.E., Aoro, G. and Lokes, B. 2013. Extreme difference in forest degradation in Borneo: comparing practices in Sarawak, Sabah and Brunei. *Plos One* 8(7): e69679. https://doi.org/10.1371/journal.pone.0069679

Chai, P.P.K. and Yii, P.C. 2002. Sapotaceae. In *Tree Flora of Sabah & Sarawak. Vol. 4*, E. Soepadmo, L.G. Saw, and R.C.K. Chung (Eds.), pp. 203–345. Kepong: Forest Research Institute Malaysia, Sabah Forestry Department & Sarawak Forestry Department.

Chambi-Legoas, R., Ortega Rodriguez, D.R., Figueiredo, F.D.M.D., Peña Valdeiglesias, J., Zevallos Pollito, P.A., Marcelo-Peña, J.L. and Rother, D.C. 2021. Natural regeneration after gold mining in the Peruvian Amazon: Implications for restoration of tropical forests. *Frontiers in Forests and Global Change* 4: 594627.

Chase, M.W., Gravendeel, B., Sulistyo, B.P., Richa, K.W. and Schuiteman, A. 2021. Expansion of the orchid genus *Coelogyne* (Arethuseae; Epidendroideae) include to *Bracisepalum*, *Bulleyia*, *Chelonistele*, *Dendrochilum*, *Dickasonia*, *Entomophobia*, *Geesinkorchis*, *Gynoglottis*, *Ischnogyne*, *Nabaluia*, *Neogyna*, *Otochilus*, *Panisea* and *Pholidota*. *Phytotaxa* 510(2): 94–134. https://doi.org/10.11646/phytotaxa.510.2.1

Chen, J.H. and Wong, K.M. 2023. *Timonius* in Borneo. Kota Kinabalu: Natural History Publication.

Convention on Biological Diversity (CBD). 2022. Kunming-Montreal Global Biodiversity Framework. https://www.cbd.int/gbf

Cristescu, R.H., Frere, C. and Banks, P.B. 2012. A review of fauna in mine rehabilitation in Australia: current state and future directions. *Biological Conservation* 149: 60–72.

de Bruyn, M., Stelbrink, B., Morley, R.J., Hall, R., Carvalho, G.R., Cannon, C.H., van den Bergh, G. 2014. Borneo and Indochina are major evolutionary hotspots for Southeast Asian biodiversity. *Systematic Biology* 63(6): 879–901. https://doi.org/10.1093/sysbio/syu047

de Wilde, W.J.J.O. 2000. Myristicaceae. In *Tree Flora of Sabah & Sarawak. Vol. 3*, E. Soepadmo, L.G. Saw (Eds.), pp. 335–473. Kepong: Forest Research Institute Malaysia, Sabah Forestry Department & Sarawak Forestry Department.

de Wilde, W.J.J.O. and Duyfjes, B.E.E. 1999. *Bayabusua*, a new genus of Cucurbitaceae. *Sandakania* 13: 1–16.

FAO. 1973. A National Forest Inventory of West Malaysia 1970–1972. Rome: FAO & UNDP.

FAO. 2025. Global Forest Resources Assessment 2025 Report: Malaysia. Rome: FAO.

Forest Department Peninsular Malaysia. 2016. Forestry Statistics. https://www.forestry.gov.my/en/2016-06-07-02-53-46/2016-06-07-03-12-29

Forest Department Sarawak. 2025. Heart of Borneo (HoB) Initiative. https://forestry.sarawak.gov.my/web/subpage/webpage_view/993

Garate-Quispe, J., Velásquez Ramírez, M., Becerra-Lira, E., Baez-Quispe, S., Abril-Surichaqui, M., Rodriguez-Achata, L., Munoz-Ushnahua, A. *et al.* 2023. Influence of distance from forest edges on spontaneous vegetation succession following small-scale gold mining in the Southeast Peruvian Amazon. *Diversity* 15: 793.

Garate-Quispe, J., Herrera-Machaca, M., Pareja Auquipata, V., Alarcón Aguirre, G., Baez Quispe, S. and Carpio-Vargas, E.E. 2024. Resilience of aboveground biomass of secondary forests following the abandonment of gold mining activity in the Southeastern Peruvian Amazon. *Diversity* 16(4): 233.

Gatti, R.C., Reich, P.B., Gamarra, J.G.P., Crowther, T., Hui, C., Morera, A., Bastin, J. *et al*. 2022. The number of tree species on Earth. *Proceedings of the National Academy of Sciences of the United States of America* 119(6): e2115329119. https://doi.org/10.1073/pnas.2115329119

Gaveau, D.L.A., Sheil, D., Yaen, H., Salim, M.A., Arjasakusuma, S., Ancrenaz, M., Pacheco, P. and Meijaard, E. 2016. Rapid conversions and avoided deforestation: examining four decades of industrial plantation expansion in Borneo. *Scientific Reports* 6: 32017. https://doi.org/10.1038/srep32017

Henderson, A. 2020. A revision of *Calamus* (Arecaceae, Calamoideae, Calameae, Calaminae). *Phytotaxa* 445: 1–656. https://doi.org/10.11646/phytotaxa.445.1.1

Hughes, A.C. 2017. Understanding the drivers of Southeast Asian biodiversity loss. *Ecosphere* 8(1): e01624. https://doi.org/10.1002/ecs2.1624

IPBES. 2018. The IPBES regional assessment report on biodiversity and ecosystem services for Asia and the Pacific, M. Karki, S. Senaratna Sellamuttu, S. Okayasu, and W. Suzuki (Eds). Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). 612 p.

IPBES. 2022. Summary for policymakers of the methodological assessment regarding the diverse conceptualization of multiple values of nature and its benefits, including biodiversity and ecosystem functions and services (assessment of the diverse values and valuation of nature). Bonn: Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

IPNI. 2025. International Plant Names Index. http://www.ipni.org

IUCN. 2025a. IUCN Green List of Protected and Conserved Areas. *International Union for Conservation of Nature and Natural Resources*. https://iucn.org/resources/conservation-tool/iucn-green-list-protected-and-conserved-areas

IUCN. 2025b. OECMs. *International Union for Conservation of Nature and Natural Resources*. https://iucn.org/our-work/topic/effective-protected-areas/iucns-work-30x30/oecms

Joppa, L.N., Roberts, D.L., Myers, N. and Pimm, S.L. 2011. Biodiversity hotspots house most undiscovered plant species. *Proceedings of the National Academy of Sciences* 108(32): 13171–13176. https://doi.org/10.1073/pnas.1109389108

Khoo, E., Tsen, S.T.L., Lee, Y.L., Sugau, J.B., Pereira, J.T., Nilus, R. and Maycock, C.R. 2022. *The Sabah Plant Red List of Dipterocarpaceae*. Kota Kinabalu: Sabah Forestry Department. 223 p.

Kiew, R., Chung, R.C.K., Saw, L.G. and Soepadmo, E. 2010. Seed plant families in Peninsular Malaysia. In *Flora of Peninsular Malaysia. Series II: Seed Plants, Vol. 1*, R. Kiew, R.C.K. Chung, L.G. Saw, E. Soepadmo, and P.C. Boyce (Eds.), pp. 10. Kepong: Forest Research Institute Malaysia.

Kiew, R., Sang, J., Rimi, R. and Joffre, A.A. 2015. *A Guide to Begonias of Borneo*. Kota Kinabalu: Natural History Publications. 293 p.

Kiew, R., Julia, S. and Ling, C.Y. 2016. The *Calcarea* group of *Begonia* (Begoniaceae) from Borneo, including four new species from Sarawak. *Gardens' Bulletin Singapore* 68(2): 239–225.

Kochummen, K.M. 1994. New species of Burseraceae from Sabah and Sarawak. *Sandakania* 5: 73–91.

Kochummen, K.M. 1996. New species of Anacardiaceae and a new variety of *Parishia maingayi* from Sabah and Sarawak. *Sandakania* 7: 81–111.

Lamb, I.P., Massam, M.R., Mills, S.C., Bryant, R.G. and Edwards, D.P. 2024. Global threats of extractive industries to vertebrate biodiversity. *Current Biology* 34(16): 3673–3684.

Ling, C.Y. and Julia, S. 2023. Additions to the *Begonia* flora of Sarawak, Borneo, II: *Begonia* species from Long Banga and Tama Abu Permanent Forest, Sarawak including four new species. *Sandakania* 24: 1–16.

Low, S.L., Wong, S.Y. and Boyce, P.C. 2018. Naming the chaos: generic redelimitation in Schismatoglottideae (Araceae). *Webbia* 73(1): S1–S100. https://doi.org/10.1080/00837792.2017.1409940

Majer, J.D. 2014. Mining and biodiversity: Are they compatible?. In *Resource Curse or Cure? CSR, Sustainability, Ethics & Governance*, M. Brueckner, A. Durey, R. Mayes and C. Pforr (Eds.). Berlin: Springer. https://doi.org/10.1007/978-3-642-53873-5_13

Ministry of Energy and Natural Resources (KeTSA). 2021. *Kerangka Pelan Transformasi Industri Mineral Negara 2021–2030*. Putrajaya: Ministry of Energy and Natural Resources. 62 p.
Ministry of Natural Resources and Environment (NRE). 2009. *National Mineral Policy 2*. Putrajaya: Ministry of Natural Resources and Environment, Malaysia. 28 p.
Ministry of Natural Resources and Environment (NRE). 2016. *National Policy on Biological Diversity 2016–2025*. Putrajaya: Ministry of Natural Resources and Environment, Malaysia. 87 p.
Ministry of Natural Resources, Environment and Climate Change (NRECC). 2022. *National Policy on Biological Diversity 2022–2030*. Ministry of Natural Resources, Environment and Climate Change Malaysia. 101 p.
Ministry of Natural Resources and Environmental Sustainability (NRES). 2024. *Kerangka Dasar Mineral Negara 3*. Putrajaya: Ministry of Natural Resources and Environmental Sustainability, Malaysia.
Ministry of Science, Technology and the Environment (MoSTE). 1998. *National Policy on Biological Diversity 1998*. Putrajaya: Ministry of Science, Technology and the Environment, Malaysia 38 p.
Neo, L., Wong, K.M. and Tan, H.T.W. 2020. A synopsis of the endemic plant genera of Borneo. *Nordic Journal of Botany* 38(9): e02871. https://doi.org/10.1111/njb.02871
O'Byrne, P. and Gokusing 2015. *Kipandiorchis* (Orchidaceae). *Malesian Orchid Journal* 16: 5–9.
Peng, C.I., Lin, C-W, Repin, R., Kono, Y., Leong, W-C. and Chung, K-F. 2015. Two new species of *Begonia*, *B. moneta* and *B. peridoticola* (Begoniaceae) from Sabah, Malaysia. *Botanical Studies* 56: Article 7. https://doi.org/10.1186/s40529-015-0087-5
PLANMalaysia. 2022. *Pelan Induk Rangkaian Ekologi Central Forest Spine (PIRECFS) 2022*. Putrajaya: Jabatan Perancangan Bandar dan Desa (PLAN Malaysia), Kementerian Perumahan dan Kerajaan Tempatan. 606 p.
Potts, M.D., Ashton, P.S., Kaufman, L.S. and Plotkin, J.B. 2002. Habitat patterns in tropical rain forests: A comparison of 105 plots in northwest Borneo. *Ecology* 83: 2782–2797. https://doi.org/10.2307/3072015
Prance, G.T. 2012. Lecythidaceae. In *Flora of Peninsular Malaysia, Series II: Seed Plants, Vol. 3*, R. Kiew, R.C.K. Chung, L.G. Saw and E. Soepadmo (Eds.), pp. 173–217. Kepong: Forest Research Institute Malaysia.
Raes, N. 2009. *Borneo: A quantitative analysis of botanical richness, endemicity and floristic regions based on herbarium records*. Leiden: National Herbarium Nederlands. 144 p.
Rimi, R., Sang, J.,Kiew, R. and Mujih, H. 2015. Eleven new species of *Begonia* (Begoniaceae) from the Crocker Range, Sabah, Malaysia. *Phytotaxa* 208(1): 1–30.
Rodrigues, A.S.L, Pilgrim, J.D., Lamoreux, J.F., Hoffmann, M. and Brooks, T.M. 2006. The value of the IUCN Red List for conservation. *Trends in Ecology and Evolution* 21(2): 71–76. https://doi.org/10.1016/j.tree.2005.10.010
Rodríguez, J.P., Balch, J.K. and Rodríguez-Clark, K.M. 2007. Assessing extinction risk in the absence of species-level data: quantitative criteria for terrestrial ecosystems. *Biodiversity Conservation* 16: 183–209. https://doi.org/10.1007/s10531-006-9102-1
Royal Botanic Gardens, Kew. 2025. World Checklist of Vascular Plants. *Plants of the World Online*. [Accessed on 7 October 2025 for Orchidaceae, Dipterocarpaceae, Begoniaceae, *Calamus* (Arecaceae), *Timonius* (Rubiaceae) of Borneo and Malaya]. https://checklistbuilder.science.kew.org/reportbuilder.do
Russo, S.E., Davies, S.J., King, D.A. and Tan, S. 2005. Soil-related performance variation and distributions of tree species in a Bornean rain forest. *Journal of Ecology* 93: 879–889. https://doi.org/10.1111/j.1365-2745.2005.01030.x
Sang, J. and Soepadmo, E. 1998. New species and new record of *Lithocarpus* Bl. (Fagaceae) from Sabah and Sarawak, Malaysia. *Gardens' Bulletin Singapore* 50: 125–150.
Saw, L.G. 2020. Ten new species of *Polyosma* (Escalloniaceae) from Borneo. *Phytotaxa* 471(2): 93–112. https://doi.org/10.11646/phytotaxa.471.2.1
Saw, L.G. and Chung, R.C.K. 2005. Towards the Flora of Malaysia. In *Status of Biological Diversity in Malaysia and Threat Assessment of Plant Species in Malaysia*, L.S.L. Chua, L.G. Kirton and L.G. Saw (Eds.), pp. 211–227. Proceedings of the Seminar and Workshop 28–30 June 2005. Kepong: Forest Research Institute Malaysia.
Szlachetko, D.J. 1995. *Jejewoodia*. *Fragmenta Floristica et Geobotanica. Supplementum* 3: 135.

Turner, I.M., Weerasooriya, A.D., Saunders, R.M.K. and Ganesan, S.K. 2014. Annonaceae. In *Tree Flora of Sabah & Sarawak. Vol. 8*, E. Soepadmo, L.G. Saw, R.C.K. Chung and R. Kiew (Eds.), pp. 1–200. Kepong: Forest Research Institute Malaysia, Sabah Forestry Department & Sarawak Forestry Department.

UNEP-WCMC. 2022. Protected Area Profile for Malaysia from the World Database of Protected Areas. *Protected Planet*. https://www.protectedplanet.net/en/country/MYS

UNEP-WCMC and IUCN 2021. Protected Planet: The World Database on Protected Areas (WDPA). https://www.protectedplanet.net

Utteridge, T., Nagamasu, H., Teo, S.P., White, L.C. and Gasson, P. 2005. *Sleumeria* (Icacinaceae): A new genus from northern Borneo. *Systematic Botany* 30(3): 635–643.

Wong, K.M. 2011. A biogeographic history of Southeast Asian rainforests. In *Managing the Future of Southeast Asia's Valuable Tropical Rainforests*, R. Wickneswari and C. Cannon (Eds). *Advances in Asian Human-Environmental Research, Vol 2*. Dordrecht: Springer. https://doi.org/10.1007/978-94-007-2175-3_2

Wong, S.Y. and Boyce, P.C. 2010. Studies on Schismatoglottideae (Araceae) of Borneo XI: *Ooia*, a new genus, and a new generic delimitation for *Piptospatha*. *Botanical Studies* 51: 543–552.

Yang, G., Crowther, T.W., Lauber, T., Zohner, C.M. and Smith, G.R. 2025. A globally consistent negative effect of edge on aboveground forest biomass. *Nature Ecology & Evolution* 9: 2036–2045. https://doi.org/10.1038/s41559-025-02840-2

Yao, T.L. 2013. Nine new species of *Thottea* (Aristolochiaceae) in Peninsular Malaysia and Singapore, with two taxa in Peninsular Malaysia redefined and a taxon lectotypified. *Blumea* 58: 245–262.

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CHAPTER 15

Conservation and sustainable utilisation of root crop genetic resources: The case of sweet potato, cassava and underutilised tuber species in Malaysia

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Abstract: Root and tuber crops play an important role in Malaysia's agricultural landscape by contributing to food security, rural livelihoods, and agrobiodiversity conservation. Among these crops, sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*) are widely cultivated due to their adaptability to diverse environments, low input requirements, and multiple food and industrial uses. In addition, several underutilised tuber species possess unique genetic traits and nutritional values that remain largely untapped. The increasing challenges posed by climate change, agricultural intensification, urbanisation, and the replacement of traditional varieties with commercial cultivars have heightened the risk of genetic erosion, threatening valuable plant genetic resources. This chapter reviews the current status of root crop genetic resources in Malaysia, with particular emphasis on sweet potato, cassava, and selected underutilised tuber species. It examines their diversity, cultural and economic significance, and the contribution of local landraces and farmer-managed varieties to agricultural resilience. The chapter further discusses major threats to genetic resources and highlights conservation strategies implemented through *ex situ* and *in situ* approaches, including the role of national germplasm collections and community-based conservation efforts. Recent advances in breeding and genetic improvement programmes aimed at enhancing yield, nutritional quality, and tolerance to biotic and abiotic stresses are also presented. Finally, the chapter outlines key challenges and opportunities for sustainable utilisation and proposes policy recommendations to strengthen the conservation, management, and future use of root crop genetic resources in Malaysia.

INTRODUCTION

Root and tuber crops have been part of Malaysia's agricultural heritage for generations. While rice remains the country's main staple food crop, sweet potato (*Ipomoea batatas*) and cassava (*Manihot esculenta*) continue to play significant roles in complementing household diets, supporting rural livelihoods, and contributing to local food cultures (Bradshaw 2010). These crops are often grown in smallholdings, village backyards, mixed farms, and semi-commercial estates, reflecting their versatility and adaptability (Best *et al.* 2006; Ngongo *et al.* 2022). Sweet potato, or locally known as *keledek*, is favoured for its quick growth cycle and wide culinary uses, from traditional *kuih* (pastries) to savory dishes. Cassava (*ubi kayu*), once seen as a survival crop, has risen in importance due to its economic value. It is used in *keropok* (crackers), starch processing, animal feed, and even emerging food industries targeting gluten-free ingredients and functional foods.

Their resilience makes these crops strategic assets for Malaysia's food security. Sweet potato and cassava tolerate poor soils, require minimal inputs, and have a natural ability to withstand short droughts, making them well-suited for climate-uncertain periods. These strengths highlight why genetic conservation and sustainable utilisation of these crops are vital for Malaysia's long-term agricultural development (Sapakhova *et al.* 2023; Abraham *et al.* 2025).

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This paper provides an overview of the current status of sweet potato and cassava genetic resources in Malaysia. It examines their diversity, highlights threats to their survival, and discusses conservation efforts led by researchers and local communities. The chapter also presents real-world insights from farmers and proposes policy recommendations to guide future work in conservation and sustainable use.



Figure 1. Left: Sweet potato (*Ipomoea batatas*); **Right:** Cassava (*Manihot esculenta*).

AGRO-BIODIVERSITY OF SWEET POTATO AND CASSAVA IN MALAYSIA

Historical roots and cultural significance

Sweet potatoes and cassava have been cultivated in Malaysia for centuries. Sweet potato is believed to have arrived during early trade routes, while cassava was introduced during colonial times. Over decades, both crops blended into local food cultures. Sweet potato is widely used in *Bubur Cha Cha*, *kuih keria*, and numerous village snacks.

Cassava, on the other hand, is central to dishes such as *tapai* (fermented cassava), *bingka ubi*, and a range of traditional cakes. In Sabah and Sarawak, cassava carries deep cultural significance. Indigenous communities cook cassava leaves as a vegetable, pound them into greens, or use them in traditional stews. These uses demonstrate how these crops are embedded in local identities and food sovereignty.

A Landscape of Rich Diversity

Malaysia's smallholders maintain an impressive range of sweet potato and cassava varieties. These "landrace" varieties are maintained by farmers over many generations and each have different colours, shapes, flavours, and cooking characteristics. In Kelantan, farmers identify sweet potato varieties by their tuber colour: purple, orange, deep yellow, or creamy white. Each colour is associated with a specific taste or culinary use—purple flesh for desserts, orange flesh for its sweetness and nutritional value, and yellow flesh for frying or steaming. Cassava varieties also differ in tuber shape, skin thickness, fiber content, and starch quality. Some varieties are preferred for 'keropok' processing due to their starch levels, while others are chosen for home cooking because of their soft texture.

Scientific evaluations conducted by MARDI have confirmed that this diversity goes beyond outward appearance. Morphological assessments and molecular studies reveal substantial differences in growth habits, disease tolerance, nutrient content, and adaptation to soil types. Such diversity forms the foundation for future crop improvement, especially in responding to climate change.

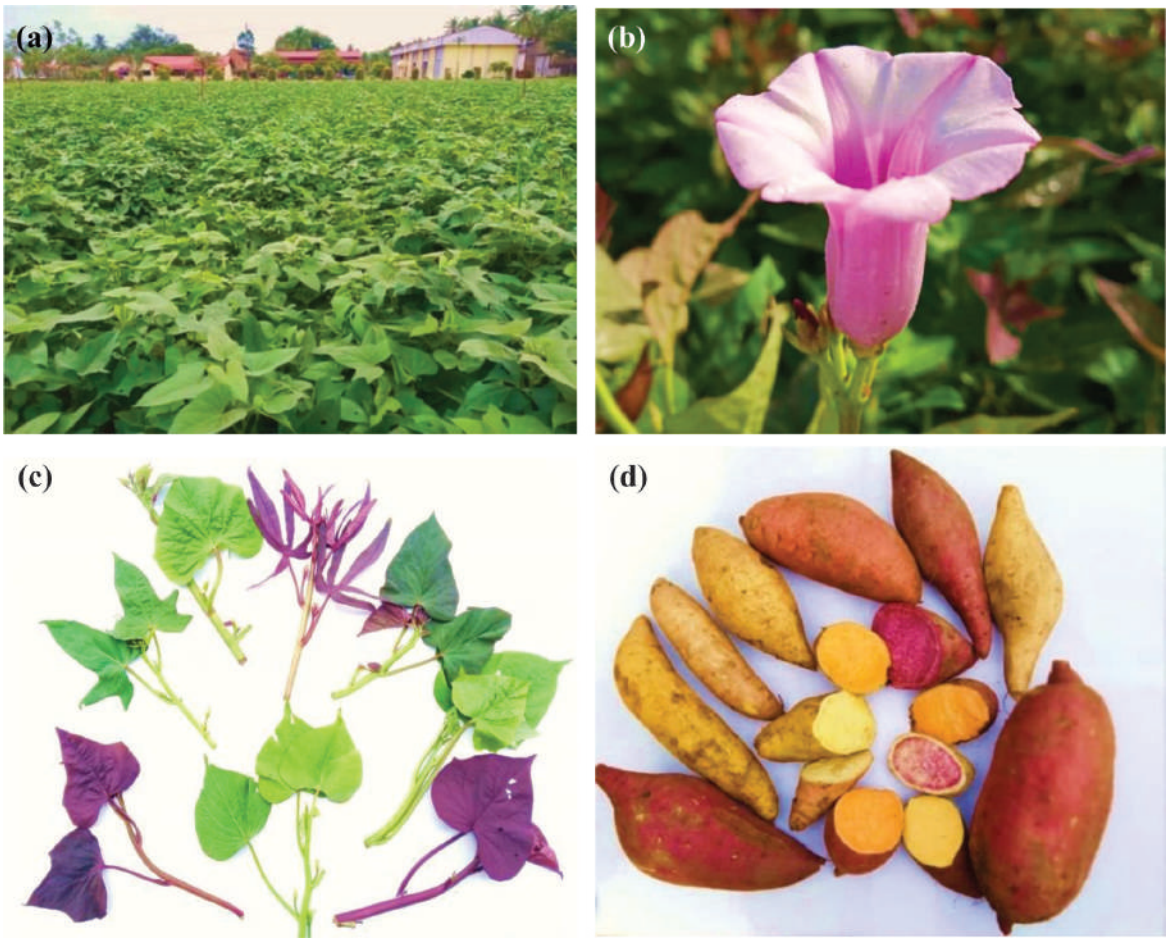

Figure 2. Morphology of the sweet potato **(a)** plant, **(b)** flower, and the variations of **(c)** leaves and **(d)** tubers cultivated at MARDI Bachok, Kelantan

THE IMPORTANCE OF CROP WILD RELATIVES OF UNDERUTILISED TUBER SPECIES OF MALAYSIA

Crop Wild Relatives (CWRs)—that is wild species which are related to modern crops—are a critical repository of traits such as drought tolerance, natural pest resistance, or enhanced nutrient content. While many farmers are unfamiliar with CWRs, researchers view them as vital sources for breeding new varieties. Protecting these wild species requires preserving forests, landscapes, and mixed farming areas where they naturally occur.

Among these, wild yams (*Dioscorea*), comprising more than 600 species within the Dioscoreaceae (Amanze *et al.* 2011; Kumar *et al.* 2017)), represent one of the most taxonomically diverse groups of monocotyledonous tuber crops worldwide. Globally, yam ranks as the fourth most important root and tuber crop after potato, cassava, and sweet potato, contributing approximately 10% of total root and tuber production (Viruel *et al.* 2016). Beyond its economic value, yam serves as a critical subsistence and famine food, particularly for smallholder farmers and forest-dependent communities during periods of food scarcity (Anuar *et al.* 2023). Nevertheless, compared with other major staple crops, yam remains relatively under-researched and under-utilised.



(a) *Ubi badak* (*Dioscorea alata*)



(b) *Ubi nasi* (*Dioscorea esculenta*)



(c) *Ubi angin* (*Dioscorea bulbifera*)



(d) *Ubi sarek* (*Amorphophallus paeniifolius*)



(e) *Ubi kemili* (*Plectranthus rotundufolius*)



(f) *Keladi seratah* (*Xanthosoma sagittifolium*)

Figure 3. Minor root crops, occasionally known as neglected root crops, include yams (*Dioscorea* and *Amorphophallus*) and edible aroids (*Plectranthus*, *Colocasia*, and *Xanthosoma*), which can be found across Malaysia.

Despite their recognised nutritional advantages—including appreciable protein content, balanced essential amino acids, and essential minerals (Shajeela *et al*. 2011; Baah *et al.* 2009)—wider utilisation of Dioscorea species is constrained by anti-nutritional` compounds and inconsistent tuber quality traits across taxa. Importantly, the extensive diversity present in wild yam species remains insufficiently characterised at the phenotypic, biochemical, and molecular levels. Many wild taxa continue to function as traditional food resources among indigenous and rural communities; systematic evaluation of their nutritional composition, phytochemical profiles, and agronomic performance however is still lacking.

Similar knowledge gaps are evident in other wild tuberous genera found in Malaysia, including *Amorphophallus*, *Xanthosoma* (Araceae) and *Plectranthus* (Lamiaceae). Several species of *Amorphophallus* (*ubi gajah*, *ubi sarek*) possess high starch content and industrial potential, yet remain under-utilised. Likewise, tuber-forming *Plectranthus* (*ubi kemili*) species, some of which are traditionally consumed or used medicinally, have received limited scientific attention regarding their nutritional quality, anti-nutritional factors, and genetic diversity. The absence of integrated morphological, biochemical, and molecular studies across these wild tuber taxa restricts their incorporation into breeding programmes, domestication strategies, and value-chain development.

More critically, inadequate understanding of population structure and genetic diversity across wild yam and other tuber species has contributed to genetic erosion, particularly under pressures from land-use change and habitat fragmentation. The limited deployment of molecular markers, genomic tools, and pre-breeding frameworks further constrains the identification and utilisation of superior genotypes carrying traits for nutritional enhancement, abiotic stress tolerance, and climate resilience (Arnau *et al.* 2017).

A concerted evaluation effort of wild tuber species in Malaysia including *Dioscorea*, *Amorphophallus*, *Xanthosoma* and *Plectranthus* is therefore urgently required. Integrating ethnobotanical knowledge with nutritional, anti-nutritional, phytochemical, and molecular characterisation would unlock their bio-prospecting potential for food and pharmaceutical industries while strengthening conservation and pre-breeding strategies. Addressing these gaps is essential to safeguard genetic resources and to reposition wild tubers as strategic components of future food and nutritional security frameworks under changing climatic and socio-economic conditions.

THREATS TO GENETIC RESOURCES

Land use change and habitat loss

Malaysia's rapid development has reshaped landscapes nationwide. Agricultural land is being converted into housing, industrial zones, highways, and large-scale plantations. As a result, areas traditionally cultivated with diverse root crops are shrinking. When small farms close or shift to new crops, unique varieties may be lost forever.

Urbanisation and decline of home gardens

Home gardens historically served as living collections of crop diversity. Many families maintained several varieties of sweet potato or cassava for household consumption. Today, however, younger generations tend to migrate to urban centers, leaving fewer people to maintain these gardens. Without new caretakers, many traditional landraces face extinction.

Erosion of traditional knowledge

Local farmers, especially the elderly, possess rich knowledge about planting materials, soil preferences, pest management, and seasonal planting cycles. This information is rarely documented. As older farmers retire, this knowledge may disappear unless captured through community documentation or collaborative projects.



Figure 4. Traditional cassava varieties cultivated for generations by a small group of farmers in Kampung Siburan, Sarawak.

Climate variability and its impacts

Increasingly unpredictable weather patterns pose new challenges. Farmers in Kelantan and Sabah report more frequent dry spells, sudden heavy rains, and pest outbreaks. Some landraces that once thrived under stable climates now struggle to produce consistent yields.

Cassava, known for drought tolerance, has shown signs of stress under prolonged heat waves, while sweet potato varieties that prefer moist soils may not survive extended drought periods. Emerging diseases—especially viral infections—can rapidly spread and wipe out susceptible varieties.

Case study 1: *Local Voices from Kelantan*

During a field visit in Bachok, farmers shared stories of how their preferred *keledek* varieties have changed over time.

Pak Hassan, a 62-year-old farmer, recalled:

"*Dulu, keledek oren ni senang hidup. Sekarang, cuaca lain, serangan serangga pun banyak. Kena tanam beberapa jenis, mana tahu yang mana boleh tahan*."

("In the past, orange sweet potato grew easily. Now the climate is different, and pest attacks are more frequent. We must plant several varieties because we don't know which ones will survive.")

His statement reflects a broader trend observed across Malaysia: maintaining diversity is a must-do conservation strategy.

CONSERVATION STRATEGIES

***Ex situ* conservation: Safeguarding diversity off-site**

Ex situ conservation involves preserving plant genetic materials outside their natural environment. MARDI plays a central role through:

- Field gene banks where living plants are grown and maintained.
- Tissue culture collections holding clean, disease-free plantlets.

These collections ensure survival of genetic resources even when field conditions change or disasters occur. *Ex situ* collections also support research such as variety testing, pest resistance screening, and breeding.



Figure 5. Sweet potato conservation at MARDI Bachok, Kelantan. Germplasm collections are planted in microplots, with vine cuttings transferred every two weeks.



Figure 6. Tissue culture of traditional and commercial varieties of sweet potato and cassava carried out at the Tissue Culture Laboratory, Agrobiodiversity and Environment Research Centre, MARDI Serdang, Selangor.

In situ and on-farm conservation: Protecting diversity where it grows

In situ conservation keeps plants in their original or traditional environments. This method helps preserve not only the plants but also the ecosystem interactions and farming knowledge that sustain them. On-farm conservation, where farmers actively grow multiple varieties, has proven especially effective. In Sabah, smallholders maintain diverse cassava types for food, feed, and cultural practices. In Sarawak, community seed exchange remains common, ensuring planting materials circulate widely among villages.

Community participation and traditional knowledge

Successful conservation efforts rely on valuing farmers' contributions. Traditional knowledge about which landraces are drought-tolerant, which resist pests, or which varieties are best for certain recipes is crucial for selecting varieties worth conserving.Programs involving community workshops, farmer field schools, and shared trials strengthen these connections. Recognising and documenting farmer knowledge through video interviews, community booklets, or digital archives helps preserve local wisdom.

CHALLENGES TO EFFECTIVE CONSERVATION

Key challenges include:

- Limited funding for genebank maintenance
- Threats from pests, diseases, and extreme weather
- Labor needed for regenerating planting materials
- Limited incentives for farmers to maintain traditional varieties
- Gaps in policies governing genetic resources and benefit sharing
- Addressing these challenges requires coordinated, long-term commitments.

Genetic improvement and breeding programs

Developing improved and mutant lines

Malaysia continues to develop improved varieties of sweet potato and cassava to support farmers and industries. Breeding programmes use conventional selection, controlled crossing, and mutation breeding, where genetic variation is induced using gamma radiation. These approaches have produced high-yielding, pest-resilient, and nutritionally enhanced lines. For instance, orange-fleshed sweet potato varieties rich in vitamin A have gained popularity due to their health benefits.

Traits Targeted for National Priorities

Sweet potatoes rich in natural antioxidants (e.g., purple-fleshed varieties) and cassava with improved starch quality offer promising commercial opportunities. Therefore, breeding focuses on traits that address Malaysia's needs:

- High and stable yields
- Resistance to major pests and diseases
- Drought and soil tolerance
- Enhanced starch content for industry

Using local germplasm to strengthen breeding

Local landraces are crucial resources because they possess traits adapted to Malaysian conditions. Integrating these varieties into breeding broadens the genetic base and ensures future crops can withstand new challenges.

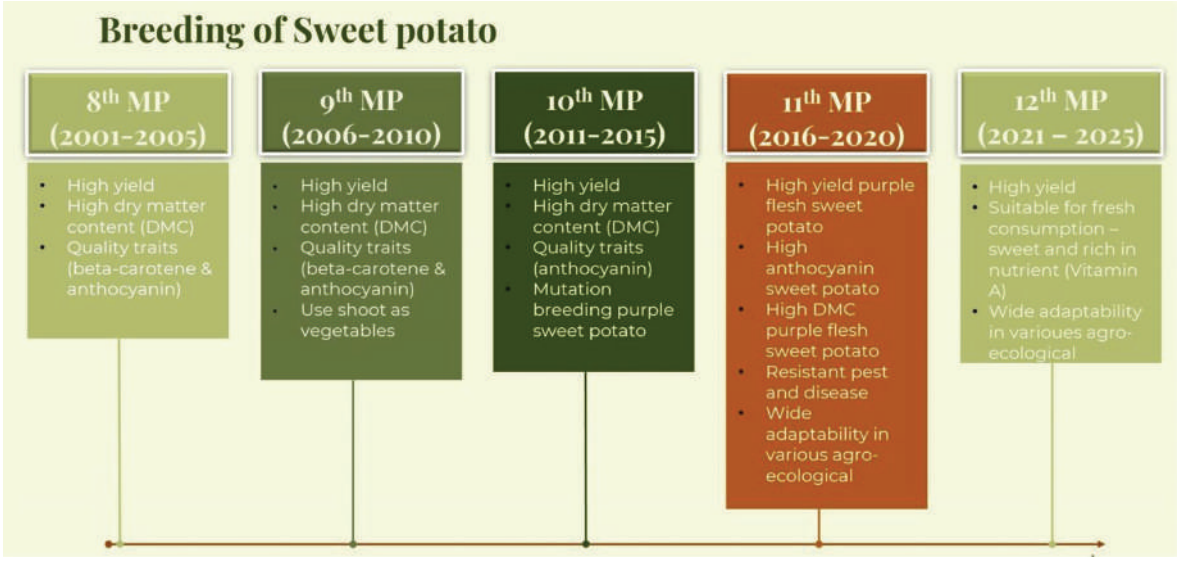

Figure 7. The diagram shows the objective of sweet potato breeding at MARDI which focuses on developing high-yield, nutrient-rich varieties that are adaptable to various agroecological conditions.

Case study 2: ***Farmer–Researcher Partnership in Sabah***

In Kota Belud, a collaborative trial between researchers and local farmers evaluated new cassava lines. While researchers emphasized yield and disease tolerance, farmers prioritised taste, cooking quality, and storage ability.

One farmer, Puan Mary, explained:

"*Ubi yang tahan simpan dan sedap rebus penting bagi kami. Bukan setakat hasil banyak.*"

("Cassava that stores well and tastes good when boiled is important to us. It's not just about high yield.")

This experience underscores the need to include farmer preferences early in breeding programmes.

CONCLUSION AND POLICY RECOMMENDATIONS

Sweet potato and cassava genetic resources hold immense potential for Malaysia's future. They support food security, rural livelihoods, and climate resilience while offering opportunities for new industries. To strengthen conservation and sustainable utilisation, the following policy actions are recommended:

- Develop a national strategy for root crop genetic resources, integrating research, extension, and community participation.
- Support on-farm conservation through incentives, community seed networks, and farmer -led documentation.

- vStrengthen *ex situ* collections with secure funding, upgraded facilities, and advanced technologies like cryopreservation.
- Promote participatory breeding so that new varieties meet farmers' real needs and preferences.
- Encourage local processing industries to utilise diverse varieties, creating market demand that supports conservation.
- Integrate root crops into national food security planning, especially as climate-resilient alternatives to water-demanding crops.
- Recognise and reward traditional knowledge holders, ensuring their skills continue across generations.

By combining scientific innovation, farmer expertise, and strong policies, Malaysia can safeguard its rich root crop heritage while unlocking new opportunities for sustainable agriculture.

REFERENCES

Abraham, W.B., Thomas, T.T. and Mamush, M. 2025. Cassava in focus: A comprehensive literature review, its production, processing landscape, and multidimensional benefits to society. *Food Chemistry Advances* 7(1): 100945. https://doi.org/10.1016/j.focha.2025.100945

Amanze, N.J., Agbo, N.J., Eke-Okoro, O.N. and Njoku, D.N. 2011. Selection of yam seeds from open pollination for adoption in yam (*Dioscorea rotundata* Poir) production zones in Nigeria. *Journal of Plant Breeding and Crop Science* 3(4): 68–73.

Anuar, S.N., Mohd Salim, J., Nikong, D., Ab Manaf, N., Sanusi, N.A., Omar, K. and Tengku Mohamad, T.R. 2023. Traditional ecological knowledge of wild tubers used by the Orang Asli Bateq Tribe on the East Coast of Peninsular Malaysia. *Malaysian Applied Biology* 52(5): 1–10. https://doi.org/10.55230/mabjournal.v52i5.co6

Arnau G., Bhattacharjee R., Sheela, M. N., Chair, H., Malapa, R., Lebot, V., Abraham, K. *et al.* 2017. Understanding the genetic diversity and population structure of yam (*Dioscorea alata* L.) using microsatellite markers. *PloS One* 12(3) : 1–17. https://doi.org/10.1371/journal.pone.0174150

Baah, F.D., Maziya-Dixon, B., Asiedu, R., Oduro, I. and Ellis, W.O. 2009. Nutritional and biochemical composition of *D. alata* (*Dioscorea* spp.) tubers. *Journal of Food, Agriculture, and Environment* 7(2) : 373–378.

Best, R., Westby, A. and Ospina, B. 2006. Linking small-scale cassava and sweet potato farmers to growth markets: experiences, lessons and challenges. *Acta Horticulturae* 703: 39–46. https://doi.org/10.17660/ActaHortic.2006.703.3

Bradshaw, J.E. 2010. *Root and Tuber Crops*. New York: Springer New York.

Kumar, S., Das, G., Shin, H.S. and Patra, J.K. 2017. *Dioscorea* spp. (a wild edible tuber): A study on its ethnopharmacological potential and traditional use by the local people of Similipal Biosphere Reserve, India. *Frontiers in Pharmacology* 8(52): 1–17. https://doi.org/10.3389/fphar.2017.00052

Ngongo, Y., Basuki, T., deRosari, B., Mau, Y.S., Noerwijati, K., daSilva, H., Sitorus, A. *et al.* 2022. The roles of cassava in marginal semi-arid farming in East Nusa Tenggara, Indonesia. *Sustainability* 14(9): 5439. https://doi.org/10.3390/su14095439

Sapakhova, Z., Raissova, N., Daurov, D., Zhapar, K., Daurova, A., Zhigailov, A., Zhambakin, K. and Shamekova, M. 2023. Sweet potato as a key crop for food security under the conditions of global climate change: A review. *Plants* 12(13): 2516. https://doi.org/10.3390/plants12132516

Shajeela, P.S., Mohan, V.R., Jesudas, L.L. and Soris, P.T. 2011. Nutritional and antinutritional evaluation of wild yam (*Dioscorea* spp.). *Tropical and Subtropical Agroecosystems* 14(2): 723–730.

Viruel, J., Segarra-Moragues, J.G., Raz, L., Forest, F., Wilkin, P., Sanmartín, I., and Catalán, P. 2016. Late Cretaceous-Early Eocene origin of yams (*Dioscorea*, Dioscoreaceae) in the Laurasian Palaearctic and their subsequent Oligocene-Miocene diversification. *Journal of Biogeography* 43(4) : 750–762. https://doi.org/10.1111/jbi.12678

State of Nature Conservation in Malaysia 2025, 183–197
doi: 10.62613/sonc2025.v1flc16

CHAPTER 16

Conservation status and strategic management of Aroids (Araceae) in Peninsular Malaysia

ZULHAZMAN, H.

Abstract: Araceae Juss. is one of the most diverse and ecologically important plant families in the humid tropics, with Peninsular Malaysia recognised as one of the major centerscentre of its diversity. This chapter reviews the current knowledge on the distribution, ecology, conservation status and economic potential of Araceae. A total of 146 species representing 28 genera are recorded in Peninsular Malaysia, including numerous endemics closely associated with distinct geological substrates such as granite, limestone, peat, and alluvial soils. Species richness is strongly influenced by climatic and edaphic factors, with the highest diversity occurring in lowland to hill dipterocarp forests, particularly in gallery wet forest habitats along streams and on steep slopes. Geological variation further contributes to microhabitat specialisation, leading to the emergence of localised endemics within limestone and granitic landscapes, and rheophytic environments. Despite their ecological significance, many Araceae remain vulnerable to habitat loss from logging, land conversion, and repeated forest disturbance. Conservation efforts for the family remain relatively limited and are largely directed toward economically important edible species, such as *Colocasia esculenta* and *Amorphophallus paeoniifolius*, while the broader diversity of wild ornamental, medicinal, and endemic taxa receives comparatively little attention. This review highlights the need for integrated conservation strategies that combine *in situ* and *ex situ* approaches, enhanced botanical inventories, hotspot identification, and collaborative efforts between agencies, research institutions, and local communities. Additionally, 41 species were identified with economic potential, emphasising the family's value for ornamental, horticultural, traditional medicine, and food resources. Overall, this synthesis underscores the importance of safeguarding Araceae diversity in Peninsular Malaysia and the opportunities for developing sustainable bioeconomic activities based on this unique plant family.

INTRODUCTION

Araceae Juss., commonly known as aroids, familiarly referred to by locals as *keladi*, is a unique family of plants characterised by having a single petal-like structure called the spathe, which encloses a central inflorescence known as the spadix (Bown 2000). The floral structure is termed an inflorescence rather than a flower because the true flowers are extremely small and arranged along the entire length of the spadix, either as unisexual or bisexual units. Araceae is classified as the fourth largest monocotyledonous family after the orchids, grasses and sedges. It is a predominantly tropical family of mesophytic herbs, climbers, and epiphytes distributed across the world's tropical and subtropical regions. The family exhibits two principal centres of species richness and endemism: tropical Asia, including Borneo, Sumatra, and New Guinea, and the Neotropics of Central and South America (Croat and Ortiz 2020).

Araceae species are generally perennial, evergreen, or seasonally dormant, with plant size ranging from extremely small to large. Their life forms vary across different habitats and are commonly categorised as hemiepiphytes, epiphytes, mesophytes, lithophytes, rheophytes,

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geophytes, helophytes, and hydrophytes (Croat 1988). The abundance and diversity of Araceae are influenced by several environmental factors, including water availability, humidity, and temperature (Mayo *et al.* 1997; Mashhor *et al.* 2012). The highest species abundance and diversity occur in wet forest galleries, particularly on steep slopes and along streams and small rivers in lowland and hill dipterocarp forests (Zulhazman *et al.* 2011a, 2013). These areas provide a broad range of microhabitats suitable for aroids. Lower slopes and valley bottoms are frequently dominated by mesophytic and helophytic genera such as *Schismatoglottis*, *Apoballis*, *Homalomena*, *Aglaonema* and *Alocasia*. Lianescent aroids such as *Anadendrum*, *Pothos*, *Rhaphidophora* and *Scindapsus* typically occupy upper slopes and ridges.

In general, the distribution of Araceae species in Peninsular Malaysia is influenced by climatic and edaphic factors. Many researchers (Baharuddin and Mashhor 2001; Boyce 2004; Mashhor *et al.* 2012; Zulhazman and Norzielawati 2019; Zulhazman *et al*. 2019) have noted that the richest habitats for Araceae occur within lowland and hill dipterocarp forests. Forest type classification in Malaysia is based on altitudinal differences (Saw 2010), and this altitudinal variation greatly influences Araceae distribution (Bown 1988; Leimbeck *et al.* 2004; Yusrin *et al*. 2013). Previous studies indicate that Araceae diversity is generally higher at lower elevations, except for certain genera such as *Arisaema*, which are more abundant in hill dipterocarp forests. Edaphic conditions such as high soil acidity and low nutrient levels, also influence the distribution of Araceae in Malaysia. Notably, species such as *Homalomena rostrata* and *Podolasia stipitata* thrive in peat and heath forests. Several *Cryptocoryne* species are highly adapted to blackwater streams and do not occur in other habitat types (Mashhor *et al.* 2012).

Variations in the geological conditions of forests also affect plant diversity (Kruckeberg 2002). Different rock compositions create distinct microhabitats that influence the diversity and spatial distribution of Araceae. In Malaysia, high levels of Araceae endemism occur in limestone areas, particularly within the genera *Amorphophallus*, *Alocasia*, *Schismatoglottis* and *Homalomena* (Boyce and Wong 2009). Meanwhile, *Homalomena wallichii* is restricted to humid lowland dipterocarp forests growing on granite and granite-derived soils (Baharuddin and Boyce 2011). In Kelantan, three taxonomically novel Araceae species have been described from different geological settings: *Alocasia farisii* from isolated limestone outcrops near the Banjaran Titiwangsa (Zulhazman *et al.* 2017a), *H. kualakohensis* from pyroclastic formations in Kuala Koh, Gua Musang (Zulhazman *et al.* 2011b), and *H. stongensis* from granitic environments around Jelawang Waterfall, Kuala Krai (Zulhazman *et al.* 2012).

DISTRIBUTION OF ARACEAE IN PENINSULAR MALAYSIA

To date, an estimated 4,604 species from 156 genera of Araceae are recorded worldwide (Boyce *et al*. 2025). Of these, 60.5% occur in the Neotropical region, followed by 32.2% in Asia, 3.3% in Africa, 1.8% in the Mediterranean, and 2.2% in other regions. The most diverse genus is *Anthurium* with approximately 1,500 species distributed in the Neotropics. A total of 44 genera are indigenous to the Malesian biogeographical region, which extends from Peninsular Malaysia through the Indonesian and Philippine archipelagos to New Guinea (Boyce and Wong 2012). Among the Araceae genera occurring in Malesia, the most species-rich are *Homalomena* (approximately 550 species), *Amorphophallus* (250 species), *Schismatoglottis* (250 species), *Alocasia* (100 species), *Rhaphidophora* (100 species), *Cryptocoryne* (70 species), *Pothos* (70 species), *Scindapsus* (35 species), *Anadendrum* (30 species), *Aglaonema* (25 species), *Apoballis* (20 species), *Piptospatha* (20 species) and *Amydrium* (5 species).

In Peninsular Malaysia, a total of 146 species belonging to 28 genera have been recorded, of which 29 species are endemic (Zulhazman *et al*. 2011a, 2012, 2017a; Mashhor *et al.* 2012). Appendix 1 gives a list of endemic species with their localities and distribution in Peninsular Malaysia. Field survey focusing on Araceae in Peninsular Malaysia continues to reveal novel and endemic species. In particular, the genus *Homalomena* has been regarded as one of the most complex and taxonomically challenging groups in the Peninsula, with many new species yet to be discovered (Ng *et al.* 2011).

From the accounts of Araceae by several researchers (Hooker 1893; Ridley 1925; Furtado 1939; Nicolson 1969; Nicolson and Sivadasan 1981; Hay 1996a, 1996b, 1998; Boyce 1998, 1999; Nguyen and Boyce 1999; Bogner and Hay 2000; Hay and Yuzammi 2000; Boyce and Hay 2001; Sofiman *et al*. 2009, 2010), it is clearly evident that Peninsular Malaysia is exceptionally rich and diverse in Araceae. The discussion on the distribution of many Araceae genera in Peninsular Malaysia, particularly in relation to ecological and geological factors, will be further elaborated in the present study.

THE ECOLOGY OF ARACEAE IN PENINSULAR MALAYSIA

The ecology and life forms of Araceae have been extensively documented by Croat (1988) and later synthesised by Mayo *et al.* (1997), both of which remain key references for the family. In Peninsular Malaysia, these aspects were comprehensively reviewed and updated by Mashhor *et al.* (2012). Many Araceae species favor moist and sheltered forest environments. Structurally and physiologically, they do not thrive in arid or cold conditions. Therefore, they are most diverse and abundant in the humid tropics, especially within tropical rainforests such as those in Peninsular Malaysia (Mayo *et al.* 1997; Bown 2000; Baharuddin and Mashhor 2001; Boyce 2004). Most Araceae species are confined to forested areas, although several, such as *Alocasia longiloba*, *Amorphophallus prainii*, *Colocasia esculenta* and *Typhonium trilobatum* may occur in both forested and areas adjacent to rural settlements (Zulhazman *et al.* 2011).

Most surveys of Araceae in Peninsular Malaysia have been conducted in inland forests, particularly lowland and hill dipterocarp forests. These forests are classified according to altitude, with changes in elevation influencing temperature, forest structure, and plant species composition (Nakashizuka *et al.* 1991; Saw 2010). As a result, Araceae species exhibit distinct distribution patterns across different altitudinal forest zones. Within these forests, Araceae diversity is highest in moist and shaded habitats, especially on steep slopes adjacent to streams and small rivers. This habitat, referred to as gallery wet forest by Boyce (2004) and Mashhor *et al.* (2012), provides a range of environmental conditions from cool, continuously humid areas near watercourses to relatively warmer sites on upper slopes and ridges with greater diurnal fluctuations in humidity. Such environmental gradients create favourable microhabitats that support a high diversity of Araceae species.

In inland forests, the genera *Apoballis*, *Homalomena* and *Schismatoglottis* dominate the lower slope zones, where conditions are cool, wet, humid, and shaded (Mashhor *et al.* 2012). The genera *Aglaonema*, *Alocasia* and *Amorphophallus* are generally distributed on upper slopes, where the environment is lighter, warmer, and characterised by fluctuating atmospheric humidity and well-drained soils. Hemiepiphytic genera such as *Amydrium*, *Anadendrum*, *Epipremnum*, *Pothos*, *Rhaphidophora* and *Scindapsus* thrive in ridge areas, which are typically too dry for many terrestrial Araceae (Putz and Holbrook 1986). Rheophytic species such as *Piptospatha perakensis* and *Homalomena griffithii* inhabit rocky streams and riverbeds, while *Rhaphidophora beccarii* grows in muddy streambanks (Baharuddin and Mashhor 2001). The helophytic species *Alocasia puber* (Hassk.) Schott thrives in sandy soils along stream margins (Croat 1988).

The peat swamp forests, located mainly in lowland areas of Peninsular Malaysia, provide a distinct habitat for Araceae (Saw 2010). These areas are characterised by deep peat deposits or white sand mixed with peat, and are suitable only for several adaptable species, such as *Homalomena rostrata*, *Podolasia stipitata* and *Rhaphidophora lobbii*. Streams containing dark brown, acidic, tannin-rich water provide specialised habitat for many *Cryptocoryne* species (Sofiman *et al*. 2009). Lowland freshwater swamp forests support other species such as *Cyrtosperma merkusii* and *R. minor* (Mashhor *et al*. 2012). In disturbed lowland forests and settlement areas, species such as *Colocasia esculenta*, *Alocasia macrorrhizos* and *A. longiloba* occur abundantly (Zulhazman *et al.* 2011a), alongside the well-known medicinal plant *Typhonium flagelliforme* (locally known as *keladi tikus*) (Baharuddin and Mashhor 1999).

Although Araceae diversity and abundance generally decline with increasing elevation, forests above 600 m a.s.l. often harbour a distinct assemblage of rare and endemic species (Bown 1988; Leimbeck *et al.* 2004; Nik-Yuszrin *et al*. 2013). Examples include *Arisaema roxburghii*, *Rhaphidophora nicolsonii*, *Scindapsus pictus* and *Schismatoglottis scortechinii*, while *A. anomalum* is notably more common at higher elevations than in lowland forests (Hay 1996a; Boyce 1999; Gusman and Gusman 2006).

The montane oak-laurel forest, occurring between 1,200 to 1,500 m a.s.l., is characterised by a relatively uniform canopy and the absence of emergent trees. Tree trunks are typically slender, rarely exceeding 40 – 50 cm in diameter at breast height (Saw 2010). In terms of Araceae, only a few genera, such as *Rhaphidophora* and *Homalomena* present in montane forests. According to Mashhor *et al*. (2012), the occurrence of Araceae becomes increasingly restricted at elevations above 1,200 m a.s.l., with very few species reported beyond 1,500 m a.s.l., suggesting that this elevation represents the upper distributional limit for most Araceae in Peninsular Malaysia.

Edaphic factors influencing Araceae distribution in Peninsular Malaysia

Edaphic factors play a crucial role in determining the distribution, abundance, and diversity of Araceae in Peninsular Malaysia. Soil properties such as moisture availability, drainage, texture, depth, pH, nutrient status, and organic matter content strongly influence the occurrence of many species. Although geological substrates indirectly affect these conditions through soil formation processes, the ecological responses of Araceae are generally associated with soil characteristics rather than the underlying rock types themselves. Despite their ecological importance, studies explicitly examining the relationship between Araceae and edaphic factors in Peninsular Malaysia remain limited (Nik-Yuszrin *et al*. 2013; Zulhazman *et al.* 2017a).

Most Araceae species in Peninsular Malaysia occur in humid forest environments with continuously moist, well-drained soils rich in organic matter. The highest diversity is generally found in gallery wet forests along streams and rivers, where high humidity, stable soil moisture, and accumulated leaf litter create favourable growing conditions (Boyce 2004; Mashhor *et al.* 2012). Species of *Homalomena*, *Schismatoglottis*, *Rhaphidophora* and *Alocasia* are particularly abundant in such habitats. Soils derived from granitic parent materials are typically acidic, highly weathered, nutrient-poor, and well-drained. These conditions favour species adapted to low nutrient availability and periodic water stress. Where sufficient soil accumulation occurs, granitic forests support a diverse assemblage of Araceae, particularly species of *Homalomena* and *Schismatoglottis*. However, shallow soils and exposed rock surfaces generally support fewer species and are dominated by specialised rheophytic and lithophytic taxa, including *Homalomena griffithii* and *Piptospatha perakensis* which are adapted to grow on rocky stream margins and exposed substrates (Boyce 2004).

Alluvial soils occurring along river valleys and floodplains provide a contrasting habitat characterised by deeper soil profiles, higher nutrient availability, and greater moisture retention (Osman 2013). These fertile environments support species such as *Alocasia puber*, *Apoballis mutata*, *Colocasia esculenta* and *Schismatoglottis calyptrata* (Wong and Boyce 2010). Periodic flooding and sediment deposition further contribute to the maintenance of suitable habitats for many moisture-loving Araceae (Croat 1988). Among the various edaphic environments in Peninsular Malaysia, limestone-derived soils support a particularly distinctive flora. Limestone habitats are characterised by alkaline conditions, high calcium concentrations, shallow soils, and heterogeneous microhabitats associated with rock crevices, cliffs, and talus slopes. These conditions have promoted the evolution of numerous habitat specialists and endemic species (Kiew 2016; Kiew *et al.* 2017). Several Araceae species, including *Rhaphidophora burkilliana*, *R. angustata*, and *Amydrium humile* are closely associated with limestone forests and are rarely encountered elsewhere.

Edaphic conditions also influence the distribution of different life forms within the family. Mesophytic species dominate moist forest soils, while geophytic genera such as *Amorphophallus*, *Arisaema* and *Typhonium* are commonly associated with seasonally dry or well-drained soils, particularly in semi-deciduous limestone forests of northern Peninsular Malaysia (Mashhor *et al*. 2012). Rheophytes occur on periodically inundated riverbanks, whereas lithophytes occupy rocky substrates with limited soil development. Although several studies have documented habitat preferences of Araceae in Peninsular Malaysia, the relationships between species distribution and specific soil properties remain poorly understood. Future research should focus on quantitative assessments of soil moisture, nutrient availability, pH, texture, and organic matter content to better understand the ecological requirements of individual species and to support conservation planning for rare and endemic taxa.

CONSERVATION STRATEGIES OF ARACEAE

Peninsular Malaysia is recognised as one of the world's biodiversity hotspots, harbouring an exceptionally rich angiosperm flora comprising well over 12,500 species, many of which are endemic to the region. Continued botanical exploration and taxonomic studies have revealed numerous additional species, particularly from limestone, montane, and lowland rainforest habitats (Saw *et al*. 2010; Kiew *et al*. 2023). However, efforts in plant conservation in general, let alone of the Araceae, have historically been weak and overlooked. Land development schemes initiated between the early 1960s and 1980s saw vast tracts of lowland forests converted into plantation estates for rubber and oil palm under the Federal Land Development Authority (FELDA). The FELDA scheme alone developed approximately 853,000 ha for plantations and settlement areas (Saw 2007).

Today, about 5.73 million ha, or 43.47% of Peninsular Malaysia's land area, remain forested (Forestry Department Peninsular Malaysia 2024). Logging is a major source of revenue for several states, including Pahang, Kedah, and Kelantan. Consequently, most lowland forests have been logged, and logging operations have expanded into hill and montane forest areas (Chan *et al*. 2023). Outside protected areas, very little virgin forest remains in Peninsular Malaysia. In some areas, logging has been repeated for two or even three cycles. An additional reason for the lack of interest in plant conservation is the general scarcity of information on plant species, populations, and their distributions. This information gap hampers the recognition of plant conservation priorities. Unlike animals, which often attract considerable public attention and conservation support, plants such as Araceae generally receive less recognition despite their important ecological roles. Many threatened plant species are overlooked because they lack the visual appeal, cultural significance, or

public profile associated with large mammals and birds. Furthermore, numerous Araceae species occur in remote forest habitats, have localised distributions, or are identifiable only during specific stages of their life cycle, making them less noticeable to the general public. As a result, conservation concerns relating to these species are often recognised and addressed primarily by a relatively small community of botanists, taxonomists, and conservation practitioners.

Plant diversity conservation is essential given the accelerating rate of biodiversity loss, particularly in regions where the highest levels of biodiversity coincide with the lowest levels of protection and the greatest need for data on species richness and endemism (Pimm *et al.* 1995). An appropriate step toward mitigating this situation is the establishment of global inventories and baseline datasets that provide sufficient knowledge on species ecology and habitat requirements to support effective conservation planning and decision -making (Prendergast *et al.* 1999). Hotspot identification is also a pragmatic approach to preventing large-scale species extinctions (Myers 1988). When species-rich habitats are clearly identified, human interventions and development activities can be minimised or more effectively monitored. Furthermore, appropriate buffer zones can be established in areas of high species diversity if development remains necessary.

Conservation initiatives targeting Araceae in Peninsular Malaysia remain limited and are largely focused on cultivated edible species such as *Colocasia esculenta* and other edible members of *Alocasia*, *Amorphophallus*, *Cyrtosperma* and *Xanthosoma*. In contrast, many wild species receive little direct conservation attention despite their restricted distributions and specialised habitat requirements. For example, several limestone-associated species, including *Rhaphidophora burkilliana*, *R. angustata* and *Amydrium humile*, are confined to isolated karst formations that are increasingly threatened by quarrying and habitat disturbance (Mashhor *et al.* 2012; Kiew *et al.* 2017). Similarly, narrowly distributed endemic species such as *Alocasia farisii* and *Homalomena kualakohensis* are known from a limited number of localities, yet no species-specific management or recovery programmes have been implemented. Consequently, the conservation of most wild Araceae in Peninsular Malaysia currently relies primarily on the protection of their habitats within forest reserves, protected areas, and limestone ecosystems rather than on targeted conservation measures.

Gene pool identification and germplasm conservation have been recognised as important strategies for safeguarding the genetic diversity of edible Araceae (Rao *et al.* 2006). For wild Araceae, however, conservation efforts are more dependent on habitat protection because many species exhibit narrow distributions, habitat specialisation, and small population sizes. Consequently, in situ conservation through the protection of natural habitats, particularly lowland forests, riparian zones, and limestone ecosystems, remains the most effective approach for ensuring the long-term survival of many wild species. *Ex situ* measures, including living collections, seed banking, and tissue culture propagation, may provide complementary strategies for conserving rare and threatened taxa.

Current *ex situ* conservation landscape in Malaysia

Ex situ conservation of plants in Malaysia is undertaken through botanical gardens, arboreta, living collections, herbaria, seed banks, and tissue culture facilities managed by research institutions, universities, and government agencies. Among the most established centres is the Kepong Botanic Gardens and associated arboreta of the Forest Research Institute Malaysia (FRIM), which maintain living collections of indigenous Malaysian plants collected from natural habitats for research, education, and *ex situ* conservation purposes (Saw *et al.* 2010). The gardens were specifically developed as a centre for living plant collections and conservation of Malaysian flora.

Another important *ex situ* conservation centre is the Rimba Ilmu Botanic Garden at the University of Malaya. Established in 1974, the garden maintains more than 1,600 – 1,700 species of living plants, primarily from Malaysia and the wider Malesian region. In addition to its living collections, Rimba Ilmu houses the Universiti Malaya Herbarium (KLU), one of the largest university herbaria in Malaysia, and plays significant roles in plant conservation, research, education, and public outreach (Ong *et al*. 2025).

The Penang Botanic Gardens also contribute to *ex situ* conservation through the maintenance of living collections of native and threatened plant species, including specialised collections of aroids, orchids, palms, and ferns. Collectively, these institutions provide important repositories for conserving plant genetic resources outside their natural habitats. However, dedicated *ex situ* conservation programmes specifically targeting threatened Araceae remain limited, and most species are conserved as components of broader botanical collections rather than through coordinated species-specific conservation initiatives.

Conservation status and population health of endemic taxa

Peninsular Malaysia is home to 29 endemic Araceae species (Appendix 1). While formal conservation assessments for many of these taxa remain incomplete, an analysis of their distribution patterns indicates that their population health is inherently vulnerable due to extreme microhabitat specialization and narrow geographic ranges.

For example, narrowly distributed endemic species such as *Alocasia farisii* (restricted to isolated limestone outcrops in Kelantan) and *Homalomena kualakohensis* (restricted to pyroclastic formations in Kuala Koh) are currently known from only a few localities. Because no species-specific management or recovery programmes exist for these taxa, their wild populations are highly susceptible to localised disturbances. Furthermore, several endemic taxa are confined to highly threatened limestone karst formations. Species such as *Rhaphidophora burkilliana* are rarely encountered outside these alkaline, shallow-soil environments and face severe population threats from ongoing quarrying and surrounding habitat disturbance.

Meanwhile, high-elevation endemics such as *Arisaema anomalum*, *Rhaphidophora nicolsonii*, and *Schismatoglottis scortechinii* are restricted to montane or hill dipterocarp forests above 600 m a.s.l., making their isolated populations vulnerable to changing environmental gradients and expanding land conversion. The urgent need for comprehensive conservation assessments (e.g., IUCN Red List) for these 29 taxa represents a critical knowledge gap that must be addressed to prioritise future conservation funding and habitat protection.

Proposed *ex situ* conservation strategies

The proposed *ex situ* conservation programme for Araceae should function using fully integrated approaches. However, current efforts lack dedicated initiatives for threatened Araceae. Therefore, urgent and targeted attention must be given to specific vulnerable taxa. The long-term survival of rare Araceae species such as *Alocasia farisii*, *Arisaema anomalum*, *A. roxburghii*, *Furtadoa mixta*, *Homalomena kualakohensis*, *Rhaphidophora corneri* and *Schismatoglottis scortechinii* may depend on maintaining viable populations *ex situ*, whether as living plants, seeds, embryos, or protocorms stored in gene banks. Although *ex situ* conservation plays an important role in safeguarding plant diversity, individuals maintained under cultivation may not fully reflect the ecological characteristics of wild populations. Differences in light intensity, humidity, soil conditions, nutrient availability, and biotic interactions can influence plant growth, morphology, phenology, and physiological performance (Ensslin *et al*. 2015; Mounce *et al.* 2017). Consequently, observations derived solely from cultivated specimens should be interpreted cautiously, particularly when assessing habitat preferences, ecological requirements, or adaptive traits of wild Araceae.

In addition to safeguarding threatened species, *ex situ* conservation programmes should also explore the sustainable utilisation and commercial potential of Araceae in line with advances in biotechnology, horticulture, and plant propagation techniques. Many members of the family possess significant economic value as ornamental plants, food crops, medicinal resources, and landscape species. Well-known examples include *Alocasia*, *Aglaonema*, *Amorphophallus*, *Colocasia*, *Cryptocoryne* and *Homalomena*, which are widely cultivated for horticultural, nutritional, or medicinal purposes. Identifying species with commercial potential can encourage their propagation under controlled conditions, thereby reducing collection pressure on wild populations while creating opportunities for sustainable use.

Ex situ conservation facilities, including botanical gardens, research institutions, and university-managed collections, can play a dual role as conservation centres and propagation hubs. Through conventional cultivation, tissue culture, micropropagation, and seed production technologies, these facilities can generate planting materials for restoration programmes, scientific research, horticultural industries, and community-based enterprises. Such initiatives are particularly important for rare and endemic species, as they can provide alternative sources of plant material while maintaining living genetic resources for future conservation needs.

The integration of conservation and sustainable utilisation offers a practical approach to enhancing the long-term viability of *ex situ* programmes. Revenue generated through the sale of legally propagated ornamental plants, certified planting materials, and value-added products can help offset conservation costs and increase public participation in plant conservation. Furthermore, the development of Araceae-based industries can create economic opportunities for local communities while promoting awareness of the importance of conserving native plant diversity. By linking biodiversity conservation with bioeconomic development, *ex situ* conservation programmes can contribute not only to the preservation of genetic resources but also to sustainable livelihoods and regional economic growth.

ARACEAE OF POTENTIAL ECONOMIC VALUE: INSIGHTS FROM A KELANTAN CASE STUDY

Many Araceae species are known to be useful to humans, and several possess strong potential for commercialisation as edible, medicinal, or ornamental plants across Peninsular Malaysia. To illustrate this economic potential, the state of Kelantan serves as a valuable case study.

A study conducted by Zulhazman (2020) identified a total of 41 Araceae species in Kelantan with economic value, including 32 species identified as potential ornamental plants. Species from the genera *Pothos* and *Scindapsus* are commonly used as indoor plants, with *Scindapsus pictus* being the most popular (Smith and Strain 1976; Ingels 2010). Species with attractive foliage, such as *Aglaonema cochinchinense*, *Alocasia farisii* and *Arisaema roxburghii*, also have strong potential for indoor cultivation (Bown 2000; Zulhazman *et al*. 2017a). Several species, including *Aglaonema nitidum*, *A. pumilum*, *A. simplex*, *Alocasia inornata* and *A. puber* are capable of cross-breeding to produce new hybrids with colourful leaf blades (Henny *et al*. 2004). Robust evergreen herbs with remarkable leaf shapes, particularly those from the genera *Epipremnum*, *Homalomena* and *Rhaphidophora* are suitable for outdoor landscaping (Bown 2000; Ingels 2010). Although many other species remain relatively unknown to the public, they possess high potential to be developed as ornamental plants (Yuzammi 2018).

Beyond ornamentals, a total of 11 Araceae species have been documented as possessing traditional medicinal value. Many of these species have long been utilised by local communities for the treatment of various ailments. For example, *Lasia spinosa* has traditionally been used in remedies associated with cancer treatment, while *Amorphophallus prainii* and *Epipremnum giganteum* have been reported as antidotes for dart poison (Baharuddin and Mashhor 1999). In addition, *Alocasia longiloba* has been used traditionally to treat skin wounds (Nurul-Hazirah *et al.* 2019) and gout (Ferid *et al*. 2020a). Owing to its medicinal potential, *A. longiloba* has also attracted scientific interest, and recent studies have investigated its phytochemical composition to identify bioactive compounds with potential therapeutic applications (Ferid *et al*. 2020b).

Furthermore, nine Araceae species have been recorded as edible plants. In the Kelantan case study, *Alocasia longiloba*, *A. macrorrhizos* and *Colocasia esculenta* are commonly cultivated as minor food crops, with their corms, petioles, and young leaves consumed after cooking (Zulhazman *et al*. 2015). Other species, including *Amorphophallus prainii*, *Colocasia gigantea*, *Homalomena truncata*, *Lasia spinosa*, *Rhaphidophora lobbii* and *Schismatoglottis calyptrata* are also utilised as food by local communities. The young shoots, leaves, petioles, and occasionally the inflorescences are consumed either as fresh salads (*ulam*) or as boiled vegetables (Baharuddin and Mashhor 1999). In some species, particularly *A. prainii* and *L. spinosa*, the underground tubers or young shoots are boiled or cooked before consumption to reduce acridity caused by calcium oxalate crystals and other irritating compounds (Lim 2015).

The development of an Araceae-based industry in Peninsular Malaysia would require collaboration among research institutions, government agencies, and the private sector. Localised frameworks, such as the one in Kelantan, can provide a blueprint for this development. In Kelantan, agencies such as the Kelantan State Forestry Department, Department of Agriculture Malaysia (Kelantan State Office), Kelantan Biotech Corporation Sdn. Bhd., Kelantan Agricultural Development Corporation, and local universities like Universiti Malaysia Kelantan (UMK), could play important roles in germplasm conservation, species evaluation, propagation, and technology transfer. Kelantan Biotech Corporation, for example, has experience in plant tissue culture and the large-scale production of ornamental and agricultural planting materials, providing a suitable platform for the propagation of commercially valuable Araceae species.

This regional model can then be integrated at the national level, where organisations such as the Forest Research Institute Malaysia (FRIM), the Malaysian Agricultural Research and Development Institute (MARDI), the Department of Agriculture Malaysia, and botanical gardens could contribute expertise in taxonomy, plant breeding, biotechnology, conservation, and commercialisation. MARDI has already undertaken research on ornamental plants, including several Araceae species, demonstrating the potential of the family for the horticultural and landscape industries.

A coordinated national programme could focus on the identification, propagation, and commercialisation of species with ornamental, medicinal, edible, or landscape value. Native species of *Alocasia*, *Aglaonema*, *Homalomena*, *Rhaphidophora*, *Schismatoglottis* and *Scindapsus* possess considerable potential for the ornamental plant market, while species of *Amorphophallus* and *Colocasia* may offer opportunities for food and nutraceutical development. Through tissue culture, nursery production, and value-added product development, these species could be cultivated sustainably, reducing harvesting pressure on wild populations while generating new economic opportunities for local communities. Such an approach would align biodiversity conservation with Malaysia's bioeconomy agenda, whereby native plant resources are conserved, utilised sustainably, and developed into commercially viable products

CONCLUSION

Araceae represents one of the most ecologically, taxonomically, and economically significant plant families in Peninsular Malaysia. The region hosts a remarkable diversity of species across a wide range of ecological zones, from lowland dipterocarp forests and peat swamps to riverine systems, granite landscapes, and limestone karsts. This diversity is strongly shaped by climatic, altitudinal, and geological factors that collectively provide unique microhabitats supporting both widespread taxa and highly localised endemics. Despite this richness, many Araceae remain poorly studied, and numerous species continue to be discovered, particularly within ecologically sensitive and geologically complex areas. The rapid loss of natural habitats, especially through logging, land conversion, and development pressures, underscores the urgent need for comprehensive conservation strategies. While several Araceae species hold substantial ornamental, medicinal, and edible value, conservation efforts for the family remain limited and fragmented. Effective long-term protection requires integrated approaches that combine *in situ* conservation within protected areas, *ex situ* propagation through botanical gardens and research institutions, and proactive collaboration between state agencies, local communities, and academic experts. Strengthening baseline data, enhancing public awareness, and identifying species-rich hotspots are essential steps to safeguard vulnerable and endemic taxa. Ultimately, the conservation and sustainable utilisation of Araceae in Peninsular Malaysia demand a holistic approach that recognises the family's ecological importance, economic potential, and cultural significance. With strategic planning, targeted research, and cross-sectoral cooperation, Araceae can continue to thrive as a vital component of Malaysia's tropical biodiversity while contributing to national bioeconomic development.

REFERENCES

Baharuddin, S. and Mashhor, M. 1999. Utilization of Malaysian aroids for medicinal purposes. In *Prosiding Persidangan Kebangsaan P&P IPTA 2001*, pp. 720–723. Penang: Universiti Sains Malaysia.

Baharuddin, S. and Mashhor, M. 2001. Endemic riverine Araceae of Peninsular Malaysia. In *Proceedings of the Fourth International Flora Malesiana Symposium 1998. Taxonomy: The Cornerstone of Biodiversity*, L.G. Saw, L.S.L. Chua and K.C. Khoo (Eds.), pp. 279–288. Kuala Lumpur: Forest Research Institute Malaysia.

Baharuddin, S. and Boyce, P.C. 2010a. Studies on Homalomeneae (Araceae) of Peninsular Malaysia I: *Homalomena asmae*, a new species from Sarawak. *Acta Phytotaxonomica et Geobotanica* 60(3): 163–166.

Baharuddin, S. and Boyce, P.C. 2010b. Studies on Homalomeneae (Araceae) of Borneo V: A new species and new supergroup record, of *Homalomena* from Sabah, Malaysian Borneo. *Tropical Life Sciences Research* 21(2): 85–90.

Baharuddin, S. and Boyce, P.C. 2011. Studies on Homalomeneae (Araceae) of Peninsular Malaysia V: *Homalomena wallichii*, refound after over 190 years. *Aroideana* 34: 24–29.

Bogner, J. and Hay, A. 2000. Schismatoglottideae (Araceae) in Malesia II – *Aridarum*, *Bucephalandra*, *Phymatarum* and *Piptospatha*. *Telopea* 9(1): 180–222.

Bown, D. 1988. Aroids: *Plants of the arum family*. London: Century Publication.

Bown, D. 2000. Aroids: *Plants of the arum family*. 2nd Ed. Portland: Timber Press.

Boyce, P.C. 1995. Aroid conservation. *Curtis's Botanical Magazine* 12(3): 173–176.

Boyce, P.C. 2000. The genus *Pothos* (Araceae-Pothoideae-Potheae) of Thailand and Indochina. *Blumea* 45(1): 147–204.

Boyce, P. C. 2004. The aroids of Borneo. *Folia Malaysiana* 5(3&4): 123–170.

Boyce, P. C. 1998. The genus *Epipremnum* Schott (Araceae-Monsteroideae-Monstereae) in West and Central Malesia. *Blumea* 43: 183–213.

Boyce, P. C. 1999. The genus *Rhaphidophora* Hassk. (Araceae-Monsteroideae-Monstereae) in Peninsular Malaysia and Singapore. *Gardens' Bulletin Singapore* 51: 183–256.

Boyce, P.C. and Hay, A. 2001. A taxonomic revision of Araceae tribe Potheae (*Pothos*, *Pothoidium* and *Pedicellarum*) for Malesia, Australia and the Tropical Western Pacific. *Telopea* 9(3): 449–571.
Boyce, P.C. and Wong, S.Y. 2009. The aroids of the West Sarawak limestone. *The International Aroid Society Newsletter* 31(2): 1–8.
Boyce, P.C. and Wong, S.Y. 2012. The Araceae of Malesia I: Introduction. *Malayan Nature Journal* 64(1): 33–67.
Boyce, P.C. and Wong, SY. 2015. Compendium Genera Aracearum Malesianum. *Aroideana* 38: 40–177.
Boyce, P.C., Wong, S.Y. and Ng, K.K. 2010. The Araceae of Borneo - The genera. *Aroideana* 33: 3–72.
Boyce, P. C., Sookchaloem, D., Hetterscheid, W.L.A., Gusman, G., Jacobsen, N., Idei, T. and Van Du, N. 2012a. *Flora of Thailand: Araceae and Acoraceae*. Bangkok: The Forest Herbarium, Royal Forest Department.
Boyce, P.C., Zulhazman, H. and Sofiman, A.O. 2012a. Studies on Monstereae (Araceae) of Peninsular Malaysia IV: The enigmatic *Rhaphidophora corneri* refound after 75 years. *Gardens' Bulletin Singapore* 64(2): 281–288.
Chan, C.K., Ling, G.H.T., Ho, C.S. and Kanniah, K.D. 2023. Sustainable forest management and effective land use policies for mitigating forest loss: The case of Malaysia. *Chemical Engineering Transactions* 106: 799–804.
Croat, T.B. 1998. History and current status of systematic research with Araceae. *Aroideana* 21: 26–145.
Croat, T.B. 1988. Ecology and life forms of Araceae. *Aroideana* 11: 4–55.
Croat, T.B., and Ortiz, O.O. 2020. Distribution of Araceae and the diversity of life forms. *Acta Societatis Botanicorum Poloniae* 89(3): 8939.
Ensslin, A., Sandner, T.M. and Matthies, D. 2015. Consequences of *ex situ* cultivation of plants: genetic diversity, fitness, and adaptation of the monocarpic perennial *Carlina acaulis*. *Biological Conservation* 186: 93–101.
Ferid, A., Arifullah, M., Fatimah, K., Suhana, Z., Zulhazman, H., Pamuru, R.R., Gundala, P.B. and Mohd-Farhan, H.R. 2020a. Micropropagation of *Alocasia longiloba* Miq. and comparative antioxidant properties of ethanolic extracts of the field-grown plant, *in vitro* propagated and *in vitro*-derived *Callus*. *Plants* 9(7): 816.
Ferid, A., Arifullah, M., Fatimah, K., Matcha, B., Zulhazman, H., Podapati, S.K. and Reddy, L.V. 2020b. Xanthine oxidase inhibitory activity, chemical composition, antioxidant properties and GC-MS analysis of keladi candik (*Alocasia longiloba* Miq.). *Molecules* 25(11): 2658.
Forestry Department Peninsular Malaysia. 2024. *Annual Report 2024*. Putrajaya: Forestry Department Peninsular Malaysia. https://www.forestry.gov.my/images/Laporan_Tahunan/2024/FULL_LAPORAN_TAHUNAN_JPSM_2024.pdf
Furtado, C.X. 1939. Araceae Malesicae: Notes on some Indo-Malaysian *Homalomena* species. *Gardens' Bulletin Singapore* 10(2): 183–238.
Guarino, L., Jarvis, A., Hijmans, R.J. and Maxted, N. 2002. Geographic Information Systems (GIS) and the conservation and use of plant genetic resources. In *Managing Plant Genetic Diversity. Proceedings of An International Conference*, Kuala Lumpur, Malaysia, 12–16 June 2000, J.M.M. Engels, V. Ramanatha Rao, A.H.D. Brown and M.T. Jackson (Eds.), pp. 387–404. Rome: International Plant Genetic Resources Institute.
Gusman, G. and Gusman, L. 2006. The genus *Arisaema*: A monograph for botanists and nature lovers. Ruggell, Liechtenstein: A.R.G. Gantner Verlag K.G.
Hay, A. 1996a. The Genus *Schismatoglottis* Zoll. & Moritzi (Araceae: Schismatoglottideae) in Peninsular Malaysia and Singapore. *Sandakania* 7: 1–30.
Hay, A. 1996b. A new Bornean species of *Colocasia* Schott with a synopsis of the genus in Malesia and Australia. *Sandakania* 7: 31–48
Hay, A. 1998. The genus *Alocasia* (Araceae-Colocasieae) in West Malesia and Sulawesi. *Gardens' Bulletin Singapore* 50: 221–334.
Hay, A. and Yuzammi. 2000. Schismatoglottideae (Araceae) in Malesia 1: *Schismatoglottis*. *Telopea* 9(1): 177.
Henny, J.R., Norman, D.J. and Chen, J. 2004. Progress in ornamental aroid breeding research. *Annals of the Missouri Botanical Garden* 91: 464–472.
Hesse, M. 2001. Principal pollen features in the arum lilies (Araceae). *Polen* 11: 5–20.

Hooker, J.D. 1893. Aroideae. In The *Flora of British India*. *Vol. 6*, pp. 490–558. London: L. Reeve & Co.
Ingels, J.E. 2010. *Ornamental Horticulture: Science, Operations, & Management, 4th ed*. New York: Delmar, Cengage Learning.
Kiew, R. 2016. *Impatiens* (Balsaminaceae) species from karst limestone in Kelantan, Malaysia, including three new species. *Gardens' Bulletin Singapore* 68(2): 225–238.
Kiew, R., Chung, R.C.K. and Saw, L.G. 2023. *Flora of Peninsular Malaysia Series II: Seed Plants, Volume 10*. Kepong: Forest Research Institute Malaysia.
Kiew, R., Rafidah, A.R., Ong, P.T. and Ummul-Nazrah, A.R. 2017. Limestone treasures, rare plants in Peninsular Malaysia – What they are, where they grow and how to conserve them. *Malaysian Naturalist* 71(1): 32–41.
Kruckeberg, A.R. 2002. *Geology And Plant Life: The Effects Of Landforms And Rock Types On Plants*. Seattle: University of Washington Press.
Leimbeck, R.M., Valencia, R. and Balslev, H. 2004. Landscape diversity patterns and endemism of Araceae in Ecuador. *Biodiversity and Conservation* 13: 1755–1779.
Lim, C.K. and Meekiong, K. 2007. The baffling *Amorphophallus bufo* Ridl. and other Peninsular Malaysia taxa. *Folia Malaysiana* 8(2): 121–132.
Mashhor, M., Boyce, P.C., Othman, A.S. and Baharuddin, S. 2012. The Araceae of Peninsular Malaysia. Penang: Penerbitan Universiti Sains Malaysia.
Mayo, S.J., Bogner, J. and Boyce, P.C. 1997. *The Genera of Araceae*. London: Royal Botanic Gardens, Kew.
Mounce, R., Smith, P. and Brockington, S. 2017. *Ex situ* conservation of plant diversity in the world's botanic gardens. *Nature Plants* 3: 795–802.
Myers, N. 1988. Threatened biotas: Hotspots in tropical forests. *Environmentalist* 10: 243–256.
Nakashizuka, T., Zulkifli, Y. and Abdul Rahim, N. 1991. Altitudinal zonation of forest communities in Selangor, Peninsular Malaysia. *Journal of Tropical Forest Science* 4(3): 233–244.
Ng, K.K., Boyce, P.C. and Sofiman, A.O. 2011. Studies on Homalomeneae (Araceae) of Peninsular Malaysia II: An historical and taxonomical review of the genus *Homalomena* (excluding *Chamaecladon*). *Gardens' Bulletin Singapore* 62(2): 277–289.
Nguyen, V.D. and Boyce, P.C. 1999. The Genus *Amydrium* (Araceae: Monsteroideae: Monstereae) with particular reference to Thailand and Indochina. *Kew Bulletin* 54: 379–393.
Nicolson, D.H. 1969. A revision of the genus *Aglaonema* (Araceae). Washington, D.C.: Washington Smithsonian Institution Press.
Nicolson, D.H. and Sivadasan, M. 1981. Four frequently confused species of *Typhonium* Schott. *Blumea* 27: 483–497.
Nik-Yuszrin, N.Y., Zulhazman, H., Fatimah, K. and Zulhisham, A.K. 2013. Assessment on diversity and abundance of Araceae in limestone and pyroclastics areas in Gua Musang, Kelantan, Malaysia. *Journal of Tropical Resources and Sustainable Science* 1: 16–24.
Nurul-Hazirah, C.H., Arifullah, M., Sirajudeen, K.N.S., Mohd Asnizam, A., Zulhazman, H. and Ibrahim, K.S. 2019. Keladi candik (*Alocasia longiloba* Miq.) petiole extracts promote wound healing in a full thickness excision wound model in rats. *Asian Pacific Journal of Tropical Biomedicine* 9(4): 140–149.
Ong, B., Thai, Y.K., Manickam, S., Sapno, S.S., Hassya, I. and Marican, N.F. 2025. Botanic Garden Profile: Rimba Ilmu (the 'Forest of Knowledge') at 50. *Sibbaldia: The International Journal of Botanic Garden Horticulture* 24(24): 1–24.
Osman, K.T. 2013. *Forest Soils: Properties and Management*. London: Springer London.
Pimm, S.L., Russell, G.J, Gittleman, J.L. and Brooks, J.L 1995. The future of biodiversity. *Science* 269: 347–350.
Prendergast, J.R., Quinn, R.M. and Lawton, J.H. 1999. The gaps between theory and practice in selecting nature reserves. *Conservation Biology* 13: 484–492.
Putz, F.E. and Holbrook, N.M. 1986. Notes on the natural history of hemiepiphytes. *Selbyana* 9: 61–69.
Rao, R., Guarino, L., Taylor, M., Hunter, D. and Jackson, G., 2006. Towards a global taro genetic resources conservation strategy. In *Proceedings of 14th Triennial Symposium of the International Society For Tropical Root Crops*, 20–26 November 2006. Thiruvananthapuram: Central Tuber Crops Research Institute.
Ridley, H.N. 1925. *The flora of the Malay Peninsula*. London: L. Reeve & Co. Ltd.`

Saw, L.G. 2007. Plant conservation in Malaysia – Meeting the challenges of the twenty-first century. In *3rd Global Botanic Garden Congress Proceedings*. Richmond: Botanic Gardens Conservation International.
Saw, L.G. 2010. Vegetation of Peninsular Malaysia. In *Flora of Peninsular Malaysia — Series II: Seed Plants, Volume 1*, R. Kiew, R.C. Chung, L.G. Saw, E. Soepadmo and P.C. Boyce (Eds.), pp. 21–45. Kepong: Forest Research Institute Malaysia.
Saw, L.G., Chua, L.S.L., Suhaida, M., Yong, W.S.Y. and Hamidah, M. 2010. Conservation of some rare and endangered plants from Peninsular Malaysia. *Kew Bulletin* 65 (4): 681–689.
Smith, C.N. and Strain, J.R. 1976. Market outlets and product mix for Florida foliage plants. *Florida State Horticultural Society* 89: 274–278.
Sofiman, O.A., Jacobsen, N. and Mashhor, M. 2009. *Cryptocoryne* of Peninsular Malaysia. Penang: Penerbit Universiti Sains Malaysia.
Sofiman, O.A., Boyce, P.C. and Keng, C.L. 2010. Studies on Monstereae (Araceae) of Peninsular Malaysia III: *Scindapsus lucens*, a new record for Malaysia, and a key to Peninsular Malaysian Scindapsus. *Gardens' Bulletin Singapore* 62(1): 9–15.
Wong, S.Y. 2009. Phylogenetic and systematic studies of the Schismatoglottideae (Araceae: Aroideae). PhD dissertation. Penang: Universiti Sains Malaysia. [Unpublished].
Wong, S.Y. and Boyce, P.C. 2010. Studies on Schismatoglottideae (Araceae) of Borneo IX: A new genus, *Hestia*, and resurrection of *Apoballis*. *Botanical Studies* 51: 249–255.
Wong, S.Y. and Boyce, P.C. 2011. Geological perambulations. *IAS Newsletter* 33 (4): 1–6.
Wong, S.Y., Boyce, P.C. and Bogner, J. 2009. Studies on Schismatoglottideae (Araceae) of Borneo VIII: A review of *Piptospatha elongata* in Sarawak. *Gardens' Bulletin Singapore* 61(1): 217–233.
Nik-Yuszrin, Y., Zulhazman, H., Fatimah, K. and Zulhisham, A. K. 2013. Assessment on diversity and abundance of Araceae in limestone and pyroclastics areas in Gua Musang, Kelantan, Malaysia. *Journal of Tropical Resources and Sustainable Science* 1: 16–24.
Yuzammi, Y. 2018. The diversity of aroids (Araceae) in Bogor Botanic Gardens, Indonesia: Collection, conservation and utilization. *Biodiversitas* 19: 140–152.
Zulhazman, H. 2020. A Study on Araceae Species Diversity and its Distribution in Kelantan, Peninsular Malaysia. PhD Dissertation. Kelantan: Universiti Malaysia Kelantan. [Unpublished].
Zulhazman, H., Asraf Fizree, M. and Nazahatul, A.A. 2015. Documentation of edible aroids in Kelantan, Peninsular Malaysia. In *Proceedings of the 6th International Seminar on Regional Network on Poverty Eradication (RENPER)*, 13-15 Nov. 2015, Sri Venkateswara University, Tirupati, India.
Zulhazman, H., Boyce, P.C. and Mashhor, M. 2011b. Studies on Homalomeneae (Araceae) of Peninsular Malaysia III: *Homalomena kualakohensis*, a new species from Kelantan. *Acta Phytotaxonomica et Geobotanica* 61(1): 35–39.
Zulhazman, H., Boyce, P.C. and Mashhor, M. 2012. Studies on Homalomeneae (Araceae) of Peninsular Malaysia IV: *Homalomena stongensis*, a remarkable new species endemic to Gunung Stong, Kelantan. *Gardens' Bulletin Singapore* 64(2): 523–527.
Zulhazman, H., Mashhor, M. and Boyce, P.C. 2011a. Notes on Araceae of Kuala Koh, Kelantan, Peninsular Malaysia. *Gardens' Bulletin Singapore* 63 (1&2): 213–218.
Zulhazman, H., Norhazlini, M.Z. and Boyce, P.C. 2019. Notes on Araceae in Pulau Pangkor, Perak, Peninsular Malaysia. *The Malaysian Forester* 82(1): 161–171.
Zulhazman, H. and Norzielawati, S. 2019. Notes on Araceae of Ulu Sat Forest Reserve, Kelantan, Peninsular Malaysia. In *Proceedings of the Ulu Sat Scientific Expedition 2019*.
Zulhazman, H., Norzielawati, S. and Boyce, P.C. 2017a. Studies on the *Alocasia* clade of Peninsular Malaysia I: *Alocasia farisii*, sp. nov. from limestone in Kelantan. *Nordic Journal of Botany* 35: 300–304.
Zulhazman, H., Norzielawati, S. and Nik Yuszrin, Y. 2017b. Notes on Araceae of Gunung Basor Forest Reserve, Jeli, Kelantan. In *Gunung Basor & Tasik Pergau Kelantan*, Z. Ibrahim, M.R.C. Abdullah, R. Abdu Raman, N.D. Abong, S. Mohd Nordin and A. Latiff (Eds.), pp. 126–131. Kota Bharu: Jabatan Perhutanan Negeri Kelantan.
Zulhazman, H., Norzielawati, S., Nik Yuszrin, Y., Mashhor, M. and Boyce, P.C. 2013. Notes on Araceae of Gunung Chamah, Kelantan. In *Gunung Chamah, Kelantan: Pengurusan hutan, persekitaran fizikal, kepelbagaian biologi dan pelancongan ekologi*, S.A. Karim, M.F. Abu Bakar, R. Rani, Y.A. Rahaman, R. Ramli, H. Zulhazman and A. Latiff (Eds.), pp. 129–134. Kota Bharu: Jabatan Perhutanan Negeri Kelantan.

APPENDIX

Appendix 1. List of endemic Araceae species in Peninsular Malaysia.

No.	Species	Location
1.	*Aglaonema flemingianum* A. Hay	Terengganu (Sekayu)
2.	*Alocasia farisii* Zulhazman, Norzielawati & P.C. Boyce	Kelantan (Jentian, Gua Ikan, Gua Pagar)
3.	*Amorphophallus bufo* Ridl.	Pahang (Telom Woods, Sg. Bertam, Cameron Highlands, Bkt. Fraser), Selangor (Ulu Langat)
4.	*Amorphophallus minor* Ridl.	Kelantan (Kuala Krai), Perak (Bkt. Larut, Bkt. Taiping), Selangor (Bt. Caves), Pahang (Pulau Manis, Sg. Pahang), Penang (Tasek Gelugor, Penara Bukit, Air Itam)
5.	*Amorphophallus perakensis* Engl.	Perak
6.	*Amorphophallus sparsiflorus* Hook.*f.*	Perak (Bkt. Larut, Bkt. Maxwell)
7.	*Arisaema anomalum* Hemsl.	Perak (Bkt. Larut), Kelantan (Chamah, Lojing)
8.	*Arisaema scortechinii* Hook.*f.*	Selangor (Bkt. Hitam), Melaka (Bujang), Pahang, Perak, Penang
9.	*Cryptocoryne affinis* N. E. Br.	Kedah, Kelantan, Negeri Sembilan Pahang, Perak, Selangor
10.	*Cryptocoryne cordata* Griff.	Johore, Kelantan, Melaka, Negeri Sembilan, Pahang, Terengganu
11.	*Cryptocoryne decus-silvae* de Wit	Southern Peninsular Malaysia
12.	*Cryptocoryne elliptica* Hook.*f.*	Perak (Bkt. Larut), Kedah, Penang
13.	*Cryptocoryne nurii* Furtado	Johore, Pahang
14.	*Cryptocoryne* x *purpurea* Ridl.	Johore, Pahang
15.	*Cryptocoryne schulzei* de Wit	Johore
16.	*Cryptocoryne zukalii* Rataj	Southern Peninsular Malaysia
17.	*Furtadoa mixta* (Ridl.) M. Hotta	Pahang (Sg. Tahan), Kelantan (Gua Ikan)
18.	*Homalomena asmae* Baharuddin & P.C Boyce	Perak (Tasik Banding)
19.	*Homalomena kualakohensis* Zulhazman, P.C. Boyce & Mashhor	Kelantan (Kuala Koh)
20.	*Homalomena pineodora* Baharuddin & P.C Boyce	Perak (Pondok Tanjung)
21.	*Homalomena scortechinii* Hook.*f.*	Perak (Ulu Bubong), Selangor (Kajang), Negeri Sembilan (Bt. Pelangi, Tampin), Johore (Sg. Tebrau)
22.	*Homalomena stongensis* Zulhazman, P.C. Boyce & Mashhor	Kelantan (Mt. Stong)
23.	*Piptospatha ridleyi* N. E. Br. *ex* Hook.*f.*	Johore (Mt. Pulai), Pahang
24.	*Pothos salicifolius* Ridl. *ex* Burkill & Holttum	Pahang (Bkt. Fraser), Border of Selangor-Pahang, Negeri Sembilan (Sg. Angsi)
25.	*Rhaphidophora burkilliana* Ridl.	Selangor (Bt. Caves)
26.	*Rhaphidophora corneri* P.C. Boyce	Terengganu (Kemaman), Kelantan (Kuala Koh)
27.	*Rhaphidophora nicolsonii* P.C. Boyce	Pahang (Brinchang)
28.	*Schismatoglottis penangensis* Engl.	Penang
29.	*Schismatoglottis scortechinii* Hook.*f.*	Johore (Mt. Pulai), Selangor (Rawang, Ginting Bidai), Pahang (Sg. Tahan), Malacca (Bujang), Perak

Sources: Hooker (1893); Ridley (1925); Furtado (1939); Lim and Meekiong (2007); Mashhor *et al.* (2012); Zulhazman *et al*. (2013, 2017b); Zulhazman (2020);
Notes: Bkt. - Bukit, Bt. – Batu, Mt. – Mountain, Sg. – Sungai.

Appendix 2. The utilised species of Araceae in Kelantan, Peninsular Malaysia.

No.	Species	Category of utilisation		
		Ornamental	**Medicinal**	**Edible**
1.	*Aglaonema cochinchinense* Engl.	√		
2.	*Aglaonema nitidum* (Jack) Kunth	√		
3.	*Aglaonema pumilum* Hook.*f.*	√		
4.	*Aglaonema simplex* Blume	√	√	
5.	*Alocasia farisii* Zulhazman, Norzielawati & P.C. Boyce	√		
6.	*Alocasia inornata* Hallier *f.*	√		
7.	*Alocasia longiloba* Miq.		√	√
8.	*Alocasia macrorrhizos* (L.) G. Don		√	√
9.	*Alocasia puber* (Hassk.) Schott	√		
10.	*Amorphophallus prainii* Hook.*f.*		√	√
11.	*Amydrium medium* (Zoll. & Moritzi) Nicolson	√		
12.	*Anadendrum microstachyum* de Ver & Becker	√		
13.	*Arisaema anomalum* Hemsl.	√		
14.	*Arisaema roxburghii* Kunth	√		
15.	*Apoballis mutata* (Hook.f.) S.Y. Wong & P.C. Boyce	√		
16.	*Colocasia esculenta* (L.) Schott		√	√
17.	*Colocasia gigantea* (Blume) Hook.*f.*			√
18.	*Epipremnum giganteum* (Roxb.) Schott	√	√	
19.	*Homalomena curvata* Engl.	√		
20.	*Homalomena galbana* Baharuddin & P.C. Boyce	√		
21.	*Homalomena griffithii* (Schott) Hook.*f.*		√	
22.	*Homalomena humilis* (Jack) Hook.*f.*	√		
23.	*Homalomena pontederifolia* Griff. ex. Hook.f.	√		
24.	*Homalomena truncata* (Schott) Hook.*f.*			√
25.	*Lasia spinosa* (L.) Thwaites		√	√
26.	*Pothos scandens* L.	√	√	
27.	*Rhaphidophora corneri* P.C. Boyce	√		
28.	*Rhaphidophora crassifolia* Hook.*f.*	√		
29.	*Rhaphidophora korthalsii* Schott	√		
30.	*Rhaphidophora lobbii* Schott	√		√
31.	*Rhaphidophora montana* (Blume) Schott	√		
32.	*Schismatoglottis brevicuspis* Hook.*f.*	√		
33.	*Schismatoglottis calyptrata* (Roxb.) Zoll. & Moritzi	√		√
34.	*Schismatoglottis scortechinii* Hook.*f.*	√		
35.	*Schismatoglottis wallichii* Hook.*f.*	√		
36.	*Scindapsus hederaceus* Miq.	√	√	
37.	*Scindapsus perakensis* Hook.*f.*	√		
38.	*Scindapsus pictus* Hassk.	√		
39.	*Scindapsus scortechinii* Hook.*f.*	√		
40.	*Scindapsus treubii* Engl.	√		
41.	*Typhonium trilobatum* (L.) Schott		√	
	Total uses	**32**	**11**	**9**


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CHAPTER 17

Conservation of non-rattan palms in Peninsular Malaysia

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Abstract: Malaysia has about 417 species of palms, about 205 species in Peninsular Malaysia, and about 271 species in Sabah and Sarawak. Recent work on the revision of the palms for the *Flora of Peninsular Malaysia* has completed drafts for the non-rattan genera of the family. This paper presents the results of the conservation assessments of these species, comprising about 112 species and their lower rank taxa, 51 (45.6%) of the taxa were preliminary assessed with conservation concern categories.

INTRODUCTION

Malaysia is home to approximately 417 palm species, with around 205 species recorded in Peninsular Malaysia and 271 species identified in Sabah and Sarawak on the island of Borneo, according to the Plants of the World Online [POWO; incorporating recent revisions and assessments by Saw (in prep., for the *Flora of Peninsular Malaysia* project)]. The Malaysian Nature Society's special publication on nature conservation, authored by Kiew and Pearce (1991), documented at least 385 palm species nationwide: 195 in Peninsular Malaysia and 213 in Sabah and Sarawak. More recently, Saw (2021) reviewed the palm conservation for Malaysia, addressing aspects such as diversity, habit, distribution, and ecology. In this work, Saw listed 417 palm species in total, with 205 species in Peninsular Malaysia and 271 species in Sabah and Sarawak.

Since Saw's compilation of Malaysian palm diversity in 2021, subsequent revisions have led to updates for several genera. Notably, Henderson's *Calamus* monograph (2020) revised the number of species from 163 to 139 for Malaysia; for *Iguanura*, numbers shifted from 15 species in Peninsular Malaysia to eight, while Sabah and Sarawak increased from 12 to 16 species (Saw 2023a; Henderson 2025). Additionally, a new species, *Licuala hairulii* Saw, has been described (Saw 2023b), and in *Pinanga*, a revision of Peninsular Malaysian species has been published (Saw 2024). Jeanson *et al*. (2025) reclassified *Arenga hastata* (Becc.) Whitmore as *Caryota hastata* (Becc.) Jeanson following molecular evidence. Table 1 presents an updated overview of palm diversity in Malaysia. Despite reductions in species counts, the palm flora of Malaysia remains highly diverse. Thirty genera in four subfamilies are native to Malaysia. Diversity is greater in Sabah and Sarawak in comparison to Peninsular Malaysia. *Calamus*, *Licuala*, *Pinanga*, *Areca*, *Iguanura* and *Korthalsia* are the most speciose genera.

This paper will not revisit topics addressed in Saw (2021), but will instead focus on conservation issues affecting non-rattan subfamilies recently revised for the *Flora of Peninsular Malaysia* (FPM) project (Saw, in prep.). The aim of this paper is to synthesise an updated diversity listing, endemism and provide preliminary national conservation status of non-rattan palms in Peninsular Malaysia. The non-rattan subfamilies include Nypoideae, Coryphoideae and Arecoideae.

With these recent revisions, palm species endemism remains high (Table 2). About 79 species (39%) are endemic to Peninsular Malaysian and 123 species (45%) are endemic to East Malaysia. In total, 201 species (48%) are Malaysian endemics. The decline in the

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number of endemics is the results of broader species circumscriptions in some species in the revisions by Henderson (2020, 2025) and Saw (2023a, 2024) despite additional new taxa described in the revisions.

Table 1. An updated summary of palm species found in Malaysia arranged by subfamilies and genera.

Subfamily	Genera	Sabah & Sarawak	Peninsular Malaysia	Malaysia
CALAMOIDEAE	*Calamus*	96	71	139
	Eleiodoxa	1	1	1
	Eugeissona	4	2	6
	Korthalsia	14	9	18
	Metroxylon (naturalised)	(1)	(1)	(1)
	Myrialepis	-	1	1
	Plectocomia	2	3	3
	Plectocomiopsis	3	4	5
	Salacca	10	7	16
NYPOIDEAE	*Nypa*	1	1	1
CORYPHOIDEAE	*Arenga* (naturalised)	4	3(1)	6(1)
	Borassodendron	1	1	2
	Caryota	3	3	4
	Corypha	1	1	1
	Johannesteijsmannia	1	4	4
	Licuala	46	42	84
	Livistona	-	4	4
	Maxburretia	-	2	2
	Phoenix	-	1	1
	Pholidocarpus	1	2	3
	Saribus	1	-	1
ARECOIDEAE	*Adonidia*	1	-	1
	Areca (naturalised)	23 (1)	4 (1)	26 (1)
	Cocos	1	1	1
	Cyrtostachys	1	1	1
	Iguanura	16	8	24
	Nenga	2	3	4
	Oncosperma	2	2	2
	Orania	2	1	2
	Pinanga	34	22	53
	Rhopaloblaste	-	1	1
Total (naturalised)		**271 (2)**	**205 (3)**	**417 (3)**

Table 2. Regional palm species endemism.

	East Malaysia	Peninsular Malaysia	Malaysia
Total number of species	271	205	417
Number of endemic species	123	79	201
Percentage of endemism (%)	45.4	38.5	48.2

METHODOLOGY

Methods used for assessing conservation status

Assessment framework

The conservation assessment follows the IUCN Red List Categories and Criteria, Version 3.1, Second edition (2012). Methods used for the national assessment follow Saw *et al.* (2010) and Yong *et al.* (2021).

Assessment categories

Taxa of conservation concern were assigned to the following IUCN Red List categories: Extinct (EX), Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). Non-threatened taxa were assigned to Near Threatened (NT), Least Concern (LC), or Data Deficient (DD). This assessment also includes the Rare (RA) category.

Use of the Rare (RA) category

The RA category was first introduced in *Flora of Peninsular Malaysia*, Series II, Volume 3 (Chua 2012) for narrow endemic taxa that are not exposed to any known direct or plausible threat, do not meet any of the five IUCN criteria, and occur in ≤ 2 sites or have an extent of occurrence (EOO) ≤ 100 km^2 or an area of occupancy (AOO) ≤ 10 km^2. Such species would otherwise be listed as Least Concern (LC). This approach is used in South Africa's national biodiversity assessment (https://nba.sanbi.org.za/content/integrated-findings/chl_rls_explained.html). These taxa are often found in protected areas. Including RA in the Malaysian Red List helps ensure that narrowly distributed endemic plants are recognised in national conservation planning, even when they are not currently threatened. Yong *et al.* (2021) followed the IUCN categories strictly and omitted RA, but it is retained here because of the conservation importance of rare, highly localised endemic species.

Spatial analysis and mapping

The GeoCAT tool (Bachman *et al.* 2011) was used to calculate the geographic range of each assessed taxon, specifically EOO and AOO, both of which are core IUCN metrics. The AOO cell width was set at 2 km, following the IUCN default. Mapping was based mainly on herbarium records managed in the BRAHMS database – a software for the management of natural history collections. Where recent collections included global positioning system (GPS) coordinates, these were used directly. For specimens without GPS data, coordinates were estimated from the gazetteer information compiled in BRAHMS or derived from Google Earth. Imprecise or undecipherable localities were excluded from the analysis. The author confirmed the identification of each record during revision of each genus for the Flora of Peninsular Malaysia project, and only records from natural ecosystems were included.

Examples of mapped distributions

Figures 1 – 4 illustrate representative distribution patterns: a widespread species (*Licuala triphylla* Griff.), an endemic species with two centres of endemism (*Livistona endauensis* J.Dransf. & K.M.Wong), a Terengganu endemic species (*Pinanga cleistantha* J.Dransf.), and a narrow endemic species (*Maxburretia rupicola* (Ridl.) Furtado). On these maps, dots represent locality records, mostly from herbarium specimens; polygons are used to calculate EOO; and the squares or circular buffers around points are used to calculate AOO. Shaded areas indicate forest cover based on the Fifth National Forest Inventory for Peninsular Malaysia (Anon. 2014), which was used to estimate the loss of forest within the recorded range.

RESULTS AND DISCUSSION

Conservation status of non-rattan palms (including lower ranked taxa)

Overview of assessed taxa

Table 3 summarises the assessments by genus, while Appendix 1 lists the taxa (species and lower-ranked taxa) of the non-Calamoideae subfamilies revised for this project that were found to have conservation concern statuses. Non-threatened species are not included. Detailed justifications for each listing will be provided when the full family revision is published (Saw, in prep.).

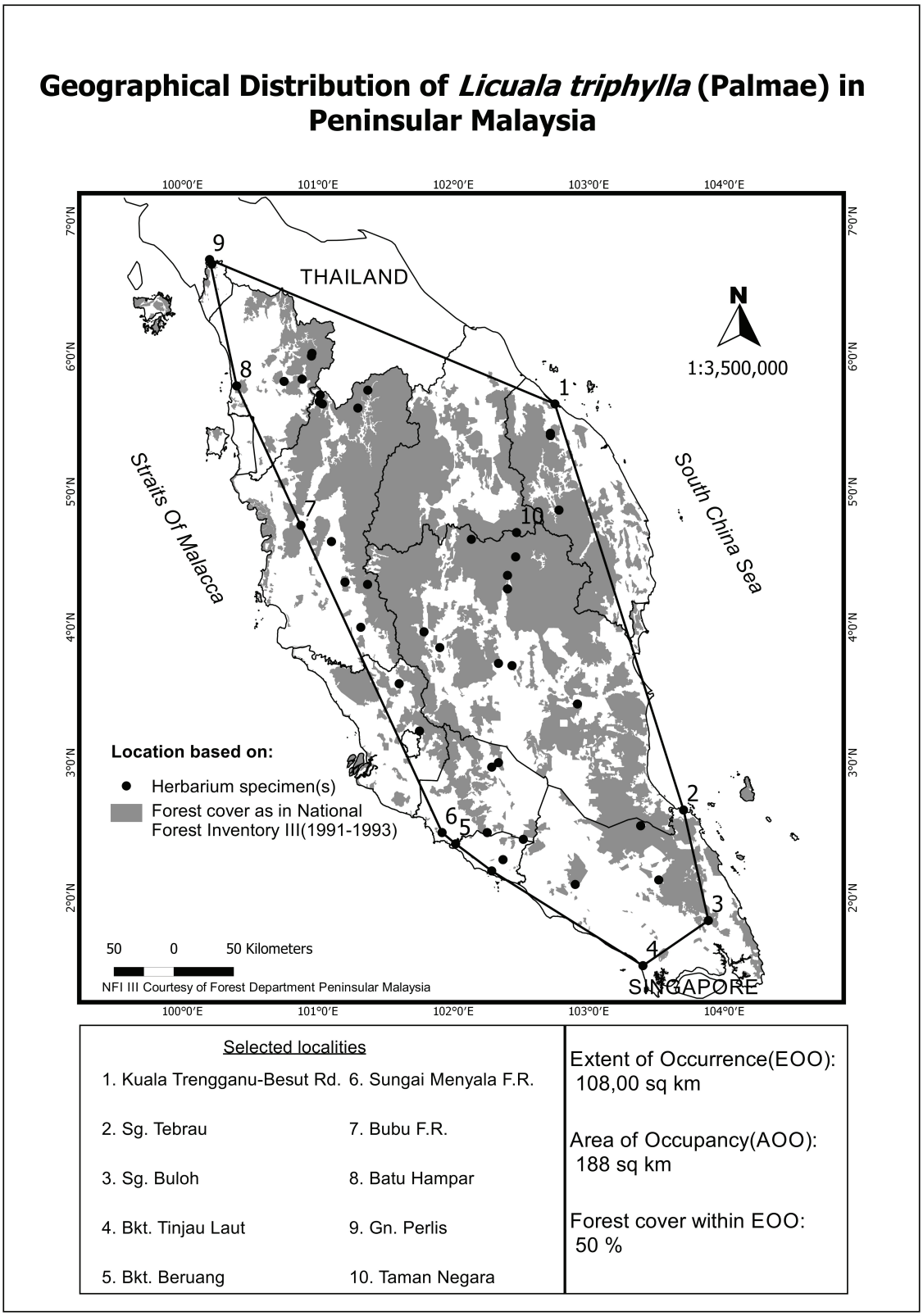

Figure 1. Distribution map of *Licuala triphylla*, a widespread species found in Peninsular Malaysia.

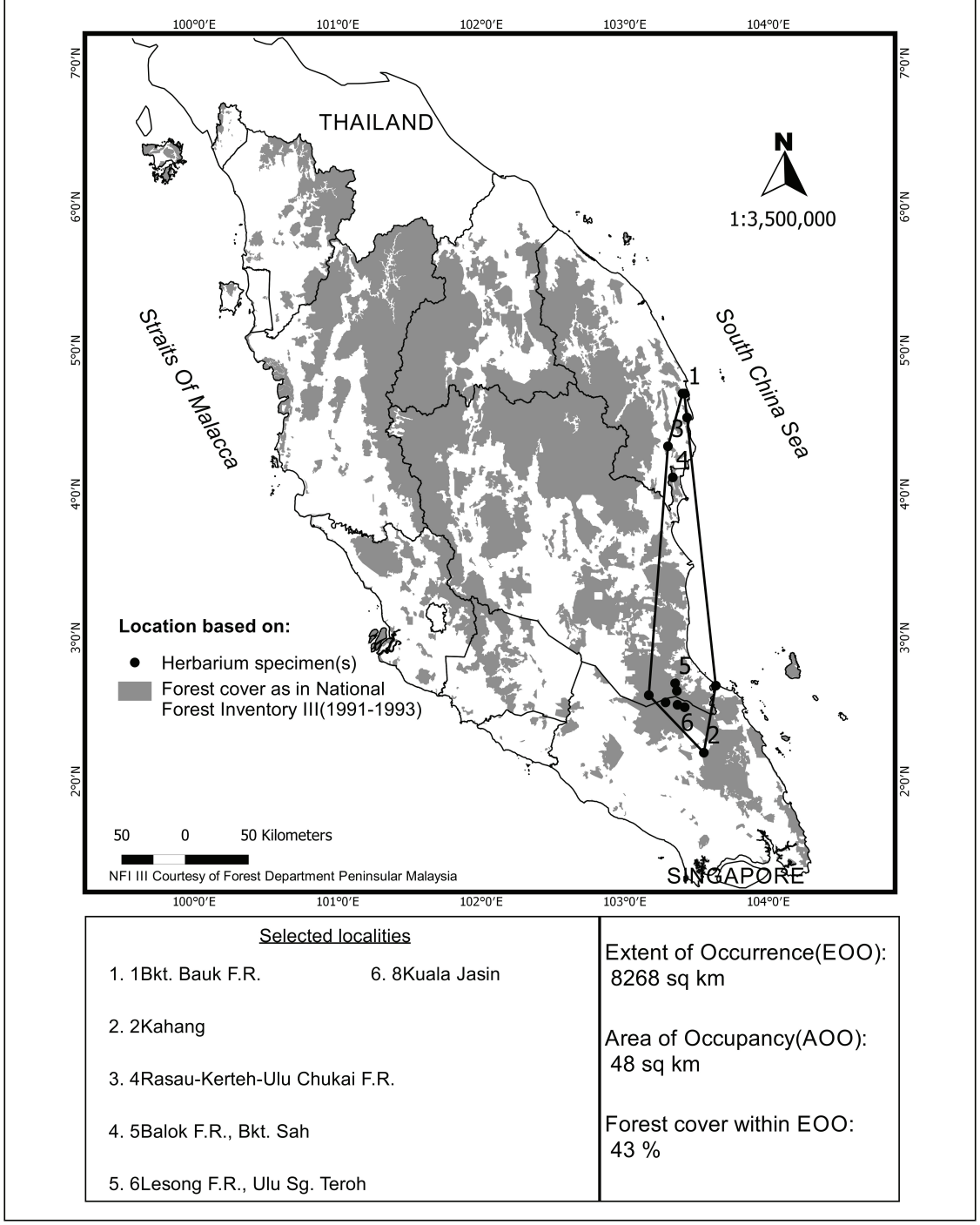

Figure 2. Distribution map of *Livistona endauensis*, a Peninsular Malaysian endemic species with two centres of distribution.

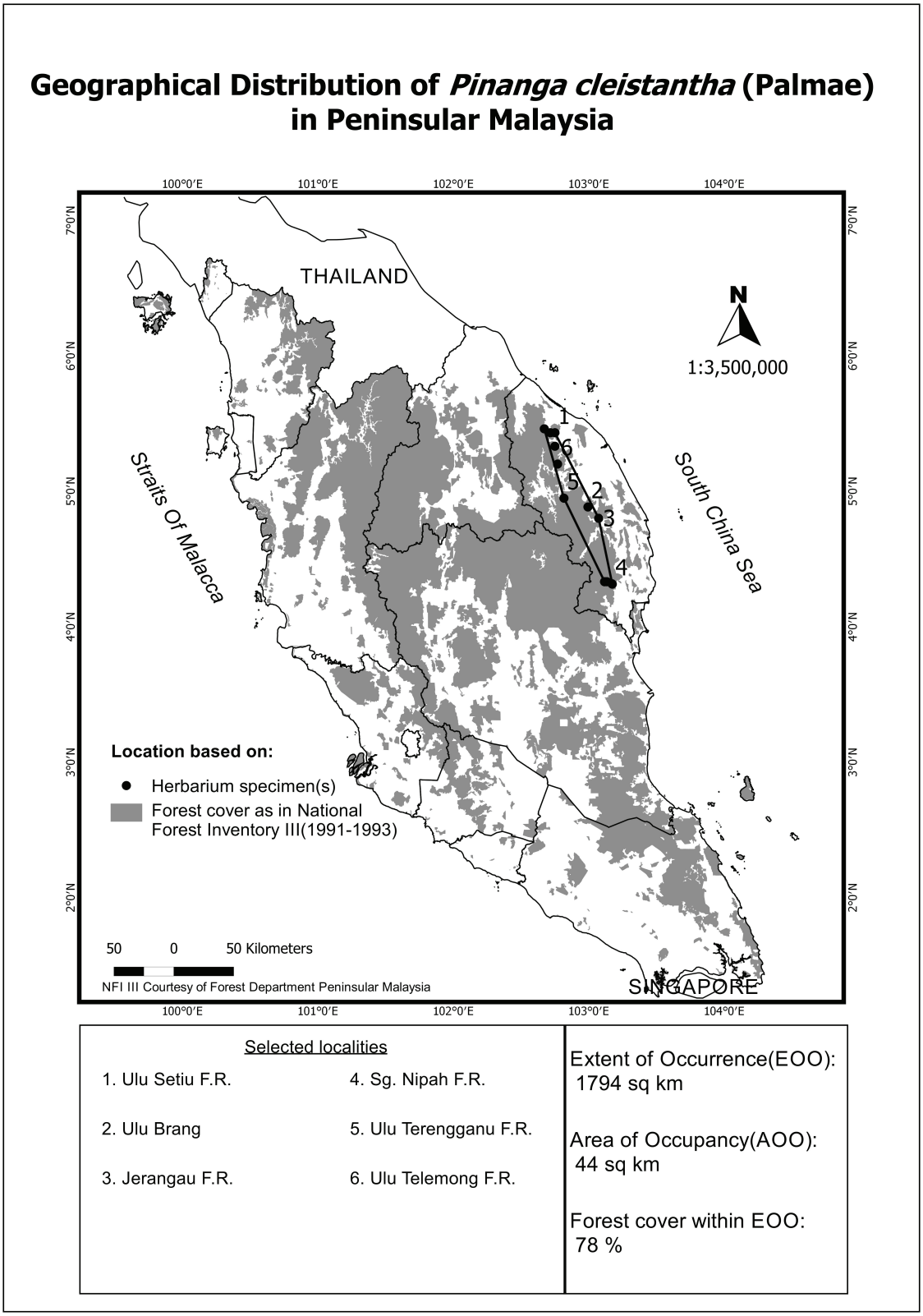

Figure 3. Distribution map of *Pinanga cleistantha*, a species endemic to the state of Terengganu.

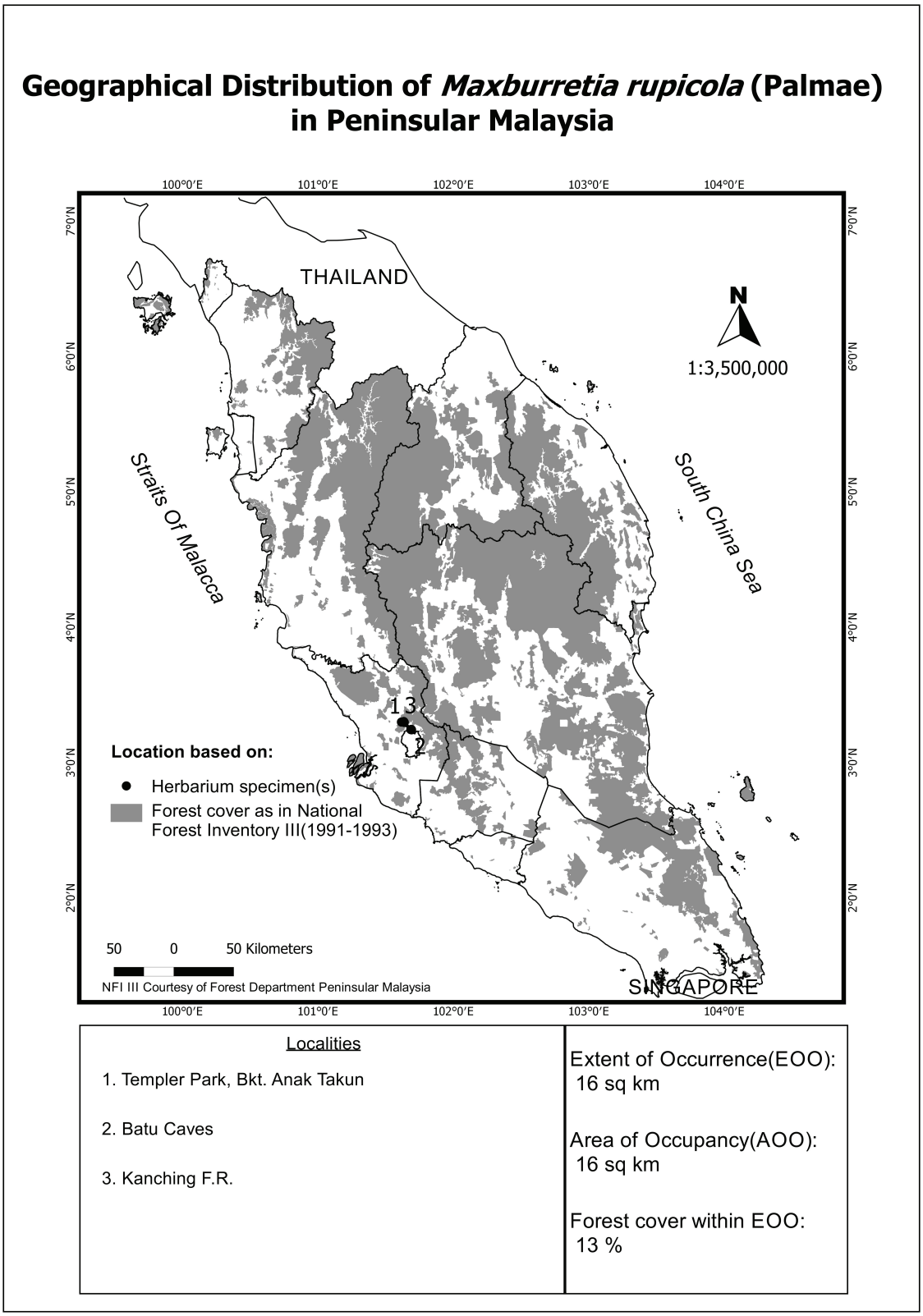

Figure 4. Distribution map of *Maxburretia rupicola*, a narrow endemic species found on two limestone outcrops in Selangor (Batu Caves and Bukit Takun-Bukit Anak Takun limestone hills).

Table 3. Summary of the genera assessed for conservation status of non-rattan species using IUCN categories and criteria for national assessment. *The Rare (RA) category was included in this assessment to include species although not threatened as their distributions are found in protected areas, but they have restricted and narrow ranges (narrow endemics), see methods for details.

Subfamily	Genera	CR	EN	VU	Threatened	RA*	NT	LC	DD	Total
Nypoideae	*Nypa*				0			1		1
Coryphoideae	*Arenga*				0		1	2		3
	Borassodendron		1		1					1
	Caryota				0			3		3
	Corypha				0			1		1
	Johannesteijsmannia		3		3			1		4
	Licuala	6	15	3	24	4	6	8	3	45
	Livistona	1		1	2	1	1			4
	Maxburretia	1			1		1			2
	Phoenix		1		1					1
	Pholidocarpus			2	2					2
Arecoideae	*Areca*			1	1		2	1		4
	Cocos				0			1		1
	Cyrtostachys				0		1			1
	Iguanura	2		2	3		1	2		8
	Nenga			1	1			2		3
	Oncosperma				0			2		2
	Orania				0			1		1
	Pinanga	5	6		11		5	8		24
	Rhopaloblaste				0			1		1
Total		**15**	**26**	**10**	**51**	**5**	**18**	**34**	**3**	**112**

Extent of conservation concern

Of the taxa assessed, 51 (45.5%) were found to be of conservation concern: 15 taxa were assessed as Critically Endangered (13.3%), 26 as Endangered (23.2%), and 10 as Vulnerable (8.9%). These values are higher than the average reported for taxa already assessed under the FPM project (Yong *et al*. 2021), which covered 1,292 taxa (see Table 4 for comparison).

Table 4. Summary of conservation status assessment of plants of Peninsular Malaysia under the FPM project for volumes published until 2021 (Yong *et al.* 2021; *Flora of Peninsular Malaysia* Series I, volumes 1–8, Series II, volumes 1–3). The summary included Dipterocarpaceae, which although have not been published in the FPM project, but there was already an earlier assessment (Chua *et al.* 2010).

Conservation status	Number of taxa (%)
Extinct (EX)	3 (0.15%)
Critically Endangered (CR)	77 (5.96%)
Endangered (EN)	120 (9.29%)
Vulnerable (VU)	173 (13.39%)
Total Conservation Concern Taxa	370 (28.63%)
Near Threatened (NT)	213 (16.49%)
Least Concern (LC)	627 (48.53%)
Data Deficient (DD)	79 (6.11%)
Total	**1,292 (100%)**

Critically Endangered taxa

Fifteen taxa – 14 species and a lower-ranked taxa – were assessed as critically endangered (CR): *Iguanura mirabilis*, *I. parvula*, *Licuala ahlidurii*, *L. cameronensis*, *L. corneri*, *L. palas*, *L. scortechinii*, *L. whitmorei*, *Livistona saribus*, *Maxburretia rupicola*, *Pinanga acaulis*, *P. auriculata* var. *merguensis*, *P. badia*, *P. sarmentosa*, and *P. sembilan*. See Table 5 for details of the critically endangered taxa, the threat these taxa are facing and some proposed conservation measures to safeguard the taxa.

Table 5. Taxa assessed as nationally critically endangered (CR) in Peninsular Malaysia with details of distribution, threat and some proposed conservation actions.

Species	Distribution	Main threat	Proposed conservation actions
Iguanura mirabilis	Endemic to Terengganu, only known from Seitu F.R.	The species is only known from a single locality which is currently a forest reserve in the lowlands which is subjected to logging.	It is proposed making the areas where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Iguanura parvula	Restricted distribution in Perak (Bintang Hijau F.R.) and Kedah (Gunung Inas F.R.). The species is also recorded in S. Thailand.	The EOO was calculated as 27 km^2 and it is only known from two localities. It has a restricted distribution in Peninsular Malaysia, distributed only in forest reserves. Its population may be subjected to logging, and this will pose a threat.	It is proposed making the areas where the species is found as a High Conservation Value Forest (HCVF) to safeguard the populations and its ecology.
Licuala ahlidurii	Endemic to Terengganu, only known from Bukit Bauk.	Although the forest is a Virgin Jungle Reserve, it is not a totally protected area and in recent years the edges of the forest reserve has been subjected to land clearance for road extension. The species is only found on the lower slopes of the forest where it is most threatened.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) on top of its current listing as a virgin jungle reserve to further safeguard the population and its ecology.
Licuala cameronensis	Endemic to Pahang, only known from 2 localities, one in Cameron Highlands and the other Kampung Sekam, about 3.4 km apart.	Population is better monitored in Cameron Highlands beside a tea estate. Very small number of individuals there.	The population in Cameron Highlands is adjacent to a tea estate. There can be encroachment into the forest reserve. It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.

Licuala corneri	Endemic to Terengganu, only known from Kemaman district (Sg. Nipah F.R., Bukit Bandi F.R., Jeram Tanduk)	Narrowly endemic to Kemaman district of Terengganu, restricted to lowland forest. All these forest reserves have been previously logged. There is concern that subsequent relogging of these reserves can further impact existing populations.	It is proposed making the areas where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Licuala palas	Endemic to Terengganu, only known from Ulu Setiu F.R.	It is the dominant understory palm there. The forest reserve can be subjected to forest conversion.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Licuala scortechinii	Distributed mainly in Kedah (Gunung Jerai F.R.) and Bukit Tapah F.R., Perak. The species is also known from S. Thailand	It has a very restricted distribution in Gn. Jerai and in S. Thailand; endemic to this small region.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology. Although Gn. Jerai is a virgin jungle reserve (VJR), a further identification of the area where the species is found will further safeguard the species.
Licuala whitmorei	Endemic to Johor, only known from Mersing F.R.	The forest reserve is subjected to logging.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Livistona saribus	Along riverbanks in Perak (e.g. Bagan Serai, Taiping Zoo), Penang (Nibong Tebal, Seberang Perai), Selangor (Klang River, Kampung Perapat, Sungai Tinggi) and Terengganu (Sungai Paka, Cukai).	In Peninsular Malaysia, all known populations are in urban areas, often near towns or residential areas. Much of the land where these populations occur is subject to potential urban development. Globally, BGCI (2021) assessed the species as Least Concern. Dowe (2009) assessed it as Vulnerable.	In Cukai, Terengganu and Seberang Prai, Penang where the species is found in heathy populations, these areas are not forest reserves and are state land reserves. They can be subjected to land conversion. It is proposed that these sites be protected.

Maxburretia rupicola	Endemic to Selangor, only known from the limestone hills of Batu Caves and Bukit Takun.	Although generally protected in Batu Caves and Bukit Takun, the population on Batu Caves have in the past been threatened by wildfires.	Although Batu Caves is protected, there is a need to ensure that a proper buffer is set around the limestone hill to safeguard it from wildfires often set off by residence living around the hill. It is proposed that the state government safeguard the hill with proper buffer zones. Bukit Takun is better protected as it is surrounded by a golf course and a forest reserve.
Pinanga acaulis	Endemic to Perak, only known from Kledang Saing F.R. and Sg. Siput.	Both forest reserves are subjected to logging.	It is proposed making the areas where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Pinanga badia	Known from a single collection from Mata Ayer F.R. at the border with Thailand. The species is also recorded in S. Thailand	It has a very restricted location at the Malaysian -Thai border. The international land border can be subjected to security action that can poise a threat to the species.	The small area on the international border can be identified as a HCVF for the species.
Pinanga auriculata var. *merguensis*	Only known from Mata Ayer F.R. in Peninsular Malaysia, the species has been recorded in S. Thailand and Myanmar.	It is critically endangered in Peninsular Malaysia due to its restricted distribution only in Mata Ayer Forest Reserve, Perlis.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Pinanga sarmentosa	Endemic to Terengganu, only known from Sg. Nipah F.R.	The species is only known from the type locality, no other sighting was seen in the area.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.
Pinanga sembilan	Endemic to Negeri Sembilan, only known from Telepa Buruk, Gunung Berembun F.R..	The forest reserve can be subjected to logging.	It is proposed making the area where the species is found as a High Conservation Value Forest (HCVF) to safeguard the population and its ecology.

Distribution pattern of Critically Endangered taxa. All taxa, except *Livistona saribus* and *Pinanga auriculata* var. *merguensis*, have narrow distributions. Most are restricted to a single state, and some are known from only one locality, i.e., *Iguanura mirabilis*, *Licuala ahlidurii*, *L. palas*, *L. whitmorei*, *P. samentosa*, and *P. sembilan*. The collection of *Pinanga badia* was made at the Malaysian Thai border close to the other known record from Peninsular Thailand. So, the species is very restricted to that small area. *Livistona saribus* is naturally widespread, ranging from Southeast China and Indochina to Peninsular Malaysia, Indonesia (Sumatra and Java), the Philippines, and Borneo (Kalimantan). However, in Peninsular Malaysia it is the most endangered of the four native *Livistona* species because all known populations occur in swamp habitats near urban areas and are therefore highly exposed to habitat loss (Saw 2025). *Pinanga auriculata* var. *merguensis* occurs mainly in Peninsular Thailand and extends marginally into Perlis, where it is known from Mata Ayer Forest Reserve. Its very small national extent of occurrence places it in the Critically Endangered category for the national assessment.

Table 5 provide some recommendations towards safeguarding these critically endangered species/taxa. For species occurring in forest reserves, the best option is for the Department of Forestry to earmark such areas as High Conservation Value Forest (HCVF), such classification will provide some level of protection for these species against conversion and logging activities. For species outside forest reserves, state governments and relevant authorities will require to legislate protection of such areas.

Factors contributing to elevated threat levels

The comparatively high proportion of threatened palms is associated with two main factors. First, palms in Peninsular Malaysia show higher endemism and a greater concentration of species with restricted distributions than the general flora. Endemism among Peninsular Malaysian plants is about 30%, whereas palms reach about 37%. Of these endemic palms, 37 taxa (31%) are narrow endemics, confined either to a single state or to areas straddling the border between two adjacent states. Second, palm diversity is concentrated in lowland and hill forests, habitats that are especially vulnerable to loss and degradation.

Reasons for the restriction distribution of these palms can be factors of habitat specialisation (e.g., *Livistona endauensis* restricted to sandstone outcrops, *Maxburretia* spp. on limestone hill ridges, *Pholidocarpus* spp. on swampy habitats). However, it does not explain the patterns observed for many species in lowland to hill forests. Other factors of geology, geological past, individual species ecology and evolution may be contributing to the isolation of these species.

Assessment criteria and broader comparison

The threatened categories were most often supported by evidence of reduction or deterioration in geographic range under criterion B, typically through B1 (extent of occurrence, EOO), B2 (area of occupancy, AOO), or both. This pattern is similar to that for Dipterocarpaceae, in which 52% of assessed taxa (91 of 174) were also considered of conservation concern (Yong *et al.* 2021). Although dipterocarps are much larger plants, they share broadly similar habitat requirements and distribution patterns with non-rattan palms. Many of dipterocarps, similar to palms are species of per humid climate and will not fair well in climatic conditions with distinct dry seasons. The distribution patterns across the different soil types are also similar to palms. Both groups are vulnerable to forest conversion and lowland habitat loss. The major differences between these two groups are in the stature of the plants, dipterocarps are mostly large forest trees whereas palms are primarily understory plants with different reproductive ecologies.

Rare (RA) taxa

Five species were assessed as Rare (RA): *Licuala hairulii*, known only from Royal Belum State Park; *L. moyseyi*, known only from the mountains of Terengganu (Gunung Lawit and Gunung Padang); *L. thoana*, restricted to Endau-Rompin State Park; *L. tiomanensis*, known only from the summit area of Gunung Kajang on Pulau Tioman; and *Livistona tahanensis*, known only from the upper slopes and ridges towards Gunung Tahan in Taman Negara. Although these species do not fall within the IUCN (2012) threatened categories (i.e., they should be listed as Least Concern), they remain nationally important because of their highly restricted distributions. Park managers and other relevant authorities should be aware of their presence so that these species must be considered for in site management and conservation planning. They also warrant special attention as distinctive components of these parks and reserves.

Overview of state-level patterns

Table 6 presents the distribution of the 56 threatened and rare taxa across the states of Peninsular Malaysia. The table also summarises the total number of palm species recorded in each state, the number of non-rattan taxa, their conservation categories by state, and the numbers of endemic, narrow endemic, and threatened non-rattan taxa, arranged from highest to lowest. The data were extracted from recent revisions prepared for the *Flora of Peninsular Malaysia* (Saw, in prep.), and the state species totals have been updated from Saw (2021). In this paper, narrow endemic taxa are defined as those restricted to a single state or occurring across the border of two adjacent states.

Table 6. State-level distribution of non-rattan palm taxa and conservation categories in Peninsular Malaysia. The number of palm species in each state was determined from herbarium specimens the Forest Research Institute Malaysia (KEP) and Singapore Botanic Gardens (SING) herbaria.

State	Total palm spp.	Total non-rattan taxa								Total Threatened	Endemic	Narrow endemic
		CR	EN	VU	RA	NT	LC	DD	Total			
Terengganu	129	8	9	8	1	9	28	0	63	25	24	16
Perak	121	2	8	5	1	11	26	1	53	15	12	4
Pahang	140	1	6	6	1	17	30	1	61	13	23	9
Johor	107	1	5	6	0	12	23	0	47	12	26	6
Kedah	65	0	7	2	0	5	20	0	34	9	5	0
Selangor	85	1	3	4	0	9	22	0	39	8	5	1
Negeri Sembilan	70	1	3	2	0	4	24	0	34	6	6	1
Kelantan	66	0	0	5	0	9	22	1	36	5	4	1
Penang	24	1	3	0	0	0	12	0	16	4	3	1
Perlis	18	1	2	0	0	1	10	0	14	3	0	0
Melaka	25	0	0	1	0	3	16	0	20	1	1	0

State-level concentration of threatened taxa

Terengganu has the highest number of threatened taxa, with 25, followed by Perak, Pahang, and Johor, each with 12 – 15 taxa. Palm diversity is also high in these states. For non-rattan palms, Terengganu and Pahang have the greatest numbers of taxa (63 and 62, respectively), followed by Perak, Johor, Selangor, Kelantan, and Negeri Sembilan. This pattern suggests that higher overall diversity is associated with a higher number of threatened taxa. Terengganu also has the largest number of narrow endemic taxa (16), followed by Pahang (9), Johor (6), and Perak (4). The concentration of narrow endemics in Terengganu is likely an important factor why it also has the greatest number of threatened species.

Conservation actions for threatened palms

The Red Listing assessment serves as a tool for prioritising species in need of conservation intervention. Yong *et al.* (2021) outlined key steps for implementing conservation actions for threatened taxa. These recommended actions are particularly relevant for palm conservation efforts in Peninsular Malaysia. Additional conservation activities may also be considered to further support the protection of threatened species.

In situ conservation

In situ conservation is often considered the best method to safeguard species due to its ability to preserve entire ecosystems and natural habitats. It allows species to continue to adapt, evolve and thrive in their natural environments. This is crucial for maintaining ecosystem functions and species interactions. Palms in Peninsular Malaysia have many species with restricted distribution and with the high number of threatened taxa, *in situ* conservation is the best option towards safeguarding the survival of these taxa in terms of cost and ecological functions. Distribution patterns are uneven for palms, and some states have greater diversity of endemic and threatened taxa. It is important that these states take special efforts towards conserving the state endemics and threatened taxa.

For taxa with narrow endemism or found in single localities, that states should identify these taxa and their locations and institute procedures to safeguard these plants in their habitats as *in situ* conservation areas. Current instruments for in situ conservation include National and State Parks, Wildlife Sanctuaries, Virgin Jungle Reserves, High Conservation Value Forest (HCVF), and other effective area-based conservation measures (OECM). For taxa range outside in these protected categories, the relevant authorities (e.g. Forest Department) can designate such forest as HCVF.

Conservation strategies for endangered taxa

Peninsular Malaysia does not have any legislative framework to protect threatened plant species. It is necessary that such legislative framework be established to underpin and guide conservation actions for threatened taxa, ensuring there is a legal basis for protection and recovery measures. Once the legislative framework is in place, it should be followed by processes that conduct comprehensive studies of the threatened taxa, including population assessments, habitat requirements, and threats analysis, to inform targeted conservation strategies. Based on the findings of these studies, prioritise conservation efforts towards taxa classified as "Endangered" and "Critically Endangered", focusing resources where they are most urgently needed. Some species-specific recommendations are given in Table 5 using currently available tools for species- and site-specific circumstances, e.g. HCVF. Where *in situ* conservation is insufficient or not immediately feasible, employ *ex situ* methods such as cultivation in botanic gardens to safeguard genetic diversity and support potential future reintroductions.

Institutional responsibilities

The Forest Research Institute (FRIM) is currently taking the lead in plant conservation efforts under the Forest Biodiversity Division for Peninsular Malaysia. The role of FRIM is mostly towards providing the scientific basis for assessments and identification of threatened species. For effective conservation of threatened species, there is a need to coordinate the work of biologists (researchers) with forest managers. Currently findings from researchers are passed to forest managers in Forest Department and other stakeholders. There is also a need to set up a centre towards such coordination for a more systematic and efficient management to safeguard threatened taxa. Similar proposals should be also considered for conservation efforts in Sabah and Sarawak.

CONCLUSION

To prevent the extinction of native plant species, it is essential that conservation initiatives are carried out in a systematic and coordinated manner. Given the current patterns of land use, active human intervention is often necessary because species are frequently put at risk, sometimes without our awareness. In the context of palm conservation in Malaysia, some foundational steps have already been undertaken. While these steps are aligned with the broader plant conservation strategies developed within the country, they remain insufficient on their own. Continued and enhanced efforts are needed to ensure the long-term survival of Malaysia's native palms. Effective conservation must ultimately be implemented at the state level. Given Terengganu's high palm diversity, strong endemism, and large number of threatened taxa, it should be prioritised for targeted surveys, habitat protection, and conservation planning for narrow endemic palms. Other states facing similar circumstances should also be prioritised for comparable surveys and conservation action.

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REFERENCES

Anon. 2014. Laporan Inventori Hutan Nasional Kelima (IHN-5). Kuala Lumpur: Jabatan Perhutanan Semenanjung Malaysia. 275 pp.

Bachman, S., Moat. J., Hill. A.W., de la Torre. J. and Scott. B. 2011. Supporting Red List threat assessments with GeoCAT: geospatial conservation assessment tool. *ZooKeys* 150: 117–126. https://doi.org/10.3897/zookeys.150.2109

Chua, L.S.L 2012. Conservation. In *Flora of Peninsular Malaysia*. Series II: Seed Plants, Vol. 3, R. Kiew, R.C.K. Chung, L.G. Saw and E. Soepadmo (Eds.), pp. 3–10.

Chua, L.S.L., Suhaida, M., Hamidah, M. and Saw, L.G. 2010. *Malaysia Plant Red list – Peninsular Malaysian Dipterocarpaceae*. Research Pamphlet No. 129. Kepong: Forest Research Institute Malaysia.

Kiew, R. and Pearce, K.G. 1991. Palms. In *The State of Nature Conservation in Malaysia*, R. Kiew (Ed.), pp. 95–100. Petaling Jaya: Malayan Nature Society.

Henderson, A. 2020. A revision of Calamus (Arecaceae, Calamoideae, Calaminae). *Phytotaxa* 445: 1–656.

Henderson, A. 2025. A revision of Iguanura (Arecaceae, Arecoideae, Areceae). *Phytotaxa* 690(2): 135–188.

IUCN. 2012. *IUCN Red List Categories and Criteria: Version 3.1*. Second edition. Gland: IUCN.

Jeanson, M.J., Couvreur, T.L.P. and Henderson, A. 2025. A revision of tribe Caryoteae (Arecaceae, Coryphoideae). *Phytotaxa* 719: 1–141.

Saw, L.G. 2021. Palms of Malaysia and their conservation. *Malayan Nature Journal* 73: 521–529.

Saw, L.G. 2023a. A revision of the genus *Iguanura* Blume (Arecaceae) in Peninsular Malaysia. *Gardens' Bulletin Singapore* 75: 73–117,

Saw, L.G. 2023b. A new species of *Licuala* from Royal Belum State Park, Perak, Malaysia. *Palms* 67(3) 115–120.

Saw, L.G. 2024. *Pinanga* of Peninsular Malaysia and Singapore. *Palms* 68(4): 160–203.

Saw, L.G. 2025. *Livistona saribus* (Palmae), the critically endangered swamp Serdang of Malaysia. *Malaysian Naturalist* 79.1: 24–29.

Saw, L.G., Chua, L.S.L., Suhaida, M., Yong, W.S.Y. and Hamidah, M. 2010. Conservation of some rare and endangered plants from Peninsular Malaysia. *Kew Bulletin* 65: 681–689.

Yong, W.S.Y., Chua, L.S.L., Lau, K.H., Siti-Nur Fatinah, K., Cheah, Y.H., Yao, T.L., Rafidah, A.R. *et al.* 2021. Malaysia Red List. Vol. 1, Part 1. Research Pamphlet No. 151. Kepong: Forest Research Institute Malaysia. 107pp.

APPENDIX

Appendix 1. List of threatened and rare non-rattan palms of Peninsular Malaysia with their preliminary conservation status assessments. *Denotes species endemic to Peninsular Malaysia; **denotes narrow endemic species (restricted to a single state or found in an area bordering between two adjacent states). The extend of occurrence (EOO) and area of occupancy (AOO) are also provided in the analysis. The criterion for each assessment follows IUCN (2012).

Species	Threat Category	Criteria	EOO (km^2)	AOO (km^2)
Areca ridleyana Becc. ex Furtado *	VU	B1ab(iii)	17,920	80
Borassodendron machadonis (Ridl.) Becc.	EN	B2ab	24,207	32
Iguanura bicornis Becc.	VU	B1ab(iii)	6,380	36
Iguanura brevipes Hook.f.	VU	B1ab(iii)	14,307	88
Iguanura mirabilis C.K.Lim **	CR	B2ab(ii,iii)	9	12
Iguanura parvula Becc.	CR	B1ab(iii)	27	12
Johannesteijsmannia lanceolata J.Dransf.*	EN	A4acd,B1ab(ii,iii), C2a(i)	3,738	36
Johannesteijsmannia magnifica J.Dransf.*	EN	B1ab(ii,iii,iv), C2a(i)	1,306	32
Johannesteijsmannia perakensis J.Dransf.*	EN	A4acd,B1ab(ii,iii,iv),C2a(i)	3,115	52
Licuala ahlidurii Saw **	CR	B2ab(iii)	0.12	4
Licuala bayana Saw **	EN	A4c; B1ab(i,iii) +2ab(i,iii)	1,241	28
Licuala cameronensis Saw **	CR	B1 b(iii), C2(a,i)	28	12
Licuala corneri Furtado **	CR	B1ab(i,ii,iii)	48	28
Licuala fractiflexa Saw **	EN	B1a,b(i,iii)	3,670	92
Licuala hairulii Saw **	RA		3	8
Licuala kamarudinii Saw **	EN	B1ab(i,iii)	934	16
Licuala kemamanensis Furtado **	EN	B1ab(i,iii)	704	36
Licuala khoonmengii Saw **	EN	B1ab(i,iii)	4,545	48
Licuala kingiana Becc. **	EN	B1ab(i,ii,iii) +2ab(i,ii,iii)	1,837	76
Licuala lanuginosa Ridl. **	EN	B1ab(i,iii)	3,002	64
Licuala longipes Griff. *	VU	B1ab(i,iii)	6,072	124
Licuala malajana Becc. var. *humilis* Saw **	EN	B1ab(i,iii)	181	16
Licuala mirabilis Furtado *	EN	B1ab(i,iii)	4,059	56
Licuala modesta Becc.	VU	B1ab(i,iii)	13,855	68
Licuala moyseyi Furtado **	RA		211.00	16
Licuala mustapana Saw **	EN	B1ab(i,iii)	1,273	16
Licuala palas Saw **	CR	B1ab(i,iii), B2ab(ii,iii)		4
Licuala peltata Roxb. ex Buch.-Ham	EN	B1ab(i,iii)		4
Licuala ruthiae Saw **	EN	B1ab(i,iii)	189	12
Licuala sallehana Saw var. *incisifolia* Saw **	EN	B1ab(i,iii)	1,450	16
Licuala sallehana Saw var. *sallahana* **	EN	B1ab(i,iii)	318	16
Licuala scortechinii Becc.	CR	B1 (b,i,iii,iv)	39	12
Licuala tenuissima Saw *	VU	B1ab(i) (iii)	12,454	32
Licuala terengganuensis Saw *	EN	B1ab(i) (iii)	4,344	56
Licuala thoana J.Dransf. & Saw**	RA		3.7	12
Licuala tiomanensis Furtado **	RA			8
Licuala whitmorei Saw **	CR	B1, B2b(i,ii,iii,iv)		8
Livistona endauensis J.Dransf. & K.M.Wong *	VU	B1b(i)	8,268	52
Livistona saribus (Lour.) Merr. ex A.Chev	CR	A1(a,c), 3, 4	48,065	48
Livistona tahanensis Becc. **	RA		0.53	8
Maxburretia rupicola (Ridl.) Furtado **	CR	B1a	16	16
Nenga grandiflora Fernando *	VU	B2a	10,498	68
Phoenix paludosa Roxb.	EN	B2ab(i) (ii) (iii)	55,375	36
Pholidocarpus kingianus (Becc.) Ridl. *	VU	B2ab(i) (ii) (iii)	44,322	40
Pholidocarpus macrocarpus Becc.	VU	B2ab(i) (ii) (iii)	62,304	40

Pinanga acaulis Ridl. **	CR	B1 B2b(i,iii)	90	16
Pinanga adangensis Ridl.	EN	B1 B2b(ii) (iii)	8	16
Pinanga auriculata Becc. var. *merguensis* (Becc.) C.K.Lim	CR	B2a b(ii,iii)		4
Pinanga badia Hodel	CR	B2a b(ii,iii)		4
Pinanga cleistantha J.Dransf. **	EN	B2b(i,iii)	1,794	44
Pinanga malaiana (Mart.) Scheff. var. *johorensis* (C.K.Lim & Saw) Saw **	EN	B2a b(ii,iii)	2,840	28
Pinanga pantiensis J.Dransf. **	EN	B2a b(I, iii)	180	20
Pinanga pectinata Becc. *	EN	B1(b,i,iii)	4,020	44
Pinanga riparia Ridl.	EN	B2b(ii,iii,iv)	28,476	48
Pinanga sarmentosa Saw **	CR	B2(a,bii)		4
Pinanga sembilan C.K.Lim **	CR	B2(a,bii)		8


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CHAPTER 18

State of orchid conservation in Malaysia

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Abstract: Malaysia is one of the world's most important centres of orchid diversity, supporting an estimated 2,300 species across a wide range of ecosystems, from lowland rainforests to montane cloud forests. This chapter reviews the current state of orchid conservation in Malaysia, highlighting the ecological, economic, and cultural significance of orchids as a national heritage resource. It examines patterns of diversity and biogeography, ecological functions, industry potential, and the major threats posed by habitat loss, illegal collection, international trade, and climate change. Case studies from the mossy forest of Cameron Highlands and the ultramafic landscapes of Gunung Kinabalu illustrate the conservation importance of high-value orchid habitats. The chapter evaluates existing *in situ* and *ex situ* conservation initiatives, including orchid rescue programmes, citizen science, DNA barcoding, and sustainable propagation efforts. It further outlines national conservation strategies, governance frameworks, research priorities, and capacity-building needs. Ultimately, orchids are presented as flagship species for biodiversity stewardship, requiring coordinated national action to ensure their long-term survival.

INTRODUCTION

The Orchidaceae is among the largest and most evolutionarily advanced families of flowering plants and represents an invaluable component of Malaysia's natural heritage. Malaysia is recognised as one of the major centres of orchid diversity in Southeast Asia, harbouring approximately 972 – 982 species in Peninsular Malaysia and an estimated 2,500 – 3,000 species in Sabah and Sarawak (Besi *et al.* 2022, 2023; Go and Khali-Aziz 2008; Go *et al.* 2014, 2019; Ong *et al.* 2017). This remarkable diversity reflects the country's wide range of ecosystems, from lowland dipterocarp forests and limestone hills to montane cloud forests and peat swamp habitats.

Orchids are renowned not only for their extraordinary beauty, but also for their ecological importance. Their highly specialised relationships with pollinators, mycorrhizal fungi, and host plants make them valuable indicators of ecosystem health and environmental integrity. Many Malaysian orchid species are endemic and occur nowhere else in the world, highlighting their significance for biodiversity conservation and scientific research. New species continue to be discovered and described, demonstrating that Malaysia's orchid flora remains incompletely documented.

Beyond their ecological value, orchids hold considerable cultural, educational, and economic importance. They have long inspired horticultural innovation, ecotourism, and public appreciation of nature, while contributing to the development of numerous internationally recognised hybrids. However, increasing pressures from habitat loss, climate change, and illegal collection threaten many wild orchid populations.

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As one of the nation's most iconic plant groups, orchids embody Malaysia's rich biological heritage and natural identity. Their conservation is essential not only for safeguarding biodiversity but also for preserving a living legacy that continues to contribute to scientific discovery, sustainable development, and national pride. This chapter highlights the significance of Orchidaceae as a national heritage resource and underscores the importance of its protection for future generations.

DIVERSITY AND BIOGEOGRAPHY OF MALAYSIAN ORCHIDS

Malaysia is one of the most important centres of orchid diversity in tropical Asia, owing to its location within Sundaland and the Malesian biogeographical region. Its complex geological history, varied topography, and diverse ecosystems have promoted the evolution and persistence of a rich orchid flora. Orchids occur across a wide range of habitats, from coastal forests, limestone karsts, and lowland dipterocarp forests to peat swamps, heath forests, montane forests, and cloud forests above 2,000 m in elevation. Estimates of Malaysia's orchid diversity range from 2,000 to 4,000 species, largely due to differences in taxonomic treatments, synonymy, uncertain historical records, and overlapping distributions between Peninsular Malaysia, Sabah, and Sarawak. Based on current taxonomic understanding, a realistic estimate is approximately 2,300 species, of which about 20% are endemic (Goverts *et al.* 2021).

Orchid diversity is unevenly distributed across the country. Sabah and Sarawak harbour particularly rich floras due to their extensive forests, geological diversity, and broad elevational gradients associated with mountain systems such as Gunung Kinabalu, Trus Madi Range, Gunung Mulu, Gunung Murud, and the Crocker Range. Peninsular Malaysia also supports significant orchid diversity, especially within the Titiwangsa Range, limestone habitats, and montane forests such as Cameron Highlands (Figure 1), Fraser's Hill, Genting Highlands, Pulau Pinang and Gunung Ledang, all of which support numerous endemic and range-restricted species.



Figure 1. Mountain system in Malaysia. **A.** Mount Kinabalu, Sabah; **B.** Cameron Highlands, Pahang; and **C.** Genting Highlands, Pahang.

Sabah is recognised as one of Southeast Asia's foremost orchid hotspots, supporting an estimated 1,500 species, including about 250 endemics (Juiling *et al.* 2020). Its exceptional diversity is driven by high rainfall, climatic stability, and remarkable geological heterogeneity, a phenomenon often referred to as the "Bornean Paradox". Particularly important are the ultramafic landscapes of Gunung Kinabalu Park, which function as ecological and evolutionary "edaphic islands," fostering highly specialised orchid communities and many endemic taxa.

Biogeographically, Malaysian orchids share strong affinities with the wider Malesian flora and reflect historical connections among Sundaland landmasses during periods of lower sea levels. Many species are shared with Sumatra, Java, Borneo, and southern Thailand, while others have evolved in isolation. Mountain peaks, limestone outcrops, and forest refugia have acted as centres of speciation, producing unique orchid assemblages found nowhere else in the world.

This extraordinary diversity and biogeographical complexity underscore the importance of orchids as a national heritage resource. Continued taxonomic research, field exploration, and conservation assessments remain essential, as new species continue to be discovered while many known taxa face increasing threats from habitat loss, climate change, and illegal collection. Understanding orchid diversity and distribution patterns is therefore fundamental to their effective conservation and sustainable management.

ECOLOGICAL IMPORTANCE OF ORCHIDS

The ecological importance of orchids extends far beyond their aesthetic and horticultural value. As one of the most diverse groups of flowering plants in Malaysia, orchids are integral components of forest ecosystems and play important roles in maintaining ecological integrity and biodiversity. Their complex life histories and specialised ecological requirements make them particularly sensitive to environmental disturbances, thereby providing valuable insights into ecosystem health and conservation status.

A defining characteristic of orchids is their dependence on symbiotic mycorrhizal fungi for seed germination and establishment. Orchid seeds are minute and lack nutrient reserves, requiring fungal partners to supply essential nutrients during early development. This specialised relationship links orchid survival directly to the health of forest soils and microbial communities. Any disruption to these below-ground ecological networks can significantly affect orchid recruitment and population persistence.

Orchids are also widely recognised as indicators of forest health due to their sensitivity to habitat changes and microclimatic conditions. Many species require narrow ranges of temperature, humidity, light intensity, and moisture availability, making them highly susceptible to forest degradation, fragmentation, and climate change. Furthermore, numerous orchids exhibit highly specialised pollination systems involving specific insects or other animal pollinators. The loss of pollinators or alterations in habitat conditions can rapidly disrupt reproductive success, often leading to population decline. Consequently, orchid diversity and abundance can serve as useful indicators of ecosystem integrity and environmental change.

In montane and cloud forest ecosystems, orchids represent a major component of epiphytic plant communities and may be regarded as keystone taxa due to their contribution to ecosystem complexity and biodiversity. Their presence supports intricate ecological interactions involving fungi, pollinators, host trees, and associated organisms. Montane forests such as those of the Cameron Highlands, Fraser's Hill, Gunung Ledang, Gunung Kinabalu, and Gunung Mulu harbour exceptionally rich orchid assemblages that contribute to the unique character and ecological functioning of these ecosystems.

The ecological significance of orchids has important implications for conservation. Because their survival depends on the maintenance of intact habitats, stable microclimates, functional pollinator networks, and healthy mycorrhizal communities, orchids are particularly vulnerable to habitat loss, climate change, and other anthropogenic pressures. Conserving orchid diversity therefore requires a holistic ecosystem-based approach that safeguards not only individual species but also the ecological processes and interactions upon which they depend. As indicators of environmental quality and components of highly specialised ecological networks, orchids occupy a central position in efforts to conserve Malaysia's forest biodiversity and ecological heritage.

The ecological importance of orchids extends beyond their role as flowering plants. Mycoheterotrophic species such as *Lecanorchis multiflora* depend entirely on mycorrhizal fungi for carbon acquisition and illustrate the complexity of below-ground ecological interactions. Similarly, jewel orchids of the subtribe Goodyerinae have been recognised as sensitive indicators of forest health due to their dependence on stable microclimatic conditions and undisturbed forest environments (Sudin and Md.-Isa 2024).

ECONOMIC LANDSCAPE: THE ORCHID INDUSTRY

Orchids represent one of the most valuable segments of Malaysia's ornamental plant industry and have long contributed to the nation's floriculture sector. Their exceptional diversity, aesthetic appeal, and market demand have supported the growth of commercial nurseries, landscaping enterprises, tissue culture laboratories, and ornamental plant businesses throughout the country. Both native and exotic orchids are cultivated extensively for domestic markets and export, making orchids an important component of Malaysia's horticultural economy.

The development of orchid hybrids has been a particular success story within the industry. Through selective breeding and biotechnology, Malaysian breeders have produced numerous registered hybrids that combine desirable floral characteristics, adaptability, and commercial value. These hybrids have strengthened Malaysia's reputation in regional and international orchid markets while reducing pressure on wild populations by providing cultivated alternatives for collectors and enthusiasts. Advances in micropropagation and tissue culture techniques have further enabled large-scale production of orchids, supporting industry growth and enhancing market accessibility.

The economic potential of the orchid sector extends beyond ornamental horticulture. Recent assessments suggest that Malaysia's native orchid resources may contribute significantly to the national bioeconomy, with an estimated potential value exceeding RM4 billion through floriculture, biotechnology, ecotourism, germplasm development, intellectual property generation, and value-added products. The country's rich orchid diversity provides opportunities for the development of new hybrids, conservation-based enterprises, research innovations, and niche export markets. Growing global demand for ornamental plants and sustainable nature-based products further enhances Malaysia's prospects as a regional hub for orchid production and innovation.

However, realising this economic potential requires balancing commercial utilisation with biodiversity conservation. The integration of orchid conservation into a sustainable bioeconomy framework offers an approach whereby economic benefits can be generated while safeguarding natural populations and their habitats. *Ex situ* conservation programmes, certified propagation systems, community-based enterprises, and sustainable nursery production can create alternative sources of income while reducing collection pressure on wild orchids. Such approaches align with national biodiversity and bioeconomy strategies, ensuring that orchid resources remain available for future generations.

Despite these opportunities, significant challenges persist. Illegal collection and trade continue to threaten many wild orchid species, particularly rare and endemic taxa that command high prices among collectors (Figure 2) (Hinsley *et al.* 2015). A growing concern is the laundering of wild-collected orchids through commercial supply chains, whereby illegally harvested plants are falsely represented as artificially propagated specimens. Unsustainable sourcing practices, inadequate traceability systems, and increasing online trade further complicate enforcement efforts. Without effective regulation, monitoring, and public awareness, commercial demand may contribute to the depletion of natural populations and undermine conservation initiatives.



Figure 2. Illegal collection and trade of Malaysian wild orchids.

The future of Malaysia's orchid industry therefore depends on its ability to transition from extractive utilisation towards a conservation-driven model that values orchids as both economic assets and irreplaceable components of the nation's natural heritage. Strengthening sustainable production systems, promoting ethical trade practices, and investing in conservation-based innovation will be critical to ensuring that economic development and biodiversity conservation progress hand in hand.

THREAT ASSESSMENT AND CONSERVATION CHALLENGES

Effective orchid conservation relies heavily on accurate threat assessments, which provide the scientific basis for determining conservation priorities, management interventions, and policy decisions. In Malaysia, conservation assessments are typically conducted as part of taxonomic revisions, during which orchid groups are systematically reviewed to clarify species boundaries, distributions, ecological requirements, and conservation status. Such revisions are essential because reliable conservation assessments depend on robust taxonomic knowledge. However, orchid revisions are often time-consuming due to the complexity of the family, the need for extensive field surveys, the examination of herbarium specimens, and the careful evaluation of historical records.

In addition to comprehensive taxonomic studies, threat assessments are sometimes undertaken for particular orchid species or groups when urgent conservation concerns arise. These situations commonly involve areas targeted for land conversion, infrastructure development, quarrying activities, or other forms of habitat disturbance that may threaten known orchid populations. Rapid assessments are often necessary to provide baseline information for conservation planning and to guide mitigation measures before habitat loss occurs. Newly described orchid species frequently require immediate conservation assessment because many are highly localised and confined to a single mountain, limestone hill, or forest fragment. Unfortunately, the publication of new species can inadvertently increase their desirability among collectors, making them immediate targets for illegal harvesting.

Habitat loss remains the greatest threat to orchid conservation in Malaysia. The conversion of natural forests for agriculture, urban expansion, tourism development, infrastructure projects, and resource extraction continues to reduce and fragment orchid habitats. Species with narrow ecological requirements or restricted distributions are particularly vulnerable to local extinction when their habitats are disturbed or destroyed. Montane forests, limestone ecosystems, and peat swamp habitats are among the most threatened environments supporting unique orchid assemblages.

Illegal harvesting and international trafficking represent additional major conservation challenges. Many Malaysian orchids are highly sought after by collectors because of their rarity, novelty, or horticultural value. Although all orchids are regulated under the provisions of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), illegal collection and trade persist. Commercial collectors often target newly discovered, endemic, and geographically restricted species, removing plants directly from the wild to satisfy market demand. In some cases, wild-collected specimens are laundered through commercial supply chains and falsely marketed as artificially propagated plants, undermining both conservation efforts and legitimate orchid enterprises.

One of the most pressing challenges in orchid conservation is the imbalance between conservation capacity and commercial collecting pressure. The number of taxonomists, field botanists, conservation practitioners, and enforcement personnel remains relatively small compared with the growing network of commercial and illegal collectors. Consequently, some orchid populations may be severely depleted before adequate scientific studies,

conservation assessments, or protective measures can be implemented. Species restricted to a single locality are especially vulnerable, and, in extreme cases, populations may be wiped out before their ecology, reproductive biology, or conservation requirements are properly understood.

Climate change is emerging as a significant long-term threat to Malaysian orchids, particularly those inhabiting montane ecosystems. Rising temperatures, reduced atmospheric humidity, altered rainfall patterns, and changes in cloud cover are expected to affect the delicate microclimatic conditions upon which many orchids depend. Cloud forests and upper montane habitats are especially vulnerable because their orchid communities are adapted to consistently cool and humid environments. As climatic conditions shift, suitable habitats may contract or move upslope, leaving high-elevation species with limited opportunities for migration and increasing their risk of extinction.

Several regions in Malaysia illustrate the cumulative impacts of these threats. In Cameron Highlands, agricultural expansion, tourism development, infrastructure construction, and climate-related changes have contributed to habitat degradation and the loss of orchid localities, particularly within montane and cloud forest ecosystems. Fraser's Hill, another important centre of orchid diversity, faces pressures associated with tourism development, forest fragmentation, and changing environmental conditions. In Sabah, montane forests associated with Gunung Kinabalu, Trus Madi Range and the Crocker Range harbour exceptional orchid diversity but remain vulnerable to climate change, illegal collection, and habitat disturbance. These regions serve as important indicators of the broader conservation challenges facing Malaysian orchids.

In Sabah, high-elevation orchid species face the additional threat of "summit squeeze", whereby rising temperatures progressively reduce suitable habitats near mountain summits. Species occurring on Gunung Kinabalu and Gunung Tambuyukon may have limited opportunities for upward migration, increasing the risk of local extinction under future climate scenarios. Illegal collection of highly desirable species such as *Paphiopedilum* continues to threaten wild populations despite CITES protection and existing enforcement mechanisms (Rajaram *et al.* 2018; Rajaram 2019).

Addressing these threats requires an integrated conservation strategy that combines taxonomic research, conservation assessments, habitat protection, climate adaptation measures, strengthened law enforcement, CITES compliance, *ex situ* conservation, and public awareness. Greater collaboration among government agencies, research institutions, local communities, conservation organisations, and the horticultural industry will be essential to ensure that Malaysia's orchid diversity is effectively documented, protected, and sustainably managed. As new species continue to be discovered and environmental pressures intensify, translating scientific knowledge into timely conservation action remains one of the most urgent priorities for orchid conservation in Malaysia.

CASE STUDIES OF HIGH CONSERVATION VALUE SITES

Mossy Forest, Cameron Highlands, Pahang

The Mossy Forest of Cameron Highlands represents one of the most important orchid conservation sites in Peninsular Malaysia and serves as an outstanding example of a high conservation-value montane ecosystem. Situated within the upper montane cloud forest zone of Banjaran Titiwangsa, the area is characterised by persistent mist, high humidity, cool temperatures, and nutrient-poor soils that support a specialised assemblage of flora and fauna. These unique environmental conditions have enabled the evolution and persistence of a rich orchid flora, making the mossy forest a critical refuge for numerous rare and endemic species.

Recent botanical surveys have documented 122 orchid taxa within the mossy forest ecosystem, including 21 taxa that are endemic to Peninsular Malaysia. This remarkable diversity highlights the site's significance as both a centre of orchid conservation and an important reservoir of genetic resources. Many of these species exhibit narrow ecological tolerances and highly restricted distributions, rendering them particularly vulnerable to environmental disturbances and habitat change.

Among the most notable species (Figure 3) are *Bulbophyllum cameronense*, *B. evansii*, *Corybas ridleyanus*, and *Coelogyne kaliana*, all of which possess highly restricted geographical ranges and are closely associated with the specialised microclimatic conditions of the montane cloud forest. The survival of these orchids depends on the continued maintenance of cool temperatures, high humidity, intact forest canopies, and functional ecological interactions involving pollinators and mycorrhizal fungi. Because of their restricted distributions and habitat specificity, these species are particularly susceptible to habitat degradation, climate change, and illegal collection.



Figure 3. Notable species that possess highly restricted geographical ranges, adapted to specialised microclimatic conditions of the montane cloud forests in Cameron Highlands. **A.** *Bulbophyllum cameronense*; **B.** *Bulbophyllum evansii*; **C.** *Corybas ridleyanus*; and **D.** *Coelogyne kaliana*.

Despite its conservation importance, the mossy forest faces increasing pressures from tourism development and recreational activities. The area has become one of the most popular ecotourism destinations in Malaysia, attracting large numbers of visitors annually. While ecotourism generates economic benefits and promotes public appreciation of biodiversity, unmanaged visitation can result in trail erosion, vegetation trampling, habitat disturbance, and the inadvertent introduction of invasive species. Increased accessibility may also facilitate illegal collection of rare orchid species. Consequently, balancing conservation objectives with sustainable tourism management remains a major challenge for the long-term protection of the site.

The mossy forest also illustrates the importance of long-term scientific monitoring in montane ecosystems. Ongoing studies are required to track changes in orchid populations, species distributions, flowering phenology, and habitat conditions, particularly in response to climate change. Given the sensitivity of cloud forest orchids to temperature, humidity, and cloud cover, the site provides an important natural laboratory for understanding how environmental changes may affect orchid diversity in tropical montane regions.

The conservation significance of the mossy forest can be better appreciated when viewed alongside other orchid-rich landscapes in Malaysia. In Peninsular Malaysia, montane regions such as Fraser's Hill, Gunung Ledang, and Banjaran Titiwangsa support distinctive orchid communities with varying levels of endemism and habitat specialisation. In Sabah, mountain systems including Gunung Kinabalu, Trus Madi Range and the Crocker Range harbour some of the highest orchid diversities in Southeast Asia, with numerous Bornean endemics and altitudinal specialists. Similarly, the montane forests of Gunung Mulu, Gunung Murud, and the Kelabit Highlands in Sarawak support unique orchid assemblages associated with sandstone, limestone, and ultramafic substrates.

Although each of these regions possesses distinct floristic characteristics, they share common conservation challenges, including habitat disturbance, climate change, illegal collection, and increasing human pressure. Together, they form a network of high conservation -value sites that collectively safeguard Malaysia's orchid diversity. Their protection is essential not only for conserving individual species but also for maintaining the ecological and evolutionary processes that have generated one of the richest orchid floras in the world.

Gunung Kinabalu and the Ultramafic Landscapes of Sabah

If the Mossy Forest of Cameron Highlands represents the flagship orchid conservation landscape of Peninsular Malaysia, then Gunung Kinabalu and its surrounding ultramafic ecosystems stand as the crown jewel of orchid diversity in Malaysian Borneo. Recognised globally as one of the most important centres of plant endemism in Southeast Asia, the Kinabalu region harbours an extraordinary concentration of orchid species shaped by millions of years of geological isolation, elevational gradients, and ecological specialisation.

A distinctive feature of the Kinabalu landscape is the extensive occurrence of ultramafic substrates, which create highly specialised environmental conditions unlike those found in most tropical forests. These soils are characterised by elevated concentrations of magnesium, nickel, chromium, and other heavy metals, while simultaneously being deficient in essential nutrients such as phosphorus, potassium, and calcium. Such extreme edaphic conditions act as powerful ecological filters, limiting the establishment of many plant species while promoting the evolution of highly specialised and often endemic taxa. As a result, ultramafic habitats function as ecological "islands" that drive speciation and generate exceptional levels of biodiversity.

Recent botanical surveys have documented more than 339 orchid species associated with Sabah's ultramafic landscapes, making these habitats among the richest orchid ecosystems in Malaysia (Majit *et al.* 2014; Md.-Isa *et al.* 2023, 2024, 2025). Many species exhibit highly specialised adaptations that enable them to survive under nutrient-poor conditions and in environments subjected to strong environmental gradients. The concentration of rare and endemic orchids within these habitats highlights their importance as reservoirs of unique genetic diversity and evolutionary heritage.

Among the most significant orchid conservation localities within Kinabalu Park is Marai Parai, an exposed ultramafic ridge located on the southern slopes of Gunung Kinabalu. Widely recognised as a botanical hotspot, Marai Parai supports a remarkable assemblage of specialised plants, many of which occur nowhere else on Earth. Recent field surveys have continued to reveal previously undocumented botanical diversity, reinforcing the area's reputation as one of the most important centres of plant endemism in Malaysia (Md.-Isa *et al*. 2024).

The discovery of *Stigmatodactylus maraiparaiensis* exemplifies the conservation significance of these ultramafic ecosystems. Described only recently from Marai Parai, this highly localised orchid is currently known from fewer than 50 mature individuals restricted to a single locality (Md.-Isa *et al.* 2025). Such species are examples of micro-endemics organisms with extremely restricted geographical distributions that may occupy only a few hectares of habitat. Micro-endemic orchids are particularly vulnerable to environmental disturbance because any alteration to their habitat can affect a substantial proportion of the global population. Their existence also suggests that additional undescribed orchid species may remain hidden within Sabah's remote mountain ecosystems.

The conservation challenges facing these habitats are considerable. Although much of the Kinabalu region is legally protected, many orchid species remain vulnerable because of their naturally restricted distributions. Illegal collection by commercial plant traders poses a continuing threat, particularly for rare and newly discovered species that attract interest from specialist collectors. Furthermore, the increasing popularity of mountain tourism creates additional pressures on fragile alpine and subalpine ecosystems, requiring careful management to balance public access with biodiversity conservation.

Climate change represents perhaps the most significant long-term threat to the orchid flora of Gunung Kinabalu. Many high-elevation orchid species occupy narrow climatic niches characterised by cool temperatures, persistent cloud cover, and high atmospheric humidity. As temperatures rise, suitable habitats are expected to shift upslope, reducing the available area for species already confined to mountain summits. This phenomenon, commonly referred to as the “summit squeeze”, places high-elevation endemics at particular risk because there is often no higher habitat available for migration. Species restricted to ultramafic ridges and upper montane zones may therefore experience severe population declines or local extinction under future climate scenarios.

The conservation significance of Gunung Kinabalu and its ultramafic landscapes provides an important contrast to the Mossy Forest of Cameron Highlands. While both ecosystems support exceptional orchid diversity and endemism, they differ fundamentally in their ecological drivers. In Cameron Highlands, orchid diversity is strongly influenced by cloud forest conditions, cool temperatures, and persistent moisture. In contrast, orchid diversity in Gunung Kinabalu is shaped by a combination of altitudinal gradients, geological complexity, and the unique environmental pressures associated with ultramafic substrates. Together, these two landscapes illustrate the extraordinary ecological breadth of Malaysia's orchid flora and underscore the need for regionally tailored conservation strategies.

As centres of endemism, evolutionary innovation, and ecological resilience, Gunung Kinabalu and the ultramafic landscapes of Sabah represent some of the most important orchid conservation sites in Southeast Asia. Their protection is not only critical for safeguarding rare and threatened species but also for preserving the evolutionary processes that continue to generate biodiversity within one of the world's richest tropical floras. Rare or endemic species like *Paphiopedilum rothschildianum*, *P. dayanum*, *P. javanicum* and *Cleisocentron merrillianum* are among the critically endangered due to illegal trade (Figure 4).



Figure 4. Rare or endemic species from Kinabalu area endangered by illegal harvesting and trade. **A.** *Paphiopedillum rothchildianaum* (Gold of Kinabalu); **B.** *Paphiopadilum dayanum*; **C.** *Paphiopedilum javanicum* and **D.** *Cleisocentron merrillianum*.

CURRENT CONSERVATION EFFORTS

Malaysia has made significant progress in orchid conservation over the past several decades through a combination of habitat protection, scientific research, *ex situ* conservation, public engagement, and sustainable utilisation initiatives. Nevertheless, the increasing pressures of habitat loss, illegal collection, climate change, and expanding commercial demand continue to challenge conservation efforts. As one of the world's centres of orchid diversity, Malaysia bears a significant responsibility to safeguard this botanical heritage through an integrated conservation framework that combines ecological protection, scientific innovation, and stakeholder participation.

In Situ conservation: Safeguarding orchids in their natural ecosystems

In situ conservation remains the most effective and sustainable approach to orchid conservation because it preserves species within the ecosystems in which they evolved. Orchids are among the most ecologically specialised groups of plants, often relying on specific microclimatic conditions, host trees, pollinators, and mycorrhizal fungi for their survival. These intricate ecological relationships are difficult, and often impossible, to replicate under artificial conditions, making habitat protection the cornerstone of orchid conservation.

Malaysia's extensive network of protected areas provides the primary foundation for in situ conservation. National parks, state parks, wildlife sanctuaries, Totally Protected Areas, and Permanent Reserved Forests collectively safeguard many of the country's most important orchid habitats. These include internationally recognised biodiversity hotspots such as the mossy forest of Cameron Highlands, Fraser’s Hill, Endau-Rompin National Park, Gunung Ledang, Pulau Pinang, Gunung Kinabalu, Crocker Range, Gunung Mulu, and numerous other montane, lowland, and limestone forest ecosystems. The designation of the mossy forest under the UNESCO Man and the Biosphere (MAB) Programme further highlights the global significance of Malaysia's orchid-rich landscapes.

Conservation efforts also benefit from the participation of indigenous and local communities. Orang Asli communities in Peninsular Malaysia and indigenous peoples in Sabah and Sarawak possess extensive traditional ecological knowledge and have long served as custodians of forest ecosystems. Their involvement in habitat stewardship, biodiversity monitoring, ecological restoration, and conservation awareness programmes strengthens local conservation capacity while promoting sustainable livelihoods.

Despite these advances, important challenges remain. Protected areas are often constrained by limited financial resources, insufficient staffing, inadequate enforcement, and the lack of long-term ecological monitoring programmes. Illegal orchid collection continues to occur even within protected forests, while external pressures such as agricultural expansion, infrastructure development, tourism activities, and forest fragmentation may compromise ecological integrity. Climate change further threatens orchid habitats, particularly montane ecosystems where species are adapted to narrow temperature and humidity ranges. Consequently, effective in situ conservation requires not only legal protection but also sustained management, scientific monitoring, habitat restoration, and community engagement.

Ex situ Conservation: Supporting recovery, research, and sustainable utilisation

Ex situ conservation plays a critical complementary role by safeguarding orchid genetic resources outside their natural habitats. Across Malaysia, botanical gardens, orchid houses, universities, research institutions, government agencies, and private collections maintain living collections that support conservation, research, education, public outreach, and species recovery programmes. Advances in orchid propagation techniques, particularly tissue culture, micropropagation, seed germination, and in vitro conservation, have significantly enhanced the capacity to conserve and multiply threatened species.

Ex situ approaches are especially valuable when wild populations face immediate threats from habitat destruction, illegal collection, or stochastic events. They also provide important opportunities for conservation research, restoration programmes, and public education. Furthermore, the cultivation and mass propagation of commercially desirable orchids can reduce harvesting pressure on wild populations by supplying legally produced plants to the horticultural market. This is particularly important for newly described species, which are frequently targeted by collectors shortly after their discovery. Rapid propagation can help buffer commercial demand while conservation measures are implemented in the wild.

However, *ex situ* conservation should not be regarded as a substitute for habitat protection. Living collections are vulnerable to pests and diseases, water shortages, equipment failures, power disruptions, and institutional constraints. Their long-term success often depends on specialised expertise and dedicated personnel, making them susceptible to disruptions in staffing and funding. Furthermore, many collections contain only a limited representation of natural populations and may fail to capture the full genetic diversity required for long-term evolutionary resilience.

Significant gaps also remain in the conservation of orchid genetic resources. Although living collections and tissue culture repositories have expanded considerably, relatively little attention has been given to long-term germplasm storage, conservation genetics, and the preservation of associated mycorrhizal fungi. As a result, current *ex situ* programmes may not adequately conserve the full spectrum of genetic and ecological diversity necessary for future restoration and recovery efforts.

EMERGING CONSERVATION APPROACHES: RESCUE, REHABILITATION, CITIZEN SCIENCE AND DNA BARCODING

In recent years, orchid conservation in Malaysia has evolved beyond traditional habitat protection and *ex situ* cultivation towards more innovative and collaborative approaches. One notable example is the orchid rescue and rehabilitation programme pioneered by Universiti Putra Malaysia in collaboration with the Forestry Department of Peninsular Malaysia, Forest Department Sarawak, the IUCN Species Survival Commission, local communities, and citizen scientists (Go and Besi 2020; Go *et al.* 2022). These initiatives focus on rescuing orchids from logging concessions and other disturbed habitats before they are lost through forest clearance, and subsequently maintaining them under *ex situ* conditions for research, propagation, rehabilitation, and eventual reintroduction into suitable habitats (Go and Besi 2020).

The programme recognises that many orchids found on felled trees within logging areas would otherwise perish before they can be documented or conserved (Besi *et al.* 2018; Besi *et al.* 2019a; Go and Besi 2020). Rescue efforts therefore serve as an important emergency conservation measure, particularly for rare, endemic, and poorly known species. Rescued plants are maintained in conservation facilities, nurseries, and botanical collections, where they can be studied, propagated, and used to establish genetically representative populations for future restoration programmes. The establishment of facilities such as the Tengku Permaisuri Norashikin Conservatory at Fraser's Hill (Figure 5) and ongoing initiatives to develop orchid conservation centres in Peninsular Malaysia and Sarawak demonstrate the growing commitment towards orchid rehabilitation and germplasm conservation.



Figure 5. The establishment of orchid rehabilitation and germplasm conservation facility. **A.** Tengku Permaisuri Norashikin Conservatory at Fraser's Hill, Pahang and **B.** Anap-Muput Wildflowers Nursery, Sarawak.

A particularly important aspect of these efforts is the integration of local communities and citizen scientists into conservation activities. Orchid enthusiasts, village communities, and local growers often possess extensive field knowledge and provide valuable support in locating, rescuing, monitoring, and cultivating threatened orchids. The scientist-community partnership model adopted by these programmes has enhanced conservation capacity while promoting public awareness and stewardship of orchid diversity. Such collaborative approaches are increasingly recognised as cost-effective mechanisms for biodiversity monitoring and species conservation in regions where scientific resources are limited.

Technological innovations have also strengthened conservation outcomes. DNA barcoding initiatives undertaken by UPM have generated molecular reference data for endangered, rare, endemic, and cryptic orchid species, facilitating accurate species identification and supporting biodiversity assessments (Chase and Fay 2009; Hosseini 2011; Moudi *et al.* 2013; Tan 2013; Go *et al.* 2015). The development of DNA barcode libraries provides valuable tools for conservation planning, taxonomic verification, and the detection of illegally traded orchid species. By combining traditional taxonomy with molecular approaches, researchers can improve the identification of biodiversity hotspots, prioritise conservation actions (Besi *et al*. 2019b, 2023) and strengthen enforcement efforts against illegal trade.

Another emerging conservation strategy involves partnerships with forest management units and timber companies operating within production forests. Collaborative projects in Sarawak, including initiatives within the Anap-Muput Forest Management Unit, demonstrate how biodiversity conservation can be integrated into sustainable forest management. Through rescue, propagation, rehabilitation, and biodiversity assessment programmes, these partnerships provide opportunities to conserve orchid diversity within managed landscapes while generating socioeconomic benefits for local communities.

Collectively, these initiatives represent a significant advancement in Malaysia's orchid conservation framework. They illustrate the growing recognition that successful orchid conservation requires a combination of habitat protection, scientific research, *ex situ* conservation, community engagement, technological innovation, and cross-sector collaboration. Such integrated approaches may serve as a model for future orchid conservation efforts throughout Southeast Asia.

TOWARDS A NATIONAL ORCHID CONSERVATION FRAMEWORK

The current state of orchid conservation in Malaysia reflects both encouraging achievements and substantial challenges. Existing initiatives have successfully protected many important habitats, enhanced scientific understanding of orchid diversity, expanded *ex situ* collections, and increased public awareness of conservation issues. Nevertheless, continued habitat degradation, illegal trade, climate change, and limited conservation resources threaten many orchid species, particularly narrow endemics and newly discovered taxa.

Moving forward, conservation efforts should be guided by a more integrated national framework that combines habitat protection, ecological restoration, conservation genetics, species recovery programmes, sustainable propagation, and community-based stewardship. Strengthening collaboration among government agencies, universities, botanical gardens, indigenous communities, conservation organisations, and the horticultural industry will be essential for improving conservation outcomes. Equally important is the need to accelerate conservation assessments, strengthen enforcement against illegal collection and trafficking, expand long-term ecological monitoring, and develop sustainable orchid production systems that reduce dependence on wild-harvested plants.

Ultimately, the future of orchid conservation in Malaysia depends on recognising that *in situ* and *ex situ* approaches are mutually reinforcing rather than competing strategies. While the protection of natural habitats must remain the highest conservation priority, *ex situ* programmes provide critical support for research, recovery, education, and sustainable utilisation. Together, these complementary approaches offer the most effective pathway for securing the long-term survival of Malaysia’s extraordinary orchid diversity and preserving an irreplaceable component of the nation’s natural heritage.

NATIONAL STRATEGY FOR ORCHID CONSERVATION

Malaysia possesses one of the richest orchid floras in the world, yet this extraordinary biodiversity faces increasing threats from habitat loss, illegal collection, climate change, and unsustainable exploitation. While important progress has been made through habitat protection, scientific research, *ex situ* conservation, and public engagement, the long-term survival of Malaysian orchids will require a coordinated national strategy that integrates conservation, sustainable utilisation, and biodiversity governance. Such a strategy should be guided by the principles of ecosystem conservation, scientific evidence, community participation, and sustainable development.

Strengthening *in situ* protection and habitat restoration

The protection of natural habitats must remain the highest priority for orchid conservation. Orchids are dependent upon complex ecological interactions involving host trees, pollinators, mycorrhizal fungi, and specialised microclimatic conditions that cannot be fully replicated outside natural ecosystems. This fundamental vulnerability highlights the necessity of anchoring local conservation measures within broader global frameworks, such as the Orchids-Status Survey and Conservation Action Plan (IUCN/SSC Orchid Specialist Group, 1996). Strengthening the management and connectivity of protected areas, particularly montane forests, limestone ecosystems, peat swamps, and lowland dipterocarp forests, is therefore essential.

Conservation efforts should focus not only on protecting existing orchid-rich habitats but also on restoring degraded ecosystems that retain potential for species recovery. Grounding these actions in baseline data from national ecological assessments, such as the environmental sector reports by the Academy of Sciences Malaysia, ensures a targeted deployment of resources (Akademi Sains Malaysia 2014). Ecological restoration programmes should incorporate orchid reintroduction, habitat rehabilitation, and the restoration of associated ecological processes. Priority should be given to high-conservation-value landscapes such as the Mossy Forest of Cameron Highlands, Fraser's Hill, Gunung Kinabalu, Crocker Range, Gunung Mulu, and other centres of orchid endemism and diversity. Long-term ecological monitoring should accompany restoration efforts to evaluate population recovery and ecosystem resilience.

Enhancing *ex situ* conservation and propagation capacity

Ex situ conservation provides an important safeguard against species loss and should be strengthened as part of a national conservation network. Botanical gardens, orchid conservatories, research institutions, universities, and specialised conservation centres should work collaboratively to establish comprehensive living collections representing Malaysia's orchid diversity. Effective management within these repositories relies heavily on standardized curatorial methodologies, such as those established in *The Herbarium Handbook* (Bridson and Forman 2000), which provide the baseline protocols for processing and identifying wild-sourced genetic material.

Particular emphasis should be placed on the development of national orchid germplasm repositories, seed banks, tissue culture facilities, and cryopreservation programmes. These resources would provide insurance against extinction while supporting research, restoration, and sustainable commercial production. Crucially, *ex situ* priority scoring should be harmonised with the most up-to-date extinction risk registries to capture taxa facing imminent wilderness collapse (IUCN 2022). Greater attention should also be given to conserving associated mycorrhizal fungi and maintaining genetically representative collections to ensure that *ex situ* programmes contribute meaningfully to long-term species recovery.

Strengthening Law Enforcement and Cross-Border Monitoring

Illegal collection and international trafficking remain among the most significant threats to Malaysian orchids. Although existing legislation and international agreements such as the CITES provide important regulatory frameworks, enforcement challenges continue to facilitate the movement of illegally sourced plants through domestic and international markets (CITES 2023). Investigative field reporting emphasizes that even in remote regions like Kelantan, unchecked commercial pressures continue to result in severe landscape disruptions (BERNAMA 2015).

A national strategy should strengthen collaboration among forestry departments, customs authorities, wildlife enforcement agencies, CITES management authorities, and international partners. Enhanced monitoring of online trade platforms, improved species identification tools, DNA-based forensic approaches, and stronger intelligence-sharing mechanisms would help combat illegal trafficking networks. Greater penalties for repeat offenders and increased public awareness of legal and conservation implications are also needed to reduce demand for illegally collected orchids.

Developing climate-adaptive conservation strategies

Climate change represents one of the greatest long-term threats to orchid conservation, particularly for montane and cloud forest species that depend on narrow environmental conditions. Rising temperatures, altered rainfall patterns, declining humidity, and shifts in cloud cover are expected to affect orchid distributions, reproductive success, and habitat suitability.

Future conservation planning should incorporate climate adaptation measures, including vulnerability assessments, long-term monitoring of orchid populations, predictive distribution modelling, and the identification of climate refugia. Conservation corridors should be maintained to facilitate species migration where possible, while *ex situ* collections should prioritise species considered highly vulnerable to future climatic changes. Climate adaptation strategies must become an integral component of orchid conservation planning at both the state and national levels.

Fostering academia–industry–community partnerships

The complexity of orchid conservation requires collaboration across multiple sectors. Universities and research institutions provide scientific expertise in taxonomy, ecology, genetics, and conservation biology, while government agencies are responsible for policy implementation and habitat management. The horticultural industry contributes propagation expertise and market access, whereas local communities provide invaluable ecological knowledge and stewardship.

Future conservation programmes should strengthen partnerships among these stakeholders through collaborative research, conservation agreements, citizen science initiatives, community-based monitoring, and knowledge-sharing platforms. Successful examples of scientist–community partnerships, orchid rescue programmes, and collaborative conservation projects demonstrate the value of inclusive approaches that combine scientific knowledge with local participation. One notable conservation initiative has been implemented in the Anap-Muput Forest Management Unit in Tatau, Bintulu, Sarawak, where orchids are systematically rescued from active logging blocks immediately after felling operations. This programme aims to safeguard orchid populations that would otherwise be lost during forest exploitation, while providing opportunities for *ex situ* conservation, propagation, research, and eventual rehabilitation into suitable habitats. This initiative should be replicated in all logging concessionaires throughout the country.

Promoting sustainable utilisation and benefit-sharing

Conservation efforts must also address the economic drivers that contribute to wild orchid collection. Sustainable utilisation strategies can generate economic benefits while reducing pressure on natural populations. Large-scale propagation of commercially desirable orchids through tissue culture and nursery production should be encouraged to supply legal markets and reduce incentives for illegal harvesting.

Equitable benefit-sharing mechanisms should ensure that local communities, Indigenous Peoples, researchers, and conservation practitioners receive appropriate recognition and benefits arising from the utilisation of orchid genetic resources. Conservation-based enterprises, ecotourism initiatives, community nurseries, and orchid cultivation programmes can provide alternative livelihoods while promoting conservation awareness and stewardship.

Integrating orchids into national biodiversity and climate policies

As one of Malaysia's most iconic and diverse plant groups, orchids should be recognised as flagship taxa within national biodiversity and climate-change frameworks. Their ecological sensitivity, high conservation value, and cultural significance make them ideal indicators for monitoring ecosystem health and environmental change. Future policy frameworks should explicitly incorporate orchid conservation within the *National Policy on Biological Diversity*, climate adaptation strategies, forest management plans, and bioeconomy initiatives. The establishment of a *National Orchid Conservation Action Plan* could provide a coordinated mechanism for setting conservation priorities, mobilising resources, monitoring progress, and strengthening collaboration among stakeholders. Such a framework would elevate orchid conservation from a species-focused endeavour to a broader national commitment towards biodiversity conservation, climate resilience, and sustainable development.

Hence, the future of Malaysia's orchids depends on a holistic conservation strategy that integrates habitat protection, scientific research, climate adaptation, sustainable utilisation, and stakeholder collaboration. By strengthening *in situ* and *ex situ* conservation efforts, improving law enforcement, fostering partnerships, and embedding orchid conservation within national biodiversity and climate policies, Malaysia can secure the long-term survival of one of its most valuable natural assets. Such a strategy will not only conserve orchid diversity but also safeguard the ecological, cultural, scientific, and economic benefits that orchids provide for future generations.

POLICY RECOMMENDATIONS AND GOVERNANCE FRAMEWORK

The long-term conservation of Malaysia's orchid diversity requires more than species-level interventions; it demands a robust governance framework that integrates biodiversity conservation, sustainable development, climate resilience, and community participation. Given that orchid habitats span multiple jurisdictions and land-use categories, effective conservation depends on coordinated policies, institutional collaboration, strong regulatory mechanisms, and sustainable economic incentives. A comprehensive governance framework should therefore align conservation objectives across federal and state agencies while fostering partnerships among academia, industry, local communities, and international stakeholders.

Harmonising federal and state biodiversity legislation

One of the major challenges in orchid conservation is the fragmented nature of biodiversity governance across Malaysia. Forests, wildlife, and land-use planning often fall under state jurisdiction, while international commitments, biodiversity policies, and trade regulations are managed at the federal level. Consequently, conservation priorities and enforcement capacities may vary considerably among states.

A national orchid conservation framework should promote greater harmonisation between federal and state legislation, policies, and conservation priorities. Legal protections within production landscapes must be strictly grounded in statutory safeguards, notably the *National Forestry Act 1984*, which empowers relevant jurisdictions to penalise unauthorised floral extractions within Permanent Reserved Forests. This structural approach must be integrated directly with long-standing national directives, such as the *National Forestry Policy 1978*, ensuring that rare epiphytic plant dynamics are thoroughly accounted for in working forest blueprints. Strengthening coordination among the Ministry of Natural Resources and Environmental Sustainability (NRES), state forestry departments, wildlife agencies, and biodiversity authorities will ensure consistent protection of threatened orchid species and their habitats across Peninsular Malaysia, Sabah, and Sarawak. Standardised conservation assessment protocols, data-sharing mechanisms, and coordinated management plans are particularly important for species whose distributions transcend administrative boundaries and for habitats of national conservation significance.

Strengthening institutional collaboration

Malaysia possesses substantial expertise in orchid research and conservation, distributed across institutions such as the Department of Wildlife and National Parks (PERHILITAN), the Malaysian Nature Society (MNS), the Forest Research Institute Malaysia (FRIM), universities, botanical gardens, and state forestry agencies. However, these strengths are often dispersed among separate programmes and projects.

Future conservation efforts should prioritise stronger institutional partnerships that integrate scientific research, conservation management, public education, and policy implementation. Universities can contribute expertise in taxonomy, conservation genetics, ecology, climate modelling, and propagation technologies, while National Parks, forestry departments, and FRIM provide critical capacities in habitat management, biodiversity inventories, and species protection. Collaborative research networks, shared databases, joint field expeditions, and coordinated conservation action plans would significantly improve the efficiency and impact of conservation initiatives. Such partnerships would also accelerate the documentation of orchid diversity, conservation assessments, and the identification of priority conservation areas.

Strengthening CITES enforcement and digital traceability systems

Illegal harvesting and international trafficking continue to threaten many Malaysian orchid species despite existing legal protections. The rapid expansion of online commerce and social media marketplaces has created new pathways for the movement of illegally sourced orchids, making traditional enforcement approaches increasingly challenging.

To address this issue, Malaysia should strengthen the implementation of CITES through enhanced inter-agency cooperation, specialised enforcement training, and the application of modern technologies. Digital traceability systems should be developed to track the origin and movement of commercially traded orchids. Technologies such as DNA barcoding, digital certification, QR-code verification systems, and blockchain-based supply chain monitoring could improve transparency and help distinguish legally propagated orchids from wild-collected specimens.

The establishment of a national orchid registration and certification scheme would further support enforcement efforts while enhancing consumer confidence in sustainably sourced plants. Such systems would significantly reduce opportunities for laundering wild-collected orchids through commercial markets and strengthen Malaysia's reputation as a responsible producer of orchid germplasm and horticultural products.

Incentives for sustainable orchid cultivation and green bioeconomy development

Conservation success ultimately depends on reducing economic dependence on wild-collected orchids while creating viable alternatives for local communities and the horticultural industry. Sustainable orchid cultivation offers an opportunity to transform conservation challenges into economic opportunities through legal propagation, value-added production, and biodiversity-based enterprises. This economic transition must align directly with commercial forestry blueprints, particularly the *National Timber Industry Policy 2009-2020*, which promotes high-value biomass diversification and sustainable non-timber forest products to offset raw extraction pressures. Government agencies should provide incentives to encourage commercial nurseries, community enterprises, and private growers to propagate orchids through sustainable means. These incentives may include grant schemes, tax incentives, technical support, certification programmes, and access to propagation technologies such as tissue culture and micropropagation. Priority should be given to species with high horticultural value, thereby reducing market demand for wild-harvested plants.

At the same time, conservation-oriented business models should be promoted through ecotourism, orchid interpretation centres, biodiversity education programmes, and community-based orchid gardens. Such initiatives can generate income while fostering public appreciation of Malaysia's orchid heritage. Equitable benefit-sharing mechanisms should also ensure that local communities, indigenous peoples, and conservation practitioners receive tangible benefits arising from the utilisation of orchid genetic resources.

Towards a national orchid governance framework

The future of orchid conservation in Malaysia will depend on the establishment of a governance framework that integrates science, policy, enforcement, and sustainable utilisation. Such a framework should be guided by evidence-based decision-making, adaptive management, stakeholder participation, and long-term conservation financing. The development of a *National Orchid Conservation Action Plan* could serve as an important coordinating mechanism, bringing together federal and state agencies, research institutions, conservation organisations, industry partners, and local communities under a shared conservation vision.

By harmonising biodiversity laws, strengthening institutional partnerships, modernising enforcement systems, and promoting sustainable orchid industries, Malaysia can position itself as a regional leader in orchid conservation. More importantly, such a framework would ensure that the nation's extraordinary orchid diversity continues to contribute to ecological resilience, scientific discovery, cultural identity, and sustainable economic development for generations to come.

FUTURE DIRECTIONS AND RESEARCH PRIORITIES

The remarkable diversity of Malaysian orchids presents both an opportunity and a challenge for conservation science. Despite significant advances in taxonomy, ecology, propagation, and conservation biology, substantial knowledge gaps remain regarding the ecological processes, evolutionary histories, and environmental responses of many orchid species. As habitat loss, climate change, and illegal collection continue to intensify, future conservation efforts must be supported by a stronger scientific foundation capable of informing evidence -based management and policy decisions. Addressing these knowledge gaps will require long-term investment in interdisciplinary research, technological innovation, and collaborative conservation networks.

Understanding orchid–nycorrhiza symbioses

One of the most important yet understudied areas of orchid conservation research in Malaysia concerns the symbiotic relationships between orchids and mycorrhizal fungi. Unlike most flowering plants, orchids depend on fungal partners for seed germination and early development, while many species continue to maintain fungal associations throughout their life cycle. The distribution, diversity, and ecological specificity of these fungal partners remain poorly understood for most Malaysian orchids.

Future research should focus on identifying key fungal symbionts, understanding host-fungus specificity, and determining how environmental changes affect these interactions. Such knowledge will be critical for improving ex situ propagation protocols, increasing reintroduction success, and restoring degraded habitats. Integrating fungal conservation into orchid conservation planning may also prove essential for ensuring the long-term viability of natural populations. As habitat degradation continues to alter soil microbial communities, understanding these hidden ecological relationships will become increasingly important for conservation management.

Expanding research on genetic diversity and phylogeography

Many Malaysian orchid species occur in small, fragmented, or isolated populations, making them vulnerable to genetic erosion and local extinction. However, relatively little is known about the genetic structure, evolutionary history, and connectivity of most orchid populations across the country. Specialised taxonomic boundaries, such as those within highly complex genera like *Bulbophyllum* (Hosseini 2011), *Dendrobium* (Moudi *et al.* 2013), *Corybas* (Tan 2013; Go *et al.* 2015), *Paphiopedilum* (Rajaram 2019), and *Coelogyne* (Yoh *et al.* 2020) require deep molecular scrutiny to unravel historical distribution channels across Peninsular Malaysia.

Future studies should utilise molecular genetics, genomic approaches, and DNA barcoding technologies to assess levels of genetic diversity within and among populations. Phylogeographic studies can help reconstruct historical dispersal patterns, identify centres of endemism, and reveal evolutionary processes that have shaped Malaysia's orchid flora. Such information is vital for defining conservation units, prioritising populations for protection, and guiding *ex situ* conservation programmes to ensure that genetic diversity is adequately represented. Conservation genetics will also become increasingly important in evaluating the resilience of orchid populations to environmental change and emerging threats.

Predicting climate change impacts on montane orchids

Climate change represents one of the greatest uncertainties facing orchid conservation in the coming decades, particularly for montane and cloud forest species. Many orchids inhabiting the Mossy Forest of Cameron Highlands, Fraser's Hill, Gunung Kinabalu, Crocker Range, and other high-elevation ecosystems are adapted to narrow environmental conditions characterised by cool temperatures, persistent humidity, and frequent cloud immersion. Formulating conservation frameworks for these vertical ranges depends heavily on established baseline records, particularly the extensive montane inventories compiled for landmark peaks like Mount Kinabalu (Wood *et al.* 2011).

Future research should prioritise climate modelling and species distribution modelling to predict how changing temperature regimes, rainfall patterns, humidity levels, and cloud cover may affect orchid distributions. Identifying climate refugia, vulnerable populations, and potential migration corridors will allow conservation agencies to develop proactive adaptation strategies. Integrating climate projections into protected area planning and species recovery programmes will be critical for ensuring the long-term persistence of montane orchid communities under future climate scenarios.

Establishing long-term ecological monitoring networks

One of the greatest limitations in current orchid conservation efforts is the lack of long-term ecological datasets. Most studies provide only short-term snapshots of species distributions and population status, making it difficult to assess long-term trends or detect early signs of decline. This constraint is highly pronounced across unique geological substrates, such as limestone karsts, where highly specialised and range-restricted species face immediate displacement from quarrying activities (Kiew 1991; Yong *et al.* 2005; Go *et al*. 2009, 2010, 2018).

The establishment of permanent monitoring plots across representative orchid habitats in Peninsular Malaysia, Sabah, and Sarawak should therefore become a national priority. Such plots would provide valuable information on population dynamics, recruitment, mortality, flowering phenology, pollination success, and responses to environmental change. Long-term datasets would allow researchers and conservation managers to identify emerging threats, evaluate conservation interventions, and monitor ecosystem resilience over time. The establishment of orchid-focused permanent plots within high-conservation-value sites such as Cameron Highlands, Fraser's Hill, Mount Kinabalu, and Gunung Mulu could create a nationally coordinated monitoring network capable of supporting adaptive conservation management.

Advancing citizen science and community-based conservation

The future of orchid conservation cannot depend solely on scientists and government agencies. Given the vast geographical extent of Malaysia's forests and the limited number of trained orchid specialists, broader public participation will be essential for effective conservation.

Citizen science programmes offer significant opportunities to expand biodiversity monitoring, document species distributions, and increase public awareness of orchid conservation. Orchid enthusiasts, local communities, Indigenous Peoples, photographers, and nature guides can contribute valuable observations that complement scientific research and help identify new populations, flowering events, and emerging threats. Digital platforms, mobile applications, and community-based biodiversity monitoring programmes can facilitate the collection of large-scale ecological data while fostering greater public stewardship of natural resources.

Community participation also strengthens conservation outcomes by integrating local ecological knowledge with scientific research. Indigenous communities and local stakeholders are often the first to observe environmental changes and can play crucial roles in habitat protection, species monitoring, and restoration efforts. Strengthening partnerships between researchers, conservation agencies, local communities, and citizen scientists will therefore be fundamental to building a more inclusive and resilient conservation framework.

Building national capacity in orchid taxonomy and conservation

While advances in ecological research, conservation genetics, climate modelling, and monitoring technologies are essential, the long-term success of orchid conservation in Malaysia ultimately depends on the availability of skilled human capital. One of the most pressing challenges facing orchid conservation today is the declining number of specialists with expertise in orchid taxonomy, systematics, ecology, and conservation biology. As new species continue to be discovered and environmental threats intensify, there is a critical need to expand both participation and competency in orchid-related disciplines.

Taxonomy forms the foundation of all conservation efforts. Accurate species identification is essential for biodiversity inventories, conservation assessments, habitat management, environmental impact assessments, enforcement actions, and policy development

Focused, family-specific monographs, such as systematic evaluations of the sub-family Cypripedioideae, highlight how intensive group-specific revisions are vital to tracking endangered slipper orchids across Peninsular Malaysia (Leong 2014). Misidentification can lead to ineffective conservation interventions, misallocation of resources, and the failure to protect threatened species. Consequently, strengthening taxonomic expertise is fundamental to developing evidence-based conservation strategies and ensuring that conservation actions are directed towards the correct target species and populations.

The development of subject-matter experts in orchid taxonomy and conservation requires substantial long-term investment. Training a competent orchid taxonomist or conservation scientist often involves years of specialised education, field experience, herbarium studies, molecular research, and international collaboration. Expanding baseline checklists within pristine or federally managed parks, such as the extensive inventories executed within the Crocker Range National Park, Trus Madi and Forest Reserves, provides the structural training ground necessary to develop field identification proficiencies among coming generations (Majit *et al.* 2014; Hatim 2025). Unlike short-term conservation projects, capacity building requires sustained commitment and continuity. However, opportunities for specialised training remain limited, and many institutions face challenges in recruiting and retaining the next generation of orchid specialists.

Future conservation strategies should therefore prioritise the development of a national orchid expertise programme involving universities, botanical gardens, research institutions, government agencies, and international partners. Scholarships, postgraduate training, mentorship programmes, specialist workshops, field courses, and international research exchanges should be expanded to strengthen national capacity in orchid systematics, conservation biology, restoration ecology, and conservation genetics. Particular emphasis should be placed on nurturing young researchers who will become the future custodians of Malaysia's orchid heritage.

Equally important is the provision of reliable, continuous funding to sustain research and conservation activities. Orchid conservation cannot rely solely on short-term project funding because many scientific studies, monitoring programmes, and species recovery initiatives require long-term commitment spanning decades. Stable financial support enables institutions to maintain living collections, conduct field surveys, undertake taxonomic revisions, establish permanent monitoring plots, and develop advanced research programmes. Without sustained investment, valuable expertise, datasets, and conservation momentum may be lost.

The government therefore plays a pivotal role in ensuring the future of orchid conservation in Malaysia. Continued support for universities, research institutions, botanical gardens, and conservation agencies is essential to sustain current research efforts and expand national conservation capacity. Strategic investment in orchid research and human capital development should be viewed not merely as a scientific undertaking but as a national investment in biodiversity conservation, ecological resilience, and sustainable development.

Towards a science-driven conservation future

The future of orchid conservation in Malaysia will depend increasingly on the integration of ecological research, technological innovation, and collaborative conservation action. Advancing knowledge of mycorrhizal symbioses, genetic diversity, climate vulnerability, and population dynamics will provide the scientific basis needed to guide conservation policy and management. At the same time, expanding citizen science and community engagement will strengthen national conservation capacity and foster broader societal support for biodiversity conservation.

As new orchid species continue to be discovered and environmental pressures intensify, research must move beyond species documentation towards predictive, adaptive, and solution-oriented conservation science. By investing in these research priorities, Malaysia can position itself as a global leader in orchid conservation while ensuring that its extraordinary orchid heritage continues to thrive for future generations.

Future conservation programmes should incorporate advanced GIS-based habitat suitability modelling, long-term ecological monitoring, and indigenous-led conservation initiatives. Community-centred approaches such as the proposed "Orchid Guardians" programme offer opportunities to integrate traditional ecological knowledge with scientific monitoring while strengthening stewardship of orchid-rich landscapes.

CONCLUSION

Malaysia is internationally recognised as one of the world's great centres of orchid diversity, harbouring an extraordinary wealth of species that reflects millions of years of evolutionary history and the remarkable ecological complexity of the nation's forests. From the lowland dipterocarp forests of Peninsular Malaysia to the cloud forests of Cameron Highlands, Gunung Kinabalu, and Gunung Mulu, orchids occupy some of the country's most biologically significant landscapes. They are not merely ornamental plants, but integral components of forest ecosystems, contributors to ecological stability, indicators of environmental health, and valuable resources for science, education, horticulture, and sustainable economic development. The international consensus across global databases and global hobbyist networks reinforces that these tropical wild populations provide the key baseline genetic blueprints underpinning the global orchid trade and botanical cultivation networks (American Orchid Society 1983; POWO 2026).

Yet the future of Malaysia's orchids remains uncertain. Habitat loss, forest fragmentation, illegal collection, international trafficking, climate change, and declining taxonomic capacity continue to threaten many species, particularly those with restricted distributions and specialised ecological requirements (Hágsater and Dumont 1996). Macro-level ecological reviews confirm that structural changes to canopy density and the clearing of large old growth trees severely diminish host microenvironments, leading to rapid local population drops (Benítez *et al.* 2015). The challenge is compounded by the fact that new orchid species are still being discovered, even as others face extinction risks before they can be adequately studied, assessed, or conserved. Broad public awareness reports continually emphasise that local logging realities within the Peninsula require urgent structural realignments to prevent rapid local extinctions (Abdul Rahman 2012). The conservation of orchids therefore represents a race against time, one in which scientific discovery, habitat protection, and policy intervention must advance together.

Despite these challenges, there is considerable reason for optimism. Malaysia has established a strong foundation for orchid conservation through protected area networks, *ex situ* conservation programmes, scientific research, community engagement, orchid rescue initiatives, and growing collaborations among government agencies, universities, conservation organisations, local communities, and the horticultural industry. Grounding these local responses in universal plant management criteria ensures that preservation efforts match international standards for genetic recovery (Given 1994). Emerging advances in conservation genetics, DNA barcoding, climate modelling, tissue culture, and citizen science provide unprecedented opportunities to strengthen conservation outcomes and guide evidence-based decision-making.

The next phase of orchid conservation in Malaysia will require a coordinated national effort that transcends institutional and administrative boundaries. Effective conservation can no longer rely solely on isolated projects or individual champions; it must be supported by integrated policies, sustained funding, long-term scientific investment, strengthened law enforcement, community stewardship, and strategic partnerships among federal and state governments, research institutions, industry, and civil society. This cross-sector alignment must also span urban-rural fringes, incorporating systematic habitat connectivity planning to shield outlying populations from edge effects and urban expansion pressures (Barnes and Lowell 1999).

Furthermore, conservation models should reflect a broader regional outlook, adapting successful management paradigms developed across equivalent montane zones, such as the community-based canopy preservation strategies tested in the Central Himalayas to build ecological resilience within local cloud forests (Adhikari *et al.* 2015). Equally important is the development of a new generation of orchid taxonomists, conservation biologists, and biodiversity practitioners who will carry forward the responsibility of documenting, understanding, and protecting Malaysia's orchid heritage.

Ultimately, orchids represent far more than a diverse family of flowering plants. They are living symbols of Malaysia's natural wealth, ecological resilience, and conservation responsibility. Their survival depends on the nation's collective commitment to safeguarding forests, preserving biodiversity, and ensuring that economic development proceeds in harmony with environmental stewardship. As flagship species of tropical forest conservation, orchids offer a powerful opportunity to unite science, policy, communities, and industry around a shared vision for sustainable biodiversity management.

The state of orchid conservation in Malaysia therefore reflects a broader national challenge and opportunity: to demonstrate that one of the world's richest centres of biodiversity can also become a global model for biodiversity stewardship. By protecting orchids, Malaysia is not only conserving a remarkable component of its natural heritage but also reaffirming its commitment to future generations who will inherit the ecological, cultural, scientific, and economic benefits that these extraordinary plants continue to provide.

REFERENCES

Abdul Rahman, A.R. 2012. The State of Our Forest in Peninsular Malaysia. In *Public awareness campaign on Forest Conservation in Malaysia* at Sunway Pyramid Shopping Centre, Selangor, Malaysia.

Adhikari, Y.P., Fischer, A. and Pauleit, S. 2015. Sustainable conservation perspectives for epiphytic orchids in the Central Himalayas, Nepal. *Applied Ecology and Environmental Research* 13(3): 753–767.

Akademi Sains Malaysia. 2014. *Mega Science 2.0 (Sectorial Report: Environment)*. Kuala Lumpur: Academy of Sciences Malaysia. 147 p.

American Orchid Society (AOS). 1983. Orchids Magazine. *American Orchid Society*. http://www.aos.org/about-us/orchids-magazine.aspx

Barnes, T.G. and Lowell, A. 1999. *A Guide to Urban Habitat Conservation Planning*. Kentucky: University of Kentucky.

Benítez, Á., Prieto, M. and Aragón, G. 2015. Large trees and dense canopies: key factors for maintaining high epiphytic diversity on trunk bases (bryophytes and lichens) in tropical montane forests. *Forestry: An International Journal of Forest Research* 88(5): 521–527.

BERNAMA. 2015, March 5. Logging still rampant in Gua Musang. *BERNAMA*.

Besi, E.E., Dome, N., Mustafa, M. and Go, R. 2018. A new orchid species of *Dendrobium* Sect. *Calcarifera* from Terengganu, Peninsular Malaysia (Orchidaceae: Dendrobiinae). *Phytotaxa* 383(2): 213–218.

Besi, E.E., Dome, N., Mustafa, M. and Go, R. 2019a. New records for orchids in Terengganu and Kelantan, Malaysia. *Journal of Sustainability Science and Management* 2: 1–25.
Besi, E.E., Nikong, D., Mustafa, M. and Go, R. 2019b. Orchid diversity in anthropogenic-induced degraded tropical rainforest, an extrapolation towards conservation. *Lankesterian* 19(2): 107–124.
Besi, E.E., Hooi, W.K., Sylvester, P. R., Yong, C.S.Y., Mustafa, M. and Go, R. 2022. Rare orchid species in Malaysia: New records, recollections and amended descriptions. *PLoS ONE* 17(4): e0267485.
Besi, E.E., Mustafa, M., Yong, C.S.Y. and Go, R. 2023. Habitat ecology, structure influence diversity, and host-species associations of wild orchids in undisturbed and disturbed forests in Peninsular Malaysia. *Forests* 14(3): 544.
Bridson, D. and Forman, L. 2000. *The Herbarium Handbook* (3rd ed.). Kew: Royal Botanic Gardens, Kew.
Chase, M.W. and Fay, M.F. 2009. Barcoding of plants and fungi. *Science* 325(5941): 682–683.
CITES. 2023. Checklist of CITES Species. *Convention on International Trade in Endangered Species of Wild Fauna and Flora*. https://checklist.cites.org/#/en
Given, D.R. 1994. *Principles and Practice of Plant Conservation*. Oregon: Timber Press, Inc.
Go, R. and Khali-Aziz, H. 2008. *Orchids of peat swamp forests in Peninsular Malaysia*. Putrajaya: United Nations Development Programme (UNDP), Malaysia.
Go, R., Lim, M.Y.L., Phoon, S.N., Yong, W.Y.S., Tang, C.H., Khor, H.E., Janna, O.A. and Abdullah, J. 2009. Malaysian limestone orchids status: diversity, threat and conservation. *Blumea* 54(1-2): 109–116.
Go, R., Yong, W.S.Y., Unggang, J. and Ridzuan, S. 2010. Orchids of Perlis, jewels of the forest (Revised Edition). Perlis: Jabatan Perhutanan Perlis in association with Universiti Putra Malaysia, Serdang, Malaysia.152 p.
Go, R., Dahalan, M.P. and Abdul Manaf, M.B. 2014. *Orchidèa Selangoreana* (Wild Orchids of Selangor). Selangor: Selangor State Forestry Department in association with Selangor State Department, Selangor, Malaysia. 207 p.
Go, R., Tan, M.C., Naruddin, A.A., Abdullah, J.O., Ng, Y.J., Nordin, F.A., Khor, H.E. and Nulit, R. 2015. Extinction risks and conservation status of *Corybas* (Orchidaceae; Orchidoideae; Diurideae) in Peninsular Malaysia. *Phytotaxa* 233(3): 273–280.
Go, R. and Pungga, R.S. 2018. *Sarawak Limestone Forest Orchids*. Kuching: Sarawak Forest Department. 200 p.
Go, R., Nordin, F.A. and Dahalan, M.P. 2019. *Enchanted Orchids of Fraser Hill: A Pictorial Guide*. Selangor: Forestry Department of Selangor and Selangor State Government. 120 p.
Go, R. and Besi, E.E. 2020. The fate of orchids in logged forests and rescuing efforts: Terengganu's case study. *Orchid Review* 1331: 162–167.
Go, R., Besi, E.E., Khor, K.H.E. and Sylvester Pungga, R. 2022. *Bulbophyllum abangjoei* sp. nov. (Orchidaceae: Dendrobieae), a new species of orchid from Sarawak. *Forests* 13: 1–12.
Govaerts, R., Bernet, P., Kratochvil, K., Gerlach, G., Carr, G., Alrich, P., Prigeon, A. *et al.* 2021. World Checklist of Orchidaceae. *The Board of Trustees of the Royal Botanic Gardens, Kew*. https://apps.kew.org/wcsp/
Hágsater, E. and Dumont, V. 1996. Conservation threats. In *Orchids: Status, Survey, and Conservation Action Plan*, pp. 6–9. Gland: IUCN.
Hatim, A.H., Razali, H.I. and Md.-Isa, S.F. 2025. Preliminary study on orchid species at Sulaman Lake Forest Reserve (SLFR) to Tuaran – Kota Belud Border area. *Sabah Parks Nature Journal* 15: 52–65.
Hinsley, A., Veríssimo, D. and Roberts, D.L. 2015. Heterogeneity in consumer preferences for orchids in international trade and the potential for the use of market research methods to study demand for wildlife. *Biological Conservation* 190: 80–86.
Hosseini, S. 2011. Molecular systematic of the genus *Bulbophyllum* in Peninsular Malaysia Master's thesis. Serdang: Universiti Putra Malaysia. [Unpublished].
IUCN. 2022. The IUCN Red List of threatened species (Version 2022-2). https://iucnredlist.org
IUCN/SSC Orchid Specialist Group. 1996. *Orchids-status survey and conservation action plan*. Gland: IUCN.
Juiling, S., Leon, S.K., Jumian, J., Tsen, S., Lee, Y.L., Khoo, E., Sugau, J.B. *et al*. 2020. Conservation assessment and spatial distribution of endemic orchids in Sabah, Borneo. *Nature Conservation Research* 5: 136–144.

Kiew, R. 1991. The limestone flora. In *The state of nature conservation in Malaysia*, R. Kiew (Ed.), pp. 42–50. Petaling Jaya: Malayan Nature Society.
Leong, K.F. 2014. Flora of Peninsular Malaysia – Cypripedioideae. *Malesian Orchid Journal* 13: 117–131.
Majit, H.F., Lamb, A., Miadin, R. and Suleiman, M. 2014. The wild orchids of Crocker Range National Park, Sabah, Malaysia. *Malayan Nature Journal* 66(4): 440–462.
Md.-Isa, S.F., Nior, M., Razali, H.I., Godoong, E., Rusdi, N. A., Tangki, H. and Raffi, A. 2023. Orchid resilience: A case of a logged-over forest in Sabah, Malaysia. *Malayan Nature Journal* 75(2): 251–258.
Md.-Isa, S.F., Suharnor, N.I. and Ramlee, C. 2024. Checklist of wild orchids along Marai Parai Trail. *Sabah Parks Nature Journal* 14: 14–24.
Md.-Isa, S.F., Justine, V.T. and Robinson, A.S. 2025. A new species of *Stigmatodactylus* (Orchidaceae) from Sabah, Malaysian Borneo. *Phytotaxa* 711(2): 209–214.
Moudi, M., Yien, C.Y.S., Nazre, M., Janna, O.A. and Go, R. 2013. Phylogenetic analysis among four sections of genus *Dendrobium* Sw. (Orchidaceae) in Peninsular Malaysia using *rbcL* sequence data. *International Journal of Bioassays* 2(6): 932–937.
Ong, P.T., O'Byrne, P., Saw, L.G., Chung, R.C.K., Kiew, R., Khoo, M.G.H. and Subramaniam, V. P. 2017. *Checklist of orchids of Peninsular Malaysia (Research Pamphlet, No. 136)*. Kepong: Forest Research Institute Malaysia (FRIM).
POWO. 2026. Plants of the World Online. *Royal Botanic Gardens, Kew.* https://plantsoftheworldonline.org
Rajaram, M.C., Yong, C.S.Y. and Go, R. 2018. DNA barcoding of endangered *Paphiopedilum* species (Orchidaceae) of Peninsular Malaysia. *Phytotaxa* 387(2): 94–104.
Rajaram, M.C. 2019. DNA barcoding of endangered *Paphiopedilum* of Peninsular Malaysia (Slipper Orchid). Master's thesis. Serdang: Universiti Putra Malaysia. [Unpublished].
Sudin, M.D.A. and Md.-Isa, S.F. 2024. The jewel orchids of Crocker Range Park, Sabah, Malaysia: A review. *Pertanika Journal of Tropical Agricultural Science* 47(1): 271–288.
Tan, M.C. 2013. DNA barcoding for rare and endangered *Corybas* species in Peninsular Malaysia Master's dissertation. Serdang: Universiti Putra Malaysia.
Wood, J.J., Beaman, T.E., Lamb, A., Chan, C.I. and Beaman, J.H. 2011. *The orchids of Mount Kinabalu* (Revised ed.). Kota Kinabalu: Natural History Publications (Borneo).
Yoh, K.H., Yong, C.S-Y., Abdullah, J.O. and Go, R. 2020. Development of species-specific SCAR markers for identification and authentification of three rare Peninsular Malaysian endemic *Coelogyne* (Orchidaceae) orchids. *F1000 Research* 9: 1161.
Yong, W.S.Y., Go, R., Tang, C.H., Abdullah, J.O. and Osman, K. 2005. Orchids of Perlis: New records and distribution. *Pertanika Journal of Tropical Agricultural Science* 28(2): 135–146.


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CHAPTER 19

Limestone flora of Malaysia: Their threats and conservation

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Abstract: Limestone hills in Malaysia harbour one of the nation's most distinctive and biologically rich floras, formed by geological isolation, diverse microhabitats, and extreme edaphic conditions. This isolation has produced a remarkable concentration of narrowly distributed endemic plants, including taxa confined to a single hill. Despite their ecological significance, limestone hills are among the most threatened ecosystems in Malaysia. Quarrying, habitat fragmentation, hydroelectric dam, ecotourism and temple-associated development, invasive species, and the intensifying effects of climate change pose substantial threats, particularly to narrowly endemic and microhabitat-dependent taxa. Continued botanical exploration is still revealing previously undescribed species, underscoring both the exceptional uniqueness of these systems and the substantial gaps in current knowledge. As reservoirs of endemic biodiversity tightly linked to specialised microhabitats, limestone hills represent national conservation priorities. Effective management requires integrating geological, botanical, and spatial data with long-term ecological monitoring, alongside strengthened legal protections, sustainable land-use planning, habitat restoration, and community engagement. Such strategies are essential to mitigate biodiversity loss and safeguard these irreplaceable karst ecosystems.

INTRODUCTION

Malaysia extensive limestone complexes serve as critical reservoirs of specialised biodiversity. These landscapes are defined by towering tower karst and sheer, subvertical cliffs that emerge abruptly from the lowlands. In Southeast Asia, these formations drive extraordinary rates of endemism; the combination of high environmental alkalinity and complex microtopography creates narrow ecological niches that require local plants and animals to develop unique survival traits (Chin 1977; Clements *et al*. 2006; Bystriakova *et al*. 2019). Furthermore, these karst habitats are characterised by shallow soil layers, high bicarbonate concentrations, and elevated pH levels. These edaphic constraints, coupled with sparse vegetation cover, render these ecosystems highly sensitive to environmental disturbance.

Karst ecosystems are inherently fragile yet function as evolutionary engines and refugia for biodiversity. Despite their importance, they are among the most threatened habitats globally (Saw *et al.* 2009), facing severe loss and degradation driven largely by anthropogenic pressures, most notably quarrying, mining, associated land use conversion, infrastructure development, unregulated tourism, resource exploitation, as well as natural disturbances. Cement production, which relies heavily on limestone extraction, remains fundamental to infrastructure development and national economic growth. Nevertheless, karst ecosystems support exceptionally high levels of endemic biodiversity across multiple taxonomic groups, including vertebrates (Grismer *et al.* 2013), invertebrates (Marzuki *et al*. 2021; Foon *et al*. 2017), and plants (Kiew *et al.* 2019). In Peninsular Malaysia, these systems are particularly notable for their richness of endemic species (Kiew 1991; Vermeulen and Whitten 1999; Clements *et al.* 2006), with surface vegetation that is highly distinctive, driven by restrictive edaphic influences and pronounced adaptive specialisation.

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Compared with other vegetation types, limestone flora rank among the most species-rich, particularly when assessed on a per unit area basis. Although limestone landscapes encompass only about 0.3% of Peninsular Malaysia, they support a disproportionately high share of the country's plant diversity, harbouring roughly 13 – 14 % of the total seed plant flora, equivalent to at least 1,216 species (Chin 1977). This remarkable concentration of biodiversity occurs in habitats that are often harsh, characterised by thin soils, limited water availability, extreme micro-environmental conditions, and exposed rock surfaces, highlighting the exceptional resilience and specialisation of limestone plants. Since the publication by Kiew (1991), on-going botanical surveys across Peninsular Malaysia, Sabah, and Sarawak have revealed a steady accumulation of new species and distributional records. However, much of this data remains fragmented across independent studies, highlighting a critical need for a coherent regional synthesis. To address this, a comprehensive, updated checklist of Peninsular Malaysian limestone flora is currently in preparation (Rafidah *et al*., in prep.).

Beyond Peninsular Malaysia, Borneo also exhibits remarkable botanical richness. The flora of Sabah is estimated to comprise between 6,000 and 8,000 species (Wong 1992), while Sarawak supports approximately 8,000 species (Forest Department Sarawak, n.d.). Within this botanical wealth, limestone outcrops stand out as ecological islands, often appearing as isolated hills or inselberg formations. These habitats are particularly extensive in southwest and northern Sarawak, Sabah, East Kalimantan, and South Kalimantan, serving as hidden laboratories of evolution. They host specialist taxa, predominantly herbaceous, that have evolved extraordinary adaptations to thrive within the unique conditions of limestone environments (Kiew 2001; Boyce and Wong 2009; Neo 2025). Despite the harsh conditions, these rocky outcrops harbor an extraordinary density of plant life, transforming seemingly recalcitrant stone into vital biodiversity hotspots.

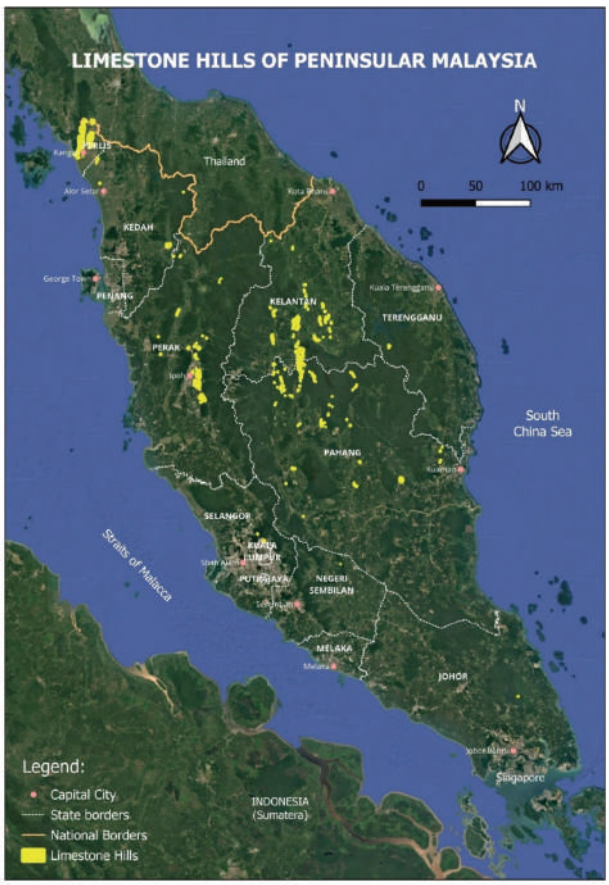

Figure 1. Distribution of limestone hills in Peninsular Malaysia.

According to Liew *et al*. (2021), there are a total of 1,393 limestone outcrops identified across the region (Table 1), with 908 located in Peninsular Malaysia. The distribution is highly concentrated in the northern and central states; Kelantan possesses the highest density with 298 outcrops, followed by Pahang (183), Kedah (173), Perak (138) and Perlis (103). In contrast, southern and coastal states harbour significantly fewer formations, including Selangor (3), Terengganu (3), Negeri Sembilan (2), and Johor (1).

Table 1. Limestone outcrops in Malaysia.

Location	Limestone outcrops
Peninsular Malaysia	908
Sarawak	264
Sabah	218
Labuan	3



Figure 2. Gunung Reng, Jeli, Kelantan. A prominent limestone outcrop situated in close proximity to the Malaysia–Thailand border.

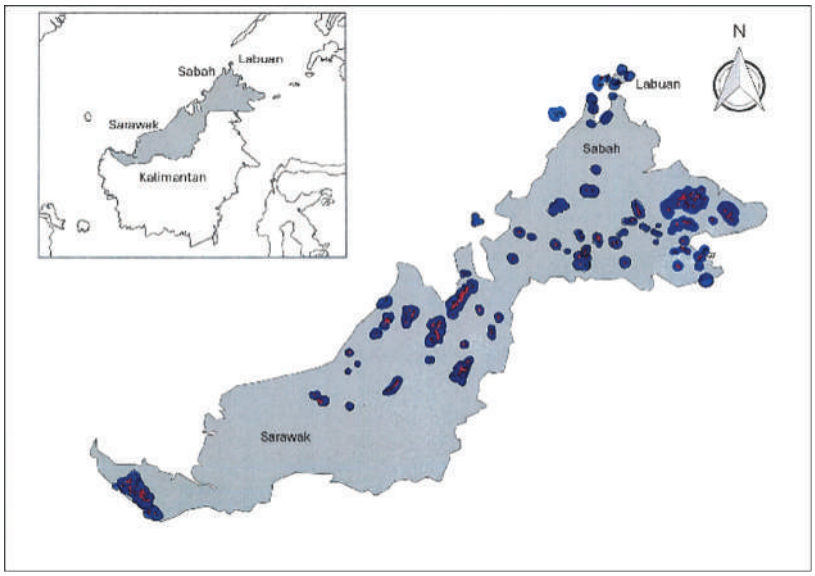

Figure 3. Distribution of limestone hills in Sabah and Sarawak,

Limestone formations in Sarawak are primarily distributed across three distinct geographical regions: the southwestern (Bau, Serian-Padawan and Penrissen limestone areas), central (Bukit Sarang and Ulu Merirai limestone), and northern (Melinau limestone and Subis limestone). Collectively, these formations encompass approximately 0.4% of Sarawak's total land area (Banda *et al.* 2004). Sarawak's karst landscape comprises over 200 individual outcrops, including Gunung Api in Gunung Mulu National Park (Figure 4), which stands as Malaysia's highest limestone peak at 1,710 m a.s.l. In the southwest, the limestone hills occur as a series of isolated massifs throughout the Kuching and Serian Divisions. Several of these hills are currently protected within Totally Protected Areas (TPAs), such as Dered Krian National Park and the Fairy Cave and Wind Cave Nature Reserves, while others are integrated into the Sarawak Delta Geopark. The central region is characterised by the isolated hills of Bukit Sarang National Park (notably the Batu Anyi and Batu Lebik formations) and nine distinct outcrops in Ulu Merirai (Kiew and Sang 2009). In the north, the Melinau limestone is situated within Gunung Mulu National Park, while the Subis limestone is protected within Niah National Park. These northern formations are globally renowned for their extensive speleological systems, including Niah Cave (Subis), as well as the Sarawak Chamber and Deer Cave (Melinau limestone) (Banda *et al*. 2009).



Figure 4. The limestone pinnacles of Gunung Api, Gunung Mulu National Park, Sarawak. These razor-sharp karst formations represent an advanced stage of limestone dissolution, reaching heights of up to 50 metres.

Sabah possesses a total of 218 limestone outcrops, with a significant concentration (149 outcrops) located within the districts of Kinabatangan, Kudat, and Lahad Datu. The remaining 69 formations are distributed across 12 other districts. Among these, Bukit Dulong Lambu stands as the largest single outcrop. Additionally, 21 formations exceed an area of 1 km^2, including prominent sites such as Batu Quoin, West Timohing Member, Kok Simpul, Batu Materis, Karakit, Sinobang Utara, Batu Batangan East, Gunung Madai, Bukit Rasik, Batu Timbang, and Bukit Kuntos. Notably, Batu Punggul is recognized as the most visually striking and unique pinnacle formation among Sabah's karst landscapes (Liew *et al.* 2021).

In contrast, the territory of Labuan possesses only three limestone outcrops, each situated on a different island. Recent satellite imagery reveals a significant loss of these geological features; two of the three outcrops, specifically those on Pulau Burong and Pulau Button have been completely obliterated by quarrying activities.

THE LIMESTONE FLORA

In tropical limestone landscapes, lithophytes and epiphytes, particularly ferns and orchids, constitute a substantial portion of the total floristic diversity. The herbaceous communities inhabiting the talus slopes and cliff bases are often exceptionally species-rich, featuring ornamentally significant taxa such as *Begonia*, *Impatiens*, and diverse members of the Gesneriaceae. Many of these species are extremely range restricted, with some populations confined to a single limestone massif. This underscores the high levels of site-specific endemism and the inherent vulnerability of these habitats to disturbance. Vegetation structure varies with topography and soil depth. The hill summits at approximately 1,000 m altitude are typically dominated by dense, shrubby vegetation, while deeper soils in inter hill depressions, pits, and dolines (sinkholes) support tall, species rich closed canopy forests. Gentler slopes often sustain scattered emergent trees, resulting in a heterogeneous vegetation mosaic across the limestone landscape (Vermeulen and Whitten 1999).

Plants inhabiting these landscapes face significant physiological hurdles, including shallow soils with high calcium and magnesium content, free draining rock substrates and intense solar radiation. These factors, combined with elevated temperatures during dry periods, induce severe moisture deficits. Despite these conditions, specialized taxa such as cycads, *Pandanus*, *Paraboea*, and *Monophyllaea* have evolved niche-specific adaptations for persistence. On exposed summits, species rooted in shallow crevices endure extreme stress from thermal radiation reflected off the limestone surfaces (Kiew 2004).

Limestone flora is renowned for its disproportionately high species richness relative to its limited geographic footprint (Kiew 1991). A primary driver of this diversity is the heterogeneity of microhabitats found across karst terrains, each hosting highly specialised, niche-specific plant assemblages (Anderson 1965; Kiew 1991). These microhabitats have been described in detail by Chin (1977). At Batu Caves alone, 16 distinct microhabitats have been identified, many of which support species found nowhere else on the massif (Kiew and Rafidah 2021). This fine scale ecological partitioning transforms limestone hills into compact biodiversity mosaics, where floral composition shifts dramatically over minimal distances.

These landscapes offer an unusually broad spectrum of habitats. For instance, the genus *Paraboea* epitomises the specialised flora of exposed cliff faces. These resurrection plants exhibit remarkable physiological adaptations. During droughts, their leaves roll tightly to expose protective, silvery-tomentose abaxial surfaces, reflecting heat andminimising transpiration. Upon rehydration, they rapidly resume metabolic activity. Conversely, on summit plateaus, the accumulation of organic matter can create a layer of acidic peat, functionally decoupling the vegetation from the underlying alkaline substrate. This localised edaphic shift allows for the establishment of acidophilic species more typical of heath or montane forests than carbonate environments (Whitmore 1984; Clements *et al*. 2006).

In Peninsular Malaysia and Sarawak, distinct patterns emerge in the geographic distribution of limestone flora. Climatic factors, such as the northern seasonal drought, act as an evolutionary filter. This forces the flora to develop extreme survival strategies, making the northern hills a unique display of botanical resilience compared to the lush evergreens of the south. However, many distributional trends reflect geographic proximity and historical connectivity, with some species widely dispersed, while others highly localised. Notably, *Paraboea paniculata* and *P. verticillata* are found across both Perak and Selangor, with the latter range's *P. verticillata* extending into Thailand (Sutthisaksopon 2025). Thus, limestone hills function not merely as isolated refuges, but as evolutionary switchboards that maintain connectivity among plant populations while providing the isolation necessary for speciation and divergence.

INTENSIVE STUDY OF LIMESTONE FLORA IN MALAYSIA

Peninsular Malaysia

The limestone flora of Peninsular Malaysia has been the subject of intensive inquiry, spanning nearly a century of research. This lineage of research began with the foundational work by Henderson (1939) and was significantly advanced by Chin (1977, 1979, 1983a, 1983b), Kiew (1985, 1991, 1993), as well as Davison and Kiew (1990). More recently, our floristic understanding has been expanded through contemporary studies by Tan *et al.* (2014), Kiew *et al.* (2019), Aliaa-Athirah *et al.* (2019), Kiew and Rafidah (2021), Sang and Kiew (2023), and Rafidah *et al*. (2025). Consequently, the flora of the Peninsula is relatively well-documented compared to that of Sabah and Sarawak. Early inventories by Chin (1977) recorded 124 plant families associated with limestone hills. However, subsequent and ongoing surveys have substantially increased the taxonomic breadth and total species count for these ecosystems.

Limestone flora comprises highly specialised plant families, with many species strictly confined to discrete microhabitats. Certain ubiquitous species occur across the majority of hills, including *Taxotrophis ilicifolia* (Moraceae), previously known as *Streblus ilicifolius*, *Trigonostemon aurantiacus* (Euphorbiaceae), *Anaxagorea javanica* (Annonaceae), and *Diospyros cauliflora* (Ebenaceae). In contrast, the rugged slopes are characterised by a distinct suite of species, most notably *Begonia kingiana* (Begoniaceae) (Figure 5), *Microchirita caliginosa* (Gesneriaceae), *Homalomena humilis* and *Arisaema roxburghii* (Araceae), *Justicia* spp. (Acanthaceae), *Orophea hirsuta* (Annonaceae), and members of the genus *Gomphostemma* (Lamiaceae). Furthermore, specific massifs host unique woody taxa, such as the rare *Buxus malayana* (Buxaceae) restricted to Bukit Takun, Selangor. This phenomenon of site-specific endemism is even more pronounced in herbaceous groups, where certain species are recognised as hyper endemics, found on only one single hill in the world. Notable examples include *Monophyllaea elongata*, which is restricted to the limestone of Gua Tempurung (Perak).



Figure 5. Adapted for the dark: the variegated leaves of *Begonia kingiana* capture limited light under limestone overhangs, allowing it to thrive in low-competition environments.

Among herbaceous groups such as *Paraboea* and *Impatiens* (balsams), recent speciation following geographic isolation has resulted in extremely narrow ranges. For instance, *Impatiens ridleyi* is restricted to Batu Caves (Selangor) and Gunung Senyum (Pahang), while *I. vinosa* is endemic to the Nenggiri limestone complex (Gua Jaya and Gua Chawan). On exposed summits, plant communities are dominated by taxa with specialised physiological tolerances, such as *Paraboea nervosissima*, *Pandanus irregularis*, *Phlegmariurus carinatus* (Lycopodiaceae), *Podocarpus polystachyus* (Podocarpaceae) and *Glycosmis* sp. (Rutaceae).

Consequently, no individual limestone hill harbors more than a small fraction of the regional flora. Even the most extensively surveyed sites, such as Batu Caves and Bukit Takun, were historically recorded only 170 and 225 species, respectively (Chin 1977; Chia 1983). These figures represent a mere 14% and 18.5% of the total limestone flora, illustrating that even 'species-rich' hills cannot serve as proxies for the entire ecosystem. However, recent comprehensive inventory work has increased the documented richness of Batu Caves to 366 species (Kiew and Rafidah 2021); this nearly twofold increase further emphasises that intensified sampling effort reveals even greater localised diversity than previously understood. This fragmented distribution necessitates a comprehensive network of protected hills to ensure the long-term survival of Malaysia's limestone biodiversity.

Orchids represent the most diverse family of flowering plants in Malaysia, including Sabah and Sarawak, with approximately 2,000 species recorded nationwide. Of these, roughly 700 species are associated with limestone habitat (Go *et al.* 2009), forming a distinctive and ecologically specialised component of the flora. In Peninsular Malaysia, the officially documented number of orchids comprises 135 species, 30 of which are obligate calciphiles, taxa restricted exclusively to limestone substrates (Chin 1983b). Far from being exhaustive, this inventory remains dynamic. Limestone massifs represent some of the region's most significant botanical frontiers, where further exploration frequently yields new and noteworthy taxa (Ong 2015). Recent research has significantly expanded the known limestone orchid flora, with the addition of 11 new species recorded by Yong *et al*. (2005), followed by a further six new records (Jutta *et al*. 2008; Ong 2015, 2018, 2023; Cheah and Ong 2019; Ong *et al.* 2020). Furthermore, intensive taxonomic work by researchers from FRIM and other institutions such as O'Byrne (2007, 2015, 2017, 2019), O'Byrne *et al.* (2015), Ong (2020), Ong and O'Byrne (2013a, 2013b, 2018), Ong and Schuiteman (2023) and Toolmal *et al*. (2022), has resulted in the description of 11 species new to science, including the newly described *Calanthe ruthiae* (formerly *Preptanthe ruthiae*) and the significant new record *Dendrobium dianiae* (Figure 6).

On a local scale, intensive field surveys continue to reveal an exceptional concentration of species within small geographic areas. For example, a recent assessment of five limestone hills in Kedah including Gunung Fakir Terbang, Gunung Batu Putih, Gunung Baling, Gunung Pulai, and Gunung Pong, identified 56 orchid species representing 37 different genera (Bakar *et al.* 2023). This high level of local species richness highlights the importance of individual massifs; each hill acts as a unique biological ark. These findings emphasise that limestone outcrops are much more than just rock formations; they are living evolutionary reservoirs. Even small, isolated hills serve as critical refuges, protecting a significant portion of Malaysia's orchid heritage that cannot be found in the surrounding landscape. Their status as hotspots for ongoing taxonomic discovery proves that we are still uncovering the true depth of biodiversity within these fragile 'islands' of stone.

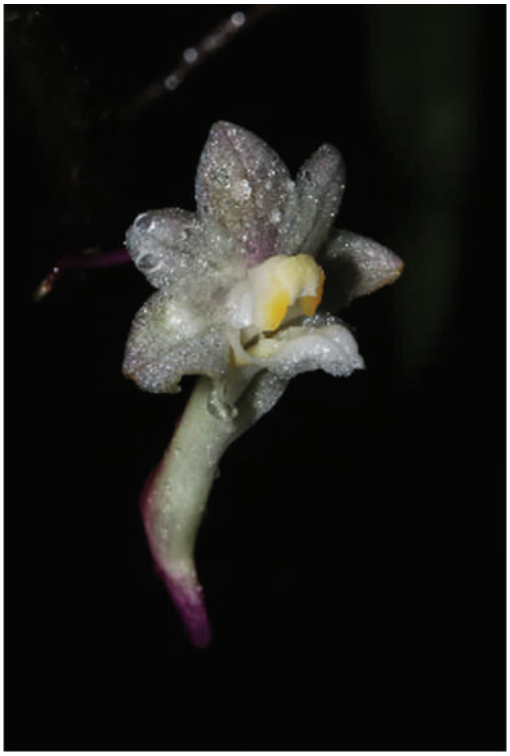

Figure 6. *Dendrobium dianiae*, a newly recorded orchid taxon in Peninsular Malaysia. Previously known from neighboring regions, its presence on local limestone hills underscores the importance of these habitats as biodiversity reservoirs.

Sabah

Kiew (2001) documented 811 species across 404 genera and 125 families in Sabah, revealing a floristic richness that rivals many better-known tropical ecosystems. Orchidaceae represents the most diverse family, followed by Euphorbiaceae, Rubiaceae, Araceae, and Acanthaceae. The most speciose genera include *Begonia*, *Ficus*, *Bulbophyllum*, *Diospyros*, and *Elatostema*.

While the preliminary framework for Sabah's limestone flora was established by Kiew and Lim (1996), field exploration remains geographically uneven. For instance, the 1996 survey of Balambangan Island recorded 260 species, but lacked a formal focus on obligate calciphiles, leaving significant gaps in the island's botanical record (Wells 1977).

Some of the most striking botanical discoveries from Sabah limestone involve highly specialised taxa. Sands (1990) described the pink-spotted *Begonia malachosticta* from Gomantong and the visually distinct *B. amphioxus* from Batu Punggul. Notably, the once-remote Batu Punggul has seen its surrounding landscape transformed by logging since the 1980s, elevating the conservation status of these specialised taxa. The Gesneriaceae family further illustrates the disparity in regional knowledge. Burtt (1978) recorded the widespread species *Monophyllaea merrilliana* from Sabah, and Kiew (2002) later described *M. burttiana*, emphasising the presence of narrowly distributed limestone specialists. Within the genus *Paraboea*, three species have been recorded from Sabah, namely *P. leopoldii*, *P. punggulensis*, and *P. sabahensis* (Burtt 1984; Kiew 2012). In contrast, Sarawak is far better documented, hosting the highest number of *Monophyllaea* species, with a total of 16 species recorded (Burtt 1978; Weber 1998; Kiew 2002, Kiew and Sang 2013), including the recently described *M. kazuea* from Gunung Stulang, Bau (Nur Athirah Nabihah and Meekiong 2024). Similarly, 11 species of *Paraboea* are known from Sarawak (Kiew 2012).

These pronounced differences in recorded species richness between Sabah and Sarawak strongly suggest that the limestone flora of Sabah remains poorly known botanically, rather than genuinely species-poor. While some groups thrive, others, such as gingers (Zingiberaceae), show reduced richness on limestone due to high seedling mortality from edaphic desiccation (Gobilik *et al*. 2000). In contrast, recent checklists of aroids (Araceae) in Sabah demonstrate significant diversity. Of the 114 aroid species (representing 29 genera) recorded across Sabah, 18 species are specifically associated with limestone, including three site-specific endemics (Wong and Joling 2021). These data reinforce the fact that while certain families are naturally limited by calcareous substrates, others remain largely under-recorded and require urgent taxonomic attention.

Sarawak

While Sarawak is globally renowned for its cavernous systems and spectacular karst geomorphology, its floristic diversity remains remarkably under-researched. To date, a comprehensive and modern checklist for the state's limestone flora remains unavailable. The prevailing estimate of approximately 600 species, established by Anderson (1965), is increasingly regarded as a significant underrepresentation in light of contemporary taxonomic advancements. At the higher taxonomic levels, the limestone flora of Sarawak exhibits strong floristic affinities with that of Peninsular Malaysia. Both regions share a dominance of families such as Annonaceae, Begoniaceae, and Gesneriaceae (*Epithema*, *Monophyllaea*, and *Paraboea*), alongside Euphorbiaceae, Moraceae, Pandanaceae, and Urticaceae (*Elatostema*, *Pilea*). Conversely, both regions show a characteristic paucity of Dipterocarpaceae, which are largely absent from the alkaline, thin-soiled limestone substrates (Kiew 1991). Among these groups, the genus *Monophyllaea* stands out as a defining ecological element of Sarawak's limestone massifs, exhibiting a level of diversity that exceeds its counterparts in the Peninsula (Kiew 2002).

Montane limestone vegetation in Sarawak represents a unique floristic assemblage within Malaysia. Anderson and Chai (1982) described these communities at elevations between 800 and 1,700 m, where the vegetation is characterised by stunted, leaning trees, an adaptation to high wind exposure and shallow, rocky substrates. The habitat forms a complex ecological mosaic. On exposed, alkaline limestone surfaces, the flora is dominated by obligate calciphiles from the families Gesneriaceae, Pandanaceae, and Urticaceae. Meanwhile, in areas where deep, acidic peat has accumulated over the rock and is covered by bryophytes, the environment supports calcifuge species. Many of these taxa are typically associated with non-calcareous montane forests, such as the granite massif of Gunung Mulu. Notable examples include conifers like *Dacrydium beccarii* and *Phyllocladus hypophyllus*, various *Rhododendron* species, and the pitcher plant *Nepenthes stenophylla*. On the most exposed summits, the vegetation is dominated by a coniferous canopy interspersed with *Leptospermum flavescens* (Myrtaceae).

Among the karst landscapes of Sarawak, the Bau limestone has been the most intensively documented, with botanical records extending back to 1845. Pioneering collections by G.D. Haviland, J.A.R. Anderson, and H.N. Ridley established the taxonomic foundation for the region. Anderson's early accounts highlighted the site-specific endemism of the area, most notably the iconic pitcher plant *Nepenthes northiana*, which is strictly endemic to these hills. Interestingly, while *Nepenthes* are absent from the limestone habitats of Peninsular Malaysia, they form a significant component of Sarawak's karst flora, marking a striking biogeographic disjunction.

Modern inventories underscore the exceptional taxonomic density of the Bau massifs. Detailed studies have since revealed the exceptional diversity of the Bau limestone flora. Kiew (2004) documented at least 440 species of flowering plants representing 189 genera

and 74 families in the understorey alone. Additional studies recorded 26 species of Zingiberaceae and three species of Marantaceae (Poulsen *et al*. 2004), six species of *Nepenthes* (Lee 2004), 139 tree species in 82 genera and 39 families (Meekiong *et al*. 2004), 120 species of ferns, and 32 orchid species (Meekiong 2004a, 2004b).

At Niah National Park, Pearce (2004) compiled an inventory of 343 taxa occurring on or near limestone, with 281 taxa identified as being specifically associated with karst substrates. This updated checklist followed the taxonomic re-evaluation of *Calanthe triplicata*, which refined the count of obligate limestone taxa to 166 (Pearce 2004). Niah is particularly significant for its hyper-endemic *Begonia* species; five taxa including *Begonia kachak*, *B. kasutensis*, *B. niahensis*, *B. stichochaeta*, and *B. subisensis* are restricted to the park's limestone massifs (Pearce 2003). In contrast, the flora of Bukit Sarang, while hosting 177 recorded species, displays a remarkably distinct floristic identity. The distinctiveness of Bukit Sarang, characterised by the absence of typical limestone specialists, suggests its biodiversity has diverged due to extreme isolation and unique local ecological conditions. (Kiew *et al*. 2007).

Meanwhile, although the Melinau limestone (Gunung Api and Gunung Benarat) has been well explored botanically, a comprehensive and complete checklist is still unavailable. Existing documentation is limited to taxonomic fragments, specialised accounts of families such as Gesneriaceae, Pandanaceae, Arecaceae, Zingiberaceae, and Begoniaceae (Jeremy 1984; Kiew 2001; Sang *et al.* 2013). The on-going discovery of new aroid species from these regions (Ipor *et al.* 2004; Boyce and Wong 2007; Wong *et al.* 2020), further underscores that even Sarawak's most famous karst formations continue to yield species new to science. These collective studies highlight the vital role that limestone habitats play in supporting a diverse range of plant communities. To truly understand the diversity of limestone flora in Sarawak, a comprehensive and modern checklist that brings all this information together is urgently needed.

Endemic species

Limestone forests are typically rich in endemic flora and show high environmental heterogeneity, driven by large-scale variation in substrate solubility (Pérez-García *et al.* 2009; Tang *et al*. 2011). Endemic species, particularly those with narrow geographical ranges, are a hallmark feature of limestone flora (Kiew *et al*. 2017). These taxa are exceptionally vulnerable to extinction from habitat disturbance, as approximately 20.8% of the total limestone flora is strictly confined to these alkaline habitats (Chin 1977; Kiew and Rafidah 2021). In Peninsular Malaysia, the degree of narrow-range endemism is remarkably high. Of the 109 endemic taxa identified (representing 57% of limestone -restricted species and varieties), nearly 100 are site-species endemics, recorded from only a single hill. A further 92 taxa are known from just two to four massifs (Kiew *et al*. 2017). Interestingly, the status of some taxa as "strictly endemic" is occasionally revised as botanical exploration expands across borders. For example, *Begonia kingiana* and *Paraboea verticillata*, once thought to be exclusive to Peninsular Malaysia, have since been recorded in Thailand. This illustrates how perceived endemism can shift with increased regional surveys. Despite these range expansions, endemism remains particularly high in certain groups like *Paraboea*. Within Peninsular Malaysia, 12 of the 19 recorded *Paraboea* species are strictly endemic to the Peninsula, with an additional three species occurring only within the shared biogeographic zone of northern Peninsular Malaysia and Southern Thailand (Kiew 2010).

Chin's (1977) classification of "exclusives" (taxa restricted solely to limestone) and "preferents" (taxa usually found on, or significantly more abundant on, limestone) offers a more nuanced ecological framework than the broader term "obligate." Interestingly, many limestone exclusives are not necessarily physiologically dependent on calcium-rich soils;

instead, they utilise these rugged terrains as competitive refuges. In the surrounding lowland rainforest, these species may be outcompeted by the dense shade and rapid growth of generalist flora. The limestone environment, characterized by higher light availability and unique soil chemistry, acts as an ecological sanctuary. Consequently, these hills function both as safe havens for persistence and as centers of evolutionary diversification, allowing specialised lineages to thrive where they would otherwise be excluded by the intense competition of the forest floor (Kiew 2004).

Borneo's endemic plant taxa are exceptionally vulnerable due to their restricted distributions and global rarity. Notably, five genera are entirely confined to the island's specialised geologies: three are obligate calciphiles restricted to limestone, while two are found exclusively on ultramafic substrates (Neo 2025). The limestone flora of Sabah and Sarawak exhibits a striking floristic disjunction. This is driven by both habitat type; coastal limestone in Sabah versus submontane massifs in Sarawak and distinct species compositions. While Sabah shows a reduced diversity in families such as Balsaminaceae, Gesneriaceae, Urticaceae, Orchidaceae, and Arecaceae (Palmae), it serves as a diversity hotspot for others. Families and genera such as Dipterocarpaceae, *Aglaia* (Meliaceae), and *Elatostema* (Urticaceae), along with *Antidesma*, *Begonia*, *Cyrtandra*, and *Lepisanthes*, are significantly better represented in Sabah than in Peninsular Malaysia (Kiew 2001). Detailed taxonomic revisions by specialists including work on *Begonia* (Sands 1990), *Paraboea* (Xu and Burtt 1991), and Orchidaceae (Chan *et al.* 1994), confirm that endemism levels in Sabah are remarkably high. These findings underscore that the "biological poverty" sometimes attributed to Sabah's limestone is often a reflection of sampling bias rather than a lack of evolutionary uniqueness.

Endemic species often exhibit fragmented distributions, with their occurrences tightly confined to specific geologies or vegetation types. A notable example is *Turpinia calciphila* (Staphyleaceae), which displays a striking disjunction, being recorded only from the widely separated Bau and Melinau limestone massifs (Wong and Neo 2019). Intensive plant collecting on Gunung Api and Gunung Benarat in Gunung Mulu National Park has uncovered numerous hill endemics, particularly in Gesneriaceae, including *Agalmyla erecta*, three species of *Cyrtandra*, six species of *Monophyllaea*, and three species of *Paraboea*, as well as in Pandanaceae, with *Pandanus calcinactus* and *P. leptophilus*. Beyond these primary families, the Melinau limestone of Gunung Api harbors unique representatives such as *Saurauia calcicola* and *S. montiflagrans* (Actinidiaceae), and *Melastoma impressinervium* (Melastomataceae). These distribution patterns underscore how individual limestone hills serve as both evolutionary cradles, where new species arise and isolated arenas for innovation, producing a flora that is highly localised yet of global conservation significance.

The genus *Begonia* stands out as a flagship taxon for limestone biodiversity, characterised by its exceptional species richness and acute sensitivity to environmental disturbance. While the genus is globally celebrated for its horticultural appeal, it exhibits a profound level of site-specific endemism across Borneo. Currently, at least 600 species are recognised on the island (Sang and Kiew 2014), however, the vast majority are hyper endemics, with many recorded from only a single limestone massif or ultramafic outcrop. This pattern of extreme localisation transforms Borneo's karst landscapes into botanical treasure troves, where individual hills support unique, non-overlapping assemblages. Consequently, these populations are intrinsically vulnerable; even localised habitat disturbance can lead to the immediate extinction of a species (Kiew *et al*. 2015). The persistent discovery of new taxa with numerous species described in recent years (Lin *et al.* 2014a, 2014b; Sang *et al.* 2015a, 2015b, 2016; Sang and Ling 2015), demonstrates that our understanding of *Begonia* remains in a state of active taxonomic discovery, with much of the genus's true diversity likely still hidden in unexplored karst regions.

There is remarkably little floristic overlap across political boundaries; an extraordinary 124 species exhibit highly restricted ranges. Of these, 105 were described only within the last three decades, underscoring a renaissance in taxonomic discovery for a genus that was historically underrepresented in botanical literature. In Sabah, the degree of specialisation is particularly acute, with approximately 90% of *Begonia* species being endemic (Kiew 2001; Kiew *et al.* 2015). These are typically site-species endemics, confined to a single massif or a localised cluster of limestone hills. This high percentage of site-specific taxa indicates that Sabah's karst landscapes function as isolated evolutionary laboratories, where even minor geographical barriers have facilitated the divergence of unique species.

On limestone, *Begonia* diversity and endemism reach particularly striking levels. In Sabah, two thirds of the 18 limestone associated species are known from a single hill, with nearly a third restricted to nearby hills, and up to four species may co-occur on a single outcrop (Kiew 1998, 2001). In Sarawak, this pattern is even more pronounced, with 45 limestone species recorded compared with 18 in Sabah. Most species are restricted to one hill or a small group of hills, with only *Begonia gueritziana* occurring more widely and extending onto other rock types. The abundance of microhabitats on limestone allows multiple species to coexist on the same hill, each occupying a distinct ecological niche. For example, five species are recorded from the Subis limestone (Pearce 2005), 19 species from limestone hills in southwestern Sarawak (Kiew and Geri 2003; Kiew and Sang 2007; Lin and Peng 2017).

Notably, no *Begonia* species are shared between the Subis limestone and other limestone areas in Sarawak. Within the limestone hills in southwestern Sarawak, of the 19 species recorded, only three species such as *B. speluncae* (Figure 7), *B. lailana*, *B. paoana* occurs across Bau, Penrissen, and Padawan-Serian, while approximately 40% (i.e. nine species) are restricted to a single area and a third occur in two of the three areas. Individual hills commonly support multiple species, such as Gunung Kawa in the Bau limestone with five species, and Gunung Manok and Gunung Bah with four species each (Kiew and Sang 2007). These patterns reveal limestone hills as powerful centers of diversification, where geological isolation and fine-scale habitat variation drive rapid speciation. The limestone *Begonia* of Borneo thus exemplifies how small, fragmented landscapes can harbor extraordinary biodiversity, while simultaneously highlighting the extreme vulnerability of these “island” ecosystems to total habitat loss.



Figure 7. *Begonia speluncae* (Begoniaceae) from the Bau limestone. This species is a specialised calciphile often found inhabiting the shaded, humid entrances of limestone caves.



Figure 8. *Gymnostachyum calcicola* (Acanthaceae). A narrow endemic species recently described in 2024, currently known only from the limestone massifs of Kelantan. Its discovery highlights the significant number of taxa still awaiting formal description within Malaysia's karst ecosystems.

THREATS TO THE FLORA OF LIMESTONE

Conservation status and legal framework

At present, the majority of limestone massifs receive no specific legal protection, with conservation occurring only incidentally where hills fall within pre-existing protected areas. In Peninsular Malaysia, a few hills benefit indirectly from National Park status, such as those within Taman Negara, though even these remain vulnerable to external infrastructure projects like the previously proposed Tembeling Dam (Kiew and Chin 1982). While some areas have been designated as "Geoparks", it is critical to note that Geopark status is a management and voluntary framework rather than a legislative tool. It does not provide the same statutory protection against quarrying or land alienation as a National Park or State Park. Sarawak maintains a more robust framework, with Gunung Api and Gunung Benarat protected within the Gunung Mulu UNESCO World Heritage Site, while other significant formations like Subis, Bukit Sarang, and portions of the Bau limestone are designated as Totally Protected Areas. However, many other hills lie within forest reserves or recreational forests, which may prohibit quarrying but still expose sensitive vegetation to significant disturbance from tourism. Ultimately, the majority of limestone hills are situated on state land without formal protection, rendering them exceptionally vulnerable to degradation.

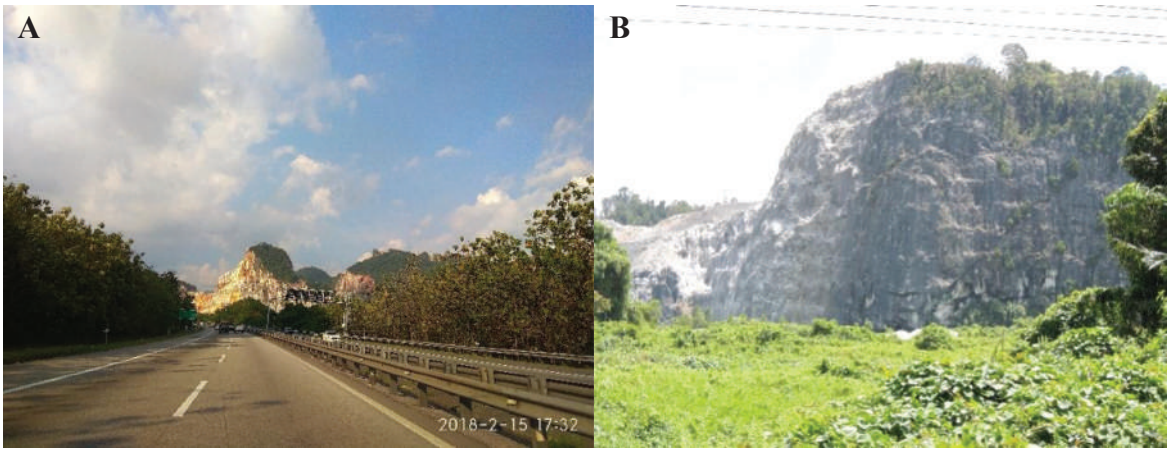

Figure 9. A. Extensive quarrying operations at Gunung Terendum, Perak. The image highlights the total removal of limestone faces, leading to the permanent loss of specialised microhabitats and the potential extinction of site-specific steno-endemic flora; **B.** Quarrying activity at Buso, Bau limestone hills, Sarawak, showing exposed karst surfaces and habitat disturbance.

Extractive industries and habitat loss

The threats facing limestone flora are numerous and often cumulative, with quarrying for cement, marble, and construction aggregate representing the most immediate and destructive pressure. This is exemplified by the ongoing situation at Gunung Kanthan in Perak, where intensifying quarrying pressure directly threatens critically endangered site-species endemic. The use of limestone for road aggregate is particularly resource-inefficient given that it is a non-renewable geological feature; granite is both more abundant and mechanically superior for construction purposes. While cement production consumes vast quantities of stone, historical mining has also left permanent ecological scars, such as the iron mining of the 1960s, which stripped nutrient-rich soils from gullies and caused irreversible damage to summit and slope vegetation. Beyond industrial aggregate, crystal mining has emerged as a significant threat, most notably at Gunung Keriang in Kedah, where the extraction of minerals destroys specialised microhabitats and endangers site-specific flora. These extractive impacts extend into Sarawak, where over a century of gold and antimony mining in the Bau area has caused lasting disturbances to the local flora (Anderson 1965).

Agricultural encroachment and the threat of fire

Agricultural expansion has proved equally damaging, particularly in regions like Ipoh where cultivation extends directly to the base of limestone hills and into the flat valleys between outcrops. This intensive land use has resulted in significant habitat loss and is linked to the suspected extinction of approximately 18 species that have not been recorded for over a century (Kiew 1991). In Kelantan and Pahang, large-scale oil palm and rubber plantations frequently surround these hills, introducing repeated burning that threatens to drive remaining endemics to extinction. While fire has always played a limited natural role such as the destruction of Gunung Api's summit vegetation in the early 1930s, modern fires are increasingly linked to human activity.

In Peninsular Malaysia, natural lightning strikes are typically accompanied by rain, which naturally limits their impact on karst vegetation. Recent summit fires, such as those documented at Batu Caves, Bukit Takun, and Gua Musang, reflect this growing anthropogenic pressure. Recovery from such events is severely delayed where soils are thin; on the flanks of Gua Tempurung, the original flora has been replaced by bamboo and hardy grasses even a decade after the fire.

Infrastructure, climate change, and cultural impacts

Karst ecosystems are increasingly vulnerable to infrastructure development and natural disasters exacerbated by climate change. Hydroelectric dams pose a terminal risk by permanently inundating the specialised vegetation at the base of limestone hills. This was observed following the construction of the Kenyir Dam in Terengganu, where several Batu Biwa hills were partially submerged, and a similar fate now threatens the Nenggiri project area in Kelantan. Such developments are catastrophic for hyper-endemic species like *Begonia jayaensis* and *Impatiens vinosa*, which are restricted to single cave systems.

Furthermore, the expansion of building infrastructure including housing, roads, and tourism facilities right to the foot of cliffs necessitates the clearing of the talus slope, a high-diversity zone. This encroachment often triggers concerns regarding rockfalls, which are a natural feature of karst weathering but become a public safety hazard when buildings are placed too close to the cliff. To mitigate this risk, authorities often resort to removing the loose rocks or installing steel nets and concrete reinforcements, both of which result in the total destruction of specialised cliff vegetation and microhabitats. In addition, extreme weather events, such as the 2025 flash floods in Perlis, cause significant physical damage to delicate underground river systems like Gua Kelam.

Crucially, religious activities on limestone hills have evolved into a major ecological pressure. While temples established within large, existing caves generally have limited impacts, the increasing number of temples constructed beneath cliff overhangs, particularly in the Ipoh area, necessitates the extensive clearing of vegetation at the cliff base. This specific practice now constitutes a serious and growing threat to limestone flora, as it permanently eliminates the shaded, humid microhabitats that harbor many of Borneo and Peninsular Malaysia's most specialized species.

Biotic threats: Poaching and invasive species

Commercial plant collection and invasive species further compound the pressures on these fragile ecosystems. Highly prized taxa, such as the endangered slipper orchids *Paphiopedilum niveum* and *P. stonei*, as well as various cycads, are frequently overharvested by collectors for the horticultural trade (Vermeulen and Whitten 1999). This demand has recently expanded to include smaller groups like “jewel orchids”, *Corybas*, and *Bulbophyllum*, further depleting wild populations (O’Byrne 2014). Simultaneously, disturbed limestone edges are increasingly colonised by non-native invasive species like *Piper aduncum*, *Chromolaena odorata*, *Mikania micrantha*, and *Clidemia hirta*, which outcompete native flora and alter the local microhabitat. As many limestone plants are narrow endemics restricted to a single site, the degradation of individual hills can translate directly into global extinctions to the narrowly endemic species.

Equally dangerous is the rise of invasive and toxic species, such as Mexico weed (*Parthenium hysterophorus*), which has been recorded at sites like Gua Tambun in Perak. This aggressive weed not only outcompetes native flora for space and nutrients but also releases allelopathic chemicals that inhibit the growth of indigenous plants. Furthermore, its presence at archaeological and tourist sites like Gua Tambun poses a health risk to visitors due to its toxic and allergenic properties.

CONSERVATION AND RECOMMENDATIONS OF THE LIMESTONE FLORA

The limestone flora of Malaysia represents a unique evolutionary legacy, characterised by exceptional levels of endemism and a specialised adaptation to karst environments (Tan *et al.* 2024). However, as the preceding sections demonstrate, these ecosystems are currently undergoing rapid degradation due to a lack of targeted legal protection and the cumulative

impacts of industrial, agricultural, and anthropogenic pressures. Limestone hills function as an "ecological archipelago", where each massif acts as an isolated island of biodiversity. Hence, the current approach of incidental conservation is no longer sufficient. To prevent the global extinction of site-restricted species, a shift toward a proactive, network-based conservation strategy is required. The following recommendations outline a comprehensive framework for the legal, industrial, and ecological management of Malaysia's karst landscapes, aimed at ensuring the long-term resilience and integrity of this irreplaceable botanical hotspot.

Redefining the legal framework

While the "Geopark" status serves as a vital branding and management framework, it lacks legislative power to prevent land-use changes. To ensure long-term survival, high-ranked biodiversity hills must be formally gazetted as Totally Protected Areas (TPAs) or State Nature Reserves. For those situated within existing forest reserves, they should be redesignated as legally protected areas, providing them with a statutory level of protection that strictly prohibits quarrying, mineral extraction, and habitat alienation.

The network-based strategy

Conservation can no longer rely on isolated flagship parks; instead, Malaysia must adopt an "Ecological Archipelago" strategy. Due to limestone flora being characterised by high site-endemicity, where a single hill may harbor unique species found nowhere else, a coordinated network of several hills must be established across all major karst regions. This includes prioritising sites in limestone hills in all regions of Sabah, Sarawak and Peninsular Malaysia to capture the full evolutionary spectrum of the regional flora.

Mandatory buffer zones

The protection of a limestone hill must extend at least 200 metres into the surrounding forest to create a mandatory buffer zone. This forested perimeter is critical for stabilising the humid microclimates at the cliff base and protecting specialised, shade-loving plants like *Begonia* and *Impatiens*. Furthermore, these buffers serve as essential fire breaks against agricultural burning and protect the hydrology of cave streams, which support unique aquatic flora such as *Cryptocoryne*.

Surface and subterranean hydrological protection

Limestone hills act as the visible towers of much larger, interconnected underground karst aquifers. These aquifers provide critical water resources for surrounding districts. Protection must extend to the entire catchment area to prevent industrial runoff and chemical contamination from reaching the groundwater. Quarrying and infrastructure projects must be strictly regulated within these hydrological zones to ensure that the water quality for both the specialised cave-stream flora and local human communities remains uncompromised.

Tiered industrial planning

Each state should implement a Karst Grading System to manage land-use conflicts between industry and ecology. High-priority hills, graded by their biological, archaeological, and recreational value should be permanently off-limits to extraction. Conversely, lower-priority hills should be allocated for quarrying in whole units rather than allowing fragmented operations that scar multiple sites. This policy should be integrated in Environmental Impact Assessments (EIAs) requirements that specifically evaluate impacts on site-restricted endemics and cave hydrology.

Mitigating Biotic and Anthropogenic Threats

Active management is required to address the cumulative pressures of invasive species, over-collection, and infrastructure. This includes the targeted removal of toxic and aggressive weeds, such as Mexico weed (*Parthenium hysterophorus*) at Gua Tambun, and the enforcement

of strict building codes that prevent new temples or tourism facilities from being built directly against the cliff face. Such "off-cliff" construction preserves the high-diversity talus zones and reduces the need for destructive rockfall mitigation measures like "scaling" or concrete reinforcement.

Integrated research and *ex situ* support

Given the high number of undescribed species, comprehensive biodiversity assessments must be prioritised to close knowledge gaps. These *in situ* efforts should be supported by *ex situ* conservation, including seed banking and the propagation of hyper-endemic species in botanical gardens. By engaging local communities in monitoring work and practice sustainable ecotourism, conservation becomes an economic asset, ensuring that these terrestrial islands are valued as irreplaceable laboratories of evolution rather than mere geological resources.

The National Action Plan (NAP) for limestone and karst conservation

To unify these efforts, Malaysia should formalise a National Action Plan (NAP) for Limestone and Karst Conservation as a central strategic roadmap. This plan would integrate karst protection into the National Mineral Policy and the National Physical Plan, establishing a "granite-first" aggregate policy to reduce the industrial demand on limestone. By creating a national inventory and a Conservation Value Score for every hill, the NAP would provide federal and state authorities with the data needed to harmonise land-use decisions, ensuring that the evolutionary potential of Malaysia's "terrestrial islands" is preserved for future generations.

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REFERENCES

Aliaa-Athirah, A.M., Kiew, R., Rafidah, A.R., Ummul-Nazrah, A.R. and Ong, P.T. 2019. Lessons from the Gua Musang massif for conservation of the Malaysian limestone flora. *Conservation Malaysia* 29: 1−3.

Allen, B.M. 1961. Some conservation problems of Malaya's hill stations. In *Nature Conservation in Western Malaysia*, *1961. An issue to mark the occasion of the twenty-first anniversary of the founding of the Malayan Nature Society, 1940-1961*, J. Wyatt-Smith and P. R. Wycherley (Eds.). Kuala Lumpur: Malayan Nature Society.

Anderson, J.A.R. 1965. Limestone habitat in Sarawak. In *Proceedings of the Symposium on Ecological Research in Humid Tropics Vegetation*, July 1963, Kuching, Sarawak, pp. 49–57. Paris: UNESCO.

Anderson, J.A.R. and Chai, P.P.K. 1982. Vegetation. *Sarawak Museum Journal* 30: 195–206.

Bakar, S.N.A., Rashid, F., Jamaluddin, M.H., Md. Azmi, M.F., Othman, A.S., Zakaria, R., Abd Rahman, A., Raffi, A. and Nordin, F.A. 2023. Unveiling limestone orchid hotspots in the karst hills of northern Peninsular Malaysia. *Diversity* 15(7): 819. https://doi.org/10.3390/d15070819

Banda, R.M., Gendang, R. and Ambun, A.U. 2004. Geology and geochemistry of the limestone in Sarawak. *The Sarawak Museum Journal* 59(80): 41−62. https://doi.org/10.61507/smj22-2004-1SS2-05

Boyce, P.C. and Wong, S.Y. 2007. Studies on Schismatoglottideae (Araceae) of Peninsular Malaysia IV: Preliminary observations of spathe senescence mechanics in *Schismatoglottis*. *Aroideana* 30: 56−70.

Boyce, P.C. and Wong, S.Y. 2009. The Aroids of the west Sarawak limestone. *The International Aroid Society Newsletter* 31(2): 1−8.

Burtt, B.L. 1978. A preliminary revision of *Monophyllaea* (Gesneriaceae). *Notes from the Royal Botanic Garden Edinburgh* 37(1): 43.
Burtt, B.L. 1984. Studies in the Gesneriaceae of the old world XLVII: Revised generic concepts for *Boea* and its allies. *Notes from the Royal Botanic Garden Edinburgh* 41(3): 401–452.
Bystriakova, N., Alves de Melo, P.H., Moat, J., Nic Lughadha, E. and Monro, A.K. 2019. A preliminary evaluation of the karst flora of Brazil using collections data. *Scientific Reports* 9: 17037. https://doi.org/10.1038/s41598-019-53104-6
Chan, C.L., Lamb, A. Shim, P.S. and Wood, J.J. 1994. *Orchids of Borneo Volume 1: Introduction and a selection of species*. London: Royal Botanic Gardens, Kew; Kota Kinabalu: The Sabah Society.
Cheah, Y.H. and Ong, P.T. 2019. *Dendrobium dianiae*. *The Orchid Review* 127(1328): 242–247.
Chin S.C. 1977. The limestone flora of Malaya 1. *The Gardens' Bulletin of Singapore* 30: 165–219.
Chin, S.C. 1979. The limestone flora of Malaya 2. *The Gardens' Bulletin of Singapore* 32: 64–203.
Chin, S.C. 1983a. The limestone flora of Malaya 3. *The Gardens' Bulletin of Singapore* 35: 137–190.
Chin, S.C. 1983b. The limestone flora of Malaya 4. *The Gardens' Bulletin of Singapore* 36: 31–91.
Clements, R., Sodhi, N.S., Schilthuizen, M. and Ng, P.K.L. 2006. Limestone karst of Southeast Asia: Imperiled arks of biodiversity. *BioScience* 56: 733–742. https://doi.org/10.1641/0006-3568(2006)56[733:LKOSAI]2.0.CO;2
Davison, G.W.H. and Kiew, R. 1990. Survey of flora and fauna of limestone hills in Kelantan with recommendations for conservation. Kuala Lumpur: Malayan Nature Society [Unpublished report].
Foon, J.K., Clements, G.R. and Liew, T.S. 2017. Diversity and biogeography of land snails (Mollusca, Gastropoda) in the limestone hills of Perak, Peninsular Malaysia. *ZooKeys* 682: 1–94. https://doi.org/10.3897/zookeys.682.12999
Forest Department Sarawak. n.d. Facts & Figures. *Forest Department Sarawak.* https://forestry.sarawak.gov.my/web/subpage/webpage_view/1170
Gobilik, J., Magintan, D., Poulsen, A.D. and Mashitah, Y. 2000. Gingers at the Dagat limestone ridge, Tabin Wildlife Reserve, Sabah. In *Tabin Limestone Scientific Expedition*, M. Mohamed, M. Schilthuizen and M. Andau (Eds.), pp. 49–59. Kota Kinabalu: Universiti Malaysia Sabah.
Go, R., Lim, M.Y.L., Phoon, S.N., Yong, W.S.Y., Tang, C.H., Khor, H.E., Abdullah, J.O. and Abdullah, J. 2009. Malaysian limestone orchids status: diversity, threat and conservation. *Blumea* 54: 109–116. https://doi.org/10.3767/000651909X474168
Grismer, L.L., Shahrul, A., Muin, M.A., Quah, E.S.H. and Wood, P.L., Jr. 2013. Phylogenetic relationships and description of a new upland species of Bent-toed Gecko (*Cyrtodactylus* Gray, 1827) of the *C. sworderi* complex from northeastern Peninsular Malaysia. *Zootaxa* 3616(3): 239–252. https://doi.org/10.11646/zootaxa.3616.3.2
Henderson, M.R. 1939. The flora of the limestone hills of the Malay Peninsula. *Journal of the Malayan Branch of the Royal Asiatic Society* 17: 13–87.
Ipor, I.B., Tawan, C.S. and Boyce, P.C. 2004. *Amorphophallus julaihii* (Araceae), a new species from Sarawak, Malaysia. *Gardens' Bulletin Singapore* 56(1-2): 153–159.
Jutta, M., Ong, P.T. and Phoon, S.N. 2008. New records for the *Flora of Peninsular Malaysia*, Family Orchidaceae 1. *Appendicula floribunda*, *Bulbophyllum elevatopunctatum*, *Cymbidium sigmoideum* and *Dendrochilum bandaharaense*. *Gardens' Bulletin of Singapore* 60(1): 37–43.
Kiew, R. 1985. The limestone flora of the Batu Luas area, Taman Negara. *Malayan Naturalist* 38(3): 30–36.
Kiew, R. 1991. Limestone flora. In *The State of Nature Conservation in Malaysia*, R. Kiew (Ed.), pp. 42–50. Kuala Lumpur: Malaysian Nature Society.
Kiew, R. 1993. A floral survey of limestone hills in Perlis with recommendations. Kuala Lumpur: WWF Malaysia. [Unpublished report].
Kiew, R. 1997. The Malaysian hills and limestone hills – threatened ecosystems. In *The State of the Environment in Malaysia*, R. Kiew (Ed.), pp. 66–73. Penang: Consumers' Association of Penang.

Kiew, R. 2001. Towards a limestone flora of Sabah. *Malayan Nature Journal* 55: 77–93.
Kiew, R. 2002. A new species of *Monophyllaea* (Gesneriaceae) from Borneo. *Gardens' Bulletin of Singapore* 54: 243–246.
Kiew, R. 2004. The limestone flora of Sarawak. *The Sarawak Museum Journal* 63(84): 79−90.
Kiew, R. 2010. Two new species of *Paraboea* (Gesneriaceae) from Peninsular Malaysia and Thailand. *Edinburgh Journal of Botany* 67(2): 209–217. https://doi.org/10.1017/S0960428610000107
Kiew, R. 2012. *Paraboea* (Gesneriaceae) in Sabah, Borneo, including a new species. *Malayan Nature Journal* 64: 1–8.
Kiew, R. and Chin, S.C. 1982. The effect of dam building on plant life in Taman Negara. *Malayan Naturalist* 35(4): 23–25.
Kiew, R. and Geri, C. 2003. *Begonias* from the Bau limestone, Borneo, including a new species. *Gardens' Bulletin Singapore* 55(4): 113–123.
Kiew, R. and Lim, S.P. 1996. Checklist of limestone plants in Sabah. Petaling Jaya: WWF Malaysia.
Kiew, R. and Rafidah, A.R. 2021. Plant diversity assessment of karst limestone, a case study of Malaysia's Batu Caves. *Nature Conservation* 44: 21–49. https://doi.org/10.3897/natureconservation.44.60175
Kiew, R. and Sang, J. 2007. *Begonia* (Begoniaceae) from limestone hills in the Kuching Division, Sarawak, Borneo, including nine new species. *Gardens' Bulletin Singapore* 58(2): 199–232.
Kiew, R. and Sang, J. 2009. Seven new species of *Begonia* (Begoniaceae) from the Ulu Merirai and Bukit Sarang limestone areas in Sarawak, Borneo. *Gardens' Bulletin Singapore* 60(2): 351–372.
Kiew, R. and Sang, J. 2013. Two new *Monophyllaea* (Gesneriaceae) species from Sarawak, Borneo. *Phytotaxa* 129(1): 59–64. https://doi.org/10.11646/phytotaxa.129.1.6
Kiew, R., Rafidah, A.R., Ong, P.T. and Ummul-Nazrah, A.R. 2017. Limestone treasures: Rare plants in Peninsular Malaysia–what are they, where they grow and how to conserve them? *Malaysian Naturalist* 71: 32–41.
Kiew, R., Sang, J., Repin, R. and Joffre, A. A. 2015. *A Guide to Begonias of Borneo*. Kota Kinabalu: Natural History Publications (Borneo).
Lee, C.C. 2004. *Nepenthes*. *The Sarawak Museum Journal* 59(80): 171–178.
Liew, T.S., Foon, J.K. and Clements, G.R. 2021. *Conservation of limestone ecosystems of Malaysia, Part I, Acknowledgements, Methodology, Overview of limestone outcrops in Malaysia, References, Detailed information on limestone outcrops of the states: Johor, Negeri Sembilan, Terengganu, Selangor, Perlis*. Kota Kinabalu: Institute for Tropical Biology and Conservation, Universiti Malaysia Sabah. https://doi.org/10.6084/m9.figshare.14907846
Lin, C.W. and Peng, C.I. 2017. Three new species of *Begonia* (Begoniaceae) from limestone hills in southwestern Sarawak, Borneo. *Taiwania* 62(2): 105–115. https://doi.org/10.6165/tai.2017.62.105
Lin, C.W., Chung, S.W. and Peng, C.I. 2014a. *Begonia hosensis* (sect. *Reichenheimia*, Begoniaceae), a new species from Sarawak, Malaysia. *Taiwania* 59(4): 326–330. https://doi.org/10.6165/tai.2014.59.4.326
Lin, C.W., Chung, S.W. and Peng, C.I. 2014b. Three new species of *Begonia* (sect. *Petermannia*, Begoniaceae) from Sarawak, Borneo. *Phytotaxa* 191(1): 129–140. https://doi.org/10.11646/phytotaxa.191.1.8
Marzuki, M.E., Liew, T.S. and Mohd-Azlan, J. 2021. Land snails and slugs of Bau limestone hills, Sarawak (Malaysia, Borneo), with the descriptions of 13 new species. *ZooKeys* 1035: 1–113. https://doi.org/10.3897/zookeys.1035.60843
Meekiong, K. 2004a. Ferns and Fern-Allies. *The Sarawak Museum Journal* 59(80): 187–192.
Meekiong, K. 2004b. Orchids. *The Sarawak Museum Journal* 59(80): 147–162.
Meekiong, K., Tan, S. and Julaihi, L. 2004. Trees of the limestone summits. *The Sarawak Museum Journal* 59(80): 91–104.
Neo, L. 2025. The endemic plant genera of Borneo: A synoptic appraisal. *Sandakania* 26: 83–99.
Nur Athirah Nabihah, M.M. and Meekiong, K. 2024. A new one-leaf plant species (Gesneriaceae: *Monophyllaea*). *Acta Phytotaxonomica et Geobotanica* 75(3): 155–160.
O'Byrne, P. 2007. New orchid species: A Thai *Dendrobium*, a Malaysian *Robiquetia* and a *Malleola* from Borneo. *Malayan Orchid Review* 41: 88–97.
O'Byrne, P. 2014. Threats to Malaysian limestone orchids. *Malayan Orchid Review* 48: 35–40.

O'Byrne, P. 2015. A Revision of *Stichorkis* in Peninsular Malaysia. *Malesian Orchid Journal* 16: 99–110.
O'Byrne, P. 2017. *Oberonia calcarea*, a new orchid species from Peninsular Malaysia. *Malayan Orchid Review* 51: 53–57.
O'Byrne, P. 2019. *Dendrobium* section *Crinifera* in Peninsular Malaysia - Precursory Notes. *Malesian Orchid Journal* 23: 19–64.
O'Byrne, P., Ong, P.T. and Vermeulen, J.J. 2015. New and little-known species of *Thrixspermum* from Peninsular Malaysia and Sulawesi. *Malesian Orchid Journal* 15: 83–108.
Ong, P.T. 2015. Limestone orchids of Peninsular Malaysia. *The Orchid Review* 123(1309): 28–36.
Ong, P.T. 2018. *Chiloschista exuperei*, a new orchid record for Peninsular Malaysia from the Perlis limestone hills. *Malayan Orchid Review* 52: 65–68.
Ong, P.T. 2020. *Sarcoglyphis elliottianum* – a new orchid species from Peninsular Malaysia. *Malayan Orchid Review* 54: 31–36.
Ong, P.T. 2023. Notes on Peninsular Malaysian Orchids 3 – *Hetaeria finlaysoniana*, a confirmation of its occurrence in Peninsular Malaysia. *Malayan Orchid Review* 57: 79–82.
Ong, P.T. and O'Byrne, P. 2013a. A new *Anoectochilus* apecies (Orchidaceae) from Peninsular Malaysia. *Malesian Orchid Journal* 11: 15–20.
Ong, P.T. and O'Byrne, P. 2013b. *Appendicula merapohensis*, a new species from Peninsular Malaysia. *Malayan Orchid Review* 47: 65–70.
Ong, P.T. and O'Byrne, P. 2018. *Preptanthe ruthiae*, a new and threatened orchid species from the Pahang limestone hills, Peninsular Malaysia. *Malesian Orchid Journal* 22: 75–80.
Ong, P.T. and Schuiteman, A. 2023. A new subspecies of *Liparis viridiflora* from the limestone hills of Peninsular Malaysia. *Malesian Orchid Journal* 26: 43–49.
Ong, P.T., Kiew, R., Rafidah, A.R. and Imin, K. 2020. *Didymoplexis micradenia*, a new orchid record for Peninsular Malaysia and a critically endangered species from the cement quarry on Gunung Kanthan, Perak. *Malesian Orchid Journal* 24: 39–44.
Pearce, K.G. 2003. Five new *Begonia* species (Begoniaceae) from the Niah National Park, Sarawak, Malaysia. *Gardens' Bulletin of Singapore* 55: 73–88.
Pearce, K.G. 2004. The vegetation and plants of Niah National Park, Borneo. *Gardens' Bulletin of Singapore* 56: 101–145.
Perez-Garcia, E.A., Sevilha, A.C, Meave, J.A. and Scariot, A. 2009. Floristic differentiation in limestone outcrops of southern Mexico and central Brazil: a beta diversity approach. *Boletín de la Sociedad Botánica de México* 84: 45–58.
Poulsen, A.D., Geri, C., Kalu, M. and Roos, M. 2004. Zingiberaceae and Marantaceae. *The Sarawak Museum Journal* 59(80): 163–170.
Rafidah, A.R., Ummul-Nazrah, A.R., Ong, P.T., Kiew, R., Chung, R.C.K., Imin, K., Aliaa-Athirah, A.M., Mohd. Hairul, M.A., Wan Syafiq, W.P. and Mohd. Syakirin, N. 2025. *Dokumentasi Biodiversiti Flora Dan Pemuliharaan Bukit Batu Kapur Negeri Kelantan*. FRIM Reports, No. 122. Kepong: Forest Research Institute Malaysia.
Rafidah, A.R. *et al.* An updated checklist of limestone flora in Peninsular Malaysia. [In preparation].
Sands, M.J.S. 1990. Six new Begonias from Sabah. *Kew Magazine* 7: 57–85.
Sang, J. and Kiew, R. 2014. Diversity of *Begonia* (Begoniaceae) in Borneo – how many species are there? *Reinwardtia* 14(1): 233–236.
Sang, J. and Kiew, R. 2016. *Begonia* (Begoniaceae) from Batang Ai National Park and vicinity, Sarawak, Borneo, including six new species. *Phytotaxa* 252(1): 17–30. https://doi.org/10.11646/phytotaxa.252.1.2
Sang, J. and Kiew, R. 2023. The biodiversity of Bukit Anak Takun, Selangor, Malaysia. *Malayan Nature Journal* 75(3): 435–440.
Sang, J. and Ling, C.Y. 2015. Eight new species of *Begonia* (Begoniaceae) from Murum Dam, Sarawak, Borneo. *Sandakania* 20: 107–128.
Sang, J., Kiew, R. and Geri. C. 2013. Revision of *Begonia* (Begoniaceae) from the Melinau limestone in Gunung Mulu National Park and Gunung Buda National Park, Sarawak, Borneo, including thirteen new species. *Phytotaxa* 99(1): 1–34. https://doi.org/10.11646/phytotaxa.99.1.1
Sang, J., Kiew, R., and Ling, C.Y. 2015a. A decade of *Begonia* (Begoniaceae) from Sarawak, Borneo. *Sandakania* 20: 129–154.

Sang, J., Kiew, R., Ling, C.Y. and Geri, C. 2015b. *Begonia* (Begoniaceae) from Kubah National Park and environs, Sarawak, Borneo, including a new species. *Sandakania* 20: 87–106.
Sang, J., Kiew, R. and Ling, C. Y. 2018. The *Begonia* flora of Gunung Mulu and Gunung Buda National Parks, Sarawak, Borneo, including five new species. *Phytotaxa* 381(1): 58–79. http://dx.doi.org/10.11646/phytotaxa.381.1.9
Saw, L.G., Chua, L.S.L. and Rahim, N.A. 2009. *Malaysia National Strategy for Plant Conservation*. Kuala Lumpur: Ministry of Natural Resources and the Environment; Kepong: Forest Research Institute Malaysia.
Sutthisaksoponi, P., Juneadi, J., Worrachottiyanon, W. and Triboun, P. 2025. *Paraboea verticillata* (Gesneriaceae), a new record for Thailand. *Thai Forest Bulletin (Botany)* 53(2): 63–66.
Tan, J.P.C., Kiew, R., Saw, L.G. and Ummul-Nazrah, A.R. 2014. Three new species from Gunung Kanthan, a limestone tower karst in Perak, Malaysia. *Phytotaxa* 177: 146–154. https://doi.org/10.11646/phytotaxa.177.3.2
Tan, J.P.C., Kiew, R. and Darbyshire, I. 2024. Prioritising Important Plant Areas (IPAs) among the limestone karsts of Perak, Malaysia. *Kew Bulletin* 79: 409–427. https://doi.org/10.1007/s12225-023-10160-6
Tang, J.W., Lu, X.T. and Yin, J.X. 2011. Diversity, composition, and physical structure of tropical forest over limestone in Xishuangbanna, South-west China. *Journal of Tropical Forest Science* 23(4): 425–433.
Toolmal, N., Ong, P.T. and Schuiteman, A. 2022. *Thrixspermum obyrneanum* (Aeridinae), a new species from Peninsular Thailand and Malaysia. *Lankesteriana* 22(2): 155–167. http://dx.doi.org/10.15517/lank.v22i2.52253
Vermeulen, J.J. and Whitten, T. 1999. *Biodiversity and Cultural Heritage in the Management of Limestone Resources: Lessons from East Asia*. Washington, D.C.: The World Bank.
Weber, A. 1998. New taxa of *Monophyllaea* (Gesneriaceae) from Peninsular Malaysia. *Beiträge zur Biologie der Pflanzen* 70: 405–406.
Wells, D.R. 1977. *A survey of the proposed Pulau Balambangan National Park, Sabah*. Petaling Jaya: WWF Malaysia.
Whitmore, T.C. 1984. *Tropical Rain Forests of the Far East*. 2nd Ed. Oxford: Clarendon Press.
Wong, K.M. 1992. Sabah's plant life: a new look at a priceless wonder. In *The Environment: The Future is in Our Hands*, 26–30. Kota Kinabalu: Intan Junior Chamber.
Wong, K.M. and Neo, L. 2019. Species richness, lineages, geography, and the forest matrix: Borneo's 'Middle Sarawak' phenomenon. *Gardens' Bulletin of Singapore* 71 (Suppl. 2): 463–496.
Wong, S.Y. and Joling, J. 2021. Checklist of aroids (Alismatales, Araceae) from Sabah (Malaysian Borneo). *Check List* 17(3): 931–974. https://doi.org/10.15560/17.3.931
Wong, S.Y., Joling, J., Pereira, J.T., Damit, A., Boyce, P.C. and Hay, A. 2020. Studies on *Potheae* (Araceae) of Borneo II: *Pedicellarum* M. Hotta subsumed into *Pothos* L., and recognition of three new species. *Webbia* 75(1): 89–103. https://doi.org/10.36253/jopt-7944
Xu, Z.R. and Burtt, B.L. 1991. Towards a revision of *Paraboea* (Gesneriaceae). *Edinburgh Journal of Botany* 48(1): 1–18.
Yong, W.S.Y., Go, R. and Ong, J. 2005. Orchids of Perlis: limestone endemics. *Conservation Malaysia* 6: 1–2.


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CHAPTER 20

The role of Permanent Reserved Forest in *in situ* conservation

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Abstract: The tropical rainforests of Peninsular Malaysia are not only important for the socio-economic development of the country but are also home to a megadiverse collection of flora and fauna. Permanent Reserved Forests are lands gazetted under the *National Forestry Act 2022 (Amendment)* to ensure sufficient forest area for ecosystem and ecological services. Currently, there are 4.85 million hectares of Permanent Reserved Forests in Peninsular Malaysia, whereas 1.91 million hectares are classified as protected forests and the remaining are production forest. This chapter aims to highlight the *in situ* conservation initiatives carried out by the Forestry Department Peninsular Malaysia in these Permanent Reserved Forests.

INTRODUCTION

The Malaysian tropical rainforests are one of the oldest in the world and rich in biological diversity. As one of mega-biodiverse countries in the world (Convention on Biological Diversity, n.d.), Malaysia recognises forests as strategic national heritage treasures, and is committed to securing sufficient forest areas for their ecosystem services, biodiversity conservation, environmental protection, and sustainable utilisation of resources towards the socioeconomic development and well-being of present and future generations (Ministry of Energy and Natural Resources 2021). In 2024, the forestry sector recorded a contribution of RM6.62 billion to the country's gross domestic product with exports valued at RM22.91 billion (Forestry Department Peninsular Malaysia 2024).

Peninsular Malaysia is blessed with forest areas covering 5.73 million hectares, or 43.47% of 13.18 million hectares of total land area (Table 1). The forest areas in Peninsular Malaysia are categorised as Protected Area (PA), State Land Forests and Permanent Reserved Forests (PRFs). The Protected Area are areas meant for the protection of wildlife, while State Lands Forests are "land-banks" to be developed for socio-economy benefits. The Permanent Reserved Forests constitute about 4.85 million ha or 84.64% of the total forests and are managed under the Sustainable Forest Management Principle. The principle emphasises that permanent forest land should be managed to achieve one or more clearly specified objectives of management with regards to the production of a continuous flow of desired forest products and services without undue undesirable effects on the physical and social environment (ITTO 2015). Currently, 4.14 million ha or 85.36% of PRFs are certified under the Malaysia Timber Certification Scheme (MTCS). This certification acknowledges that these PRFs are sustainably managed and the wood produced are legal. The PRFs are further divided based on forest types for better management (Table 2) (Figure 1).

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Table 1. Forest areas in Peninsular Malaysia.

Forest area	Total area (ha)	Percentage (%)
Permanent Reserved Forest	4,853,170	84.76
Proposed Permanent Reserved Forest	83,608	1.46
Protection Forest	250,352	4.37
Stateland Forest	538,816	9.41
Total	**5,725,946**	**100.00**

Source: Forestry Department Peninsular Malaysia (2024).

Table 2. Major Forest Types in Permanent Reserved Forest, Peninsular Malaysia.

Forest area	Total area (ha)	Percentage (%)
Inland Forests	4,550,004	93.75
Peat Swamp Forest	212,104	4.37
Mangrove Forest	91,062	1.88
Total	**4,853,170**	**100.00**

Source: Forestry Department Peninsular Malaysia (2024).

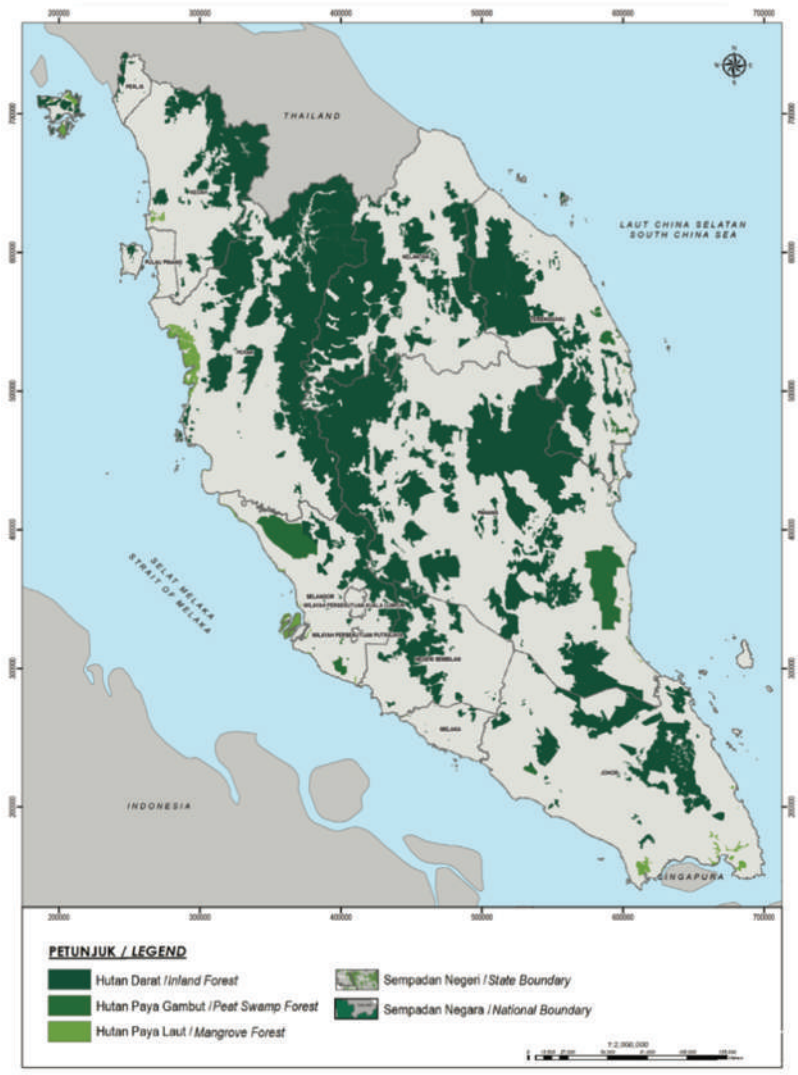

Figure 1. Major forest types in Permanent Reserved Forests.

The Permanent Reserved Forests

Permanent Reserved Forests (PRFs) are land constitute by State Authority and notified in Gazette as stated under Section 7, National Forestry Act 2022 (Amendment) or Act 313. The establishment of PRF allows for proper planning and better management of the valuable renewal resources to enhance commercial returns while ensuring environmental conservation. PRFs shall be classified into 12 functional classes to promote sustainable forest management and multiple uses of the forest. Section 10, Act 313 allows classification of PRF under one or more classes which shall be descriptive of the purpose or purposes for which the land is being or intended to be used. The classification is as followed:

a. Timber production forest under sustained yield;
b. Soil protection forest;
c. Soil reclamation forest;
d. Flood control forest;
e. Water catchment forest;
f. Forest sanctuary for wildlife;
g. Virgin jungle reserved forest;
h. Amenity forest;
i. Education forest;
j. Research forest;
k. Forest for federal purposes and
l. Forest state park

The production forest in Peninsular Malaysia only constitutes timber production forest under the sustained yield class. The concept of sustained yield is that the annual volume harvested must correspond with the volume increment of the forest timber taken from the forest (Mohd *et al.* 1988). These forests are managed under the Selective Management System, which aims to optimise the management objectives of economical and efficient harvesting and sustainability of the forest at minimum forest development costs. Thang (1987) explained that the system was established to meet the following requirements:

"*...that it has the flexibility to manage highly variable forest conditions and changes in the socio-economic environment; that it is rationally based on inherent characteristics of the forest and prevailing socio-economic conditions; and that it will allow for the optimisation of forest management goals which are, namely, (a) an economic cut, (b) the sustainability of the forest, and (c) the minimum costs for forest development.*"

The remaining classes are meant for protection. The management of protection forests are limited to the demarcation of boundaries and enforcement of activities, as entry is not allowed without permission from the authority. As for the amenity forests and forest state parks, management activities adhere to the respective management plans developed. Act 313 does not specify that logging activity cannot be carried out in these protected forest areas. However, it is the management's decision not to allow logging activities due to the importance of these areas for social, environmental, and wildlife protection.

THE FORESTRY POLICY OF PENINSULAR MALAYSIA

Forests are no longer considered as a resource of timber production merely for the socio -economic development of the country. In fact, the protection functions of forest resources such as biodiversity, environmental stability, preserving community culture are becoming increasingly important. The government has recognised that forest management needs to take into consideration the new emerging issues faced by forestry sectors such as water supply and food security, climate change, and improving livelihood standards. To address

this, Malaysia has taken into account the new developments in the formulation of forestry policies and legislations. The Peninsular Malaysia Forestry Policy covered the aspects of sustainable forest management, conservation and protection of biodiversity and forest ecosystem services, mitigation and adaptation of climate change impact, empowerment of research and development as well as information sharing (MENR 2021).

The Peninsular Malaysia Forestry Policy outlined nine main pillars, in which the second pillar aims to enhance focus on conservation of forest biodiversity to prevent degradation of ecosystem, species extinction and depletion of genetic resources (Forestry Department of Peninsular Malaysia 2021). The pillar have two main strategies:

I. Conservation of forest biodiversity through intensifying conservation efforts, including information gathering, *in situ* and *ex situ* initiatives to protect rare, threatened and endecmic (RTE) species.
II. Improve knowledge and scientific documentation on forest biodiversity by acquiring detailed information regarding diversity of flora and fauna especially of undiscovered species and document as a reference in decision-making to ensure that the national biodiversity can be managed sustainably.

IN SITU CONSERVATION INITIATIVE

Forest biodiversity scientific expedition

The Forestry Department of Peninsular Malaysia focuses its efforts on conserving and preserving forest biodiversity to prevent ecosystem degradation, species extinction, and the loss of genetic resources, while taking into account the interests of both social and the environment. Since 1999, JPSM has actively conducted scientific expeditions on forest biodiversity, which serve as a key foundation in understanding the richness of the nation's forest biodiversity. The main objective of these scientific expeditions is to gather detailed information on the biodiversity present in PRFs, which can assist researchers and scientists in deepening their scientific understanding of forest ecosystems.

Continuous efforts through these scientific expeditions have further enriched the nation's biodiversity knowledge base with data and various new discoveries that play a critical role in shaping more strategic and sustainable conservation directions for flora and fauna, while also supporting improvements in the overall management of natural resources. Numerous significant findings, including new, endemic, and unique species of flora and fauna, have been successfully recorded and documented (Appendix 1). As a reflection of the outcomes from 50 scientific expeditions conducted, a total of 39 seminars have been held and 31 proceedings of the *Forest Biodiversity Series* have been successfully published, serving as important references and guides in national biodiversity studies. To date, the expeditions have managed to record 6,766 species of flora (higher and lower plants) and 2,552 fauna (invertebrates and vertebrates). Besides documenting forest biodiversity, the expedition also indirectly act as an out-door laboratory by providing a first-hand experience to future researcher or scientist. The expedition has seen young students participating in the expedition and in the later years coming back as the lead researches.

Virgin Jungle Reserve Forests

Virgin Jungle Reserve (VJR) are forest areas designated as a primary reference site for ecological, botanical, and forest management studies, while also preserving biodiversity and natural forest ecosystems. To date, there are 126 VJR areas covering 32,876.22 hectares in Peninsular Malaysia, encompassing various ecosystems as listed in Appendix 2. VJR areas also serve as an important element in complying with Principles 6 and 8 of the Malaysian Criteria and Indicators (MC&I) for Sustainable Forest Management (SFM), which emphasise the conservation of high conservation value forests.

Box 1.
Richetia kuantanensis (Ashton) Ashton & J. Henk. was declared extinct in 2010 (Chua *et al.* 2010). The only collection on the species was in 1936 in Bukit Goh before the area was converted into plantation. In 1971, the species was described as *Shorea kuantanensis* (Ashton 1978). There were efforts by Forestry Department of Peninsular Malaysia and Pahang Forestry Department to locate the population at the type locality and its vicinity after but there was no success. FDPM continuous efforts in recording rare and threatened species led to the discovery of *R. kuantanensis* in 2014 located at Lata Tembakah Recreational Forest (Mohd. Nasir *et al.* 2017).

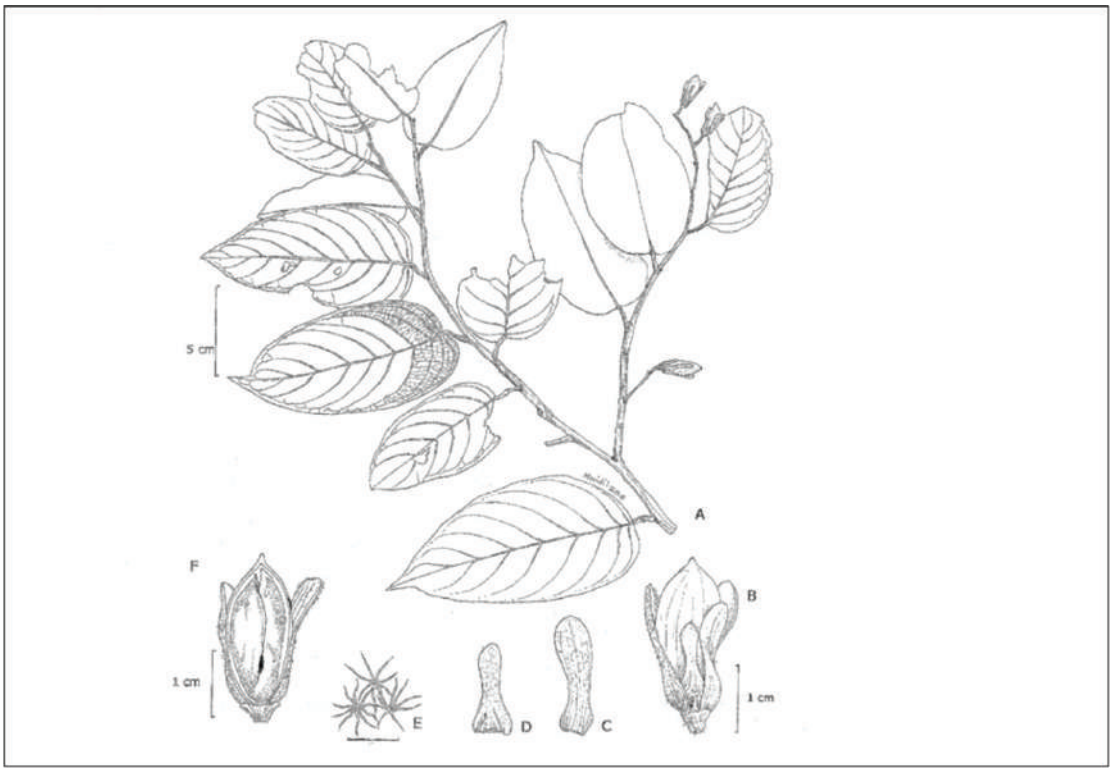

Figure 2. A. Twig of *R. kuantanensis* (Ashton) Ashton & J. Henk.; **B.** Fruit, note the calyx enclosed three-quarter of the nut, hence the nut exceeded the calyx; **C and D.** Spatulate fruit calyx, note the indumentum; **E.** Hair on fruits calyx; and **F.** longitudinal section of the open fruit to show the cotyledons. Source: Mohd. Nasir 2369 (KEP).

High Conservation Value Forests

High Conservation Value (HCV) forests refer to forests of outstanding or critical importance in terms of biological, ecological, social, and cultural values. Initially introduced in 1999 by the Forest Stewardship Council (FSC) for Forest Management Certification, the HCV concept has since been adopted globally and expanded into the agriculture and plantation sectors (HCV Malaysia Toolkit Steering Committee 2018). HCV areas are established to ensure long-term protection, particularly where such areas may be at risk from management practices such as harvesting or development activities.

A total of 44 HCV forests have been established, covering an area of 1,976.59 hectares across Peninsular Malaysia (Appendix 3). The Director-General of Forestry Peninsular Malaysia Circular No. 9 of 2024: *Guidelines for the Management of High Conservation Value (HCV) Areas in Permanent Reserved Forests (PRF) in Peninsular Malaysia* has been enforced as a guiding document for the management of HCV areas.

Ecological plots
Ecological plots are permanent reference areas established for long-term studies on the structure, function, and changes within forest ecosystems. The establishment of ecological plots helps provide continuous scientific data to support sustainable forest management. A total of 16 ecological plots have been established since 2008 (Appendix 4).

Ethnobotany plots
Ethnobotanical plots are designated areas within PRF for the study and conservation of plant species with traditional, cultural, and medicinal value to local communities. The establishment of ethnobotanical plots also aims to document traditional knowledge related to the identification and use of plants for medicine, wildlife food sources, handicrafts, and other customary purposes. To date, only four ethnobotanical plots have been established within PRFs which are located in Kelantan (1 plot), Pahang (1 plot), and Kedah (2 plots) as shown in Appendix 5.

CONCLUSION

Permanent Reserved Forests, among other forests, play a vital role in conserving Malaysia's biodiversity while supporting essential ecosystem services. In Peninsular Malaysia, the Forestry Department of Peninsular Malaysia has strengthened *in situ* conservation through scientific expeditions and scientific research and also established of Virgin Jungle Reserve and High Conservation Value forests to safeguard Malaysia's natural heritage. The Forestry Department is committed to preserve and conserve forest biodiversity, taking into consideration of people's interests and the national responsibility as stipulated and ratified in the international multilateral agreements.

REFERENCES

Ashton, P.S. 1978. Flora Malesiana Precursors: Dipterocarpaceae. *Gardens' Bulletin of Singapore* 31(1): 41–42.

Ashton, P.S. and Heckenhauer, J. 2022. Tribe Shoreae (Dipterocarpaceae subfamily Dipterocarpoideae) finally dissected. *Kew Bulletin* 77: 885–903. https://doi.org/10.1007/s12225-022-10057-w

Convention on Biological Diversity (CBD). n.d. Malaysia – Country Profile. *Convention on Biological Diversity*. https://www.cbd.int/countries/profile?country=my

Chua, L.S.L., Suhaida, M., Hamidah, M. and Saw, L.G. 2010. *Malaysia Plant Red List: Peninsular Malaysian Dipterocarpaceae. Research Pamphlet No. 129*. Kepong: Forest Research Institute Malaysia.

Forestry Department of Peninsular Malaysia. 2021. *Peninsular Malaysia Forestry Policy*. Kuala Lumpur: Forestry Department of Peninsular Malaysia.

Forestry Department of Peninsular Malaysia. 2024. *Annual Report 2024*. Kuala Lumpur: Forestry Department Peninsular Malaysia.

HCV Malaysia Toolkit Steering Committee. 2018. *Malaysian National Interpretation for the Identification of High Conservation Values*. Kuala Lumpur: HCV Malaysia Toolkit Steering Committee.

International Tropical Timber Organization (ITTO). 2015. *Voluntary guidelines for the sustainable management of natural forest*. Yokohama: International Tropical Timber Organization.

Ministry of Energy and Natural Resources. 2021. *Malaysia Policy on Forestry*. Putrajaya: Ministry of Energy and Natural Resources.

Mohd., R., Hadi, Y., Mohamed, S., Mukhtar, A. and Abdul Ghani, A. N. 1988. Sustained yield as an objective of Malaysian forest management. *Malaysian Forester* 51(1): 6–22.

Nasir, M.M., Richard, A.M., Nor Akhirrudin, M., Endot, S. and Latiff, A. 2017. New discovery of *Shorea kuantanensis* Ashton (Dipterocarpaceae) in Peninsular Malaysia. *Malaysian Forester* 80(2): 125–128.

Thang, H.C. 1987. Forest management systems for tropical high forest, with special reference to Peninsular Malaysia. *Forest Ecology and Management* 21(1–2): 3–20.

APPENDICES

Appendix 1. Selected list of Forest Biodiversity Scientific Expedition significant findings from 1999 – 2024.

No.	Species	Locality / Year	Significance
	FLORA		
	FAMILY: Achariaceae		
1.	*Ryparosa scortechinii*	Gunung Tebu (2012)	Endemic
	FAMILY: Annonaceae		
2.	*Annona glabra*	Matang Mangrove (2002)	New record
	FAMILY: Arecaceae		
3.	*Iguanura belumensis*	Belum Royal State Park (1999)	Endemic
4.	*Johannesteysmannia lanceolata*	Gunung Angsi (2007)	Endemic
5.	*Licuala stongensis*	Gunung Stong (2003)	Endemic
6.	*Licuala acutifida*	Bukit Panchor (2008)	Endemic
	FAMILY: Begoniaceae		
7.	*Begonia herveyana*	Melaka (2008)	Endemic
	FAMILY: Dipterocarpaceae		
8.	*Richetia kuantanensis*	Lata Tembakah (2017)	New record
9.	*Neobalanocarpus heimii*	Mandi Angin (2004)	Biggest tree
10.	*Shorea lumutensis*	Pangkor (2009)	Endemic
	FAMILY: Gnetaceae		
11.	*Gnetum globosum*	Kenong (2004)	New record
	FAMILY: Lythraceae		
12.	*Sonneratia griffithii*	Merbok (2013)	Rare species
	FAMILY: Orchidaceae		
13.	*Cleisostoma* sp.	Gunung Tebu (2012)	New species
14.	*Paphiopedilum barbatum*	Belumut (2009)	Endemic
	FAMILY: Polypodiaceae		
15.	*Tectaria shahidaniana*	Wang Kelian, Perlis (2000)	New species
	FAMILY: Rafflesiaceae		
16.	*Rafflesia kerrii*	Gunung Stong (2003)	Biggest flower
	FAMILY: Rhizophoraceae		
17.	*Bruguiera hainesii*	Merbok (2013)	Rare species
	FAMILY: Thismiaceae		
18.	*Thismia perlisensis*	Bukit Jernih (2024)	New species
	FAMILY: Tiliaceae		
19.	*Brownlowia tersa*	Hutan Paya Laut Merbok (2013)	Rare species
20.	**FAMILY: Zingiberaceae**		
21.	*Alpinia suriana*	Cameron Highlands (2007)	New record
22.	*Etlingera terengganuensis*	Mandi Angin (2004)	Endemic
	Hornstedtia conica	Belum (2003)	Endemic
	FAUNA		
	FAMILY: Cercopithecidae		
23.	*Macaca arctoides*	Perlis State Park (1999)	New record
	FAMILY: Cyprinidae		
24.	*Paedocypris* sp.	Bukit Bauk (2006)	Formerly the smallest vertebrate in the world
	FAMILY: Gekkonidae		
25.	*Cyrtodactylus quadrivirgatus*	Gunung Tebu (2012)	New record
	FAMILY: Molossidae		
26.	*Optomops* sp.	Cameron Highlands (2007)	New record

27.	**FAMILY: Rhacophoridae**		
28.	*Rana montjerai*	Jerai (2005)	New species
	Theloderma licin	Ulu Muda (2003)	New species
29.	**FAMILY: Tetrigidae**		
	Eufalconius sekayu	Hulu Terengganu (2024)	New species

Appendix 2. List of high conservation value forests established in permanent reserved forests in Peninsular Malaysia.

State	Forest Reserve	No. of plots	Year established	Significance
Johor	Gunung Arong	1	2008	*Cotylelobium melanoxylon*
	Panti	2	2015	*Dryobalanops beccari*
	Panti	3	2018	*Hopea auriculata*
	Panti	4	2024	*Neobalanocarpus heimii*
	Ulu Sedili	5	2024	*Richetia peltata*
	Labis	6	2024	*Dipterocarpus tempehes*
	Kluang	7	2024	*Richetia blumutensis*
Kedah	Gunung Jerai	1	2013	*Paphiopedilum callosum*
	Merbok	1	2013	*Phoenix palludosa*
Kelantan	Gunung Stong Tengah	1	2016	*Licuala stongensis*
	Lojing	2	2015	*Rafflesia kerri*
Perlis	Mata Ayer	1	2007	*Cycas clivicola*
Melaka	Bukit Senggeh	1	2020	*Begonia herveyana*
	Batang Melaka	2	2020	*Begonia herveyana*
Negeri	Setul	1	2007	*Vatica yeechongii*
Sembilan	Sungai Menyala	2	2007	*Lowland dipterocarp forest*
	Tampin	3	2018	*Begonia tampinica*
Pahang	Gunung Benom (Lata Jarum)	1	2009	*Rafflesia cantleyi*
	Endau-Rompin (Padang Tujuh)	2	2012	*Tropical heathforest*
	Pontian	3	2013	*Canarium reniforme* *Bruguiera hainesii*
	Lentang	4	2014	*Anthoshorea bentongensis*
	Paya Pasir	5	2015	*Eurycoma longifolia*
Perak	Chikus	1	2015	*Dipterocarpus coriaceus*
	Sungai Pinang	2	2007	*Shores lumutensis*
	Segari Melintang	3	2007	*Shorea lumutensis*
	Kledang Saiong	4	2016	*Vatica abdulrahmaniana*
	Kledang Saiong	5	2016	*Parashorea globosa*
	Pangkor Selatan	6	2018	*Hopea auriculata*
	Kledang Saiong	7	2007	*Johannesteijsmannia perakensis*
	Bubu	8	2018	*Anthoshorea lamellata*
	Temengor	9	2007	*Rhizanthes infanticida*
	Temengor	10	2007	*Salt Lick*
	Gerik	11	2016	*Rafflesia cantleyi*
	Pulau Kalumpang	12	2007	*Pre-historic site*
	Pulau Kecil	13	2015	*Bruguiera hainesii*

Pulau Pinang	Bukit Panchor	1	2014	*Iguanura corniculata*
	Taman Negara Pulau Pinang	2	2018	*Hopea bracteata* var. *penangiana*
Selangor	Kanching	1	2010	*Hopea subalata*
	Kanching	2	2007	*Hopea subalata*
	Semangkok	3	2007	*Rubishorea platyclados*
	Kuala Langat Selatan	4	2018	*Rubroshorea teysmanniana*
Terengganu	Jerangau	1	2004	*Dipterocarpus sarawakensis*
	Jerangau	2	2008	*Johannesteijsmannia altifrons*
	Pasir Raja	3	2008	*Neobalanocarpus heimii*

Appendix 3. List of virgin jungle reserves in Peninsular Malaysia.

State	No.	Forest Reserve	Year established
Johor	1	Ma'okil	1994
	2	Gunung Ledang	1996
	3	Air Hitam	2000
	4	Kluang	1954
	5	Renggam	1959
	6	Labis	1959
	7	Lenggor	1960
	8	Panti	1960
	9	Panti	1996
	10	Ulu Sedili	1964
	11	Ulu Sedili	1976
	12	Bukit Hantu	2001
	13	Gunung Arong	1951
	14	Labis	2005
	15	Kuala Sedili	2014
Kedah	1	Bukit Perangin	1960
	2	Bukit Perangin	1960
	3	Gunung Raya	1976
	4	Sungkop	1950
	5	Gunung Jerai	1960
	6	Gunung Jerai	1960
	7	Gunung Jerai	1960
	8	Gunung Jerai	1960
	9	Rimba Teloi	-
	10	Bukit Perak	1975
	11	Bukit Perak	1975
	12	Ulu Muda	2013
	13	Gunung Inas	1962
	14	Gunung Machinchang	1976
	15	Gunung Machinchang	1978
	16	Gunung Machinchang	1977
Kelantan	1	Chabang Tongkat	1976
	2	Lebir	1961
	3	Relai	1960
	4	Sg Durian	1967
	5	Temangan	1959
	6	Ulu Sat	1967

	7	Ulu Temiang	1967
	8	Nenggiri	1996
	9	Perias	2002
	10	Gunung Rabong	2002
	11	Batu Papan	2002
	12	Lojing	2006
	13	Jeli	1967
	14	Gunung Basor	1996
	15	Stong Utara	1996
	16	Stong Tengah	2002
	17	Stong Selatan	2005
Perlis	1	Mata Ayer	1991
	2	Bukit Bintang	1995
Melaka	1	Tanjung Tuan	1953
	2	Batang Melaka	1964
	3	Bukit Senggeh	1964
Negeri	1	Angsi	1959
Sembilan	2	Berembun	1990
	3	Berembun	1959
	4	Pasoh	1995
	5	Serting	1995
	6	Sungai Menyala	1948
	7	Tebong	1964
	8	Pasir Panjang	1990
Pahang	1	Balok	1985
	2	Balok	1991
	3	Pekan	1993
	4	Beserah	1953
	5	Bukit Galing	1989
	6	Lepar	1986
	7	Lesong	1984
	8	Lesong	1990
	9	Lesong	1990
	10	Menchali	1981
	11	Jengka	1990
	12	Kemasul	1975
	13	Paya Pasir	1976
	14	Tekam	1996
	15	Terenggun	1975
	16	Batu Gangan & Bau Gangan (Tambahan)	2005
	17	Sg Kial & Hsk Sungai Kial (Tambahan)	1986
	18	Hulu Teranum	2005
	19	Hulu Teranum	1997
Perak	1	Segari Melintang	1951
	2	Lumut	1951
	3	Pangkor Utara	1960
	4	Gunung Besout	1960
	5	Bukit Tapah	1960
	6	Sungai Pinang	1960
	7	Bukit Kinta	1962
	8	Bukit Larut	1962
	9	Bintang Hijau	1962
	10	Kledang Saiong	1962
	11	Bubu	1963

	12	Tanjung Hantu	1951
	13	Pulau Kecil	1996
	14	Pulau Gula	1996
	15	Pulau Sangga Besar	1996
	16	Pulau Sangga Kecil	1996
	17	Trong	1996
	18	Pulau Pasir Hitam	1996
	19	Sungai Tinggi	1996
Pulai Pinang	1	Pantai Acheh	1972
	2	Teluk Bahang	1976
	3	Bukit Kerajaan	2012
Selangor	1	Semangkok	1916
	2	Ulu Langat	1969
	3	Bukit Lagong	1947
	4	Bukit Tarek	1914
	5	Ulu Langat	2005
	6	Ulu Gombak	1959
	7	KualaLangat	1927
	8	Pulau Klang	1994
	9	Sungai Lalang	1970
	10	Bukit Jugra & Bukit Jugra (T)	1904
	11	Sungai Lalang	2005
	12	Bukit Cherakah	2005
Terengganu	1	Bukit Bauk	1954
	2	Jambu Bongkok	2009
	3	Jerangau	1963
	4	Rasau Kerteh	1963
	5	Gunung Tebu	1973
	6	Bukit Sal	1963
	7	Pulau Tenggol	2009
	8	Sungai Nipah	1978
	9	Kuala Kemaman	2009
	10	Bukit Terendak	2009
	11	Pelagat	2009
	12	Pulau Redang	2009

Appendix 4. List of arboretums in Permanent Reserved Forests in Peninsular Malaysia.

State	#Arboretums	Location	Year established
Johor	1	Jemaluang Nursery	2019
Kedah	1	Bukit Perangin Forest Reserve	2006
Kelantan	1	Semerak Forest Reserve	2019
Melaka	1	Melaka Botanical Garden	2008
Negeri Sembilan	1	Lenggeng Forest Reserve	2019
Pahang	1	Rotan Tunggal Forest Reserve	1984
Perak	2	Jebong Forest Reserve	2012
		Pangkor Utara Forest Reserve	2011
Perlis	1	Bukit Bintang Forest Reserve	2000
Pulau Pinang	2	Balik Pulau Forest Reserve	2006
		Teluk Bahang Forest Reserve	1997
Selangor	2	Kanching Forest Reserve	1993
		Rantau Panjang Forest Reserve	2025
Terengganu	2	State Forest Nursery of Terengganu (Chalok)	2003
		Forestry Training Centre of Terengganu	2020

Appendix 5. List of ecological plots in Permanent Reserved Forests in Peninsular Malaysia.

State	#Plots	Forest Reserve	Year established
Pahang	1	Tranum	2008
Melaka	3	Bukit Senggeh	2008
		Tanjung Tuan	2008
		Batang Melaka	2018
Perlis	1	Mata Ayer	2009
Perak	1	Bintang Hijau	2009
Negeri Sembilan	2	Sungai Menyala	2010
		Berembun	2018
Kedah	1	Bukit Perangin	2011
Terengganu	1	Gunung Tebu	2012
Pahang	2	Batu Gangan	2017
		Pekan	2017
Selangor	1	Semangkok	2018
Kelantan	1	Lebir	2018
Pulau Pinang	1	Bukit Kerajaan	2018
Johor	1	Lenggor	2018

Appendix 6. List of ethnobotanical plots in Permanent Reserved Forests in Peninsular Malaysia.

State	#Plots	Forest Reserve	Year established
Kelantan	1	Batu Papan	2011
Pahang	1	Sungai Kial (Tambahan)	2012
Kedah	2	Gunung Jerai	2013
		Gunung Jerai	2019

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CHAPTER 21

State of nature conservation of mangroves in Malaysia

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Abstract: Malaysia's mangroves are ecologically rich and socioeconomically vital coastal ecosystems, not only supporting biodiversity, but also fisheries, shoreline protection, and climate regulation. This chapter reassesses their status since 1991, highlighting improved knowledge, expanded protection, and increased recognition of ecosystem services, including the now "popular" blue carbon. Despite restoration progress, mangroves continue to decline due to multiple anthropogenic threats, including urbanisation, agriculture and aquaculture expansion, pollution, and climate change, with recent losses outpacing gains from restoration. Current challenges include inconsistent mapping, and ineffective restoration practices and governance. Moving forward, integrated management, ecosystem-based restoration, community stewardship, and coherent national policies are essential to ensure resilient, biodiversity-rich and most importantly, functional mangrove ecosystems for Malaysia's sustainable future.

INTRODUCTION

Mangroves occupy a narrow niche at the land-sea interface that is both ecologically and economically important. In Malaysia, mangrove ecosystems have long supported coastal livelihoods, fishery production, sustainable forestry (i.e., in Matang Mangrove Forest Reserve – MMFR), shoreline stability, and a rich coastal biodiversity. In the 1991 *State of Nature Conservation* (SoNC) assessment, Ong and Gong (1991) described Malaysia's mangroves as being "*extremely productive… (yet) being reclaimed or extirpated for alternative use at an alarming rate*". They highlighted widespread clearing of mangroves for infrastructure development (e.g., airports, ports and reservoirs), agriculture, aquaculture (especially for tiger prawn *Panaeus monodon*) and timber products (e.g., woodchip, poles and charcoal). In addition, fragmented governance hampered the gazettement of mangroves as protected areas, and there were fundamental gaps in our understanding of the ecological processes and values of Malaysian mangroves (Ong and Gong 1991). At that time, mangroves covered ca. 2% of Malaysia's total land area (650,000 ha), with losses in Peninsular Malaysia estimated at 20% over the past two decades. No mangroves have been gazetted for conservation, i.e. as national parks (Ong and Gong 1991).

More than three decades later, Malaysia remains among the top mangrove nations globally, though the anthropogenic pressures identified in 1991 persist in new and evolving forms. Encouragingly, ecological functions are better understood, there is a new-found momentum in mangrove restoration and mangroves have entered national and international agendas on climate change and biodiversity conservation. However, continued mangrove loss, inconsistencies in mapping (which affects governance), fragmented institutional mandates, and the uneven quality of restoration still undermine conservation gains. In this 2025 *State of Nature Conservation*, we reassess the status, values, pressures, governance, and future pathways for mangroves in Malaysia. We compare national trends to global trajectories presented in the *State of the World's Mangroves* (Leal and Spalding 2024), while explicitly revisiting and responding to the unanswered questions posed by Ong and Gong (1991).

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EXTENT, DISTRIBUTION AND STATUS

Malaysia is home to the third and sixth largest extent of mangrove habitat worldwide according to estimates from Mangrove Forests of the World (Hamilton and Casey 2016) and Global Mangrove Watch (Bunting *et al.* 2022), respectively. In Southeast Asia, our mangrove extent is second only to Indonesia (Hamilton and Casey 2016; Bunting *et al.* 2018). Recent remote-sensing estimates of our national mangrove coverage ranges from 469,000 ha in *Mangroves of the World*, to 552,000 ha in *Global Mangrove Watch* and 587,000 ha in *Status of Mangroves in Malaysia* (Omar 2024). These discrepancies likely arise from differences in classification approaches, spatial resolution, and treatment of degraded or regenerating stands. Mangroves are unevenly distributed across the country, with east Malaysia hosting more than 60% of the country's mangroves. Major mangrove complexes are dominated by deltaic and estuarine systems, mainly distributed in Lower Kinabatangan-Segama Wetlands in Sabah, Rajang-Belawai-Paloh delta and Kuching Wetlands National Park in Sarawak, Matang in Perak, Klang Islands Mangrove Forest Reserve in Selangor, Sungai Merbok Mangrove Forest Reserve in Kedah, and Sungai Pulai Mangrove Forest Reserve in Johor.

Since the early 1990s, Malaysia has experienced a net decline in mangrove forest cover, with national estimates indicating persistent loss in recent years. Global datasets suggested a sharp decline in the rate of loss as compared to the last century, with approximately only 3 – 6% of mangroves being lost over 2000 – 2012 (Hamilton and Casey 2016; Richards and Friess 2015). However, these apparent gains in slowing loss rates should not be interpreted as a signal of security, as Malaysia is clearly not out of the woods yet. Recent national data pointed towards a 7% mangrove loss over just six years (2017 – 2023), with 80% of this loss being recorded in Sabah alone due to urbanisation, industrialisation and residential expansion (Omar 2024). Though global patterns demonstrate that losses are increasingly counterbalanced by localised gains due to natural sediment accretion, landward migration, and mangrove restoration (Leal and Spalding 2024), in Malaysia the overall decline in mangrove forest cover outweighed the gains (Omar 2024). Reversing this trajectory will require urgent action to reduce ongoing human pressures, improve land-use planning and prioritise ecosystem restoration (Friess *et al.* 2020).

The silver lining is that the protection of mangroves in Malaysia has expanded considerably since the 1990s. Unlike in the 1991 SoNC assessment, prominent mangrove areas in the country are now protected under a diverse designation, including forest reserves, Ramsar sites, wildlife sanctuaries, and national and state parks (Table 1). According to *Status of Mangrove in Malaysia*, 94% of mangroves are gazetted as Permanent Reserved Forests in Malaysia under the National Forestry Act 1984 (Omar 2024). Malaysia now hosts six Ramsar sites with mangrove ecosystems (Table 1), recognised as "Wetlands of International Importance", with Kuala Gula–Matang area proposed as the country's 8th Ramsar site (Azhari and Hassan 2021). Furthermore, two mangrove areas are included in the Kilim Karst Geoforest Park and the Penang Hill Biosphere Reserve, designated under the UNESCO Global Geopark and UNESCO Man and Biosphere Programmes, respectively. Collectively, these designations reflect strong and growing national and international recognition of the ecological and cultural importance of mangroves in Malaysia. Though a welcomed development that signified a pivotal mindset change (from production to protection), formal designation does not necessarily equate to effective conservation. Mangrove loss and degradation continue to occur within PFRs, driven mostly by development pressures at boundaries (Wong *et al.* 2020; Lucas *et al.* 2021; Omar 2024). Furthermore, Malaysia lacks a consolidated national mangrove protected-area map, resulting in inconsistencies across Federal reports, State inventories, and global databases. Hence, while Malaysia has made meaningful progress in formally protecting mangroves, the conservation status of mangroves ultimately depends not on coverage alone, but on ecosystem integrity and governance coherence.

Table 1. Prominent protected areas in Malaysia where mangroves are a primary or significant habitat.

State	Protected area	Approximate area (ha)	State-level	International -level
Kedah	Sungai Merbok Mangrove Forest Reserve	4,000 ha	√	
	Kilim Karst Geoforest Park (Langkawi UNESCO Global Geopark) / Kisap Forest Reserve 500-million-year-old coastal karst ecosystem coexisting with mangroves.	10,000 ha (includes mangroves)	√	√
Penang	The Penang Hill Biosphere Reserve A model for harmonising urban development with conservation from the hilltop to the sea (including mangrove ecosystem situated within Penang National Park).	12,000 ha (includes mangroves)	√	√
Perak	Matang Mangrove Forest Reserve Gazetted in 1906; world's best managed mangrove production forest.	40,000 ha	√	
Selangor	Kuala Selangor Nature Park / Malawati Forest Reserve Collaboratively managed by state government and Malaysian Nature Society.	300 ha	√	
	Klang Islands Mangrove Forest Reserve		√	
Johor	Pulau Kukup Johor National Park (Ramsar site) One of the largest uninhabited mangrove islands in the world.	600 ha	√	√
	Tanjung Piai Johor National Park (Ramsar site) Southernmost mangroves of mainland Eurasia.	500 ha	√	√
	Sungai Pulai Mangrove Forest Reserve (Ramsar site) The largest intact riverine mangrove system in Peninsular Malaysia.	9,000 ha	√	√

Sabah	Kota Kinabalu Wetland Centre (Ramsar site) Recognised as a State Cultural Heritage Site	20 ha	√	√
Sarawak				
	Lower Kinabatangan–Segama Wetlands (Ramsar site) The largest contiguous mangrove area in the Southern Sulu Sea.	79,000 ha	√	√
	Sepilok Laut Mangrove Forest Reserve	4,300 ha	√	
	Maruap Mangrove Forest Reserve	31,000 ha	√	
	Kuching Wetlands National Park (Ramsar site)	7,000 ha	√	√
	Rajang Mangroves National Park Malaysia's largest deltaic mangrove national park.	9,000 ha	√	
	Bako National Park	3,000 ha (includes mangroves)	√	
	Maludam National Park	43,000 ha (includes mangroves)	√	

BIODIVERSITY VALUES AND ECOSYSTEM SERVICES

Recognition of biodiversity values of mangroves have expanded tremendously since the 1991 SoNC assessment. Perspectives have sharply pivoted from viewing mangroves primarily as production forests, with largely anecdotal evidence on their benefits to local fisheries (Ong and Gong 1991), to the current comprehensive understanding of their biodiversity values and the wide range of ecosystem services they provide (Figure 1).

Malaysia lies within the global epicentre of mangrove diversity (i.e., the Indo-West Pacific biogeographic region) and is home to one of the most species-rich mangrove floras and fauna in the world. More than 40 true mangrove species can be found in Malaysian mangroves (Lee *et al.* 2015), including globally threatened and range-restricted taxa such as *Bruguiera* × *hainesii* and *Sonneratia griffithii* (Polidoro *et al.* 2010). Furthermore, Malaysian mangroves provide crucial habitat for a wide array of terrestrial, avian, coastal and marine fauna, including marine megafauna (e.g., dolphins, rays, crocodiles, and dugongs) and endangered terrestrial species (e.g., proboscis monkey *Nasalis larvatus* in Bornean mangroves). In addition, Malaysian mangroves form critical nodes along the East Asian–Australasian Flyway, offering feeding and roosting habitats for migratory shorebirds and waterbirds of international conservation concern, including the endangered oriental darter *Anhinga melanogaster* and Nordmann's greenshank *Tringa guttifer* (Zakaria and Rajpar 2015). For this reason, key mangrove areas are designated as Important Bird and Biodiversity Areas

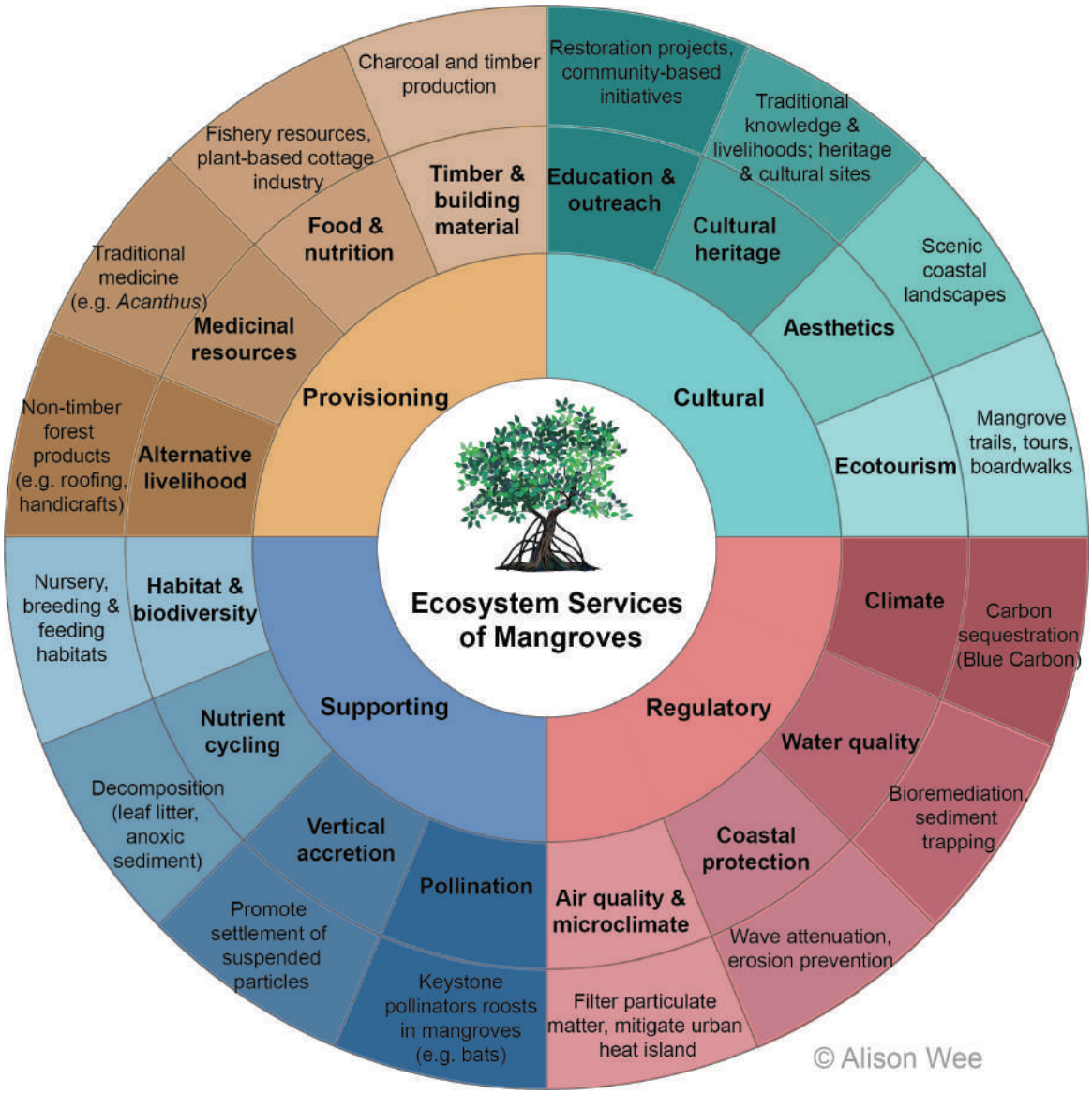

Figure 1. Ecosystem services of mangroves, particularly in the context of Malaysia.

(IBAs) (i.e., Teluk Air Tawar-Kuala Muda Wetlands in Penang) and Ecologically or Biologically Significant Marine Areas (EBSA) (i.e., the mangrove belt of the north Selangor coast, and Bako-Buntal Bay in Sarawak), as well as the Important Marine Mammal Areas (IMMAs) (i.e., Matang Mangroves and Coastal Waters; Similajau-Kuala Nyalau Coastline; Kuching Bay; Satun-Langkawi Archipelago; and Mersing Archipelago).

The ecological (and economical) importance of Malaysian mangroves is further underscored by their high productivity and strong functional linkages to coastal fisheries (Chong *et al.* 2007). Since the 1990s, research has firmly established mangroves as essential nursery, feeding, and refuge habitats for commercially important fishery species, including penaeid prawns (*Penaeus* spp.), mud crabs (*Scylla* spp.), and a wide range of finfish taxa (Sasekumar *et al.* 1992; Azmir *et al.* 2019; Mustafa Kamal *et al.* 2022). This aligns with global estimates that mangrove supports an annual abundance of ~800 billion fishes, prawns, bivalves and crabs (zu Ermgassen *et al.* 2024), with four million small scale fishers depend

directly on mangrove-associated resources worldwide (zu Ermgassen *et al.* 2020). In recognition of the provisioning services provided by mangrove habitats, Malaysia hosted the Third International Symposium on Mangroves as Fish Habitat in 2018, with the goal of "Connecting the Hemispheres" of scientists, researchers, industry professionals, economists, educators, and government officials (Bulletin of Marine Science 2018). Besides provisioning for fishery resources, mangroves in Malaysia, specifically the MMFR, are also globally renown for over a century of silviculture for charcoal production and construction. Established in 1902, the MMFR operates on 30-year rotational cycles with natural regeneration and enrichment planting, supplying charcoal and poles, while retaining continuous forest cover (Ismail *et al.* 2020; Lucas *et al.* 2021). The perpetuity of silviculture practices in MMFR validates the 1991 SoNC's argument that mangroves can also be conserved through rational use. However, MMFR's singular success has not been widely replicated elsewhere in Malaysia, and it remains a unique model for commercial-scale exploitation of mangrove trees with a long management history (Chen *et al.* 2024).

The importance of mangroves in coastal protection became particularly evident following the 2004 Indian Ocean tsunami, which marked a turning point in Malaysia's appreciation of mangroves beyond provisioning functions. Post-disaster assessments demonstrated that intact mangrove forests significantly reduced wave energy and prevented the loss of human lives and property damage, thus reinforcing their role as natural coastal defences (Kathiresan and Rajendran 2005). In recognition of this, the then Ministry of Natural Resources and Environment launched the "Tree Planting Program with Mangroves and Other Suitable Species Along National Coastlines" in 2005, that planted a total of nine million seedlings of mangroves and other coastal tree species across 3820 ha of coastal areas as of September 2025 (BERNAMA 2025; Ministry of Natural Resources and Environment 2014). In parallel, Malaysian mangroves have gained global prominence as important blue carbon ecosystems, with aboveground and belowground carbon stock ranging from 60 to 180 Mg C ha^{-1}, and from 290 to 470 Mg C ha^{-1}, respectively (Lee *et al.* 2025). Though promising, Malaysia's blue carbon financing mechanism is still in its infancy, with blue carbon projects being initiated in only Sabah and Johor now. The overall recognition of regulatory services provided by mangroves have propelled mangrove restoration initiatives in Malaysia, led not only by the government, but also the public and private sectors.

HUMAN PRESSURES

Human pressures on Malaysian mangroves have always been a tug-of-war between nature conservation and economic development. The pressures themselves have evolved since the 1991 SoNC assessment, though the resulting impacts remain largely the same, i.e. mangrove cover loss, degradation, and fragmentation. Generally, outright large-scale clearing has slowed in many areas. Instead of wholesale deforestation, contemporary pressures are increasingly chronic and cumulative, with compounding effects of altered hydrology, habitat fragmentation, pollution, and sea-level rise. As highlighted in the 1991 SoNC, conversion of mangroves for aquaculture emerged as a major threat in the late 1980s and early 1990s, particularly shrimp farming in the pursuit of the so-called "*pink gold*" (Ong and Gong 1991; Warne 2011; Mangrove Action Project 2018). Large-scale conversion to aquaculture has slowed in recent years; encroachment into mangrove areas are now often illegal operations. However, we are left to grapple with the devastating impacts of abandoned, disease-ridden or under productive aquaculture ponds, alongside the challenges of rehabilitating them back to mangrove habitats due to unsuitable hydrological, topographical and soil conditions (e.g., Tangah *et al.* 2020). In the early 21st century, the dominant driver of mangrove loss has shifted to agriculture, particularly mangrove conversion to oil palm plantations. Southeast Asia lost over 100,000 ha of mangroves between 2000 and 2012,

with oil palm identified as one of the leading agricultural replacement land uses (Richards and Friess 2015). This is especially acute in coastal Sabah and Sarawak where plantation expansion is concentrated (Yan *et al.* 2020). Together, land conversion for aquaculture and agriculture purposes accounted for >50% of mangrove loss in Malaysia (Richards and Friess 2015), signifying cultivation as the single largest threat to mangroves.

Simultaneously, urbanisation and coastal infrastructure development have intensified since the 1991 SoNC assessment, particularly in Peninsular Malaysia. Mangroves have been cleared for ports (e.g., Senari Port in Sarawak), industrial estates (e.g., Pulau Indah in Selangor), tourism (e.g., Kuantan River waterfront in Pahang) and residential areas (e.g., Kudat district in Sabah). Notably, there are several land reclamation projects at various stages of implementation that directly impact mangroves, including Forest City in Johor, Penang South Islands, and Kedah Coastal Extension. Such large-scale projects pose wide-ranging and irreversible threats to mangroves, not only in the form of direct habitat loss, but also indirect processes such as altered coastal hydrodynamics and disrupted sediment flow (Chee *et al.* 2017). Furthermore, coastal urbanisation disproportionately affects fringing and estuarine mangroves, as it creates manmade physical barriers to the landward migration of mangroves driven by sea level-rise, a phenomenon known as "coastal squeeze" (Lovelock and Reef 2020). Without significant changes in land use planning, urbanisation will persist as a threat to mangroves in Malaysia as human populations pushes further into forested land. In contrast to the increasing threats of urbanisation, mangrove loss and degradation due to timber harvesting has greatly reduced since the 1990s. This is particularly apparent in the wood chip industry that once led to the destruction of vast mangrove areas – 15,000 ha over 25 years in Sarawak and 70,000 ha over 15 years in Sabah – but has since ceased as the operations were no longer economically viable (Chong 2006). Furthermore, permanent forest reserves in Malaysia (including almost all mangrove forests) are currently under a 15-year moratorium on monoculture plantations, with the Selangor state government imposing a 25-year moratorium since 2010 (Murughan *et al.* 2026). Logging is generally prohibited, and when it does occur, is largely limited to illegal harvesting and clearing (for agriculture, aquaculture and settlement), and to areas where alternative livelihoods are limited.

The emerging threats on mangroves of the early 21st century are arguably pollution and climate change, not so much because these pressures are new, but because our understanding of their scale, mechanisms, and long term impacts has deepened substantially. We now have a better understanding of how indirect pressures, such as sediment runoff (Mohd Kamal *et al.* 2025), industrial effluents (El-Turk *et al.* 2019), untreated sewage (Magam *et al.* 2016), and marine debris accumulation (Abd. Rahim *et al.* 2025), could impact the mangroves from upstream and beyond. These pressures result in multiple negative consequences in mangroves, including the impairment of benthic productivity and processes, disruption of trophic linkages, degradation of water quality, tree mortality and stunted growth, and the bioaccumulation of pollutants in the food web. In addition to land-base pressures, Malaysian mangroves are facing a growing threat from the sea. Climate change is accelerating sea level rise, which can outpace sediment accretion and root growth, leading to mangrove drowning (Friess *et al.* 2023). Alarmingly, with the absence of landward migration (i.e., coastal squeeze), some mangroves in Kelantan, Terengganu and Sabah could be submerged and lost by the turn of the next century (Lovelock *et al.* 2015). Globally, over 60% of mangrove loss is attributed to direct and indirect human activities, often acting synergistically rather than independently (Leal and Spalding 2024). Understanding the vulnerability of mangrove ecosystems to indirect pressures from their surroundings prompted a more systemic view of these processes, aptly encapsulated in the synonymous concepts of "mountains-to-mangroves", "ridge-to-reef", "catchment-to-coast" and "source-to-sea" (e.g., Salomons *et al.* 2005). Unfortunately, this integrated perspective has yet to be adopted in the governance of mangroves in Malaysia.

CHANGING PERCEPTION AND ACTION

In the 1991 SoNC assessment, Ong and Gong advocated for the "rational sustainable use" of mangrove forests for silviculture and to support coastal fisheries. This demonstrates that while the ecological and economical values of mangroves were recognised, the perception of mangroves were largely human-centric and utilitarian. Indeed, our long-standing experience with mangrove silviculture, epitomised by the century-old MMFR in Perak, shaped our then perception that a good way to conserve mangroves was through rational use on a sustainable yield basis (Ong and Gong 1991). MMFR demonstrated that mangroves, unlike many other tropical forest types, could be managed productively without ecosystem collapse, provided that rotation lengths, regeneration processes and hydrological regimes were respected (Chen *et al.* 2024). In this sense, MMFR serves as both a national and global benchmark for sustainable mangrove forestry. The rational use perspective – expanded to include contributions to coastal fisheries – also serve as an argument against mangrove conversion to other competing (more lucrative) land use types (Ong and Gong 1991).

Since then, the mangrove management landscape in Malaysia has shifted towards a paradigm that emphasises restoration and ecosystem rehabilitation. Large scale mangrove planting campaigns have become a prominent feature of national and state initiatives, exemplified by the "Tree Planting Programme with Mangroves and Other Suitable Species Along National Coastlines" that has been running since 2005. Replanting of mangrove species under this program mostly focused on the west coast of Peninsular Malaysia, Sabah and southern Sarawak (Figure 2). In addition, private and public institutions, in collaboration with state Forestry Departments and the Ministry of Natural Resources and Environmental Sustainability, have collectively planted more than 360,000 mangrove seedlings under the national initiative "100 Million Tree Planting Campaign (2021 – 2025)" within the Greening Malaysia Programme (100 Juta Pokok, n.d.). Besides governmental agencies, several non-profit organisations have emerged as champions of mangrove restoration in Malaysia, including the Malaysian Nature Society, Global Environment Centre, WWF-Malaysia, Wetlands International Malaysia and the Global Mangrove Alliance Malaysia chapter. While these efforts have raised public awareness for mangrove conservation, leading to overall positive outcomes (Friess *et al.* 2020), there is growing recognition that planting effort alone does not equate to conservation success.



Figure 2. Map showing planting locations under the "Tree Planting Program with Mangroves and Other Suitable Species Along National Coastlines". Adapted from e-pesisir (Malaysia Space Agency, n.d.).

Consistent with findings in the State of the World's Mangroves (Leal and Spalding 2024) and supported by evidence from Malaysia, many planting initiatives suffered from fundamental ecological shortcomings. Monospecific planting, dominated by *Rhizophora* spp., often fails in sites where natural hydrological conditions are unsuitable; poor site selection results in high seedling mortality; and short term project metrics obscures the importance of long term functional recovery (Leal and Spalding 2024). Furthermore, monitoring, reporting and verification of restoration success is largely absent, limiting our abilities to improve on failures and replicate successes. Perhaps this is why Malaysia is still struggling to achieve a net gain in mangrove cover despite the mass mobilisation of resources and manpower for restoration.

Instead of a tunnel vision focusing on sheer planting numbers alone, mangrove restoration in Malaysia should adopt a more holistic approach that emphasises on planning, adaptive management and community engagement (Beeston *et al.* 2023). Specifically, restoration initiatives must align with the principles of Ecological Mangrove Restoration (EMR), which prioritises the restoration of natural hydrology, sediment dynamics, and species zonation before active planting. Based on this framework, the most important question any restoration initiative should ask is actually "Can my site be restored?" Without this initial thought process, mangrove restoration risks being "*syok sendiri*" (self-congratulatory) with questionable long-term success. Besides promoting habitat recovery and natural regeneration, a key goal of the EMR is for restored mangroves to closely resemble native floristic composition (Figure 3). Therefore, mangrove replanting should veer away from monoculture plantation and prioritise a multi-species stand, to ensure long-term productivity and ecological resilience (Li *et al*. 2025). To take this one step further, ecosystem restoration is typically more successful when restoration stocks have higher genetic diversity or are locally adapted (da Silva *et al.* 2025). In pursuit of planting numbers, mangrove restoration in Malaysia have long relied on the use of non-locally sourced seedlings, with the most common supplier being nurseries located in Kuala Sepetang near MMFR (pers. comm.). However, recent evidence suggests that this may result in artificial genetic mixing among populations, implicating the natural genetic structure of mangroves in Peninsular Malaysia (Mugundha-Kumar *et al.* 2026). Hence, it is imperative that future restoration initiatives prioritise local seedlings to conserve the naturally occurring genotypes. Lastly, the quantification of restoration outcome should focus on functional recovery instead of mere structural recovery (forest cover). Emerging technologies, such as environmental DNA (Wee *et al.* 2023) and bioacoustics (Rahim *et al*. 2025), have shown promising progress in tracking functional guilds and community dynamics in mangroves. Together, these changes can move mangrove restoration in Malaysia from symbolic action toward resilient, functionally intact coastal ecosystems.

More recently, Malaysian mangroves gained a new level of valuation through their recognition as blue carbon ecosystems (Lee *et al.* 2025). This represents yet another profound shift in the perception of mangroves, from sources of timber to long term carbon sinks. Mangroves sequester and store disproportionately large quantities of carbon as compared to other terrestrial ecosystems, particularly within their deep, anoxic sediments. Hence, mangroves are regarded as an important nature-based solution for climate change (Alongi 2020). As such, mangrove restoration projects now serve three simultaneous objectives – ecosystem restoration, biodiversity conservation and carbon sequestration. Recognising blue carbon as a potent strategy to achieve net zero emissions, ASEAN launched the Blue Carbon and Finance Profiling Project in 2025 to integrate blue carbon strategies into national and regional development plans (ASEAN 2025). Following this, the federal government of Malaysia started exploring the creation of a Blue Carbon Credit Trading Platform in the country, in collaboration with the Sabah Maju Jaya Secretariat and the Sabah State Forestry Department (Ministry of Finance Malaysia 2025). As the State with the largest mangrove area, Sabah has positioned itself as a leader in blue carbon in Malaysia – it hosted the Sabah

International Blue Economy Conference in 2024, put forth a Sabah Mangrove Action Plan (2024 – 2033) and will become the Blue Economy Hub for Malaysia. The inaugural blue carbon initiatives are set to be in Sabah and Johor. These are all promising developments that point towards a stronger stewardship of mangrove ecosystems catalysed by the blue carbon agenda. However, this growing emphasis on blue carbon also warrants caution. If not grounded in transparent governance and rigorous monitoring, blue carbon initiatives risk reducing mangroves to carbon commodities, potentially incentivising poorly designed restoration, genetic homogenisation, or the exclusion of local communities. Ensuring that climate finance complements rather than compromises ecosystem integrity will be essential for lasting benefits of the blue carbon agenda.



Figure 3. A multi-species replanted mangrove forest in Johor, which closely resembles the structure and species composition of nearby natural mangrove forests.

Ultimately, the convergence of ecosystem restoration and climate finance presents Malaysia with a rare opportunity to redefine mangrove conservation – not merely as an environmental obligation, but as a strategic vehicle to advance multiple national agendas in sustainable development. To ensure that this opportunity can be realised while balancing social and economic development needs, Malaysia should draw lessons from Sabah and develop a National Mangrove Action Plan. This will ensure that mangrove governance is harmonised across all states and a coherent roadmap and clear targets are established for mangrove conservation.

TOWARD THE NEXT STATE OF NATURE: PATHWAYS TO SUSTAINABILITY

We have come far from where we were during the 1991 SoNC assessment. Where ecological knowledge used to be lacking (as urgently noted by Ong and Gong), we now have a wealth of knowledge on local mangrove biodiversity and ecology, complemented by a thriving research network, i.e. The Malaysian Mangrove Research Alliance and Network (MyMangrove) (Amir *et al.* 2020). Where legal protection of mangroves was once fragmented and unclear, a growing network of nationally and internationally recognised protected areas (e.g. Ramsar, UNESCO programmes) now safeguards these ecosystems. And where Malaysian mangroves were historically valued primarily as production forests, they are

today increasingly recognised for their full suite of ecosystem services – most notably coastal protection, fisheries support, and their critical role as blue carbon sinks. Taken together, this SoNC finds that Malaysia has made substantial progress since 1991, especially in recognising the value of mangroves.

Moving forward, four inter-connected priorities emerge as pathways toward the next SoNC. First, Malaysia must reconcile mangrove extent maps through harmonised national monitoring (supported by consistent ground truthing) that aligns with data platforms such as the Global Mangrove Watch, to track mangrove cover change more accurately and improve governance. Second, restoration success must be redefined by functional recovery, rather than by the number of seedlings planted, aligning practice with EMR principles. Third, mangroves must continue to be recognised for their multifunctional roles (instead of carbon alone) and fully integrated into climate policy, including nationally determined contributions (NDCs), adaptation planning, disaster risk reduction, and blue economy strategies. Finally, long term sustainability depends on empowering coastal communities as stewards, through proper land tenure, inclusive governance, and equitable benefit sharing that align conservation objectives with local livelihoods. Together, these pathways highlight the fact that the next State of Nature Conservation for Malaysian mangroves must move beyond planting and restoration and move toward integrated management – where science, policy, finance, and community stewardship converge to secure resilient mangrove ecosystems for generations to come.

REFERENCES

Anon. 100 Juta Pokok. (n.d.). Penghijauan Malaysia: Kempen Penanaman 100 Juta Pokok , "Pokok Kita, Kehidupan Kita" 2021-2025. https://www.100jutapokok.gov.my/

Abd Rahim, N.H., Satyanarayana, B., Ibrahim, Y.S., Not, C., Idris, I., Jani, J.M. Cannicci, S. and Dahdouh-Guebas, F. 2025. Distribution of marine debris in the mangroves of a semi-enclosed lagoon system. In *Microplastic Pollution,* pp. 167–180. Singapore: Jenny Stanford Publishing. https://doi.org/10.1201/9781003660064-5

Alongi, D.M. 2020. Global significance of mangrove blue carbon in climate change mitigation. *Sci* 2(3): 67. https://doi.org/10.3390/sci2030067

Amir, A.A., Foong, S.Y., Kaur, C.R., Satyanarayana, B., Sharma, S., Ismail, A., Awang, N.A. *et al.* 2020. The strategic establishment of the Malaysian Mangrove Research Alliance and Network (MyMangrove). *Malayan Nature Journal* 72(4): 577–595.

Association of Southeast Asian Nations (ASEAN). 2025, May 21. ASEAN, Japan, and UNDP launch blue carbon and finance profiling project to accelerate sustainable blue economy in Southeast Asia. *ASEAN*. https://asean.org/asean-japan-and-undp-launch-blue-carbon-and-finance-profiling-project-to-accelerate-sustainable-blue-economy-in-southeast-asia/

Azhari, N.E.M. and Hassan, M.F. 2021, June 16. Kuala Gula-Matang Set to be Malaysia's Eight Ramsar Site. *Bernama*. https://www.bernama.com/en/news.php?id=1972375

Azmir, I.A., Amin, S., Esa, Y., Yasin, I.S.M. and Ara, R. 2019. A snapshot study on larval fish diversity in selected mangrove areas of Peninsular Malaysia, Malaysia. *Journal of Academia* 7(2): 112–123.

Beeston, M., Cameron, C., Hagger, V., Howard, J., Lovelock, C.E., Sippo, J., Tonneijck, F.H., van Bijsterveldt, C. and van Eijk, P. 2023. Best practice guidelines for mangrove restoration. Global Mangrove Alliance.

BERNAMA. 2025, September 21. Gov't allocates over RM71 million for mangrove conservation, maintenance – Johari. *Bernama*. https://www.bernama.com/en/news.php?id=2469757

Bulletin of Marine Science. 2018. Mangroves as fish habitat 3. https://bullmarsci.org/MAFH3/about.html

Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R. M., Thomas, N., Tadono, T., Worthington, T.A., Spalding, M., Murray, N. and Rebelo, L.M. 2022. Global Mangrove Extent Change 1996–2020: Global Mangrove Watch Version 3.0. *Remote Sensing* 14: 3657. https://doi.org/10.3390/rs14153657

Chee, S.Y., Othman, A.G., Sim, Y.K., Adam, A.N.M. and Firth, L.B. 2017. Land reclamation and artificial islands: Walking the tightrope between development and conservation. *Global Ecology and Conservation* 12: 80–95. https://doi.org/10.1016/j.gecco.2017.08.005

Chen, D., Satyanarayana, B., Wolswijk, G., Abd Rahim, N.H., Amir, A.A., Hugé, J. and Dahdouh-Guebas, F. 2024. Historical ecological monitoring and appraisal for extractive uses and other values in Malaysia unveils consequences of regime shifts in 120 years of mangrove management. *Journal for Nature Conservation* 79: 126582. https://doi.org/10.1016/j.jnc.2024.126582

Chong, V.C. 2006. Sustainable utilization and management of mangrove ecosystems of Malaysia. *Aquatic Ecosystem Health & Management* 9(2): 249–260. https://doi.org/10.1080/14634980600717084

Chong, V.C. 2007. Mangroves-fisheries linkages—the Malaysian perspective. *Bulletin of Marine Science* 80(3): 755–772.

da Silva, J.M., Bertola, L.D., DeWoody, J.A., Steeves, T., Sunnucks, P., Vilaça, S.T. and Hoban, S. 2025. Conserving genetic and genomic diversity in accordance with the Global Biodiversity Framework. *Annual Review of Animal Biosciences* 14: 399–428. https://doi.org/10.1146/annurev-animal-030424-070756

ELTurk, M., Abdullah, R., Zakaria, R.M. and Bakar, N.K.A. 2019. Heavy metal contamination in mangrove sediments in Klang estuary, Malaysia: Implication of risk assessment. *Estuarine, Coastal and Shelf Science* 226: 106266. https://doi.org/10.1016/j.ecss.2019.106266

Friess, D.A., Yando, E.S., Abuchahla, G.M., Adams, J.B., Cannicci, S., Canty, S.W., Cavanaugh, K.C. *et al.* 2020. Mangroves give cause for conservation optimism, for now. *Current Biology* 30(4): R153–R154. https://doi.org/10.1016/j.cub.2019.12.054

Friess, D.A., Chen, L., Cormier, N., Krauss, K.W., Lovelock, C.E., Raw, J.L., Rogers, K., Saintilan, N. and Sidik, F. 2023. Mangrove forests and climate change: impacts and interactions. In *Climate Change and Estuaries*, M.J. Kennish, H.W. Paerl and J.R. Crosswell (Eds.), pp. 381–400. Boca Raton: CRC Press. https://doi.org/10.1201/9781003126096-22

Hamilton, S.E. and Casey, D. 2016. Creation of a high spatio-temporal resolution global database. *Global Ecology and Biogeography* 25(6): 729–738.

Ismail, S.M., Amir, A.A., Ariffin, N.H.S. and Latiff, A. 2020. Conservation and management of mangroves in Peninsular Malaysia: A historical perspective. *Malayan Nature Journal* 72(4): 425–439.

Kathiresan, K. and Rajendran, N. 2005. Coastal mangrove forests mitigated tsunami. *Estuarine, Coastal and Shelf Science* 65(3): 601–606. https://doi.org/10.1016/j.ecss.2005.06.022

Leal, M. and Spalding, M.D. 2024. *The state of the world's mangroves 2024*. Global Mangrove Alliance. https://doi.org/10.5479/10088/119867

Lee, S.S., Muhamad, A. and Tong, J. 2015. *Mangrove Guidebook for Malaysia*. Petaling Jaya: Wetlands International Malaysia.

Lee, S.L., Chee, S.Y., Huxham, M., Jamilah, M., Choo, J., Kaur, C.R., Amir, A.A. *et al.* 2025. Blue carbon ecosystems in Malaysia–status, threats, and the way forward for research and policy. *The Journal of Environment & Development* 34(1): 225–265. https://doi.org/10.1177/10704965241284366

Li, Z., Li, Y. and Fan, B. 2025. Diverse restored mangrove stands enhance carbon storage compared to monospecific plantation: a meta-analysis. *Forest Ecology and Management* 578: 122446. https://doi.org/10.1016/j.foreco.2024.122446

Lovelock, C.E., Cahoon, D.R., Friess, D.A., Guntenspergen, G.R., Krauss, K.W., Reef, R., Rogers, K. *et al.* 2015. The vulnerability of Indo-Pacific mangrove forests to sea-level rise. *Nature* 526(7574): 559–563. https://doi.org/10.1038/nature15538

Lovelock, C.E. and Reef, R. 2020. Variable impacts of climate change on blue carbon. *One Earth* 3(2): 195–211. https://doi.org/10.1016/j.oneear.2020.07.010

Lucas, R., Otero, V., Van De Kerchove, R., Lagomasino, D., Satyanarayana, B., Fatoyinbo, T. and Dahdouh-Guebas, F. 2021. Monitoring Matang's mangroves in Peninsular Malaysia through Earth observations: A globally relevant approach. *Land Degradation & Development* 32(1): 354–373. https://doi.org/10.1002/ldr.3652

Magam, S.M., Zakaria, M.P., Halimoon, N., Aris, A.Z., Kannan, N., Masood, N., Mustafa, S. *et al*. 2016. Evaluation of distribution and sources of sewage molecular marker (LABs) in selected rivers and estuaries of Peninsular Malaysia. *Environmental Science and Pollution Research* 23: 5693–5704. https://doi.org/10.1007/s11356-015-5804-9

Malaysian Space Agency (MYSA). (n.d.). e Pesisir: Coastal and marine GIS public portal. https://epesisir.mysa.gov.my/gis/_public/index_public.php

Mangrove Action Project. 2018, April. Map calls for attention to mangrove loss in Pitas, Sabah in Malaysia. *Mangrove Action Project.* https://mangroveactionproject.org/2018/04/map-calls-for-attention-to-mangrove-loss-in-pitas-sabah-in-malaysia/

Ministry of Finance Malaysia. 2025, August 27. Federal government to develop policy guidelines and explore creation of blue carbon credit trading platform. *Ministry of Finance Malaysia.* https://www.mof.gov.my/portal/en/news/press-citations/federal-govt-to-develop-policy-guidelines-and-explore-creation-of-blue-carbon-credit-trading-platform

Ministry of Natural Resources and Environment. 2014. Laporan Kajian Penilaian Outcome Program Penanaman Pokok Bakau dan Spesies-spesies yang Sesuai di Pesisiran Pantai Negara. https://www.mybis.gov.my/pb/1738

Mohd Razali, S., Radzi, M.A., Marin, A. and Samdin, Z. 2022. A bibliometric analysis of tropical mangrove forest land use change from 2010 to 2020. *Environment, Development and Sustainability* 24(10): 11530–11547. https://doi.org/10.1007/s10668-021-01935-7

Mohd Kamal, M.A., Hamid, N.B., Mokhtar, M., Daud, M.E., Kaamin, M., Sahat, S., Mohammad Azmi, M.A., Sanik, M.E. and Thane, S.M. 2025. Impact of sedimentation on mangrove forests in West Coast, Peninsular Malaysia. *Journal of Advanced Research Design* 138(1): 151–161. https://doi.org/10.37934/ard.138.1.151161

Mugundha-Kumar, A., Taguchi, H., Rowntree, J. K., Ishikawa, N., Suyama, Y. and Wee, A.K. 2026. Mangrove restoration should consider the unique genetic structure of the extant populations. *Ecological Research* 41(6): e70135.

Murughan, M., Roslan M.K., Johar, M., Zubaidah, H., Seca, G. and Pakhriazad, H.Z. 2026. Exploring the drivers of forest management certification in Malaysia. *Journal of Tropical Forest Science* 38(1): 65–77. https://doi.org/10.26525/jtfs2026.38.1.65

Mustafa Kamal, A.H., Sinden, A., Idris, M.H., Al-Asif, A.-., Hamli, H., Musa, N., Piah, R.M. *et al.* 2022. Diversity of fisheries in Sarawak, Northwest Borneo: Present status and conservation issues. *Borneo Journal of Resource Science and Technology* 12(1): 32–51. https://doi.org/10.33736/bjrst.4651.2022

Omar, H. 2024. *Status of Mangrove in Malaysia*. Kepong: Forest Research Institute Malaysia.

Ong, J.E. and Gong, W.K. 1991. Mangroves. In *State of Nature Conservation in Malaysia*, R. Kiew (Ed.), pp. 22–28. Petaling Jaya: Malaysian Nature Society.

Polidoro, B.A., Carpenter, K.E., Collins, L., Duke, N.C., Ellison, A.M., Ellison, J.C., Farnsworth, E.J. 2010. The loss of species: mangrove extinction risk and geographic areas of global concern. *PloS One* 5(4): e10095. https://doi.org/10.1371/journal.pone.0010095

Rahim, A.K.H.A., Puan, C.L., Mah, A.N.M.M.A., Zakaria, M., Jamaludin, N. and Wahaf, N.S.A. 2025. Bioacoustic assessment of mangrove health: Influence of habitat characteristics on bird richness. *Biotropica* 57(1): e13427. https://doi.org/10.1111/btp.13427

Richards, D.R. and Friess, D.A. 2016. Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. *Proceedings of the National Academy of Sciences* 113(2): 344–349. https://doi.org/10.1073/pnas.1510272113

Salomons, W., Kremer, H.H., Turner, R.K., Andreeva, E.N., Arthurton, R.S., Behrendt, H., Burbridge, P. *et al*. 2005. The catchment to coast continuum. In *Coastal Fluxes in the Anthropocene*, C.J. Crossland, H.H. Kremer, H.J., Lindeboom, J.I.M. Crossland and M.D.A. Tissier (Eds.), pp. 145–200. Berlin: Springer. https://doi.org/10.1007/3-540-27851-6_4

Spalding, M.D. and Leal, M. 2021. *The State of the World's Mangroves*. Global Mangrove Alliance.

Tangah, J., Chung, A.Y. and Chan, H.T. 2020. *Rehabilitation of Mangroves in Sabah: The SFD-ISME Collaboration (2014-2019).* International Society for Mangrove Ecosystems.

Warne, K. 2011. Pink gold and a blue revolution. In *Let Them Eat Shrimp: The Tragic Disappearance of the Rainforests of the Sea*, K. Warne (Ed.), pp. 29–37. Washington, DC: Island Press/Center for Resource Economics. https://doi.org/10.5822/978-1-61091-024-8

Wee, A.K., Salmo Iii, S.G., Sivakumar, K., Then, A.Y., Basyuni, M., Fall, J., Habib, K.A. *et al.* 2023. Prospects and challenges of environmental DNA (eDNA) metabarcoding in mangrove restoration in Southeast Asia. *Frontiers in Marine Science* 10: 1033258. zhttps://doi.org/10.3389/fmars.2023.1033258

Wong, C.J., James, D., Besar, N.A., Kamlun, K.U., Tangah, J., Tsuyuki, S. and Phua, M.H. 2020. Estimating mangrove above-ground biomass loss due to deforestation in Malaysian Northern Borneo between 2000 and 2015 using SRTM and landsat images. *Forests* 11(9): 1018. https://doi.org/10.3390/f11091018

Yan, J., Gao, S., Xu, M. and Su, F. 2020. Spatial-temporal changes of forests and agricultural lands in Malaysia from 1990 to 2017. *Environmental Monitoring and Assessment* 192(12): 803. https://doi.org/10.1007/s10661-020-08765-6

Zakaria, M. and Rajpar, M.N. 2015. Assessing the fauna diversity of Marudu Bay mangrove forest, Sabah, Malaysia, for future conservation. *Diversity* 7(2): 137–148. https://doi.org/10.3390/d7020137

zu Ermgassen, P.S., Mukherjee, N., Worthington, T.A., Acosta, A., da Rocha Araujo, A. R., Beitl, C.M., Castellanos-Galindo, G.A. *et al.* 2020. Fishers who rely on mangroves: Modelling and mapping the global intensity of mangrove-associated fisheries. *Estuarine, Coastal and Shelf Science* 247: 106975. https://doi.org/10.1016/j.ecss.2020.106975

zu Ermgassen, P.S., Worthington, T.A., Gair, J.R., Garnett, E.E., Mukherjee, N., Longley-Wood, K., Nagelkerken, I. *et al.* 2024. The global fish and invertebrate abundance value of mangroves. *bioRxiv* 2024-05. https://doi.org/10.1101/2024.05.02.591889

State of Nature Conservation in Malaysia 2025, 293–314
doi: 10.62613/sonc2025.v1flc22

CHAPTER 22

Conservation status, governance challenges and the path to integrated landscape management of Peat Swamp Forests in Peninsular Malaysia

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Abstract: Peat Swamp Forests (PSF) were once among Malaysia's most extensive wetland ecosystems, and remain critically important for biodiversity conservation, carbon storage, hydrological processes, and sustainable resource use. Historically, they occupied about 2.56 million ha, equivalent to nearly 8% of Malaysia's land area and roughly 720,000 ha or 5.45% of the land area in Peninsular Malaysia. The PSF areas in Peninsular Malaysia declined by 66% from an estimated 670,000 ha in 1981 to 226,000 ha in 2010. Between 2010 to 2026, the PSF area declined further 5% to an estimated 192,788 ha in 2026. PSFs are habitat to a large number of rare, threatened, and endangered (RTE) species, with many specially adapted to its unique acidic wetland environment. Their specialised plant communities support a wide range of animal species, including 140 species of fish, with more than 60 blackwater species restricted to this habitat in Peninsular Malaysia. In the past half-century, PSFs have been logged, cleared, drained, burnt, and developed for other commercial uses, especially oil palm plantations. PSF areas have been totally lost or reduced to less than 1% in Kelantan, Perak and Negeri Sembilan, while only 3.5% remain in Johor; extensive PSFs only persist in Selangor and Pahang with an estimated total area of 170,000 ha. While PSF areas have declined in all states between 2010 to 2026, the significant increase in Selangor reflects the success of proactive conservation measures leading to reduced fires and enhanced forest recovery. Successful conservation measures developed for PSFs in Selangor are now being introduced in Pahang and Johor. The montane peatland forest of Pahang have also been recently documented. This chapter highlights governance and resourcing issues, as well as key challenges, opportunities, and policy recommendations to further enhance the conservation of PSFs in Peninsular Malaysia.

INTRODUCTION

General overview: A landscape of water, carbon and complexity

Peat swamp forests (PSFs) originally covered 2.56 million ha or nearly 8% of the land area of Malaysia, and about 720,000 ha or 5.45% of the land area of Peninsular Malaysia (DOE 2019b). They are naturally waterlogged lowland tropical rainforests growing on deep accumulations of organic soil known as peat, receiving water primarily from rainfall with minimal input from groundwater or surface water (Takada *et al.* 2016). This rain-fed or ombrotrophic character gives peat swamp forests their distinctively nutrient-poor and highly acidic nature, setting them apart from other wetland forest types across the region (Page *et al.* 2012).

Peat is composed of approximately 10% solid organic matter and 90% pore space (DOA 2023). Under persistently waterlogged conditions, these pores remain saturated, creating oxygen-poor environments that maintain the peat in an anaerobic state. In this state, microbial activity and organic matter decay are significantly reduced, allowing carbon-rich

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plant material to accumulate over long periods of time. Peat accumulates when organic matter addition exceeds breakdown, typically at only 0.5 to 3 millimetres per year (DOE 2019a; Parish *et al.* 2019). In Malaysia, peat soil is formally defined as having organic matter content exceeding 65% and depth greater than 50 cm (DOA 2023; Paramananthan *et al.* 2018). Maintaining a water table within 10 – 30 cm of the surface is critical, as any lowering of this threshold transforms the peat environment from to an aerobic state, thereby introducing oxygen into the peat profile and accelerating oxidative decomposition. This process increases carbon emissions, land subsidence and renders the highly combustible peat layer increasingly vulnerable to fires and prolonged smouldering combustion (Che Azmi *et al.* 2021).

Peatlands in Malaysia are recognised as Environmentally Sensitive Areas (ESA) under the Section 6B of the Town and Country Planning 1976 (Act 172), in the National Physical Plan 4 (NPP 4) (Rengasamy and Parish 2021), and the Guidelines for Planning and Management of Environmentally Sensitive Areas (PLANMalaysia, 2025). The peatland area in Peninsular Malaysia and estimated remaining peat swamp forest, according to state, is given in Table 1 and illustrated in Figure 1.

Table 1. Estimated area of peatlands and remaining peat swamp forest in Peninsular Malaysia.

State	Area of peatlands (ha)*	% against Total Peatland in PM	Area of PSF in 2010 (ha) (WI-2010)+	Area of PSF in 2026 (ha) (GEC)++	% of PSF area in 2026 against Total Peatland in each state
Federal Territories (Kuala Lumpur and Putrajaya)	383	0.05	44	25	6.53
Johor	187,151	26.00	16,304	6,386***	3.41
Kelantan	7,692	1.07	5,626	80	1.04
Negeri Sembilan	6,220	0.86	1,729	0	0.00
Pahang	201,693**	28.02	129,759	102,773	50.96
Perak	75,124	10.44	4,574	300	0.40
Selangor	173,198	24.06	16,231	73,224	42.28
Terengganu	68,338	9.49	51,579	10,000	14.63
TOTAL	**719,799**	**100**	**226,021**	**192,788**	**26.78**

Data source:

* Department of Agriculture (2023); Department of Environment (2019a).

** Including upland peat data from Department of Agriculture (2024).

*** Data from assessment of PSF in Johor in 2023-2025 by GEC and Johor State Forestry Department.

+ WI (2010) refers to Wetlands International (2010) using a parameter of 70% tree cover.

++ GEC refers to data collected and analysis in 2026 undertaken by Global Environment Centre for this paper using satellite imagery and ground truthing for Selangor and Pahang States and Satellite imagery for other states.

It can be seen that between 2010 to 2026, the area of peat swamp forest in Peninsular Malaysia has declined by 15% from 226,021 in 2010 to 192,788 in 2026. The area of PSF in all states declined except for Selangor that showed a significant increase. The increase in Selangor can be attributed to recovery in PSF after the logging moratorium imposed in 2010, as well as fire prevention and restoration action especially in NSPSF from 2008 onwards. The decline in the other states is linked to extensive logging, land conversion, drainage and fires. It may also be linked to the smaller size and fragmented nature of the peatlands in these states making them more vulnerable to degradation.

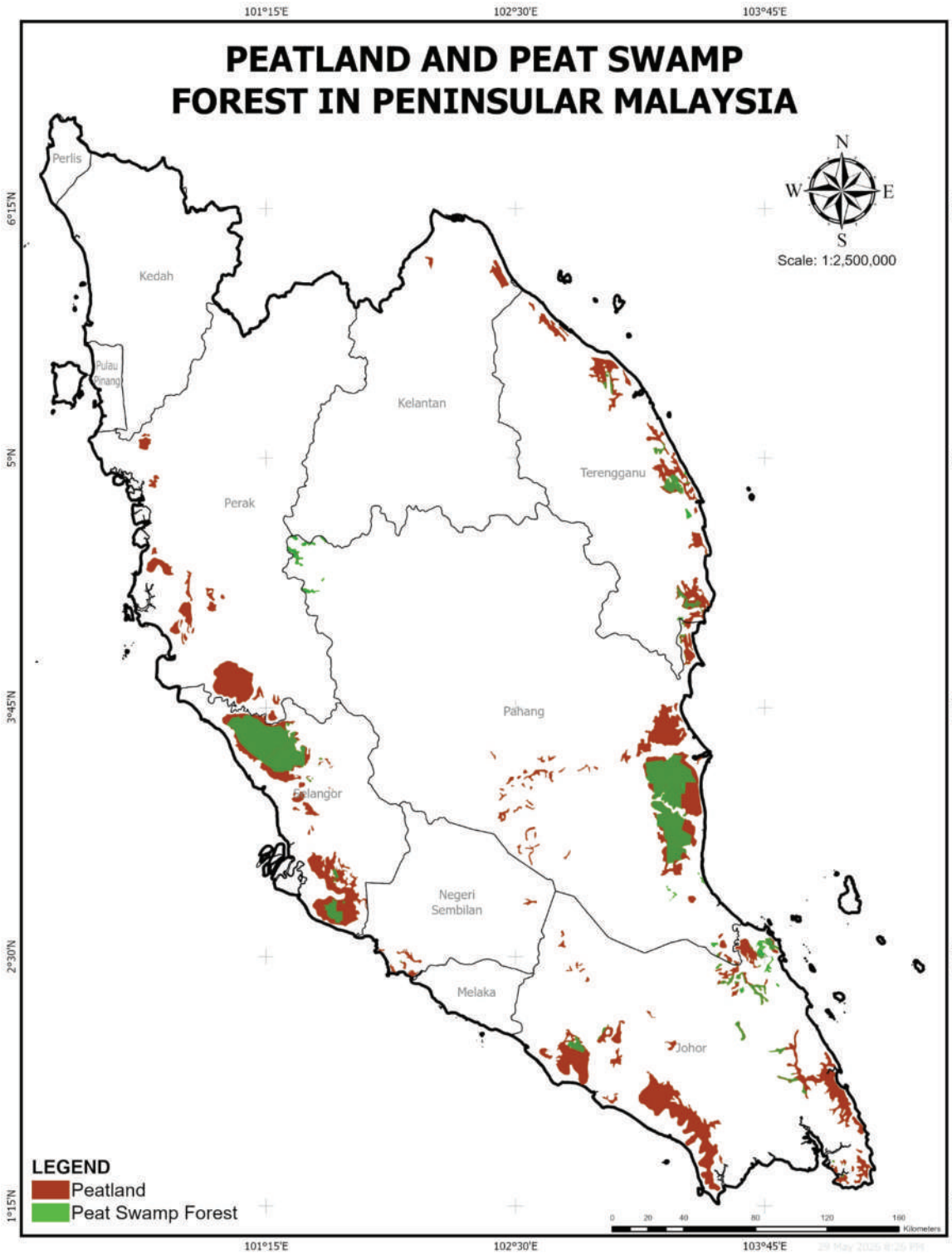

Figure 2. Extent of peatlands and remaining peat swamp forests in Peninsular Malaysia (Source: peatland extent from DOA 2019 and 2024; PSF from this study).

Types of peatlands and peat swamp forest

There are two main types of peatlands and peat swamp forest formed based on altitudinal gradients (DOA 2023). Lowland peat in Peninsular Malaysia occurs under inundated or waterlogged conditions normally in coastal or riverine lowlands at an altitude of 1 – 100 m a.s.l., whereas upland peat is normally found above 1500 m in non-inundated conditions and confined to limited areas with high rainfall.

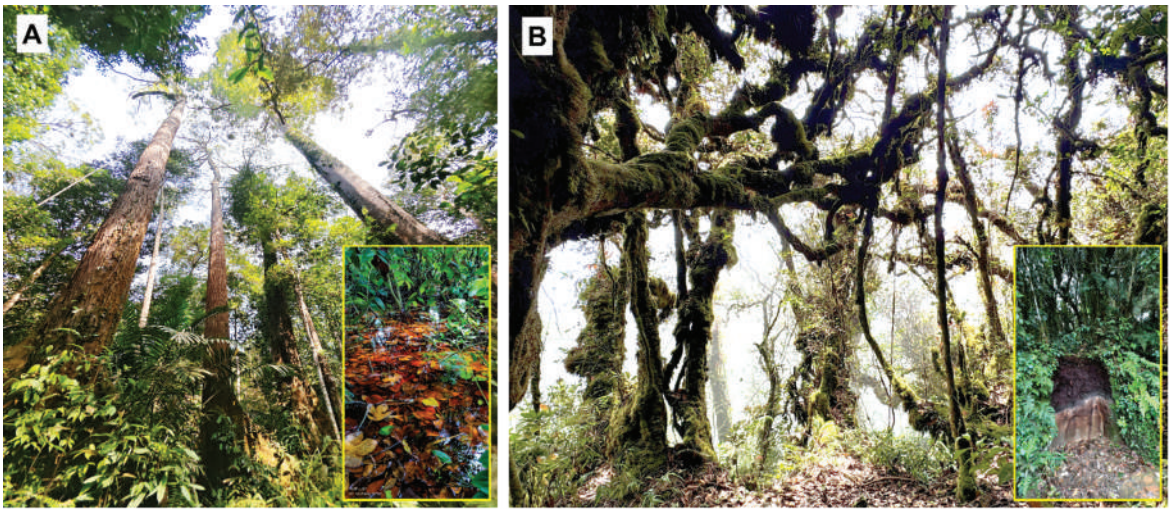

Figure 2. (A) lowland peat swamp forest (Kuala Langat South Forest Reserve, Selangor) and **(B)** upland/montane peat forest (Mossy Forest, Cameron Highland, Pahang) across different altitudinal gradients in Peninsular Malaysia.

Lowland peat swamp forests

Lowland peatlands can be divided further into topogenous and ombrogenous peatlands. Topogenous peatlands occur in depressions in the landscape such as river valleys or lake basins, while ombrogenous peatlands develop in floodplains between adjacent lowland river valleys.

Ombrogenous peatlands

In Peninsular Malaysia, ombrogenous lowland peat swamp forests developed primarily through post-glacial geomorphological and hydrological processes in former coastal lagoons and deltaic plains located between major river systems. The underlying peat typically forms a dome-shaped structure, with peat depth generally increasing progressively from the margins towards the centre, ranging from approximately 3 to 10 metres deep (DOE 2019a), and is commonly underlain by clay or sandy mineral substrates. Water in these systems is highly acidic, with pH ranging from 3.5 to 5.0, while having a distinctive dark-brown-to-black colouration due to high concentrations of dissolved humic substances derived from partially decomposed organic matter (DOA 2023).

Figure 3 illustrates the formation of ombrogenous peat swamp forests in low-lying coastal or riverine basins where drainage is poor and water tends to accumulate. Over time, continuous waterlogging creates anaerobic conditions that slows down the decomposition of plant material such especially wood and roots. This leads to the gradual build-up of partially decomposed organic matter, forming a thick layer of peat. As this peat layer deepens, it influences forest structure and hydrology, resulting in a unique ecosystem adapted to permanently wet, nutrient-poor and acidic conditions typical of lowland peat swamp environments (DOE 2019a).

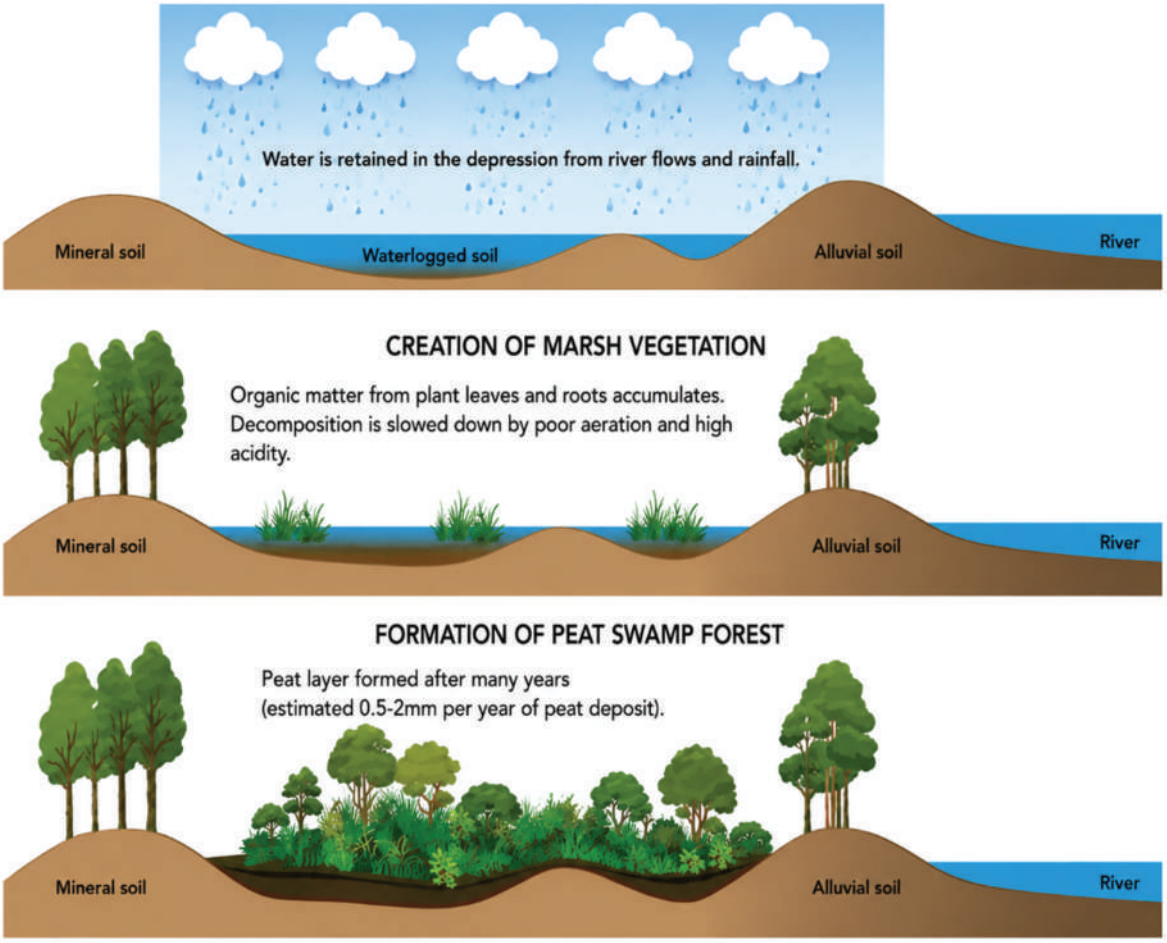

Figure 3. Cross-sectional diagram of a dome-shaped lowland peat deposit illustrating peat formation processes. [Modified from DOE (2019a)].

These forests exhibit distinct vegetation adapted to the unique peatland environment, with a characteristic three-layered canopy structure. Typical species include *ramin melawis* (*Gonystylus bancanus*), *meranti paya* (*Rubroshorea platycarpa*), *jelutong* (*Dyera polyhylla*) and *geronggang* (*Cratoxylum arborescens*): all well adapted through buttress roots, aerenchyma tissues and specialised seed dispersal mechanisms (Giesen *et al*. 2018).

Topogenous peatland

Topogenous peatland, also known as river valley or lake basin peatlands, develop in inland depressions, along river channels, or within and around lake basins where the water table is high. Sediment accumulation or tectonic activity may reduce drainage efficiency, resulting in persistently elevated water levels that create permanent swamp conditions conducive to peat formation. In Peninsular Malaysia, these peatlands occur mainly in the Bera district of Pahang, particularly at Bera Lake. These peatlands receive water inputs from surrounding low hills, making them relatively more mineral- and nutrient-rich compared to ombrotrophic peatlands. As a result, they support distinct vegetation communities adapted to high water tables, including palms, sedges, and other swamp species as well as areas of peat swamp forest. They also occur to a limited extent in other locations where topography restricts inflowing water from nearby hills and in areas adjacent to ombrotrophic peat domes.

Upland and montane peatland

At elevations exceeding 1,000 metres a.s.l., cooler temperatures, high rainfall, and reduced evapotranspiration slow decomposition sufficiently to allow upland or montane peat formation (Page and Baird 2016). At Cameron Highlands, Pahang, upper montane, cloud or mossy forest exists at 1,500 to 2,000 metres a.s.l. along the top of the Titiwangsa Mountain Range, where organic soil accumulates to depths of 1 to 3 metres beneath a canopy of moss-draped and gnarled trees as shown in Figure 4. These upland peat ecosystems are typically characterised by persistently moist conditions, low nutrient availability, and slow nutrient cycling rates, which collectively favour long-term organic matter accumulation (Osman 2018). An estimated 6,000 to 10,000 ha of upland peat is found in Cameron Highlands. Patches of upland peat are also believed to occur elsewhere along the Titiwangsa Range at Frasers Hill and Genting Highlands, but no comprehensive survey has been undertaken yet.



Figure 4. Field photograph and cross-section of highland peat formation at Gunung Brinchang, Cameron Highlands. Photo credit: Global Environment Centre (GEC).

Both lowland and upland peat systems store carbon at densities far exceeding dryland forests. The waterlogged and anaerobic conditions within peat soils enable the long-term sequestration and storage of large quantities of organic carbon accumulated over thousands of years (Page and Baird 2016). When drained or disturbed, this stored carbon is rapidly oxidised and released into the atmosphere as carbon dioxide, thereby contributing significantly to greenhouse gas emissions and climate change. Consequently, the conservation and sustainable management of peat swamp forests constitute a strategic national priority in supporting Malaysia's commitment to achieving net-zero greenhouse gas emissions by 2050 (Varkkey *et al.* 2024).

ECOSYSTEM FUNCTIONS OF PEAT SWAMP FORESTS IN PENINSULAR MALAYSIA

Carbon storage and climate regulation

Peat swamp forests are among the most carbon-dense terrestrial ecosystems on Earth, because carbon is stored not only in above-ground biomass but also in substantial below-ground pools, including living root biomass and long-term accumulated organic matter in peat soils (Pan *et al*. 2024). Globally, peatlands store more than 550 billion tonnes of carbon, representing approximately 30% of soil carbon worldwide (Parish *et al.* 2021),

while Southeast Asian deposits alone hold an estimated 68.5 billion tonnes (Page *et al.* 2011). Findings from the North Selangor Peat Swamp Forest show that median below ground peat carbon stocks reach approximately 1,401 tonnes per hectare, with stocks approximately twelve times higher than above ground biomass carbon pools (Brown *et al.* 2023). Drained or disturbed tropical peatlands are persistent net sources of greenhouse gases. Such emissions directly undermine national climate mitigation commitments, including Malaysia's net-zero emissions aspiration by 2050 under the national climate framework.



Figure 5. Endangered, Rare and Threatened (ERT) Peat Swamp Forest tree species from Peninsular Malaysia. Note: CR – Critically Endangered; EN – Endangered; NT – Near Threatened; VU – Vulnerable.

Hydrological regulation
Intact peat swamp forests function as natural water reservoirs within lowland catchments, absorbing rainfall and releasing it gradually to sustain river flows during dry periods while moderating peak flood events. This buffering capacity contributes to catchment-scale hydrological stability and water security. Coastal peatlands in Selangor and Johor serve as critical ecological buffers preventing saltwater intrusion into freshwater systems and agricultural land (Polgar and Jaafar 2018), particularly under conditions of rising sea levels and land subsidence. Where these peatlands have been drained, hydrological alteration has led to soil subsidence, increased fire susceptibility, reduced water retention capacity and enhanced saline intrusion in coastal zones. These impacts have long-term implications for potable water supply, agricultural productivity, infrastructure stability and community livelihoods (Parish *et al.* 2021).

Biodiversity and socioeconomic value
Peninsular Malaysia's peat swamp forests support highly specialised, evolutionarily adapted and often endemic species assemblages, making them globally significant for conservation (Posa *et al.* 2011). According to the International Union for Conservation of Nature (IUCN), many of these species are listed in the Red List of Threatened Species (IUCN 2025), underscoring the urgent need for their conservation and protection as a matter of utmost priority. The North Selangor Peat Swamp Forest alone harbours more than 60 threatened species, including Malayan tapirs (*Tapirus indicus*, Endangered), sun bears (*Helarctos malayanus*, Vulnerable), smooth-coated otters (*Lutrogale perspicillata*, Vulnerable), and leopards (*Panthera pardus*, Endangered) (Sasidhran *et al*. 2016). Critically threatened tree species (Figure 5) include *ramin melawis* (*Gonystylus bancanus*, Critically Endangered), *meranti paya* (*Rubroshorea platycarpa*, Endangered), and *jelutong* (*Dyera polyhylla*, Vulnerable). Endemic blackwater fish species including *Betta persephone* (Endangered), *B. livida* (Endangered), *B. tomi* (Endangered), and *B. tussyae* (Endangered) are confined exclusively to these habitats. Beyond biodiversity conservation, these forests sustain local communities through timber, non-timber forest products, fisheries, and ecotourism, making their conservation both an ecological necessity and a long-term socioeconomic imperative.

SITUATIONAL ANALYSIS: A LEGACY OF DRAINAGE AND FRAGMENTED GOVERNANCE

Over the past five decades, a significant portion of Peninsular Malaysia's peat swamp forests have been systematically cleared, drained, and converted for a wide range of purposes, including agricultural cultivation, plantation development, settlement expansion, and infrastructure construction (Parish *et al.* 2021). While these land use changes contribute to national and state economic development, they have generated severe and compounding ecological consequences. Drained peatlands subside at rates of 2 – 5 cm per year, depending on drainage intensity and land use type (Wösten *et al*. 2008; Hooijer *et al*. 2012). Continued subsidence increases flood exposure, reduces land elevation relative to sea level in coastal areas, and elevates infrastructure damage and disaster risk.

The peat swamp forests of Peninsular Malaysia have undergone especially rapid reduction since 1981 as shown in Table 2. It is assumed that all peatlands (719,799 ha) in Peninsular Malaysia (DOE 2019b) were originally forested. In 1981, 670,000 ha hectares (93%) was still thought to be forested (UNDP 2006). Thereafter, there was a rapid decline (66% decline in 30 years) until 2010, where when only 226,000 ha of relatively intact peat swamp forests was recorded (Wetlands International 2010). Since then, the area of peat swamp forests has declined at a slower rate of 1% per year with the current extent estimated as 223,425 ha. The changes between states however have not been even. However, the changes have not been even. In the last 15 years, the PSF areas have declined in Terengganu,

Negeri Sembilan and Pahang, but have increased in Selangor as a result of conservation measures. Of the remaining PSFs, about 94% is within designated the Permanent Reserved Forests, while with the remaining found within state land forests (Forestry Department of Peninsular Malaysia 2022).

Table 2. Change in area of PSF in Peninsular Malaysia.

Year	Estimated area of peat swamp forests (ha)	Reference
Original	719,799*	DOE, 2019b
1981	670,000	(UNDP, 2006)
1991	330,000	(UNDP, 2006)
2006	300,000	(UNDP, 2006)
2010	226,021	(WI, 2010)
2026	192,788	This paper

*Assuming all areas with peat soil were originally vegetated with peat swamp forest.
Case studies from different peatland landscapes in Peninsular Malaysia are given in Annex 1.

Conservation actions

As at 2009, almost all of the peat swamp forests within Permanent Reserve Forests were designated as production forests and subject to logging. However, in 2010, Selangor imposed a moratorium on further logging statewide and initiated a fire prevention and restoration programme in the PSF, which has led to an increase in the area of PSFs after 2015. In 2023, the Pahang State initiated a peatland conservation and forest carbon project in 96,569 ha of Southeast Pahang Peat Swamp Forest, which has led to the phasing-out of logging in the largest remaining peat swamp complex in Peninsular Malaysia.

The majority of peat swamp forests outside the forest reserves (on state land) have generally been heavily logged and converted to oil palm or other uses. In 2019, the National Land Council imposed a ban on further conversion of forest and peatlands for oil palm; conversions for other purposes still continue however. In recent years, several proposed development projects in PSF have been discontinued as a result of public pressure. In southern Selangor, the state government proposed to de-gazette 931 ha (97% of the forest) of the Kuala Langat North Forest Reserve (KLNFR) in February 2020 for a mixed development project (New Straits Times 2020). Following strong public and stakeholder opposition, the proposal was abandoned and almost all the reserve was re-gazetted in May 2023 (MalayMail 2023). In Terengganu, about 1,029 ha of virgin peat swamp forest, which had been degazetted from the Belara Forest Reserve in 2017 and leased to a private company under a 99-year agreement, was proposed for oil palm development in 2024. However, following significant public objection, the Environmental Impact Assessment (EIA) was subsequently rejected. Efforts to enhance the protection of this area are still ongoing with a multi-stakeholder workshop organised in June 2026 to identify priority conservation actions.

According to Malaysia's Fourth Biennial Update Report (BUR4), drainage-based land use on peatlands released an estimated 8 million tonnes of carbon dioxide in 2019 alone (Ministry of Natural Resources, Environment and Climate Change 2022). Beyond direct emissions, the lowering of water tables through drainage exposes deep peat layers to oxidation and fire, with studies confirming that degraded and unmanaged peatlands experience fire activity at rates more than 25 times higher than those recorded in intact peat swamp forests (Miettinen *et al.* 2017).

Governance context

A critical governance challenge further compounds these ecological pressures. Peatland management in Peninsular Malaysia is characterised by institutional fragmentation, overlapping mandates, and varying levels of coordination across sectors as well as limitations in dedicated restoration financing and structured multi stakeholder engagement, especially in decision-making (United Nations Environment Programme 2022). Forestry Departments manage peatland areas gazetted as Permanent Reserved Forests, while Department of Agriculture, Malaysian Palm Oil Board, land offices, local governments, private sector actors, and local communities manage peatlands located outside reserved forest boundaries under distinct regulatory frameworks and development priorities. This multi-agency arrangement reflects the broader federal-state governance structure of Malaysia, where land matters fall primarily under state jurisdiction. Critically, a significant area of degraded peatland outside Permanent Reserved Forests, particularly areas without active land use or formal gazettement, lacks clearly assigned long-term management responsibility, which may increase vulnerability to recurrent fire, invasive species encroachment, continued carbon loss, and unmanaged drainage. Clarifying institutional responsibility for such landscapes is therefore an important step toward effective restoration planning.

In order to address fragmented management across peatland landscapes, Integrated Management Plans (IMPs) have been developed for several peatland landscapes, including the Integrated Management Plan for the North Selangor Peat Swamp Forest (IMP-NSPSF) 2025-2034, the Integrated Management Plan for the South Selangor Peat Swamp Forest (IMP-SSPSF) 2025-2034, and the Integrated Management Plan for the Southeast Pahang Peat Swamp Forest (IMP-SEPPSF) 2026-2035 (Selangor State Forestry Department 2025a, 2025b; Pahang State Forestry Department 2026), as well as State Action Plans for Peatlands (SAPP) for Selangor and Pahang 2026-2035, and the Johor State Peat Swamp Forest Management Plan 2021-2030 (Johor State Forestry Department 2021). In addition, a National Action Plan for Peatlands (NAPP) is being prepared for 2026-2035, which is currently being finalised by the Ministry of Natural Resources and Environmental Sustainability.

Financial and resource allocation patterns

The fragmentation of peatland governance is starkly reflected in resource allocation patterns, particularly in fire management expenditure. In Pahang, peatland fires within the Southeast Pahang landscape have recurred regularly, with significant fire events in 2014 and 2019 associated with substantial suppression costs that exceeded investments in prevention and long-term restoration initiatives (Smith *et al.* 2018; GEC 2023). Across the three major peat swamp forest landscapes of Selangor, Pahang and Johor, fire incidents have periodically affected the South Selangor Peat Swamp Forest, the Southeast Pahang Peat Swamp Forest, and peatland areas in southern Johor. Available assessments suggest that recurring suppression expenditures have generally outpaced investments in prevention, hydrological restoration and landscape level peat management (Smith *et al.* 2018; GEC 2023).

This pattern contrasts with international best practice guidance, which recommends that more than 80% of peatland fire management resources be directed toward prevention and preparedness rather than suppression (ASEAN 2015). Such preventive approaches are widely regarded as more cost effective and environmentally sustainable in peatland landscapes. A further structural consideration is that national level peatland policy frameworks operate alongside state level land administration authority, which can create coordination challenges in ensuring consistent implementation, financing continuity and cross boundary restoration for degraded peatlands outside gazetted forest reserves across Peninsular Malaysia. Strengthened intergovernmental coordination mechanisms may therefore enhance policy coherence and implementation effectiveness.

CHALLENGES AND OPPORTUNITIES

A broad range of ecological, institutional and socioeconomic dynamics shape peat swamp forest management across Peninsular Malaysia. While each landscape exhibits unique local conditions, several cross-cutting challenges and emerging opportunities are evident. These are synthesised in Table 3 and organised around key thematic dimensions, including hydrology, governance, fire management, economics and community rights.

Table 3. Summary of key challenges and opportunities in peat swamp forest conservation across Peninsular Malaysia across five key themes.

Theme	Challenge	Opportunity
Hydrology	Drainage fragments peatland domes, triggers oxidation, subsidence and fire across multiple land uses within a single hydrological unit.	Peat Hydrological Unit (PHU)-based planning and canal blocking programmes as demonstrated at Raja Musa deliver measurable hydrological recovery.
Governance	No single agency holds comprehensive responsibility for any peatland landscape, creating chronic management gaps and resource fragmentation.	Integrated Management Plans for NSPSF and SSPSF (2025-2034) establish a formal multi-agency framework aligned with national and ASEAN policies.
Fire Management	Suppression costs consistently and substantially exceed prevention investment across Selangor, Pahang and Johor.	Community-based landscape and water level monitoring and FDRS-based warnings in NSPSF, SSPSF and SEPPSF demonstrate cost-effective fire prevention strategies.
Economics	Drainage-based land use generates short-term returns at the cost of long-term subsidence, flooding and carbon loss.	Paludiculture and Malaysia's Bursa Carbon Exchange (BCX) and REDD+ mechanisms provide viable financial alternatives to drainage-based land use.
Community Rights	Indigenous Peoples and local communities remain inadequately recognised in formal governance despite proven stewardship capacity.	Formalising co-management frameworks delivers measurable, cost-effective and socially equitable conservation outcomes.

Addressing these challenges requires a fundamental shift from reactive and fragmented management approaches toward proactive, landscape-scale governance supported by sustained and predictable financing mechanisms and strengthened, meaningful partnerships with Indigenous Peoples and local communities across Peninsular Malaysia's remaining PSFs within Permanent Reserved Forests and state lands.

POLICY RECOMMENDATIONS: A WAY FORWARD

Securing the long-term sustainability of Peninsular Malaysia's PSFs requires a decisive shift from fragmented and largely reactive management approaches toward integrated, proactive and adequately resourced governance across multiple levels of administration. The policy recommendations provided in Table 4 are organised around five core imperatives: protection, conservation, restoration, payment for ecosystem services and community wellbeing.

Table 4. Policy recommendations for improving peat swamp forest management in Peninsular Malaysia.

Imperative	Recommendation	Key actions
Protect and Manage	Adopt the Peatland Hydrological Unit (PHU) as the primary planning and regulatory boundary	Enshrine hydrological landscape boundaries in State Action Plans for Peatlands (SAPPs) and the revised National Action Plan on Peatlands (NAPP). Align all forestry, agriculture, water resources and local government mandates around shared peatland protection objectives. Strengthen enforcement against encroachment and illegal drainage within and adjacent to gazetted peat swamp forest reserves.
	Mainstream peatland protection into national and state planning frameworks	Reflect peatland objectives explicitly in the 13th Malaysia Plan, National Physical Plan, State Structure Plans, REDD+ land use planning, agricultural development policies and national wetland frameworks. Ensure that sectoral development decisions do not undermine the hydrological integrity of peatland landscapes across Peninsular Malaysia.
Conserve	Establish a coordinated cross-sectoral governance framework	Formalise the National/State Peatland Working Committees and National/State Peatland Steering Committees as long-term, active inter-agency coordination platforms at both federal and state levels. Develop and gazette State Action Plans for Peatlands for all states with significant peat swamp forest coverage including Selangor, Pahang and Johor.
	Strengthen baseline data, monitoring and research	Invest in systematic biodiversity assessments, peat depth mapping, carbon stock measurement and hydrological monitoring across all major peat swamp forest landscapes. Integrate remote sensing, GIS mapping and community-based monitoring into a national peatland observatory framework to support evidence-based adaptive management.
Restore	Rebalance expenditure from fire suppression to fire prevention and restoration	Allocate at least 80% of state fire management budgets to preventive measures including hydrological restoration, canal blocking, rewetting, early warning systems and community fire monitoring, in line with international best practice (Association of Southeast Asian Nations, 2015). Treat restoration investment as essential long-term infrastructure rather than exceptional post-disaster expenditure.
	Implement integrated landscape restoration through PHUs	Scale-up canal blocking, rewetting and natural regeneration programmes across degraded peat landscapes in Selangor, Pahang and Johor, using the 6R approach of rewetting, reduction of fire, revegetation, revitalisation, reporting and monitoring as well as resource mobilisation as the operational framework for restoration planning and implementation.

Payment for Ecosystem Services	Develop and activate carbon finance and PES mechanisms for peat swamp forests	Accelerate the development of verified carbon projects within intact and restoring peat swamp forest landscapes, utilising Malaysia's Bursa Carbon Exchange (BCX) and international REDD+ mechanisms. Establish payment for ecosystem services frameworks that compensate state governments, forest managers and private landowners for maintaining hydrological integrity, carbon stocks and biodiversity values.
	Develop a long-term peatland investment framework to 2035	Formulate a 10-year financing strategy drawing on public budgets, private sector contributions, green bonds, carbon finance and international development cooperation to ensure sustained and predictable funding for peatland protection, restoration and management across all states in Peninsular Malaysia.
Community Wellbeing	Formalise and fund community co-management as standard practice	Legally recognise and financially support local and Orang Asli communities as frontline peatland guardians through formal co-management agreements. Provide sustainable livelihood support, capacity building and equitable benefit-sharing arrangements that incentivise long-term community stewardship of peat swamp forests.
	Promote paludiculture and sustainable peatland-compatible livelihoods	Support the transition of communities and smallholders on degraded peatlands (especially around forest reserves) toward paludiculture, including cultivation of species such as sago palm (*Metroxylon sagu*), *jelutong* (*Dyera polyphylla*), *gelam* (*Melaleuca* spp.), aquaculture and non-timber forest product harvesting, as economically viable alternatives to drainage -based land use that maintain hydrological function and community wellbeing.

Taken together, these recommendations constitute a coherent and actionable framework for strengthening the governance of peat swamp forests in Peninsular Malaysia. Their effective implementation requires sustained political commitment, enhanced institutional coordination and long-term financial investment at both federal and state levels. However, the ecological, economic and social benefits, including reduced flood risk, preserved carbon stocks, conserved biodiversity, and improved community livelihoods, are expected to substantially outweigh the costs of continued inaction.

CONCLUSION

Peninsular Malaysia's peat swamp forests, spanning Selangor, Pahang, Terengganu, Johor, and beyond, represent among the most carbon-dense terrestrial ecosystems in the region, storing carbon at densities far exceeding those of dryland forests. They also play a critical role in regulating freshwater hydrology across densely populated coastal lowlands, sustaining irreplaceable biodiversity and supporting communities that have long served as their most committed custodians. The scientific evidence is compelling. Peatlands must remain hydrologically intact to maintain their ecological function. Hydrological integrity must

therefore be restored and maintained at the landscape scale, while fire prevention must consistently take precedence over reactive suppression. Governance arrangements require stronger coordination across agencies, tenure systems and administrative levels. Communities must be formally recognised and adequately supported as frontline stewards with meaningful roles in monitoring, restoration, and management. Conservation investment must be sustained, strategic, and proportionate to the ecological and socioeconomic value of these ecosystems. Case studies from northern and southern Selangor, Southeastern Pahang, and Johor demonstrate that restoration is achievable, that community partnership delivers results and that integrated management frameworks can align ecological, economic and social objectives within a single landscape. Growing institutional commitments across all four landscapes signal a genuine readiness to shift from reactive crisis management toward proactive stewardship. What remains limiting is not the absence of knowledge, but rather the need for stronger coordination in governance, financing, and political prioritisation. By recognising peat swamp forests as irreplaceable natural infrastructures rather than marginal or degraded land and ensuring these landscapes remain wet, empowering local communities in stewardship roles, and making certain that policies are coherently implemented, Malaysia can safeguard these critical ecosystems as enduring ecological assets for future generations.

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REFERENCES

Association of Southeast Asian Nations (ASEAN). 2015. *ASEAN Guidelines on Peatland Fire Management*. Jakarta, Indonesia: ASEAN Secretariat.

Brown, C., Boyd, D.S., Sjögersten, S. and Vane, C.H. 2023. Detecting tropical peatland degradation: Combining remote sensing and organic geochemistry. *PLoS One* 18(3): e0280187. https://doi.org/10.1371/journal.pone.0280187

Che Azmi, N.A., Mohd Apandi, N. and Rashid, A.S. 2021. Carbon emissions from the peat fire problem - a review. *Environmental Science and Pollution Research* 28(14): 16948–16961. https://doi.org/10.1007/s11356-021-12886-x

Daim, N. 2021. Temuan community leads reforestation of fire-damaged peatlands. *New Straits Times*.

Department of Agriculture Malaysia (DOA). 2020. *Siri Tanah Organik Malaysia: Paya Gambut*. Putrajaya: Department of Agriculture Malaysia.

Department of Agriculture Malaysia (DOA). 2023. *Garis Panduan Pengurusan Pertanian di T anah Gambut Sedia Ada*. Putrajaya: Department of Agriculture Malaysia. https://www.doa.gov.my/doa/resources/aktiviti_sumber/sumber_awam/penerbitan/buku/garis_panduan_pengurusan_pertanian_tanah_gambut.pdf

Department of Environment Malaysia (DOE). 2019a. *Draf Pelan Induk Pengurusan Tanah Gambut Sering Terbakar di Malaysia 2021-2030*. Putrajaya: Department of Environment Malaysia. [Unpublished report].

Department of Environment Malaysia (DOE). 2019. *Prosedur Tetap Operasi Melaksanakan Program Mencegah Kebakaran Tanah Gambut Untuk Mengatasi Jerebu di Malaysia*. Putrajaya: Department of Environment Malaysia.

Enggang Holdings Sdn. Bhd. 2025. Pahang Peatland Restoration Project (PPRP) Project Description Document. Submitted to Verra Verified Carbon Standard (VCS). https://registry.verra.org/

Forestry Department Peninsular Malaysia (FDPM). 2022. *Annual Report 2022*. Putrajaya: Forestry Department Peninsular Malaysia. https://www.forestry.gov.my/my/pusat-sumber/penerbitan/laporan-tahunan

Forestry Department Peninsular Malaysia (FDPM). 2024. *Statistik Kawasan Hutan Paya Gambut dan Tanah Tinggi Negeri Pahang*. Putrajaya: Kementerian Sumber Asli dan Kelestarian Alam.

Forestry Department Peninsular Malaysia (FDPM). n.d. Jenis Hutan. *Forestry Department Peninsular Malaysia.* https://www.forestry.gov.my/my/perkhidmatan/info-perhutanan/jenis-hutan

Forest Research Institute Malaysia (FRIM). 2022. *Ekosistem Hutan Paya Gambut di Malaysia: Pemuliharaan dan Cabaran*. Kepong, Malaysia: Forest Research Institute Malaysia.

Giesen, W., Wijedasa, L.S. and Page, S.E. 2018. Unique Southeast Asian peat swamp forest habitats have relatively few distinctive plant species. *Mires and Peat* 22: 1–13. https://doi.org/10.19189/MaP.2017.OMB.287

Global Environment Centre (GEC). 2026. *Annual report (January 2023 – December 2025): Conservation of coastal forest and peatlands in Gunung Arong Forest Reserve, Johor*. Petaling Jaya: Global Environment Centre.

Global Environment Centre (GEC). 2023. Initial Assessment Report Towards the Formulation of ESG Conservation Project(s) in the Southeast Pahang Peat Swamp (SEPPF) Landscape. *Global Environment Centre.* https://gec.org.my/reference-project/initial-assessment-report-towards-the-formulation-of-esg-conservation-projects-in-the-southeast-pahang-peat-swamp-seppf-landscape/

Global Environment Centre and Yayasan Pahang Plantation Holdings. 2025. Pencegahan Kebakaran dan Pemuliharaan di Bahagian Tenggara Hutan Simpan Pekan Kemas Kini Kemajuan: Januari – Mac 2025, Kemaskini No. 1/2025. *Yayasan Pahang Plantation Holdings.* https://ypph.com.my/YPPH/berita.php?idberita=25

Hooijer, A., Page, S., Jauhiainen, J., Lee, W.A., Lu, X.X., Idris, A. and Anshari, G. 2012. Subsidence and carbon loss in drained tropical peatlands. *Biogeosciences* 9(3): 1053–1071. https://doi.org/10.5194/bg-9-1053-2012

IUCN. 2025. The IUCN Red List of Threatened Species. Version 2025-2. https://www.iucnredlist.org

Johor State Forestry Department (JSFD). n.d. *Pelan Pengurusan Kebakaran Hutan Paya Gambut*. Iskandar Puteri, Johor: Johor State Forestry Department. https://forestry.johor.gov.my/images/pdf/2023/PELAN_PENGURUSAN_KEBAKARAN_HPG.pdf

MalayMail. 2023, June 3. Selangor MB: Re-gazetting of Kuala Langat North Forest Reserve finalised. *MalayMail*. https://www.malaymail.com/news/malaysia/2023/06/03/selangor-mb-re-gazetting-of-kuala-langat-north-forest-reserve-finalised/72317

Miettinen, J., Shi, C. and Liew, S. C. 2017. Fire distribution in Peninsular Malaysia, Sumatra and Borneo in 2015 with special emphasis on peatland fires. *Environmental Management* 60(4): 747–757.

Ministry of Natural Resources, Environment and Climate Change. 2022. *Malaysia: Fourth Biennial Update Report Under the United Nations Framework Convention on Climate Change*. Putrajaya: Ministry of Natural Resources, Environment and Climate Change.

New Straits Times. 2020, February 5. Jabatan Perhutanan Negeri Selangor: Notis Penyiasatan Awam di bawah Seksyen 11, Akta Perhutanan Negara Enakmen (Pemakaian) 1985 (Subkaedah 7(2)). *New Straits Times*. [Print edition.]

Osman, K.T. 2018. Peat soils. In *Management of Soil Problems*, pp. 145–183. Cham: Springer Cham.

Page, S., Hooijer, A., Rieley, J., Banks, C. and Hoscilo, A. 2012. The tropical peat swamps of Southeast Asia: human impacts on biodiversity, hydrology and carbon dynamics. In *Biotic Evolution and Environmental Change in Southeast Asia*. *The Systematics Association Special Volume, 82*, D. Gower, K. Johnson, J. Richardson, B. Rosen, L. Rüber, and S. Williams (Eds.), 406–433. Cambridge: Cambridge University Press.

Page, S.E. and Baird, A.J. 2016. Peatlands and global change: response and resilience. *Annual Review Of Environment And Resources* 41(1): 35–57. https://doi.org/10.1146/annurev-environ-110615-085520

Pahang State Forestry Department (PSFD). 2023. *Laporan Tahunan Jabatan Perhutanan Negeri Pahang 2023*. Kuantan: Pahang State Forestry Department. https://forestry.pahang.gov.my/download/Laporan-Tahunan-2023.pdf

Pahang State Forestry Department (PSFD). 2024. *Laporan Tahunan Jabatan Perhutanan Negeri Pahang 2024*. Kuantan: Pahang State Forestry Department. https://forestry.pahang.gov.my/download/Laporan-Tahunan-2024.pdf

Pahang State Forestry Department (PSFD). 2026a. *Penilaian Semula dan Pembangunan Pelan Pengurusan Bersepadu (Integrated Management Plan) Hutan Paya Gambut Pahang Tenggara 2026–2035 Bagi Projek Sustainable Management Of Peatland Ecosystems In Malaysia (SMPEM)*. Kuantan: Pahang State Forestry Department. [Unpublished report].

Pahang State Forestry Department (PSFD) 2026b. *Pahang State Action Plan on Peatlands (SAPP Pahang) 2026–2035*. Kuantan: Pahang State Forestry Department. [Unpublished report].

Pan, Y., Liu, J., Zhang, M., Huang, P., Hipesy, M., Dai, L. and Zhang, Z. 2024. The below-ground biomass contributes more to wetland soil carbon pools than the above-ground biomass—a survey based on global wetlands. *Journal of Plant Ecology* 17(5): rtae017. https://doi.org/10.1093/jpe/rtae017

Paramananthan, S., Lee, P.X., Wong, M.K., Van Ranst, E., Wüst, R.A.J., and Vijiandran, J.R. 2018. A comparative study of the use of organic carbon and loss on ignition in defining tropical organic soil materials. *Communications in Soil Science and Plant Analysis* 49(5): 626–634. https://doi.org/10.1080/00103624.2018.1435683

Parish, F., Lew, S.Y., Faizuddin, M. and Giesen, W. 2019. *RSPO Manual on Best Management Practices (BMPs) for Management and Rehabilitation of Peatlands*. (2nd Edition). Kuala Lumpur: Roundtable for Sustainable Palm Oil.

Parish, F., Lew, S.Y. and Mohd Hassan, A.H. 2021. National strategies on responsible management of tropical peatland in Malaysia. In *Tropical Peatland Eco-management*, M. Osaki, N. Tsuji, N. Foead and J. Rieley, pp. 677–723. Singapore: Springer Singapore.

PLANMalaysia, 2025. *Panduan Perancangan dan Pengurusan Kawasan Sensitif Alam Sekitar [Guide for Planning and Management of Environmentally Sensitive Areas]*. Putrajaya: Department of Town and Country Planning Malaysia. https://www.planmalaysia.gov.my/uploads/content-downloads/file_20260122115136.pdf

Polgar, G. and Jaafar, Z. 2018. Ecotourism and the Future of the Forested Wetlands of Sundaland. In *Endangered Forested Wetlands of Sundaland: Ecology, Connectivity, Conservation*, pp. 89–93. Cham: Springer Cham.

Posa, M.R.C., Wijedasa, L.S. and Corlett, R.T. 2011. Biodiversity and conservation of tropical peat swamp forests. *BioScience* 61(1): 49–57. https://doi.org/10.1525/bio.2011.61.1.10

Rengasamy, N. and Parish, F. 2021. Sustainable peatland management focusing on community -based peatland rehabilitation in Malaysia. In *Tropical Peatland Eco-management*, M. Osaki, N. Tsuji, N. Foead and J. Rieley, pp. 651–662. Singapore: Springer Singapore.

Sasidhran, S., Adila, N., Hamdan, M.S., Samantha, L.D., Aziz, N., Kamarudin, N., Puan, C.L., Turner, E. and Azhar, B. 2016. Habitat occupancy patterns and activity rate of native mammals in tropical fragmented peat swamp reserves in Peninsular Malaysia. *Forest Ecology and Management* 363: 140–148. https://doi.org/10.1016/j.foreco.2015.12.037

Selangor State Forestry Department (SSFD). 2014. *Integrated Management Plan for North Selangor Peat Swamp Forest 2014-2023*. Shah Alam: Selangor State Forestry Department. https://gec.org.my/wp-content/uploads/2024/02/201511_imp-nspsf-vol-1_web-03.pdf

Selangor State Forestry Department (SSFD). 2025a. Integrated Management Plan for North Selangor Peat Swamp Forest 2025-2034. Shah Alam: Selangor State Forestry Department.

Selangor State Forestry Department (SSFD). 2025b. Integrated Management Plan for South Selangor Peat Swamp Forest 2025-2034. Shah Alam: Selangor State Forestry Department.

Smith, T.E.L., Evers, S., Yule, C.M. and Gan, J.Y. 2018. In situ tropical peatland fire emission factors and their variability, as determined by field measurements in Peninsula Malaysia. *Global Biogeochemical Cycles* 32(1): 18–31. https://doi.org/10.1002/2017GB005709

Takada, M., Shimada, S. and Takahashi, H. 2016. Tropical peat formation. In *Tropical Peatland Ecosystems*, M. Osaki and N. Tsuji (Eds.), pp. 127–135. Tokyo: Springer Tokyo.

UNDP. 2006. Malaysia's Peat Swamp Forests: Conservation and Sustainable Use. Kuala Lumpur: UNDP Malaysia.

United Nations Environment Programme (UNEP). 2022. Global Peatlands Assessment – The State of the World's Peatlands: Evidence for action toward the conservation, restoration, and sustainable management of peatlands. Main Report. Nairobi: Global Peatlands Initiative & United Nations Environment Programme.

Varkkey, H., Ashfold, M., Anshari, G.Z., Lechner, A.M., Seah, S., Wijayanti, N., Alkaf, F.T. and Masran, S.A. 2024. Mitigating carbon emissions and haze in Southeast Asia's peatlands: opportunities and challenges in integrating policy and governance. Singapore: ISEAS Publishing. https://www.iseas.edu.sg/wp-content/uploads/2024/09/TRS21_24.pdf

Wetlands International. 2010. A quick scan of peatlands in Malaysia. Petaling Jaya: Wetlands International-Malaysia.

Wösten, J.H.M., Clymans, E., Page, S.E., Rieley, J.O. and Limin, S.H. 2008. Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia. *Catena* 73(2): 212–224. https://doi.org/10.1016/j.catena.2007.07.010

APPENDIX

Annex 1. Case Studies: Peat Swamp Forest Management Across Peninsular Malaysia

The four case studies presented in this Annex span the length of Peninsular Malaysia, from the urban fringe of Greater Kuala Lumpur to the coastal plains of Pahang and the southern frontier of Johor. Each landscape reflects distinct ecological conditions, governance histories and human pressures, yet all share a common imperative: long term conservation of peat swamp forests demands integrated landscape-scale management, sustained financial and institutional support and genuine partnership with local and Indigenous communities.

Johor Peat Swamp Forests: Rediscovery and Restoration at the Southern Frontier

Johor's peat swamp forests as shown in Figure A1 represent one of the most recently documented and least systematically characterised peatland landscapes in Peninsular Malaysia. Through rapid field assessment and GIS mapping cross-referenced against state peatland distribution data and Permanent Reserved Forest boundaries, six peat swamp forest areas have been identified in Johor, comprising four Permanent Reserved Forests and two Class Two Protected Forests, namely Ayer Hitam Utara (2,804.47 ha), Ayer Hitam Utara Tambahan (358.85 ha), Gunung Arong (1,483.90 ha), Gunung Arong Tambahan (95.15 ha), Sedili Kecil (676.51 ha) and Pantai Timur (967.55 ha), with a combined peat swamp forest extent of approximately 6,386 hectares across the six areas (Johor State Forestry Department 2021).

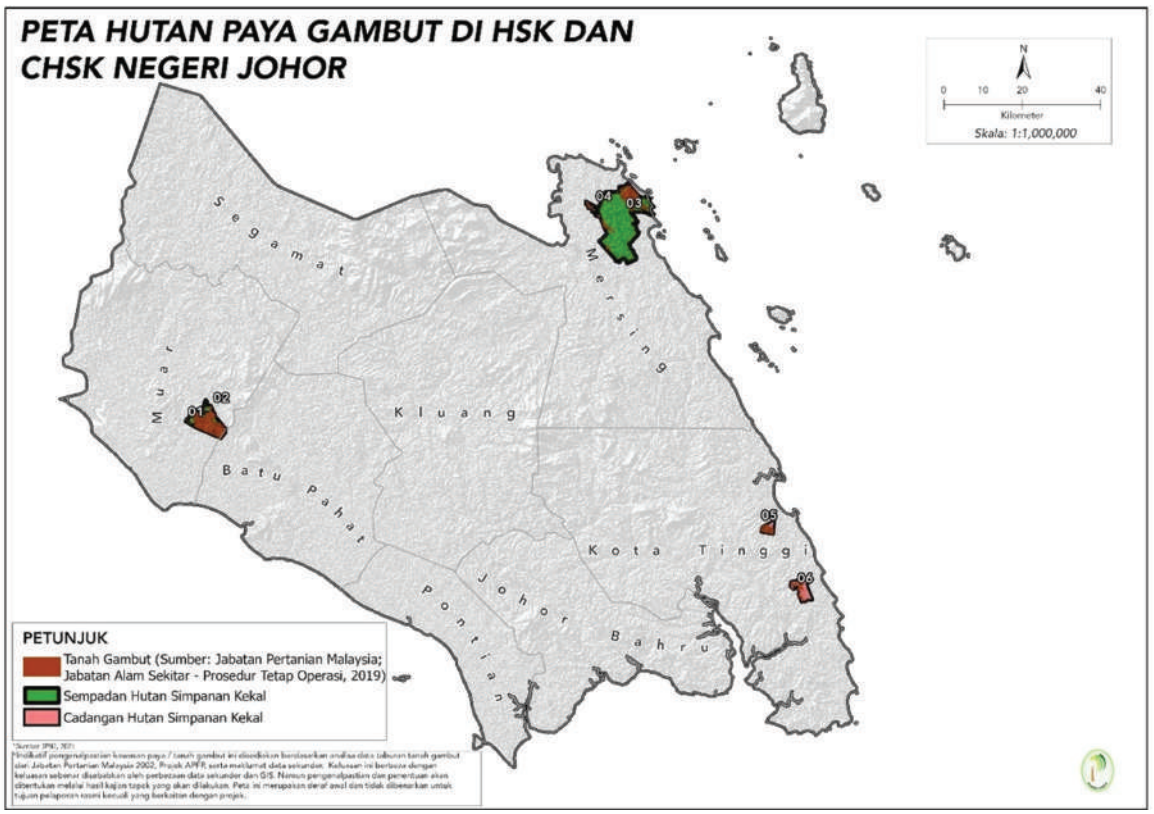

Figure A1. Distribution of peat swamp forests within gazetted and proposed Permanent Reserved Forests across Johor, showing six identified peat swamp forest areas across the Muar, Mersing and Kota Tinggi districts (Johor State Forestry Department 2021).

Field assessments confirmed significant variation in peat depth and forest condition across these sites. Ayer Hitam Utara contains peat ranging from 0.5 metres in degraded compartments to 8.16 metres in relatively intact interior areas, supporting species including *kempas* (*Koompassia malaccensis*), *meranti paya* (*Rubroshorea platycarpa*), *ramin melawis* (*Gonystylus bancanus*) and *mersawa paya* (*Anisoptera marginata*). Gunung Arong supports peat depths of up to 4.75 metres in areas identified as having high conservation potential, while Sedili Kecil and Pantai Timur, with depths of 2.73 to 3.20 metres, retain good forest structure despite localised fire damage and edge disturbance (Johor State Forestry Department 2021; GEC 2023–2025).

The condition of these forests ranges from well-stocked intact stands to heavily degraded areas with high fire risk, reflecting the consequences of drainage, encroachment and the absence of formal integrated landscape level management framework over time. The Johor State Peat Swamp Forest Management Plan 2021 to 2030, together with the seven-year conservation project at Gunung Arong Forest Reserve in Mersing Undertaken by GEC with support of TH Plantations Berhad, represents the most significant commitment to date to reverse degradation trends through integrated assessment, community engagement, hydrological restoration and biodiversity conservation interventions (Johor State Forestry Department 2021).

The Southeast Pahang Peatland Landscape: Scale, Fire, and Indigenous Communities

The Southeast Pahang Peat Swamp Forest (SEPPSF) as shown in Figure A2 is the largest remaining peatland complex in Peninsular Malaysia, encompassing a total gazetted area of 97,650.33 hectares within Permanent Reserved Forests, primarily distributed across the Pekan forest district (86,065 ha) and Rompin (11,585.33 ha) (modified from Pahang State Forestry Department, 2023). The landscape comprises the Pekan, Kedondong, Nenasi and Resak Forest Reserves, with additional areas gazetted since 2010 to strengthen landscape connectivity and hydrological integrity. It provides critical habitat for threatened species within the peat swamp ecosystem, including the sun bear (*Helarctos malayanus*) and Malayan tapir (*Tapirus indicus*), Hairy-nosed otter (*Lutra sumatrana*) and flat-headed cat (*Prionailurus planiceps*), alongside 38 freshwater fish species and 141 recorded tree species including *ramin melawis* (*Gonystylus bancanus*) and *meranti* (*Shorea* spp.) (Enggang Holdings Sdn. Bhd. 2025). The landscape further supports 26 Orang Asli villages/sub-villages from the Jakun sub-group who remain closely dependent on forest resources for sustenance and livelihood.

Despite its ecological significance, the SEPPSF faces severe and compounding pressures. Large-scale drainage of surrounding state land has fundamentally fragmented the natural hydrological system, lowering water tables across extensive peat areas and rendering them highly susceptible to recurrent fire. Suppression costs have consistently and substantially exceeded investments in prevention and hydrological restoration, reflecting an unsustainable pattern of reactive rather than proactive management (Smith *et al.* 2018; GEC 2023). In response, the Pahang State Forestry Department, in collaboration with other government technical departments, the Global Environment Centre and private sector partners, has initiated targeted interventions including peatland rewetting through canal blocking, community-based fire monitoring and active engagement of surrounding Orang Asli communities as frontline stewards. The fire prevention and conservation project at the Bukit Leelau Mini landscape in the western portion of the landscape has prevented peatland fires for seven years since March 2019, through effective cross-agency multiple-disciplinary partnership. GEC has been facilitated regular patrols by Orang Asli villagers to prevent fires and monitor water levels and encroachment. On the eastern side of SEPPSF, a similar project implemented since 2021, has made measurable progress in reducing fire incidence and restoring hydrological function as a foundation for longer-term landscape recovery (GEC and Yayasan Pahang Plantation Holdings 2025).

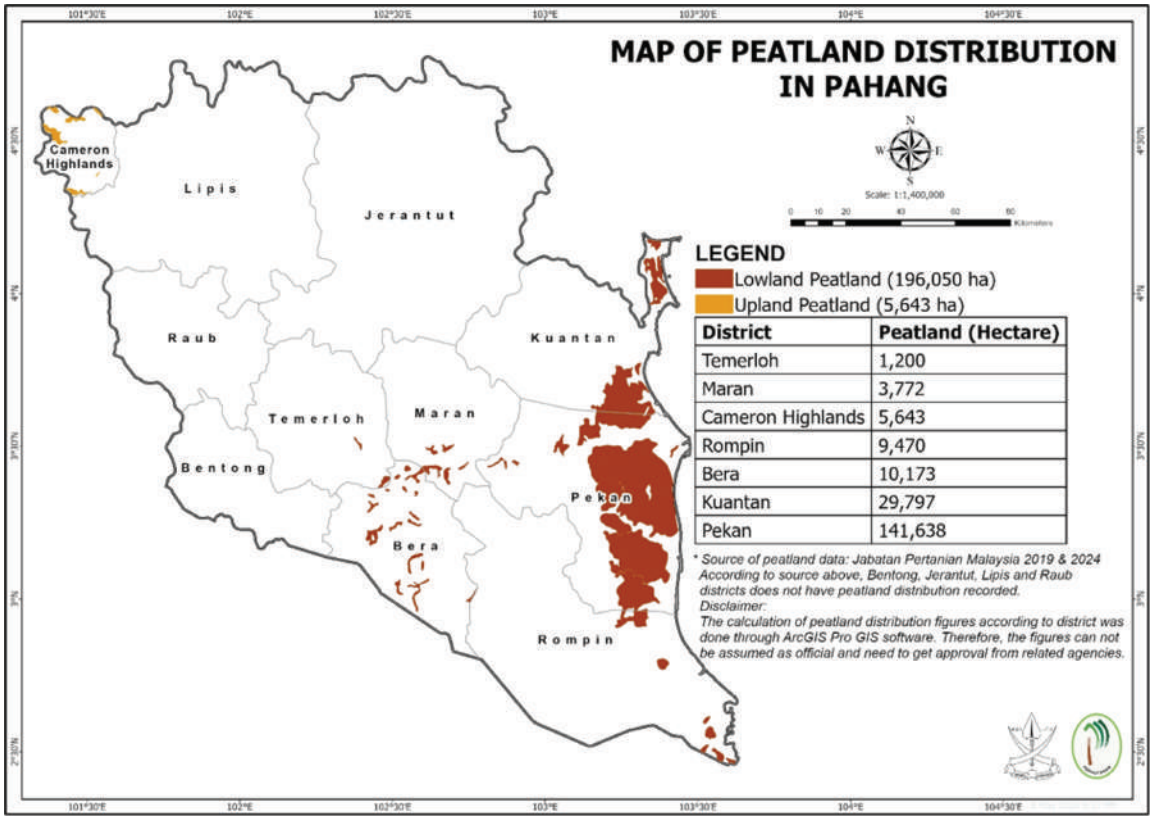

Figure A2. Distribution of peatland in Pahang.

North Selangor Peat Swamp Forest: Managing at Scale

The North Selangor Peat Swamp Forest (NSPSF) (Figure A3) covering 81,530 hectares across five Permanent Reserved Forests in Kuala Selangor, Sabak Bernam and Hulu Selangor, is the second largest contiguous peat swamp forest in Peninsular Malaysia. It harbours 107 tree species, 173 bird species, 46 mammal species and more than 120 fish species, alongside critically threatened flora including *ramin melawis* (*Gonystylus bancanus*, Critically Endangered), *meranti bakau* (*Rubroshorea uliginosa*, Endangered) and *meranti paya* (*Rubroshorea platycarpa*, Endangered). The NSPSF complex stores an estimated 143.63 million tonnes of carbon, with 137 million tonnes sequestered in below-ground peat soils and 6.63 million tonnes in above-ground biomass. This carbon stock is equivalent to 527 million tonnes of CO_2e, highlighting the significant climate mitigation potential that can be realised through the continued protection and conservation of this reserve. (Selangor State Forestry Department 2025a).

Despite its protected status, the NSPSF faces significant pressures from drainage, encroachment and recurring fires that have collectively undermined the ecological integrity of portions of the landscape. The Raja Musa Forest Reserve has nonetheless emerged as a restoration model, where a partnership between the State Forestry Department, GEC, local communities and the private sector since 2008. A combination of: canal blocking and rewetting degraded peatlands; community-based fire prevention; water level monitoring using piezometers; and active replanting of native species have successfully rehabilitated degraded areas and led to a 99% reduction in fires since 2014. These experiences have directly informed the preparation of the third Integrated Management Plan (2025 to 2034), which adopted six targeted management zones integrating climate mitigation, hydrological restoration, biodiversity conservation and sustained community engagement across the entire landscape (Selangor State Forestry Department 2025a).

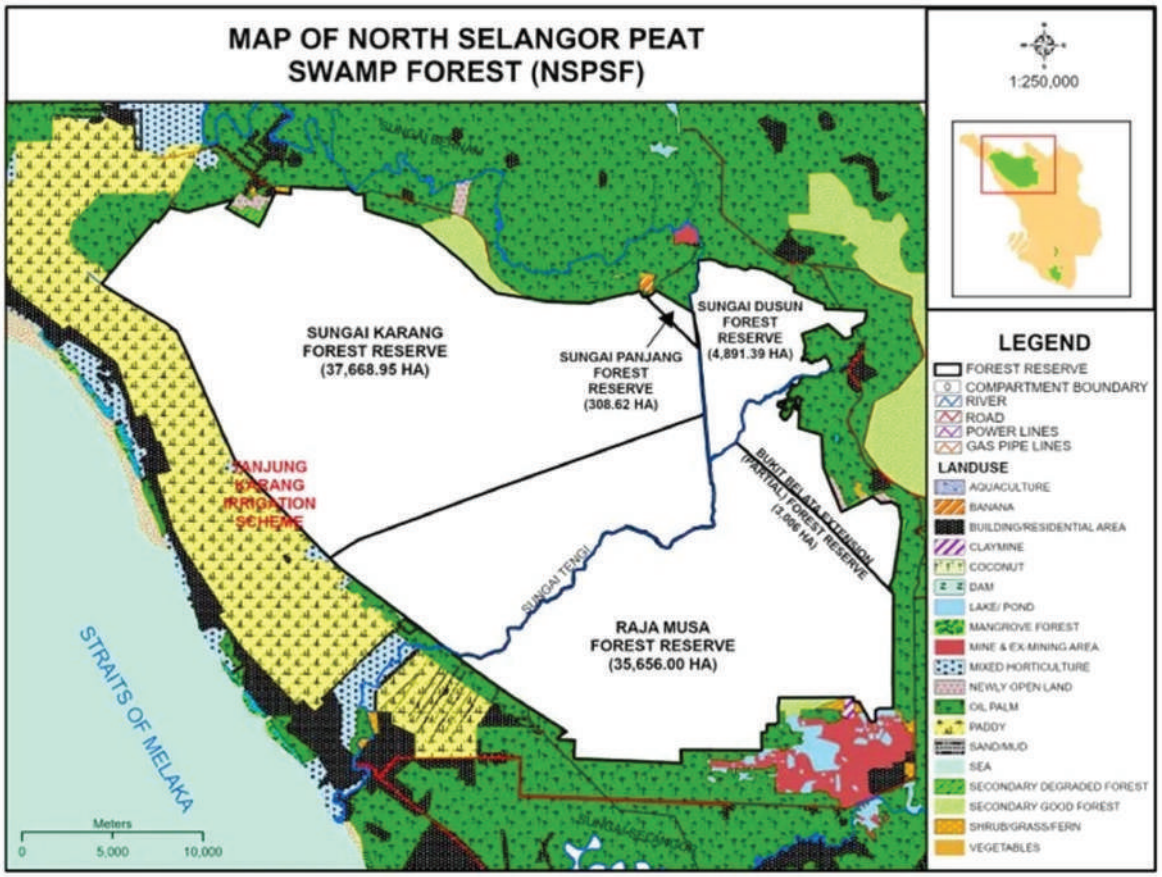

Figure A3. Map of the North Selangor Peat Swamp Forest (NSPSF) showing the five Permanent Reserved Forests comprising Raja Musa Forest Reserve (35,656 ha), Sungai Karang Forest Reserve (37,668.95 ha), Sungai Panjang Forest Reserve (308.62 ha), Sungai Dusun Forest Reserve (4,891.39 ha) and Bukit Belata Extension Forest Reserve (3,006 ha), together with the diversity of surrounding land uses including aquaculture, agriculture, plantations and residential areas (Selangor State Forestry Department, 2025a).

The South Selangor Peatland Landscape: Conservation at the Urban Fringe

The South Selangor Peat Swamp Forest (SSPSF) (Figure A4), covering 9,514.42 hectares across four Permanent Reserved Forests in Kuala Langat and Sepang districts, represents some of the last remaining peat swamp forest in southern Selangor. First gazetted in 1927, the landscape underwent significant transformation from 1974 onward due to degazettment of large portions of the landscape due to development pressures, leaving these remnant forests as critical refuges for threatened species including *meranti bunga* (*Rubroshorea teysmanniana*, Critically Endangered), *meranti bakau* (*Rubroshorea uliginosa*, Endangered) and *meranti paya* (*Rubroshorea platycarpa*, Endangered). The intact peat area of the SSPSF contains approximately 439,276 tonnes of biomass carbon stock, which is equivalent to 1.61 million tonnes of CO_2e. Based on the average peat depth measurements, the SSPSF is estimated to store about 9.29 million tonnes of below-ground carbon, corresponding to 34.09 million tonnes of CO_2e. (Selangor State Forestry Department 2025b).

A defining conservation challenge for this landscape has been the persistent threat of encroachment, drainage and recurring peat fires within and adjacent to the Kuala Langat South Forest Reserves. Given the SSPSF's location at the urban fringe of Greater Kuala Lumpur and its immediate proximity to Kuala Lumpur International Airport, peat fires in

this landscape carry consequences that extend well beyond ecological loss, directly affecting air quality, public health, airport operations and the livelihoods of surrounding communities. Active fire prevention through hydrological restoration, canal blocking and sustained water table management is therefore the single most critical management intervention required to safeguard what remains of this landscape. The local Temuan Orang Asli community, who have maintained a long presence within and around these forests, have demonstrated meaningful commitment to forest stewardship through active participation in replanting and monitoring efforts (Koshy 2023). Their continued involvement in fire prevention, early warning monitoring and rehabilitation activities represents an invaluable and underutilised resource in the long-term protection of the SSPSF. The IMP-SSPSF 2025-2034 formalises this integrated approach across four management zones, embedding fire prevention, nature-based hydrological restoration and sustained community engagement as the cornerstones of landscape management (Selangor State Forestry Department 2025b).

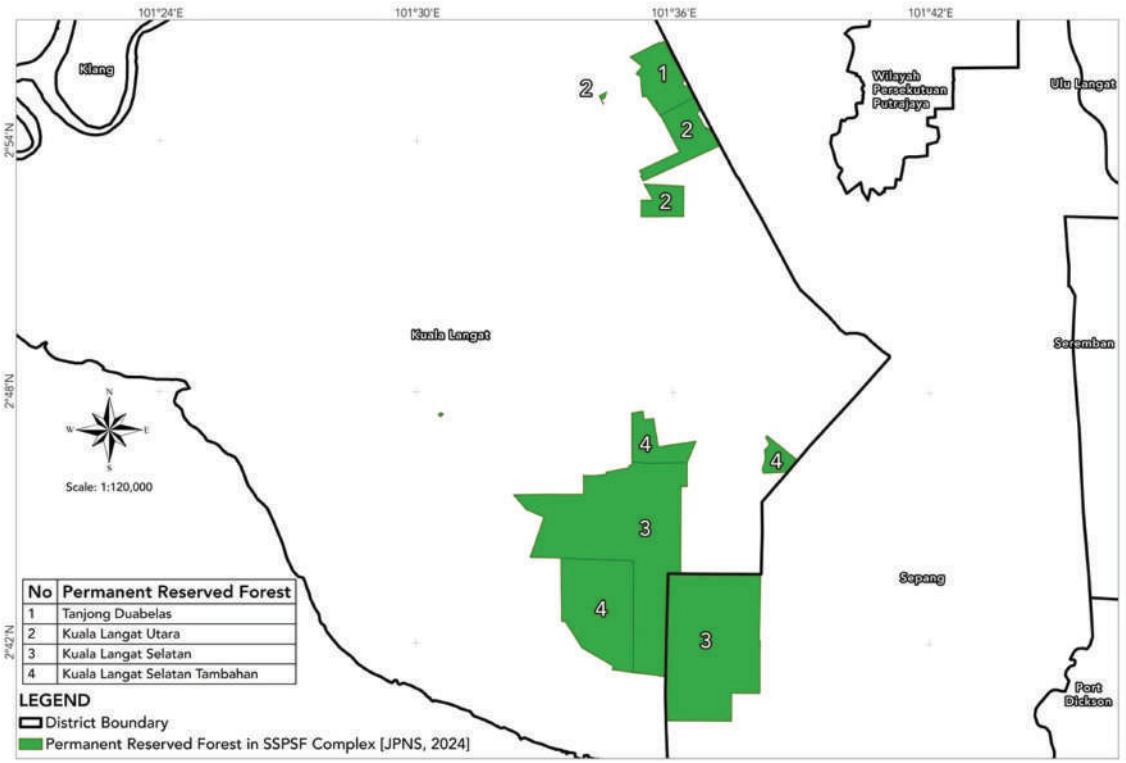

Figure A4. Gazetted Permanent Reserved Forests of the South Selangor Peat Swamp Forest (SSPSF) complex across the Kuala Langat and Sepang districts in the southern Selangor, covering a total area of 9,514.42 hectares across four forest reserves (Selangor State Forestry Department 2025b).

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CHAPTER 23

Rimba Ilmu and its role in plant conservation

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Abstract: Rimba Ilmu Botanic Garden, established in 1974 within Universiti Malaya, represents Malaysia's first university-based botanic garden and the largest campus forest garden in the Klang Valley. Originally developed from an abandoned rubber estate, it has evolved into a 57.3-hectare living repository housing approximately 1,500 tropical plant species, including numerous rare, endemic, and threatened taxa. Designed as a tropical rainforest garden, Rimba Ilmu integrates *ex situ* conservation, research, education, and public engagement within an urban setting. The garden maintains significant collections of Dipterocarpaceae, endemic palms, wild fruit trees, bamboos, citrus relatives, medicinal plants, and culturally important species. Its Conservatory of Rare Plants and Orchids safeguards hyper-endemic and threatened taxa, while the Medicinal Plant Collection preserves traditional knowledge associated with Malaysia's multicultural heritage. Together, these collections support germplasm conservation, crop improvement potential, and biocultural diversity. Rimba Ilmu is closely linked to the KLU Herbarium, which houses over 81,000 specimens and underpins national and international taxonomic projects, including the *Flora of Peninsular Malaysia and Flora Malesiana*. The integration of living collections and herbarium resources strengthens research in systematics, ecology, conservation biology, and biodiversity assessment. Beyond plant conservation, the garden sustains diverse fauna, demonstrating the ecological value of urban secondary forests. However, Rimba Ilmu faces challenges, including human resource and financial constraints, infrastructure limitations, wildlife management issues, and increasing environmental pressures such as extreme weather events. Strengthening institutional recognition, long-term planning, scientific research capacity, and collaborative networks will be essential to ensure its sustainability. As a living laboratory and conservation centre, Rimba Ilmu stands as a model for university -based tropical botanic gardens in urban Malaysia, bridging biodiversity conservation, scientific advancement, and community engagement.

INTRODUCTION

Established in 1974, Rimba Ilmu is a university botanic garden with the aim of supporting research and teaching in plant sciences, as well as conserving native plant species. Located within the Universiti Malaya campus in Kuala Lumpur (Figure 1), this botanic garden offers convenient access to students, educators, tourists, and nature enthusiasts alike. As Malaysia's first and oldest university botanic garden, today it stands as the largest campus forest garden, sustaining remarkable biological diversity in the Klang Valley. It is among the few systematically and scientifically organised botanic gardens in Malaysia, where most plant species cultivated are properly identified and labelled.

Originally covering 40 hectares in 1974, Rimba Ilmu has since expanded to 57.3 hectares and now serves as a living repository of approximately 1,500 tropical plant species, including rare, endemic and high conservation value taxa, making it a centre for conservation, research, and education (Mohamed 2000; Ong *et al.* 2025). The planting in

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the garden began in the early 1970s, when a piece of abandoned rubber estate within the campus was transformed into a botanical collection (Staton 1977; Wong and Mohamad 1997). Living samples were brought from different forests in Malaysia, targeting plant groups commonly referred to in botanical teaching, as well as research materials from various botanists and research students. Over the years, the Garden has accumulated a good number of diverse plant species in almost every plant form, from tiny bryophytes to low ferns, shrubs, epiphytes, climbers, palms, bamboos, and giant tall trees. These plants originated from different habitats, ranging from mangroves, peat swamp forests, streams and river banks, dipterocarp forests, heath forests, karst hills, and a small representation of highland species.

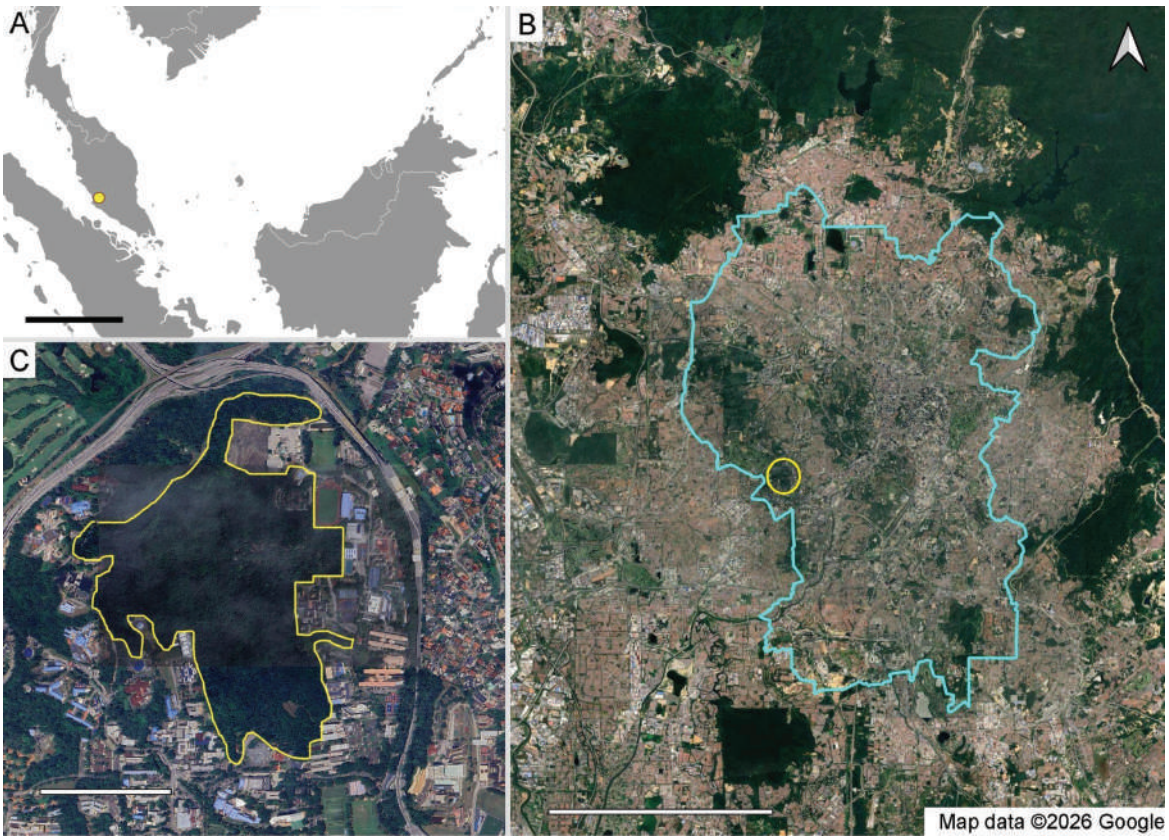

Figure 1. Map showing the location of Rimba Ilmu Botanic Garden (yellow) in **(A)** Peninsular Malaysia; **(B)** Federal Territory of Kuala Lumpur; and **(C)** close-up of the location within Universiti Malaya. Scale bars: A = 500 km, B = 10 km, and C= 0.5 km.

Building a rainforest garden

Since its establishment, the Rimba Ilmu Botanic Garden has adopted the concept of a tropical forest garden. The concept is reflected by its name: "*Rimba*" in Malay means forest, and "*Ilmu*" means knowledge. Many rainforest tree species were introduced and some portion of the original vegetation (the abandoned rubber trees with thick secondary growth) was set aside untouched for it to recover into a tropical lowland forest. Besides the timber species, several thematic collections were established, corresponding to the major research themes since the establishment of the garden and covering rainforest species that have specific anthropogenic uses or with certain cultural values (Soepadmo 1977; Stone 1977) (Figure 2). With Malaysia being a megadiverse country that is represented by more than 15,000 vascular plant species (Saw and Chung 2015), the conservation of Malaysian flora in Rimba Ilmu was prioritised towards native species with high conservation value and cultural importance in the country, which is a strategy that has been practised since its establishment (Stanton 1977).



Figure 2. The sketch map showing the different thematic collections in Rimba Ilmu (not according to scale).

Rimba Ilmu is generally low-lying, with an elevation range of 40 – 140 m above sea level. The soil is largely infertile and poor for agricultural purposes, but according to Stanton (1977) and Stone (1977), may still serve as a gallery of the rainforest species. The topography is largely undulating with ravines and gradual (10º) to steep slopes (30º – 45º) for about three-quarters of the total area. The major flat and more gentle area is located on its eastern side and has been the major planting area since 1971. A portion of the eastern flat area is low-lying and collects water, therefore forming a freshwater swamp area, where many swamp and riverine species were introduced and cultivated (Figure 2). The swamp area is home to some interesting palm species, including sago palm species (*Metroxylon sagu* Rottb. and *M. salomonense* (Warb.) Becc.), *kelubi* (*Eleiodoxa conferta* (Griff.) Burret), a relative of *salak* (*Salacca glabrescens* Griff.), *pinang raja* (*Cyrtostachys renda* Blume) and tree species such as *pulai paya* (*Alstonia spatulata* Blume), as well as herbs and shrubs that is common on wet ground, e.g., *Benstonea affinis* (Kurz) Callm. & Buerki, *Eriocaulon* spp. and members of Cyperaceae. A row of *gapis* (*Saraca cauliflora* Baker) was planted along

the stream bank, producing abundant, vibrant yellow to orange flowers every time they bloom. On one end of the *gapis* is a few clumps of handsome palm, *Arenga undulatifolia* Becc. – a native to Borneo – the other end erected with a few individuals of *pelawan* (*Tristaniopsis whiteana* (Griff.) Peter G.Wilson & J.T.Waterh.). Along the water's edge, several aroids are present, for instance, the thorny *Lasia spinosa* (L.) Thwaites and the elephant ears *Alocasia* and *Colocasia* spp. Meanwhile, the water itself supports the growth of the native water lily, *Barclaya motleyi* Hook.f., a few *Cryptocoryne* spp., the carnivorous *Utricularia* spp. and the non-native aquarium plant, *Mayaca fluviatilis* Aubl. All the aforementioned species were brought into cultivation at different periods of time during the last 52 years, establishing and forming a rather stable marsh and swamp system which also sustains other flora and fauna groups, including aquatic insects, reptiles, birds, and fishes.



Figure 3. (A) Entrance towards garden; **(B)** entrance to garden; **(C)** activity centre; **(D)** *Grammatophylum speciosum*; and **(E)** *Johannesteijsmannia lanceolata*.

After more than 50 years of development, most trees in the garden have grown into their lofty size, giving the garden a more or less forest-like appearance. The tall big trees with their wide-arching branches form the tree canopies that shield the ground from direct exposure to the sunlight and precipitation, helping to keep the lower canopy area cool and relatively humid. Old branches and fallen leaves on the ground accumulate over time to form a thick layer of plant litter. These organic materials were decomposed by fungi and ground-burrowing invertebrates that gradually migrated into the garden by chance. The on-site nutrient recycling process forms a thick layer of organic substrate, and together with its "forest-like" microclimate, conditions the soil to receive more rain forest species. With this in consideration, replanting of native tree species has been a regular activity, where around 100 to 300 individuals of trees representing different families were planted annually since the 2020s.

SPECIES WITH CONSERVATION IMPORTANCE

As the dominant timber member in the Malaysian rainforest, members of Dipterocarpaceae have been heavily felled in the Malaysian forest and thus warrant special attention in Rimba Ilmu. Today, there are more than 40 Dipterocarpaceae species being cultivated in the garden. Among these, there are species that have been classified as threatened under the IUCN Red List such as *Dipterocarpus rigidus* Ridl., *Dryobalanops tempehes* Slooten, and *Vatica flavida* Foxw. (IUCN 2026) (Table 1). Some of these early planted Dipterocarpaceae are as tall as 30 – 40m with girth size at breast height reaching 120 cm. Nevertheless, more plantings have been added over the years, incorporating both existing species and new additions. Of these, *Richetia kuantanensis* (P.S.Ashton) P.S.Ashton & J.Heck. is a species once thought extinct in the wild but was rediscovered in 2014 (Nasir *et al*. 2017), along with other hyper-endemic species like *V. yeechongii* Saw, which adds exceptional conservation value to the garden. Many of the said species cultivated have reached maturity and begun to bloom in the last few years.

Besides the Dipterocarpaceae, Rimba Ilmu garden is rich with representatives of popular timber species, including the national tree of Malaysia, *merbau* (*Intsia palembanica* Miq.), *kempas* (*Koompassia malaccensis* Maingay), and *nyatoh* (*Palaquium* spp.) amongst others. There are also examples of important timber species that warrant further conservation attention, for instance, Bornean ironwood (*Eusideroxylon zwageri* Teijsm. & Binn.), a highly durable, but slow-growing timber that is Sarawak's official state tree and has a strong cultural connection with local tribes in Borneo. Other forest tree species, *cempaka* (Magnoliaceae), *kedondong* (Burseraceae), *medang* (Lauraceae), *mempening* (Fagaceae), *penarahan* (Myristicaceae), *podo* (Podocarpaceae), and members of Elaeocarpaceae, Euphorbiaceae, Fabaceae, Malvaceae, Myrtaceae, Sapindaceae, etc., were variously planted in the garden. In recent years, planting has expanded into secondary forest areas dominated by old rubber trees, aiming to enrich species diversity and enhance forest recovery. An elaboration on the secondary forest and spontaneous species (i.e., those colonised through natural events) that occurred in the Rimba Ilmu has been provided by Ong *et al*. (2025).

The centerpiece of the woody plant collection are the endemic tree species (Table 2), including *Dillenia albiflos* (Ridl.). Hoogland, *Glenniea penangensis* (Ridl.) Leenh., *Maingaya malayana* Oliv., as well as various endemic palms, such as *Livistona endauensis* J.Dransf. & K.M. Wong, *Johannesteijsmannia lanceolata* J.Dransf., *J. magnifica* J.Dransf., and *J. perakensis* J.Dransf. etc. The genus *Johannesteijsmannia* is only represented by four species worldwide, where Rimba Ilmu Garden has all four of them (including *J. altifrons* (Rchb.f. & Zoll.) H.E.Moore), where three of these species have already reached their mature stage by blooming and bearing fruits. The assembling of a diverse array of tree species is to simulate Malaysian rainforest vegetation, while also functioning as a long-term experiment to assess the co-existence and inter-relationship of these different tree species.

Table 1. Examples of tree species with important conservation value found in Rimba Ilmu are shown here. Two conservation statuses are provided for each species listed: the upper row indicates the Malaysian Red List status according to Yong *et al*. (2021a, 2021b), while the lower row indicates the global IUCN Red List status according to the IUCN Red List (2026). The classification of Dipterocarpaceae follows Ashton and Heckenhauer (2022).

	Family	Species	Red list category	Notes
1.	Arecaceae	*Borassodendron machadonis* (Ridl.) Becc.	Malaysia: NE IUCN: VU	Peninsular Malaysia
2.	Dipterocarpaceae	*Anisoptera laevis* Ridl.	Malaysia: LC IUCN: VU	Peninsular Malaysia and Borneo
3.	Dipterocarpaceae	*Anthoshorea bracteolata* (Dyer) P.S.Ashton & J.Heck.	Malaysia: LC IUCN: EN	Peninsular Malaysia and Borneo
4.	Dipterocarpaceae	*Anthoshorea hypochra* (Hance) P.S.Ashton & J.Heck.	Malaysia: VU IUCN: EN	Peninsular Malaysia
5.	Dipterocarpaceae	*Anthoshorea roxburghii* (G.Don) P.S.Ashton & J.Heck.	Malaysia: NT nearly meeting VU	Peninsular Malaysia
6.	Dipterocarpaceae	*Dipterocarpus baudii* Korth.	Malaysia: LC IUCN: VU	Peninsular Malaysia
7.	Dipterocarpaceae	*Dipterocarpus costatus* C.F.Gaertn.	Malaysia: VU IUCN: EN	Peninsular Malaysia
8.	Dipterocarpaceae	*Dipterocarpus elongatus* Korth.	Malaysia: VU IUCN: CR	Peninsular Malaysia and Borneo
9.	Dipterocarpaceae	*Dipterocarpus gracilis* Blume	Malaysia: LC IUCN: VU	Peninsular Malaysia and Borneo
10.	Dipterocarpaceae	*Dipterocarpus grandiflorus* (Blanco) Blanco	Malaysia: LC IUCN: EN	Peninsular Malaysia and Sabah
11.	Dipterocarpaceae	*Dipterocarpus rigidus* Ridl.	Malaysia: VU IUCN: VU	Peninsular Malaysia and Sarawak
12.	Dipterocarpaceae	*Dipterocarpus tempehes* Slooten	Malaysia: EN IUCN: EN	Peninsular Malaysia and Borneo
13.	Dipterocarpaceae	*Dryobalanops aromatica* C.F.Gaertn.	Malaysia: NT IUCN: VU	Peninsular Malaysia and Borneo
14.	Dipterocarpaceae	*Dryobalanops oblongifolia* Dyer	Malaysia: LC IUCN: EN	Peninsular Malaysia
15.	Dipterocarpaceae	*Hopea beccariana* Burck	Malaysia: LC IUCN: VU	Peninsular Malaysia and Borneo

16.	Dipterocarpaceae	*Hopea johorensis* Symington	Malaysia: VU IUCN: VU	Peninsular Malaysia
17.	Dipterocarpaceae	*Hopea kerangasensis* P.S.Ashton	Malaysia: EN IUCN: VU	Peninsular Malaysia and Sarawak
18.	Dipterocarpaceae	*Hopea odorata* Roxb.	Malaysia: VU IUCN: VU	Peninsular Malaysia
19.	Dipterocarpaceae	*Hopea pedicellata* (Brandis) Symington	Malaysia: NT nearly meeting VU IUCN: EN	Peninsular Malaysia and Borneo
20.	Dipterocarpaceae	*Hopea subalata* Symington	Malaysia: EN IUCN: EN	Peninsular Malaysia
21.	Dipterocarpaceae	*Neobalanocarpus heimii* (King) P.S.Ashton	Malaysia: NT IUCN: EN	Peninsular Malaysia
22.	Dipterocarpaceae	*Parashorea densiflora* Slooten & Symington	Malaysia: NT IUCN: NT	Peninsular Malaysia
23.	Dipterocarpaceae	*Rubroshorea dasyphylla* (Foxw.) P.S.Ashton & J.Heck.	Malaysia: VU IUCN: NT	Peninsular Malaysia and Borneo
24.	Dipterocarpaceae	*Rubroshorea kunstleri* (King) P.S.Ashton & J.Heck.	Malaysia: NT IUCN: LC	Peninsular Malaysia and Borneo
25.	Dipterocarpaceae	*Rubroshorea pauciflora* (King) P.S.Ashton & J.Heck.	Malaysia: LC IUCN: NT	Peninsular Malaysia and Borneo
26.	Dipterocarpaceae	*Rubroshorea platyclados* (Slooten ex Endert) P.S.Ashton & J.Heck.	Malaysia: LC IUCN: NT	Peninsular Malaysia and Borneo
27.	Dipterocarpaceae	*Shorea foxworthyi* Symington	Malaysia: VU IUCN: VU	Peninsular Malaysia and Borneo
28.	Dipterocarpaceae	*Shorea laevis* Ridl.	Malaysia: LC IUCN: VU	Peninsular Malaysia and Borneo
29.	Dipterocarpaceae	*Shorea materialis* Ridl.	Malaysia: EN IUCN: EN	Peninsular Malaysia and Sarawak
30.	Dipterocarpaceae	*Shorea maxwelliana* King	Malaysia: LC IUCN: NT	Peninsular Malaysia and Borneo
31.	Dipterocarpaceae	*Shorea sumatrana* (Slooten) Desch	Malaysia: NT IUCN: EN	Peninsular Malaysia

32.	Dipterocarpaceae	*Vatica flavida* Foxw.	Malaysia: CR IUCN: CR	Peninsular Malaysia
33.	Dipterocarpaceae	*Vatica nitens* King	Malaysia: NT IUCN: NT	Peninsular Malaysia and Borneo
34.	Dipterocarpaceae	*Vatica pauciflora* Blume	Malaysia: NT IUCN: VU	Peninsular Malaysia and Borneo
35.	Dipterocarpaceae	*Vatica stapfiana* (King) Slooten	Malaysia: VU IUCN: VU	Peninsular Malaysia and Borneo
36.	Dipterocarpaceae	*Vatica yeechongii* Saw	Malaysia: CR IUCN: CR	Peninsular Malaysia
37.	Hamamelidaceae	*Maingaya malayana* Oliv.	Malaysia: NE IUCN: VU	Peninsular Malaysia
38.	Lauraceae	*Eusideroxylon zwageri* Teijsm. & Binn.	Malaysia: NE IUCN: VU	Borneo
39.	Lecythidaceae	*Careya arborea* Roxb.	Malaysia: VU IUCN: LC	Peninsular Malaysia
40.	Thymelaceae	*Aquilaria hirta* Ridl.	Malaysia/IUCN: VU	Peninsular Malaysia
41.	Thymelaceae	*Aquilaria malaccensis* Lam.	Malaysia: VU IUCN: CR	Peninsular Malaysia and Sabah

Table 2. Examples of Malaysian endemic plant species cultivated at Rimba Ilmu.

	Family	Species	Notes
1.	Arecaceae	*Licuala khoonmengii* Saw	Endemic to Pahang
2.	Arecaceae	*Licuala sallehana* Saw	Endemic to Terengganu
3.	Arecaceae	*Livistona endauensis* J. Dransf. & K.M.Wong	Endemic to Endau-Rompin and Bukit Bauk, Terengganu
4.	Balsaminaceae	*Impatiens vinosa* Kiew	Endemic to Kelantan
5.	Begoniaceae	*Begonia abdullahpieei* Kiew	Hyper-endemic to Perak
6.	Begoniaceae	*Begonia alpina* L.B.Sm. & Wassh.	Hyper-endemic to Genting Highland
7.	Begoniaceae	*Begonia conipila* Irmsch. ex Kiew	Endemic to Sarawak's limestone area
8.	Begoniaceae	*Begonia holttumii* Irmscher	Endemic to Peninsular Malaysia
9.	Begoniaceae	*Begonia kingiana* Irmsch.	Native to Peninsular Malaysia - Limestone area
10.	Begoniaceae	*Begonia nurii* Irmsch.	Limestone species
11.	Begoniaceae	*Begonia rajah* Ridl.	Endemic to Terengganu and Johor
12.	Begoniaceae	*Begonia reginula* Kiew	Endemic to Terengganu and Negeri Sembilan
13.	Begoniaceae	*Begonia rhoephila* Ridl.	Endemic to Selangor, Peninsular Malaysia
14.	Begoniaceae	*Begonia ruthiae* S.Julia	Endemic to Sabah. Grows in shady areas along riverbanks or on wet rocks at elevations between 200 and 500 m.
15.	Begoniaceae	*Begonia sirukitii* S.Julia & C.Y. Ling	Endemic to Sarawak. It grows on rocky cliffs or forested slopes near riverbanks
16.	Begoniaceae	*Begonia yenyeniae* J.P.C.Tan	Endemic to Endau-Rompin National Park, Johor
17.	Cycadaceae	*Cycas clivicola* K.D.Hill	A karst hill species, confined to northern Malay Peninsula
18.	Dilleniaceae	*Dillenia albiflos* (Ridl.) Hoogland	Endemic to Endau-Rompin
19.	Lecythidaceae	*Barringtonia corneri* Kiew & K.M.Wong	Endemic to Endau-Rompin area. Johor, Peninsular Malaysia
20.	Orchidaceae	*Bulbophyllum macrochilum* Rolfe	Endemic to Malaysia
21.	Orchidaceae	*Dendrobium pensile* Ridl.	Endemic to Peninsular Malaysia
22.	Orchidaceae	*Paphiopedilum rothschildianum* (Rchb.f.) Pfitzer	Endemic to Sabah. Also known as Gold of Kinabalu.
23.	Orchidaceae	*Paphiopedilum stonei* (Hook.f.) Pfitzer	Endemic to Sarawak
24.	Zingiberaceae	*Burbidgea nitida* Hook.f.	Endemic to Sarawak
25.	Zingiberaceae	*Globba nawawii* Ibrahim & K.Larsen	Endemic to Terengganu

Between the trees lies the understorey species of ferns, shrubs, herbs and climbers which were introduced for the garden, whereas a good number were self-established after the vegetation had grown into a partial forest look. Several tree ferns (*Alsophila latebrosa* Wall. ex Hook., *Sphaeropteris glauca* (Blume) R.M.Tryon, *S. moluccana* (R.Br. ex Desv.) R.M.Tryon, and *S. trichodesma* (Scort.) R.M.Tryon) were planted in the last 52 years. There are also the king fern (*Angiopteris evecta* (G.Forst.) Hoffm.), golden chicken fern (*Cibotium barometz* (L.) J.Sm.), and other fern and lycophyte species (e.g., *Adiantum* spp., *Asplenium* spp., *Drynaria* spp., *Selaginella* and *Tectaria* spp.). Among the fern collection, there is a rare and endangered fern, *Nephrolepis abrupta* (Bory) Mett., that was rescued from a karst hill in Perak that has been half quarried. A filmy fern, *Tricomanes* sp., and a gesneriad herb producing white flowers, *Codonoboea platypus* (C.B.Clarke) C.L.Lim is present in the shaded and humid ravine, with both likely to be the original species of the land that have survived the early forest conversion. Other shrub species like members of Liliaceae,

Pandanaceae, Rubiaceae, *Tacca* spp., *Thottea* spp. are also commonly present among the big trees. Meanwhile, native herb species like *Crinum asiaticum* L., *Hellenia speciosa* (J. Koenig) S.R.Dutta, *Orchidantha longiflora* (Scort.) Ridl., and *Proiphys amboinensis* (L.) Herb. were introduced for cultivation, however many of these species prefer slightly open areas and are often present in clumps at the edge of vegetation.

ESTABLISHING GERMPLASM COLLECTIONS

One of the very important functions of a botanic garden is sustaining living materials for future crop improvement programs. In the early 20th century, the world witnessed the role of tropical botanic gardens in the introduction and proliferation of two economically important crops that have reshaped the human lifestyle, namely rubber from the Singapore Botanic Gardens and oil palm from the Bogor Botanic Garden. With this in mind, Rimba Ilmu has embarked on a program to collect and preserve the local wild fruit tree species since its establishment (Soepadmo 1977). The collection includes notable species such as wild durian (*Durio graveolens* Becc., *D. oxleyanus* Griff., *D. wyatt-smithii* Kosterm.), malay apple (*Syzygium aqueum* (Burm.f.) Alston, *S. malaccense* (L.) Merr. & L.M.Perry), mangosteen and its relatives (*Garcinia mangostana* L., *G. celebica* L., etc.), *rambutan* (*Nephelium lappaceum* L.), *langsat* (*Lansium domesticum* Corrêa), and various breadfruit species like *Artocarpus* spp. With a collection of different members of the same genus, Rimba Ilmu serves as a resource for genetic improvement of native original species.

Emphasis has also been given to cultivate the "forgotten" fruit tree species ("*buah nadir*" in Malay), like *bacang* (*Mangifera foetida* Lour.), *buah perah* (*Elateriospermum tapos* Blume), *buah sengkuang* (*Dracontomelon dao* (Blanco) Merr. & Rolfe), *ceri terengganu* (*Lepisanthes alata* (Blume) Leenh.), *kundang* (*Bouea macrophylla* Griff.), *meninjau* (*Gnetum gnemon* L.), *nam-nam* (*Cynometra cauliflora* L.), *rambai* (*Baccaurea macrophylla* (Müll.Arg.) Müll.Arg., *B. motleyana* (Müll.Arg.) Müll.Arg.), *sentul* (*Sandoricum koetjape* (Burm.f.) Merr.), *tampoi* (*Baccaurea macrocarpa* (Miq.) Müll.Arg.), and *tempunik* (*Artocarpus rigidus* Blume) amongst others. They were once popular in rural areas, but are gradually disappearing from the fruit market due to the lack of large-scale production and supply inconsistencies. By conserving these species, the materials will always be available for further field and laboratory research to enhance the diversity of fruit trade in the country.

The Rimba Ilmu Citrus and Citroid Collection was initiated in the early 1980s, while the Bambusetum was launched in 2000. The former targets agricultural-importance crops while the latter focuses on species with landscaping value and industrial importance. During its peak, The Citrus and Citroid Collection comprises 51 species in 20 genera (Wong and Santiago 1997), with some plants variously planted in Rimba Ilmu where *kemuning gajah* (*Merrillia caloxylon* (Ridl.) Swingle), an extremely rare species, can still be found in this collection. Meanwhile, there are no less than 30 different bamboo species cultivated in the Bambusetum, covering exotic species (e.g., *Vietnamosasa pusilla* (A.Chev. & A.Camus) T.Q.Nguyen), species only known in cultivation (e.g., *Bambusa glaucophylla* Widjaja), local species (e.g., *Gigantochloa latifolia* Ridl.) and local endemic species (e.g., *Schizostachyum lengguanii* K.M.Wong). Some interesting examples are the giant bamboo (*Dendrocalamus giganteus* Munro), thorny bamboo (*Bambusa bambos* (L.) Voss), slender climbing bamboo (*Dinochloa malayana* S.Dransf.) and a much larger version of climbing bamboo, *Dinochloa scabrida* S.Dransf. Many of the bamboo planted in the Bambusetum produce edible bamboo shoots, but there are also examples of ornamental species (e.g., *Thyrsostachys siamensis* Gamble, *Bambusa vulgaris* Schrad. ex J.C.Wendl.) and species important for craft and construction (e.g., *Schizostachyum brachycladum* (Kurz ex Munro) Kurz).

THE CONSERVATORY OF RARE PLANTS AND ORCHIDS

The installation of The Conservatory of Rare Plants and Orchids in 2000 greatly enhanced the collection of threatened and rare plant species. This facility displays living specimens of the rarest and most threatened species in Peninsular Malaysia, focusing on wild orchids, *Begonias*, pitcher plants, gingers, aroids, wild pandans, miniature palms, and other shade and humid loving shrubs.

There are three groups of rarity displayed in the conservatory:

1. Plant species that are naturally endemic or restricted to particular localities or sites. If these are destroyed or transformed drastically, such species will be endangered. Technically, this is termed as hyper-endemic, and examples of these collections are *Begonia abdullahpieei* Kiew, *B. alpina* L.B.Sm. & Wassh., *Etlingera corneri* Mood & Ibrahim, *Impatiens vinosa* Kiew, *Licuala sallehana* L.G.Saw, *Paraphalaenopsis laycockii* (MR.Hedn.) A.D.Hawkes, and *Salacca minuta* Mogea.
2. Species that have a relatively wide distribution outside of Malaysia, but which are infrequently encountered (and thus rare) in the country. For example, *Calanthe tankervilleae* (Banks) M.W.Chase and *Vandopsis gigantea* (Lindley) Pfitzer.
3. Species that were once much more common, usually in lowland forests, but whose range and population have decreased as a result of habitat reduction. Such species may become threatened if the habitat area further decreases. Examples are *Agrostophyllum stipulatum* subsp. *bicuspidatum* (J.J.Sm.) Schuit, *Barringtonia corneri* Kiew & K.M.Wong, *Coelogyne asperata* Lind., and *Pandanus albifrons* B.C.Stone.

Besides, The Conservatory of Rare Plants and Orchids also acts as a site for experimental introduction of highland species. Plants collected from the highlands in Malaysia are first nurtured and acclimatised here, before being transferred into the garden (or continued to be maintained within the conservatory if the species prefers a higher humidity environment). *Dacrycarpus imbricatus* (Blume) de Laub., *Pandanus klossii* Ridl, and *Paphiopedilum rothschildianum* (Rchb.f.) Stein, are among such examples. The facility also displays endemic wild orchid species that were badly threatened by overharvesting such as *Bulbophyllum macrochilum* Rolfe, *Dendrobium pensile* Ridl., and *Paphiopedilum stonei* (Hook.) Stein.

CONSERVATION OF TRADITIONAL KNOWLEDGE

Rimba Ilmu has also played a role in the conservation of local and traditional knowledge, in addition to the preservation of forest plant species. The key setup that addresses this aspect is the Medicinal Plant Collection, established at the garden's inception (Table 3). More than 380 medicinal plant species have been recorded in Rimba Ilmu (Mohamed 2000), with about 80 of them cultivated at the core Medicinal Plant area (Wong 2001). The medicinal plants maintained in the garden are represented by native rainforest species (e.g., *Curculigo latifolia* Dryand. ex W.T.Aiton, *Eurycoma longifolia* Jack, *Labisia pumila* (Blume) Fern., *Scaphium macropodum* (Miq.) Beumée ex K.Heyne) as well as foreign species that have long been introduced to Malaysia for their medicinal uses (e.g., *Euphorbia tirucalli* L., *Jatropha multifida* L., *Senna alata* (L.) Roxb.). The traditional Malay medicinal practice has a highly mixed origin, with elements of Arabic, Indian (Ayurvedic), Javanese, Siamese, Sundanese, local natives, and others. This is well reflected by the great diversity of the medicinal herbs maintained by the rural communities. In a multiracial society like Malaysia, knowledge is often shared freely, where traditional Malay medicinal herbs are also appreciated and have entered the traditional medicinal practice of other ethnic groups. Rimba Ilmu's medicinal plant collection provides a glimpse into the country's rich medicinal flora, selectively preserving some of the most interesting species, from species with rich alkaloids

to those with high bioprospecting potential. Among the examples are agarwood (*Aquilaria hirta* Ridl. and *A. malaccensis* Lam.), *dukung anak hutan* (*Phyllanthus watsonii* Airy Shaw), *gelam* (*Melaleuca cajuputi* Maton & Sm. ex R.Powell), *petawali* (*Tinospora crispa* (L.) Hook.F. & Thomson), snakeroot (*Rauvolfia serpentina* (L.) Benth. ex Kurz), *temu hitam* (*Curcuma aeruginosa* Roxb.), *temu kunci* (*Boesenbergia rotunda* (L.) Mansf.), and others.

Table 3. Examples of plant species with important medicinal and cultural value that can be encountered in Rimba Ilmu.

	Family	Species
1.	Apiaceae	*Eryngium foetidum* L.
2.	Apocynaceae	*Catharanthus roseus* (L.) G.Don
3.	Arecaceae	*Cocos nucifera* L.
4.	Aristolochiaceae	*Thottea tomentosa* (Blume) Ding Hou
5.	Asphodelaceae	*Aloe vera* (L.) Burm.f.
6.	Asteraceae	*Elephantopus scaber* L.
7.	Blechnaceae	*Stenochlaena palustris* (Burm.f.) Bedd.
8.	Costaceae	*Hellenia speciosa* (J.Koenig) S.R.Dutta
9.	Euphorbiaceae	*Baccaurea ramiflora* Lour.
10.	Euphorbiaceae	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.
11.	Fabaceae	*Parkia speciosa* Hassk.
12.	Lauraceae	*Litsea garciae* Vidal
13.	Malvaceae	*Urena lobata* L.
14.	Melastomataceae	*Melastoma malabathricum* L.
15.	Menispermaceae	*Tinospora crispa* (L.) Hook.f. & Thomson
16.	Opihioglossaceae	*Helminthostachys zeylanica* (L.) Hook.
17.	Oxalidaceae	*Averrhoa carambola* L.
18.	Phyllanthaceae	*Phyllanthus oxyphyllus* Miq.
19.	Piperaceae	*Piper betle* L.
20.	Poaceae	*Cymbopogon nardus* (L.) Rendle
21.	Primulaceae	*Labisia pumila* (Blume) Benth. & Hook.f. ex Fern.-Vill.
22.	Rutaceae	*Citrus medica* L.
23.	Simaroubaceae	*Eurycoma longifolia* Jack
24.	Thymelaeaceae	*Aquilaria malaccensis* Lam.
25.	Zingiberaceae	*Alpinia galanga* (L.) Willd.
26.	Zingiberaceae	*Curcuma longa* L.
27.	Zingiberaceae	*Etlingera elatior* (Jack) R.M.Sm.
28.	Zingiberaceae	*Zingiber officinale* Roscoe

Several plant species with culinary value are cultivated alongside medicinal plants within the study area (Table 3). These species include *asam gelugur* (*Garcinia atroviridis* Griff. ex T.Anderson), tamarind (*Tamarindus indica* L.), *buah keluak* or *kepayang* (*Pangium edule* Reinw.), cashew (*Anacardium occidentale* L.), and lemongrass (*Cymbopogon citratus* (DC.) Stapf). In addition, several species commonly consumed as Malay salad (*ulam*) are cultivated within the same area, including *kesum* (*Persicaria ordorata* (Lour.) Sojak), *pegaga* (*Centella asiatica* (L.) Urban), *sambung nyawa* (*Gynura procumbens* (Lour.) Merr.), and young noni shoot (*Morinda citrifolia* L.). Many of these species are also traditionally regarded as having therapeutic properties. Spice crops are likewise interplanted among the medicinal herbs, such as nutmeg (*Myristica fragrans* Houtt.), clove (*Syzygium aromaticum* (L.) Merr. & L.M.Perry), basil leaves (*Ocimum basilicum* L.), *salam* leaves (*Syzygium polyanthum* (Wight) Walp.), cinnamon (*Cinnamomum verum* J.Presl.), black pepper (*Piper nigrum* L.), and turmeric (*Curcuma longa* L.). Notably, nutmeg and clove were introduced to Malaysia through the historical spice trade and represent some of the earliest forms of

commercial crop cultivation in Peninsular Malaysia. The diversity of culinary species and spices cultivated reflects the close relationship between Malaysia's rich food heritage and its multicultural society, correspondingly, the assemblage of medicinal and food plants at Rimba Ilmu mirrors this cultural heritage.

Other culturally important plants which could be encountered in the Rimba Ilmu Garden include, the betel piper (*Piper betle* L.) and the betel nut palm (*Areca catechu* L.), the two important components of the traditional sirih pinang or betel nut chewing custom. The lontar palm (*Borassus flabellifer* L.), with its huge and hardy palm leaf that was used as an early writing material in the Southeast Asian region before paper became affordable. The sugar palm (*Arenga pinnata* (Wurmb) Merr.), a forest species that was once commonly cultivated in rural areas for sugar production and fibre. The high-quality fibre is readily available on the surface of its trunk, and was once a popular ingredient for rope making. Besides, the fibre has been used in producing brooms, brushes, mats, and reinforced polymer composites in boat making in some local cultures. Both lontar and sugar palms were cultivated in Rimba Ilmu. There are also examples of poisonous plants in Rimba Ilmu, e.g., flame lily (*Gloriosa superba* L.) and *ipoh* tree (*Antiaris toxicaria* (J.F.Gmel.) Lesch.). The flame lily is highly lethal because the plant contains high levels of colchicine, a toxic alkaloid, but surprisingly, it is a popular herb in traditional medicine. Meanwhile, *ipoh* tree produces poisonous latex that is often collected by the native tribes and applied to the darts used in blowpipes for hunting.

SCIENTIFIC CONTRIBUTIONS AND SOCIAL IMPACTS

Currently, Rimba Ilmu is in the process of cataloguing all of their living and dried specimens. The Herbarium of Universiti Malaya, with its acronym KLU, houses more than 81,000 individuals of dried specimens, including historical collections dating as far back as 1908. With the digitisation of said records, a digital bridge can be created between researchers and Rimba Ilmu, making Rimba a reference centre in supporting knowledge transfer. The living collection in the garden and the herbarium collection have been essential resources for botanical research since the installation of these facilities. These materials were consulted in the major national projects like *Tree Flora of Peninsular Malaysia*, *Tree Flora of Sabah and Sarawak*, and later *Flora of Peninsular Malaysia*, as well as referred to in international projects like *Flora Malesiana*. Materials from Rimba Ilmu have been sourced by local and foreign researchers for a wide range of research, from systematic, phylogeny, anatomy, ecology, physiology, biochemistry and plant health to conservation status assessment. In addition to that, Rimba Ilmu is also maintaining a good relationship and active research collaborations with many local and overseas research institutions and botanical collection centres, supporting various biodiversity and conservation projects.

Moving away from academia, Rimba Ilmu works closely with many local agencies and organisations, from private, governmental to non-governmental organisations (NGOs) in promoting nature conservation and education. Among the regular partners in the last ten years are the Malaysian Nature Society (MNS), Kebun-kebun Bangsar, TRAFFIC International, Malaysia Cave and Karst Conservancy, Sunda Shelves, Forest House, YELL, and Roots and Shoots Malaysia. Other than that, Rimba Ilmu also facilitates and organises various training programs for local community groups, NGOs and students, particularly in the topics of reforestation and nature appreciation. Rimba Ilmu also plays a role in Klang Valley greening projects such as Rantaian Urban Green Spaces (RUGS). Besides functioning as a resource centre for the project, Rimba Ilmu contributes many wildlings for planting through the Free Tree Society, particularly in the effort of creating the Bangsar Ecological Connector.

IMPORTANCE OF FLORA-FAUNA INTERACTIONS AT RIMBA ILMU

The presence of diverse fauna is a key measure of the health and biodiversity of an environment. Rimba Ilmu has now developed into a mature secondary forest, where it has become a home to a significant number of terrestrial life such as small mammals, birds, reptiles, amphibians, and invertebrates (Ong *et al*. 2025). The diverse plant composition and vegetation stratification provide the heterogeneous microhabitats and niches required for different faunal species to thrive. For example, the different sections of the garden offer varied "architectures" that support specific spider guilds, resulting in 96 spider species recorded from the garden (Dzulhelmi and Norma-Rashid 2014). Rimba Ilmu also supports a diverse composition of insects that occupy different habitat niches, such as pygmy grasshoppers and odonates (understory and river vicinity), beetles and katydids (foliage and garden canopy), and fireflies and crickets (shrubs and grasses).

While generalist faunal species are no stranger to urban forests, specialists such as butterflies are also found under the canopy of these forests, as long as their necessities are met. Butterflies depend on their host plants as their caterpillars depend exclusively on specific host plants for survival (Syaripuddin *et al.* 2015). Occasionally-sighted butterflies such as Malaysia's national butterfly, the Rajah Brook birdwing, feed on the Aristolochiaceae that are found in the garden. Other insects showcasing host plant dependency include fruit flies which are attracted to plants by specific chemical compounds. The petals of *Murraya paniculata* (*kemuning lada*) produce chemicals that attract male fruit flies, other than for their consumption and sequestration (Chuah *et al.* 2001).

The wild fruit trees and young plant shoots growing within the garden serve as a "cafeteria" for our four-limbed visitors: the macaques, civets and frugivorous bats; which feed on various parts of plants such as fruits, leaves and petioles (Koh and Norma-Rashid 2020). Among the 11 bat species recorded, the Lesser Asiatic yellow bat (*Scotophilus kuhlii*) is an exclusive urban dweller, as Rimba Ilmu provides specific roosting and foraging niches that are absent in nearby primary and secondary forests (Nasir *et al*. 2021).

CHALLENGES AND FUTURE DIRECTIONS

The effective management and long-term sustainability of Rimba Ilmu Botanic Garden face multiple interrelated challenges arising from operational, financial, institutional, environmental, and ecological pressures. As the garden continues to grow in scope and public relevance, these challenges must be addressed through coordinated planning, adequate resourcing, and a clearly articulated management vision.

Maintaining a large and taxonomically diverse living collection requires a high level of horticultural, taxonomic, and ecological expertise. The large physical area of the garden further compounds these challenges, making regular maintenance, pest and disease surveillance, and safety inspections increasingly challenging. Without sufficient human resources and technical support, the long-term health and scientific value of the living collections would be at risk. In recent years, Rimba Ilmu has experienced a steady increase in visitors, including students, researchers, schools, and members of the general public. Visits range from self-guided tours to structured educational and interpretive programmes. Despite this growing demand, many of the garden's amenities such as pathways, seating, interpretive panels, rest areas and safety features are outdated, limited in number, or in need of major refurbishment. The protection of living collections and the safety of visitors require immediate attention. Current security measures are insufficient to address the garden's scale and complexity. Furthermore, the growing demand for guided nature interpretation walks underscores the need to train and hire more qualified nature guides.

As part of the university campus, the garden's operations and long-term direction are sometimes influenced by changing institutional priorities and administrative leadership. However, a botanic garden plays a critical role as a living laboratory, conservation centre, and educational resource. Its function must therefore be clearly defined, formally recognised, and embedded within the university's strategic framework. A comprehensive, long-term management plan developed through consultation and supported at the institutional level is essential to ensure continuity, resilience, and accountability, regardless of governance changes.

As a rainforest garden in an urban setting, Rimba Ilmu is frequently exposed to intense thunderstorms. Lightning strikes have repeatedly killed mature trees, while strong winds during severe storms have caused large-scale destruction. Over the past twenty years, at least three major storm events have uprooted more than a hundred large trees, resulting in significant ecological and financial losses. Wildlife such as long-tailed macaques, and stray dogs often seek refuge in Rimba Ilmu. While their presence reflects the ecological value of the garden, uncontrolled populations can lead to serious management issues. The long-tailed macaques often damage plant collections by grazing and snapping, leaving plants unsightly and weakened. Both macaques and stray dogs also threaten visitors and displace other smaller, but ecologically important species, disrupting the gradual recovery of forest ecosystems within the garden. Effective, ethical, and science-based wildlife management strategies are therefore urgently needed to restore ecological balance and protect both people and plants.

By deepening collaboration with local and international conservation centres, Rimba Ilmu can rise in the ranks as a leading university-based conservation institution, locally and internationally, establishing itself as a centre for tropical biodiversity conservation in urban Malaysia. As a scientific institution, Rimba Ilmu must keep itself intellectually alive through research. Trained and committed personnel with interest and enthusiasm need to be recruited, and funding for such research activities needs to be raised, as pointed out by Mohamed (2000). With its diverse plant collection capturing natural and cultural diversity and its rich scientific knowledge, Rimba Ilmu appeals as a one-stop centre for laypeople and researchers, endures, and continues to flourish. Going forward, stronger financial and human resources will help advance the garden's development.

REFERENCES

Ashton, P.S. and Heckenhauer, J. 2022. Tribe Shorea (Dipterocarpaceae subfamily Dipterocarpoideae) finally dissected. *Kew Bulletin* 77(4): 885–903. https://doi.org/10.1007/S12225-022-10057-W

Chuah, C.H., Yong, H.S. and Takabayashi, J. 2001. Male fruit fly (Diptera: Tephritidae) attractants from *Murraya paniculata* (Rutaceae) flowers. *Malaysian Journal of Chemistry* 3(1): 24–28.

Dzulhelmi, M. and Norma-Rashid, Y. 2014. Spider assemblages in Rimba Ilmu Botanical Garden, Kuala Lumpur, Malaysia. *Sains Malaysiana* 43(4): 497–502.

IUCN. 2026. The IUCN Red List of Threatened Species. Version 2025-2. https://www.iucnredlist.org

Koh, W. and Norma-Rashid, Y. 2020. Ethnoprimatology: Human-macaque interface in the University of Malaya campus. *Malaysian Journal of Science* 39(3): 17–44. https://doi.org/10.22452/mjs.vol39no3.2

Mohamed, H. 2000. The herbarium and botanic garden of University of Malaya. In *Proceedings of the First and Second Symposia on Collection Building and Natural History Studies in Asia*, Matsuura, K. (Ed.). *National Science Museum Monographs* 18: 69–75.

Nasir, N.M., Nasir, D.M. and Ramli, R. 2021. Diversity of bats in three selected forest types in Peninsular Malaysia. *Turkish Journal of Zoology* 45(2): 142–155. https://doi.org/10.3906/zoo-1912-50

Nasir, M.M., Richard, A.M., Akhirrudin, M.N., Endot, S. and Latiff, A. 2017. New discovery of *Shorea kuantanensis* Ashton (Dipterocarpaceae) in Peninsular Malaysia. *Malaysian Forester* 80: 125–128.

Ong, B., Yong, K.T., Sugumaran, M., Siti Syuhada, S., Ilyana, H. and Nurul Fitrah, M. 2025. Botanic garden profile: Rimba Ilmu (the 'Forest of Knowledge') at 50. *Sibbaldia: the International Journal of Botanic Garden Horticulture* 24(24). https://doi.org/10.24823/Sibbaldia.2025.2100

Saw, L.G. and Chung, R.C.K. 2015. The flora of Malaysia projects. *Rodriguésia* 66(4): 947–960. https://doi.org/10.1590/2175-7860201566415

Stone, B.C. 1977. Research themes for the University of Malaya Botanic Garden. In *The Role and Goals of Tropical Botanic Gardens*, B.C. Stone (Ed.), pp. 63–68. Proceedings of a symposium, Rimba Ilmu Botanic Garden of the University of Malaya, Kuala Lumpur, Malaysia, in conjunction with the ceremonial opening of the Rimba Ilmu by the Chancellor of the University, D.Y.M.M. Raja Permaisuri Agong, August 1974.

Soepadmo, E. 1977. Conservation of wild fruit tree species. In *The Role and Goals of Tropical Botanic Gardens*, B.C. Stone (Ed.), pp. 207–210. Proceedings of a symposium, Rimba Ilmu Botanic Garden of the University of Malaya, Kuala Lumpur, Malaysia, in conjunction with the ceremonial opening of the Rimba Ilmu by the Chancellor of the University, D.Y.M.M. Raja Permaisuri Agong, August 1974.

Stanton, W.R. 1977. Closing address: Synthesis, progress, policy and regional collaboration. In *The Role and Goals of Tropical Botanic Gardens*, B.C. Stone (Ed.), pp. 227–238. Proceedings of a symposium, Rimba Ilmu Botanic Garden of the University of Malaya, Kuala Lumpur, Malaysia, in conjunction with the ceremonial opening of the Rimba Ilmu by the Chancellor of the University, D.Y.M.M. Raja Permaisuri Agong, August 1974.

Syaripuddin, K., Sing, K.W. and Wilson, J.J. 2015. Comparison of butterflies, bats and beetles as bioindicators based on four key criteria and DNA barcodes. *Tropical Conservation Science* 8(1): 138–149.

Wong, K.M. and Mohamad, M. 1997. *Rimba Ilmu Guidebook No. 1: Rimba Ilmu—The University of Malaya's Garden of a Thousand Species—An Introduction to Malaysia's First University Botanic Garden*. Kuala Lumpur: Institute of Biological Sciences, University of Malaya.

Wong, K.M. and Santiago, L.A. 1997. *Rimba Ilmu Guidebook No. 2: The Rimba Ilmu's Citrus and Citroid Collection*. Kuala Lumpur: Institute of Biological Sciences, University of Malaya.

Wong, K.M. 2001. *Rimba Ilmu Guidebook No. 3: Medicinal Plants, Rain Forests and Us*. Kuala Lumpur: Institute of Biological Sciences, University of Malaya.

Yong, W.S.Y., Chua, L.S.L., Lau, K.H., Siti-Nur Fatinah, K., Cheah, Y.H., Yao, T.L., Rafidah, A.R. *et al.* 2021a. *Malaysia Red List: Plants of Peninsular Malaysia*. Vol. 1, Part I. Research Pamphlet No. 151. Kepong: Forest Research Institute Malaysia.

Yong, W.S.Y., Chua, L.S.L., Lau, K.H., Siti-Nur Fatinah, K., Cheah, Y.H., Yao, T.L., Rafidah, A.R. *et al*. 2021b. *Malaysia Red List: Plants of Peninsular Malaysia*. Vol. 1, Part II. Research Pamphlet No. 151. Kepong: Forest Research Institute Malaysia.

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CHAPTER 24

Plant adaptation strategies to climate change in Malaysian agriculture

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Abstract: Climate change poses significant effects and challenges to Malaysia's agricultural sector through rising temperatures, altered rainfall patterns, and increasing occurrences of extreme weather events. These climatic changes affect crop productivity, water availability, pest and disease dynamics, and the overall resilience of farming systems. An overview is provided of the current and projected impacts of climate change on major agricultural subsectors in Malaysia, namely rice, oil palm, rubber, and cocoa. Particular attention is given to the vulnerability of these crops to temperature stress, rainfall variability, droughts, and floods. Key adaptation strategies that can enhance agricultural resilience are examined, including the development of climate-resilient crop varieties, improved water management practices, climate-smart agriculture, and the use of climate information services and digital technologies. Sector-specific adaptation measures are discussed for rice, oil palm, rubber, and cocoa production systems. The importance of policy support, institutional strengthening, research, development, innovation, and multi-stakeholder collaboration in facilitating effective adaptation is also highlighted. Strengthening climate resilience through integrated and location-specific adaptation strategies will be essential and critical to sustaining agricultural productivity, ensuring food security, and supporting the long-term sustainability of Malaysia's agricultural sector in a changing climate.

INTRODUCTION

Climate change has emerged as one of the most pressing global challenges, with far-reaching implications for natural systems, socio-economic development, and food security. In Malaysia, the agriculture sector is particularly vulnerable to climate variability and change due to its strong dependence on climatic factors such as temperature, rainfall distribution, and seasonal stability (IPCC 2021; NRES 2024). Given its strategic role in ensuring national food supply, sustaining rural livelihoods, and supporting agro-based industries, climate-induced risks to agriculture represent a critical national concern. Global observations indicate a clear warming trend in surface temperatures alongside significant changes in precipitation patterns over the past century, reflecting the growing influence of climate change on the Earth's climate system (Figures 1 and 2).

In particular, observed and projected climatic changes, including rising temperatures, shifting rainfall patterns, and an increasing frequency and intensity of extreme weather events are already exerting measurable impacts on agricultural productivity in Malaysia (NRES 2024). These changes affect crop growth cycles, water availability, pest and disease dynamics, and livestock performance, thereby heightening risks to food security and farm income stability (FAO 2019az). Hence, a clear understanding of climate change trends and their sector-specific impacts on Malaysian agriculture is essential for guiding effective adaptation strategies and evidence-based policy interventions.

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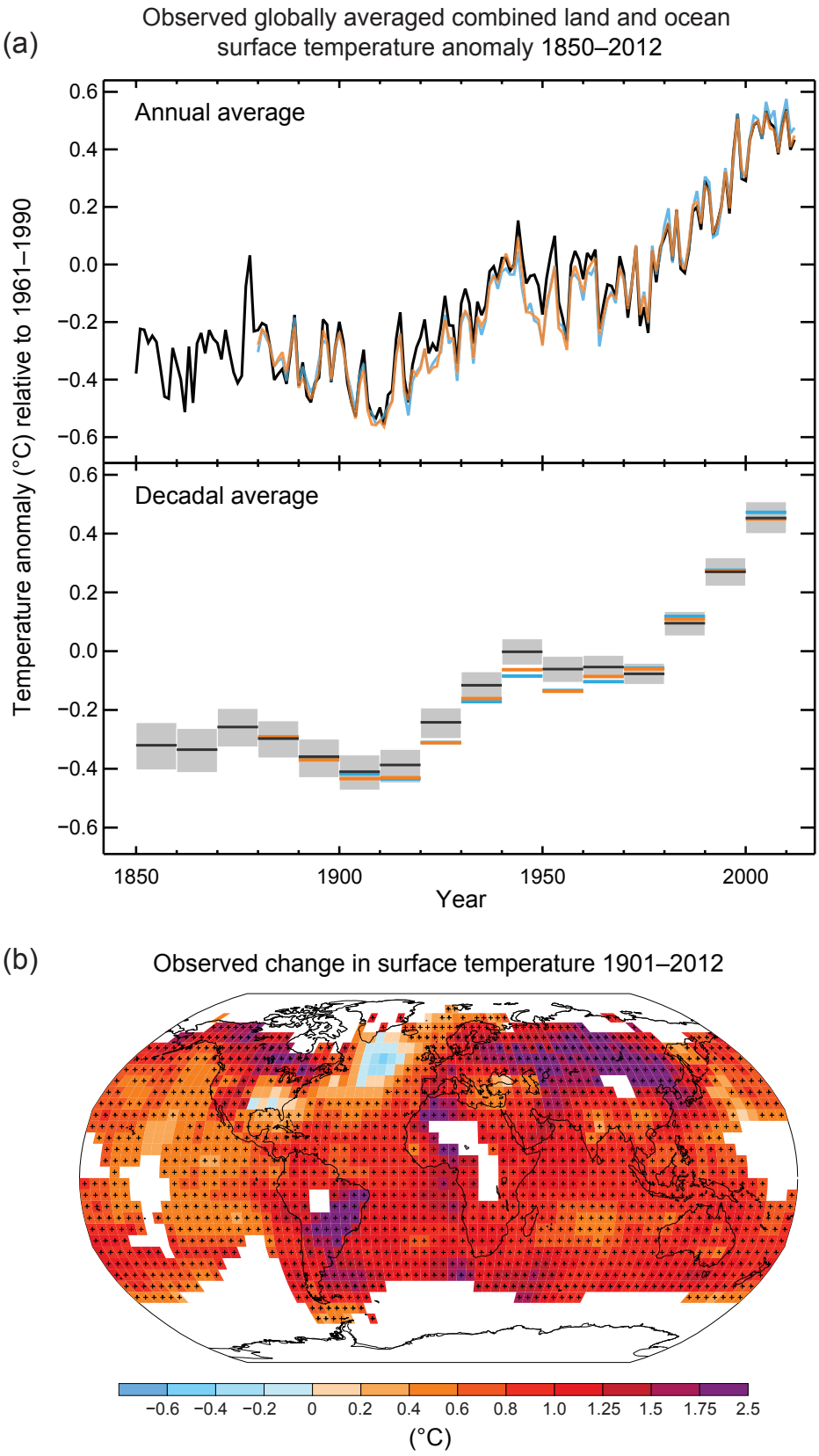


Figure 1. Global surface temperature anomalies and spatial patterns of observed temperature change during 1901–2012 (Source: IPCC 2013).

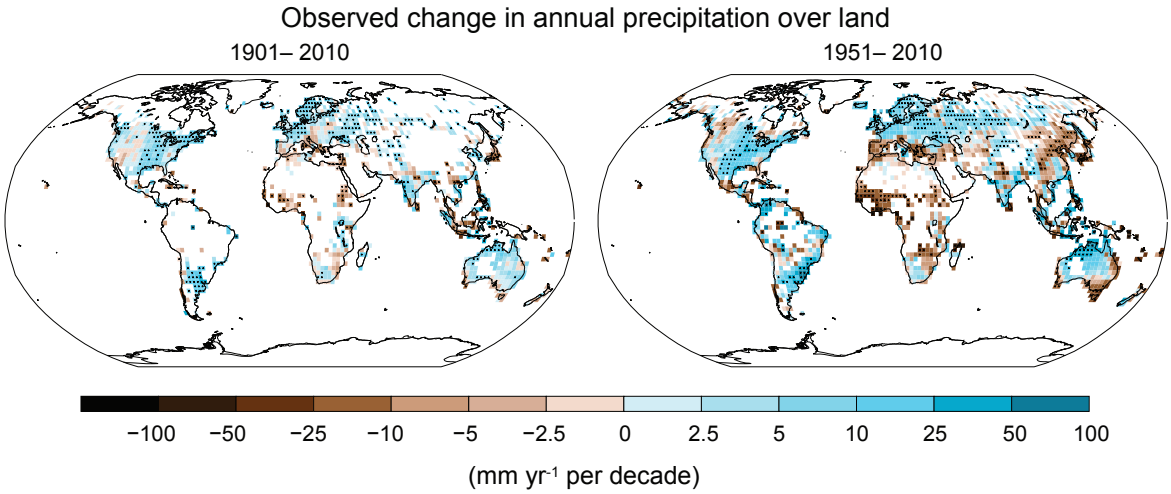


Figure 2. Spatial distribution of observed annual precipitation changes over land during 1901–2010 and 1951–2010 (Source: IPCC 2013).

In response to increasing climate variability and long-term climate change, building climate-resilient agricultural systems has become a national priority. Climate resilience in agriculture refers to the capacity of farming systems to anticipate, absorb, and adapt to climate-related stresses while sustaining productivity, ecosystem functions, and livelihoods (IPCC 2022). In the Malaysian context, strengthening resilience is particularly crucial given the sector's high sensitivity to temperature extremes, rainfall variability, and climate-related hazards such as floods and droughts.

Therefore, national policy frameworks, such as Malaysia's Fourth National Communication (NC4) Report to the United Nations Framework Convention on Climate Change (UNFCCC), underscore the importance of sector-specific and location-appropriate adaptation strategies to enhance agricultural resilience (NRES 2024). Effective adaptation extends beyond individual farm-level measures and requires an integrated approach encompassing crop genetic improvement, enhanced water and crop management, climate -smart agricultural practices, and enabling institutional and policy support. Accordingly, this section synthesises key adaptation strategies across major agricultural subsectors in Malaysia, with a particular focus on strengthening climate resilience in crop production.

OVERVIEW OF CLIMATE CHANGE IN MALAYSIA

Malaysia is located in the humid tropics and experiences relatively uniform temperatures throughout the year, with mean annual temperatures ranging between 26ºC and 28ºC and annual rainfall generally exceeding 2,000 mm (Tang 2019). Despite this apparent climatic stability, long-term observations indicate significant changes in key climate variables. According to Malaysia's NC4 to the UNFCCC, the country has experienced a clear warming trend over recent decades (Figure 3a), with mean surface temperatures increasing by approximately 0.14 – 0.25ºC per decade in some regions (NRES 2024).

In addition to rising temperatures, changes in rainfall patterns (Figure 3b) have been observed, characterised by increased variability in seasonal rainfall distribution rather than uniform changes in total annual precipitation (NRES 2024). Certain regions have experienced more intense rainfall events over shorter periods, while others are exposed to longer dry spells, thus flood and drought risk respectively. These changes are consistent with broader regional climate trends reported for Southeast Asia (IPCC 2021).

Climate projections for Malaysia indicate continued warming throughout the 21st century under both moderate and high greenhouse gas emission scenarios, accompanied by greater rainfall variability and an increased likelihood of extreme climate events (IPCC 2021; NRES 2024). These projected changes are expected to exacerbate climate risks for climate-sensitive sectors, particularly agriculture.

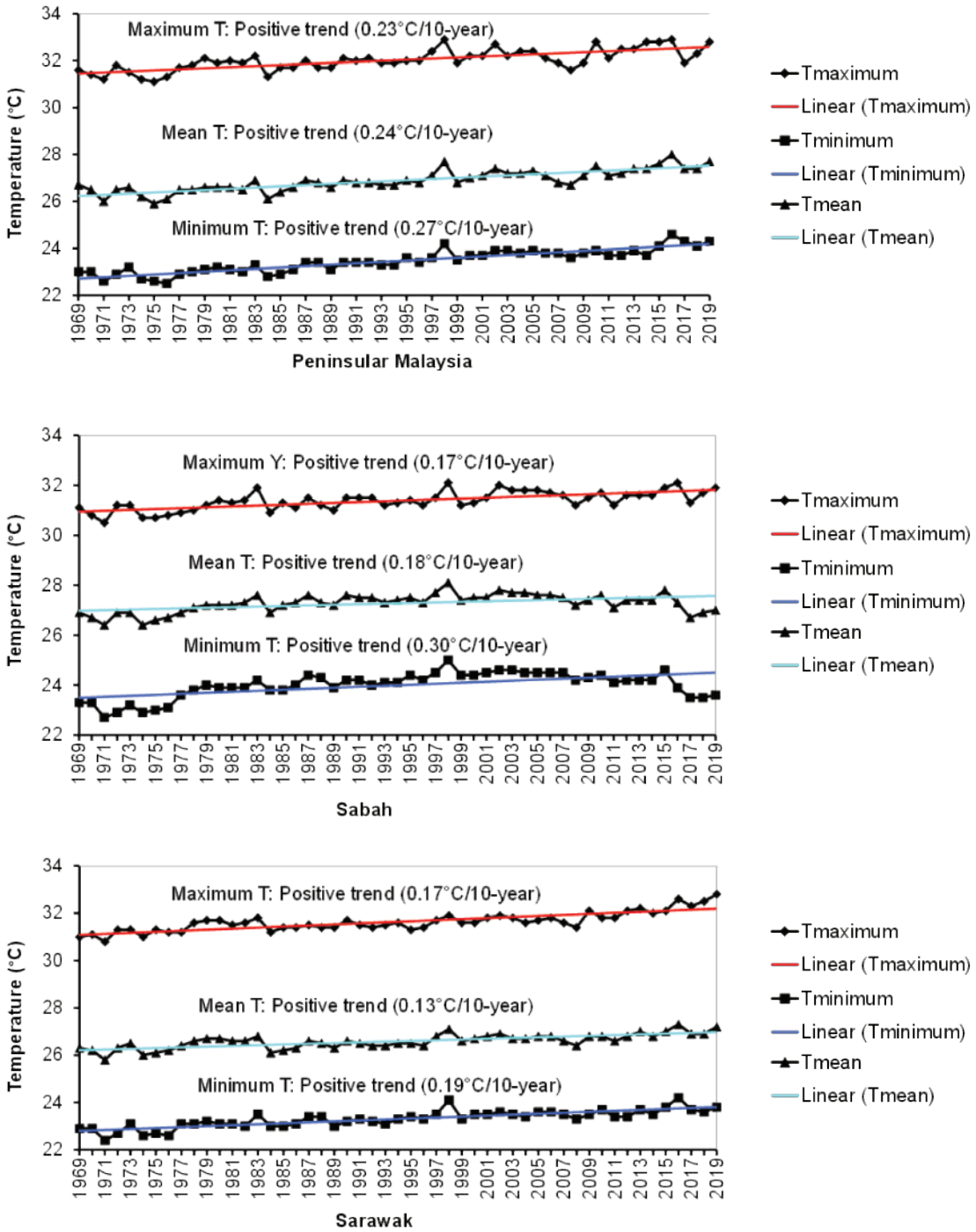
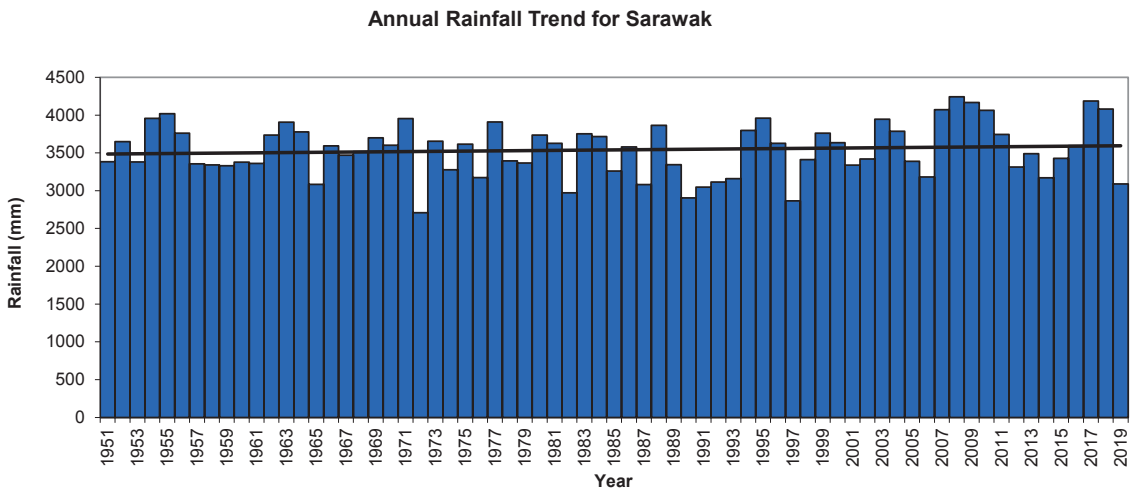
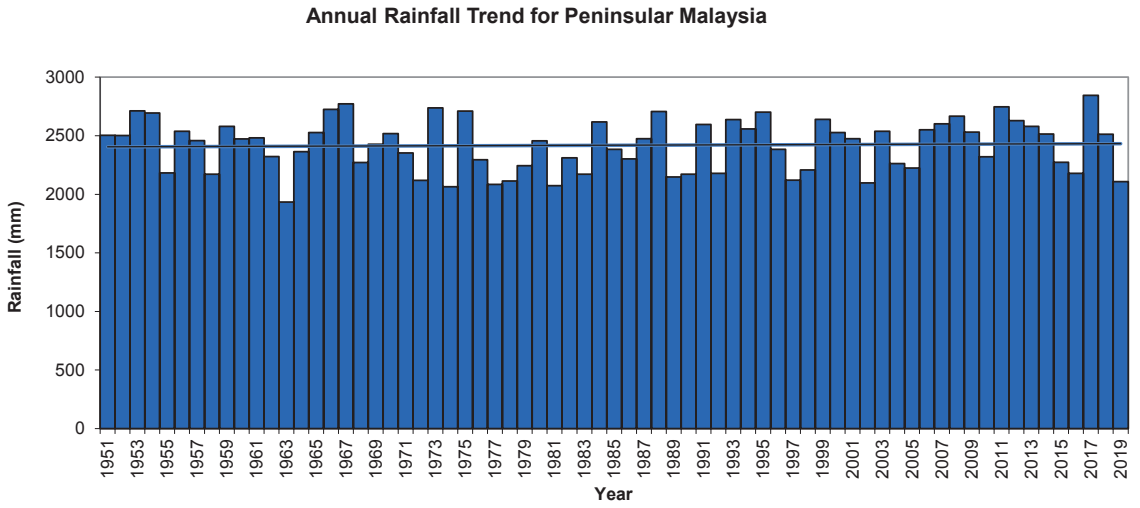


Figure 3. (a) Observed trends in annual maximum and mean minimum temperatures in Peninsular Malaysia, Sabah and Sarawak (NRES 2024).





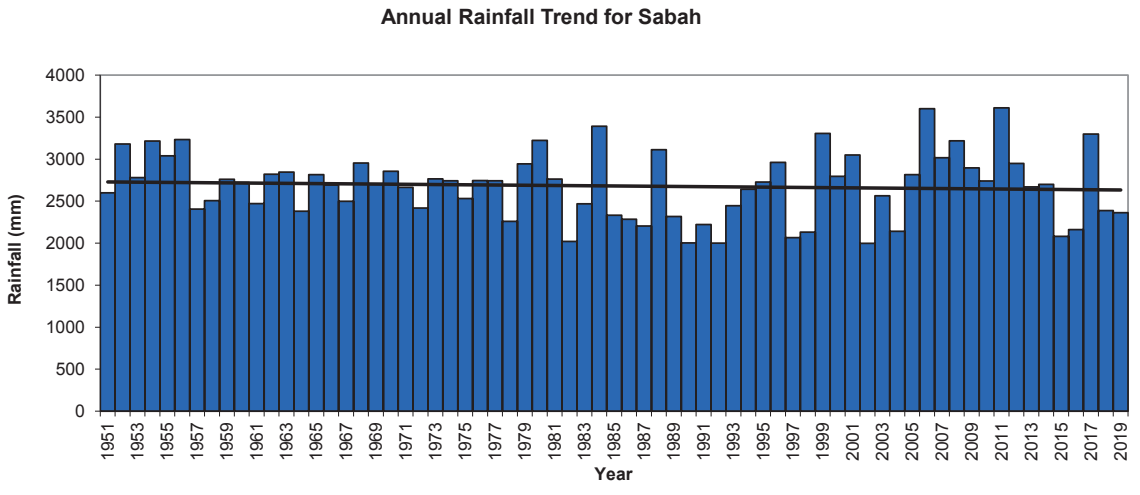


Figure 3. (b) Observed trends in annual rainfall trends in Peninsular Malaysia, Sabah and Sarawak (NRES 2024).

IMPACTS OF CHANGING CLIMATE ON THE AGRICULTURAL SECTOR

Climate change affects agriculture through multiple interconnected pathways, influencing crop physiology, water resources, soil conditions, and pest and disease dynamics. The magnitude and nature of impacts vary across subsectors depending on biological sensitivity, management practices, and agro-ecological conditions (FAO 2019b). In Malaysia, key agricultural subsectors such as rice, oil palm, rubber, cocoa, and livestock have demonstrated varying degrees of vulnerability to climate-induced stresses (NRES 2024).

Impacts on rice

Rice is Malaysia's most important staple crop and is highly sensitive to changes in temperature and water availability. Elevated temperatures, particularly during critical growth stages such as flowering and grain filling, have been associated with increased spikelet sterility, reduced grain quality, and yield losses (Peng *et al*. 2004; Wassmann *et al.* 2009). High night -time temperatures accelerate plant respiration and shorten the grain-filling period, leading to lower yields (Peng *et al.* 2004). Changes in rainfall patterns further exacerbate production risks in rice systems. Excessive rainfall and flooding can damage seedlings, disrupt field operations, and increase disease incidence, while prolonged dry spells may cause water stress, particularly in rain-fed and supplementary-irrigated areas (NRES 2024). Elevated temperatures can adversely affect rice growth throughout its life cycle, resulting in reduced survival, impaired reproductive development, lower grain yield and diminished grain quality (Figure 4). These climate-related stresses contribute to yield instability and heighten vulnerability among smallholder rice farmers.

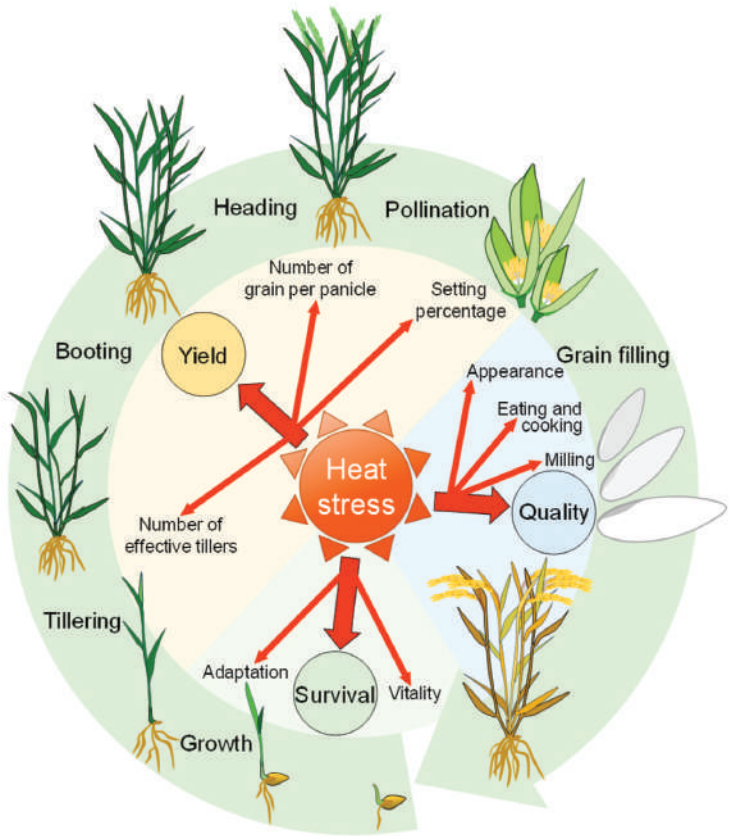


Figure 4. Continuous high temperature inhibits rice survival, yield, and quality by threatening all life stages of rice (Liu *et al.* 2025).

Impacts on oil palm

Oil palm is a major commercial or commodity crop and a key contributor to Malaysia's agricultural economy. Climate variability, particularly changes in temperature and rainfall, affects oil palm productivity by influencing flowering, fruit development, and fresh fruit bunch (FFB) formation (Corley and Tinker 2016). Prolonged periods of high temperature can induce heat stress which reduces photosynthetic efficiency and bunch yield. Rainfall anomalies, especially droughts, have been shown to reduce inflorescence initiation and increase abortion rates, often with a lagged effect on yield (NRES 2024). Conversely, excessive rainfall and flooding can impair root function and nutrient uptake, further constraining productivity. Under prolonged drought conditions, oil palm may exhibit a range of physiological and reproductive disorders, including reduced female flower production, bunch malformation, inflorescence abortion, and premature frond senescence (Figure 5). These impacts highlight the sensitivity of oil palm systems to both temperature and rainfall variability.

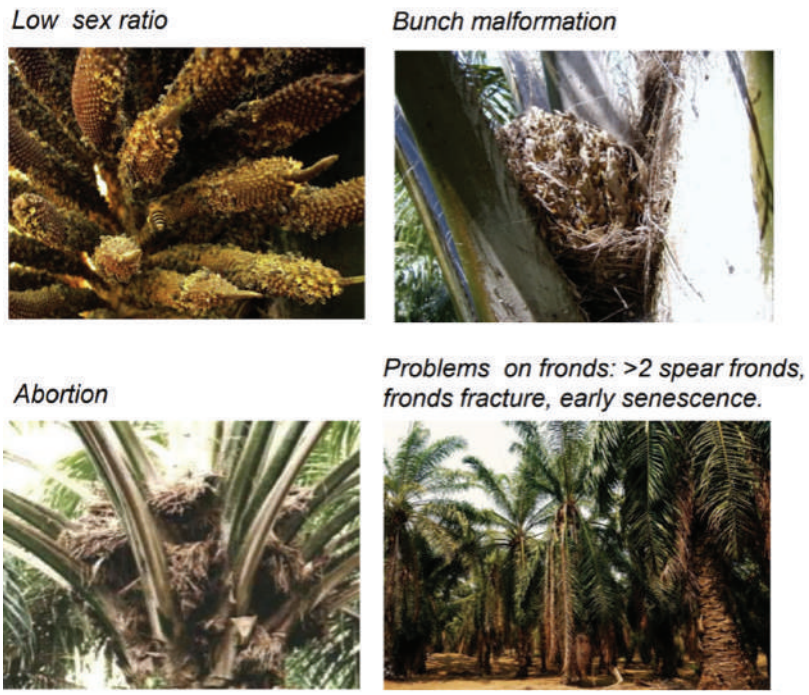


Figure 5. Effects of drought stress on oil palm, showing low sex ratio, bunch malformation, inflorescence abortion, and frond deterioration associated with prolonged water deficit (Rahutomo 2016).

Impacts on rubber

Rubber cultivation is sensitive to both rainfall variability and temperature extremes. Excessive rainfall disrupts tapping activities, reduces latex yield, and increases the incidence of fungal diseases, while prolonged dry periods can induce water stress and reduce latex flow (NRES 2024). Rising temperatures may further exacerbate physiological stress on rubber trees, affecting growth and productivity. High rainfall and prolonged humid conditions can also promote the development and spread of fungal diseases such as Pestalotiopsis leaf fall disease, which may reduce tree vigour and latex production (Figure 6). Extreme events such as floods and droughts can also cause physical damage to plantations and increase tree mortality, posing significant risks to the smallholder livelihoods that dominate Malaysian rubber production.



Figure 6. Rubber tree leaves infected by *Pestalotiopsis* leaf fall disease, a fungal disease favoured by prolonged periods of high rainfall and humidity (The Stringer 2021).

Impacts on cocoa

Cocoa production is highly sensitive to microclimatic conditions, requiring relatively stable temperature and moisture regimes. Increased temperatures and prolonged dry periods can lead to flower and pod abortion, reduced bean quality, and increased susceptibility to pests and diseases (Schroth *et al.* 2016). Changes in rainfall patterns may also increase the prevalence of diseases such as black pod, further threatening cocoa yields (NRES 2024). Black pod rot caused by *Phytophthora palmivora* is among the most destructive diseases affecting cocoa and is often favoured by prolonged wet and humid conditions (Figure 7). Given its climatic sensitivity, cocoa production in Malaysia is expected to face increasing challenges under future climate change scenarios, particularly in areas experiencing greater rainfall variability.



Figure 7. Black pod rot disease caused by *Phytophthora palmivora*, one of the most destructive diseases affecting cocoa production and a disease favoured by warm and humid environmental conditions (Vanegtern *et al*. 2015).

ADAPTATION STRATEGIES FOR CLIMATE-RESILIENT AGRICULTURE IN MALAYSIA

To address the growing risks posed by climate variability and long-term climate change, Malaysia has increasingly focused on developing and implementing adaptation strategies to enhance the resilience of its agricultural systems. Given the diversity of agro-ecological conditions and the varying sensitivity of crops to climate stressors, adaptation measures must be sector-specific, location-appropriate, and integrated across multiple levels of management.

In the agricultural context, effective adaptation encompasses crop genetic improvement, climate-responsive water and crop management, climate-smart farming practices, and enabling institutional and policy support. The key adaptation strategies for major agricultural subsectors in Malaysia, particularly rice, oil palm, rubber, and cocoa, namely, practical measures and strategic interventions, strengthen adaptive capacity, safeguard productivity, and support the long-term sustainability of national food and commodity production under a changing climate.

Adaptation Strategies for Rice

Rice is highly sensitive to climate stressors such as heat, drought, and flooding, particularly during critical growth stages. Adaptation strategies for rice production in Malaysia, therefore, focus on enhancing tolerance to climatic stresses while improving resource-use efficiency and management flexibility.

Crop genetic improvement and plant breeding play a central role in enhancing rice resilience to climate change. Breeding efforts have focused on developing varieties with improved tolerance to high temperatures, drought, and submergence, as well as varieties with shorter growth durations that reduce exposure to climatic risks (Wassmann *et al.* 2009; Mohanty *et al.* 2013). Heat-tolerant rice varieties are particularly important in addressing yield losses associated with elevated daytime and nighttime temperatures, which can cause spikelet sterility and reduce grain filling (Peng *et al*. 2004). Similarly, the development of drought-tolerant and submergence-tolerant varieties helps mitigate yield losses under increasingly variable rainfall conditions. Advances in molecular breeding, marker-assisted selection, and genomics have further accelerated the development of climate-resilient rice varieties, enabling more targeted and efficient breeding programmes (Mohanty *et al*. 2013). In Malaysia, national breeding programmes led by research institutions such as MARDI have contributed to the development and dissemination of improved rice varieties adapted to local agro-climatic conditions, forming a critical pillar of climate adaptation in the rice sector (NRES 2024).

Water management is a key adaptation strategy for rice production under changing rainfall patterns and increasing water scarcity. Improved irrigation efficiency and adaptive water management practices help reduce vulnerability to both drought and flooding. One widely promoted approach is Alternate Wetting and Drying (AWD), also known as Safe AWD, which involves periodic drying of paddy fields rather than continuous flooding, thereby reducing water use while maintaining yields (FAO 2017). Figure 8 shows the Safe AWD research plot at MARDI Seberang Perai, Pulau Pinang, conducted by Malaysian Agricultural Research & Development Institute (MARDI) in 2024. Climate-informed irrigation scheduling, supported by weather forecasts and seasonal climate outlooks, further enhances farmers' capacity to manage water more effectively under variable conditions. In irrigated rice systems, improved canal management, on-farm water control, and infrastructure maintenance are also critical adaptation measures to ensure a reliable water supply during dry periods and minimise flood-related damage during extreme rainfall events (NRES 2024).

Climate-smart crop management practices complement genetic and water-based adaptation strategies by improving overall system resilience. These practices include adjustments in planting dates to avoid exposure to heat stress or excessive rainfall, integrated nutrient management to maintain soil fertility under changing conditions, and improved pest and disease management in response to climate-induced shifts in pest dynamics (FAO 2019b). The use of climate information services, digital advisory tools, and early warning systems enables farmers to make informed decisions regarding planting, fertiliser application, and harvest timing. Collectively, these climate-smart practices enhance adaptive capacity while contributing to productivity and sustainability in rice-based farming systems.



(a) Safe AWD research plot (b) Gas sample collection (c) Monitoring of field water level

Figure 8. Safe AWD research plot at MARDI Seberang Perai, Pulau Pinang in 2024.

Adaptation strategies for oil palm

Adaptation strategies for oil palm focus on improving tolerance to heat and water stress, enhancing plantation management, and strengthening institutional support systems. According to the NC4, breeding and selection of oil palm varieties with improved tolerance to drought and heat stress are important long-term adaptation measures (NRES 2024).

At the plantation level, improved soil and water conservation practices, such as mulching, terracing, and effective drainage systems, help reduce moisture stress and minimise damage from extreme rainfall events (Figure 9). Diversification of planting materials, improved fertiliser management, and better pest and disease monitoring also help reduce climate-related risks. Strengthening advisory services and integrating climate risk information into plantation management planning further support adaptive capacity in the oil palm sector.



Figure 9. Plantation-level adaptation measures, including mulching and terracing, support more stable growing conditions under changing climate patterns. (Source: Applied Agricultural Resources Sdn. Bhd.)

Adaptation strategies for rubber

Rubber adaptation strategies emphasise improved planting materials, flexible management practices, and risk reduction measures. The use of climate-resilient rubber clones with enhanced tolerance to drought and disease is highlighted in NC4 as a key adaptation pathway (NRES 2024). A previous study found that the RRIM3001 rubber clone exhibited superior tolerance to soil moisture deficits, highlighting its potential as a drought-resilient clone that can enhance the sustainability and climate resilience of rubber production in water-scarce regions of Malaysia (Rohaizad *et al.* 2024) (Figure 10).

Management-based adaptations include adjusting tapping schedules during periods of excessive rainfall, implementing soil moisture conservation practices, and improving drainage to reduce flood damage. Agroforestry and intercropping systems have also been promoted as adaptation options to diversify income sources and improve microclimatic conditions within rubber plantations.



Figure 10. RRIM 3001 clone, commonly referred to as the "1Malaysia" clone, was bred in 1976 through controlled hand pollination between IAN 873 (female parent) and PB 235 (male parent), under a breeding programme conducted by the former Malaysian Rubber Board. (Source: Hosnan 2014).

Adaptation strategies for cocoa

Cocoa adaptation strategies focus on mitigating heat and moisture stress through improved farm management and crop diversification. Shade management, through agroforestry systems, is a critical adaptation strategy that helps regulate temperature, reduce evapotranspiration, and improve soil moisture retention (Schroth *et al*. 2016).

Additional measures include the use of improved cocoa varieties with greater tolerance to climatic stress, enhanced soil fertility management, and integrated pest and disease control to address climate-induced increases in disease pressure. These strategies are consistent with the adaptation priorities outlined in NC4 for climate-sensitive perennial crops (NRES 2024). The findings of Osman *et al.* (2017) highlighted MCBC 1, MCBC 4, MCBC 5, MCBC 6, MCBC 8, and MCBC 9 as promising drought-and water-stress-tolerant clones, with MCBC 10 and MCBC 3 showing tolerance to drought and water stress, respectively (Figure 11).

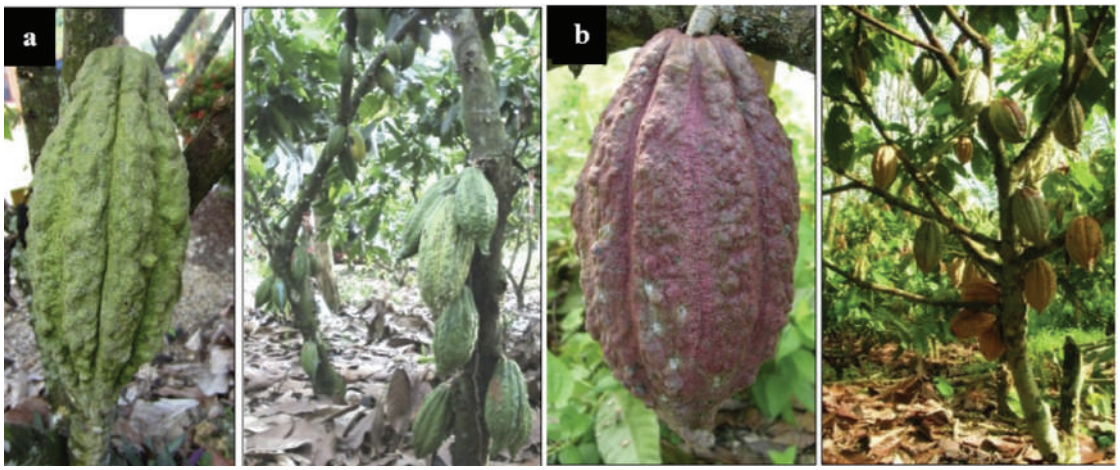


Figure 11. MCB cocoa clones. **(a)** MCBC 5 and **(b)** MCBC 6 are among the clones that showed tolerance to both drought and water stress conditions in Malaysia.

INTEGRATION, POLICY SUPPORT AND FUTURE DIRECTIONS

Effective adaptation to climate change in agriculture requires an integrated and coordinated approach that links scientific innovation, farm-level practices, institutional capacity, and policy support. Isolated adaptation measures, while beneficial, are often insufficient to address the complex and interconnected risks posed by climate change. In Malaysia, strengthening climate-resilient agriculture therefore depends on integrating adaptation strategies across crops, livestock systems, and scales of governance.

National policy frameworks provide an important foundation for supporting agricultural adaptation. Malaysia's Fourth National Communication (NC4) Report to the UNFCCC highlights agriculture as a climate-sensitive sector and emphasises the need to mainstream climate change adaptation into agricultural planning, research, development and innovation, and extension services (NRES 2024). Alignment with broader national and international frameworks, including Climate-Smart Agriculture (CSA) principles and the Sustainable Development Goals (SDGs), further reinforces the integration of adaptation, productivity, and environmental sustainability objectives.

Institutional support plays a critical role in enabling the adoption and scaling of adaptation strategies. Strengthening agricultural research systems, extension services, and climate information delivery is essential to ensure that climate-resilient technologies and practices reach farmers effectively. The use of climate services, such as seasonal forecasts and early warning systems, can enhance decision-making related to planting schedules, water management, and risk reduction. Capacity building for farmers and extension officers is equally important to improve awareness, technical knowledge, and adaptive capacity at the local level.

Looking forward, future adaptation efforts in Malaysia should prioritise innovation, inclusivity, and long-term resilience. Continued investment in climate-resilient crop breeding, digital agriculture, and data-driven decision-support tools will be essential and crucial for addressing emerging climate risks. Greater emphasis should also be placed on strengthening multi-stakeholder collaboration among government agencies, research institutions, the private sector, and farming communities. Integrating adaptation with mitigation co-benefits, where feasible, can further enhance the sustainability of agricultural systems. Collectively, these directions will be vital for ensuring that Malaysia's agricultural sector remains productive, resilient, and sustainable under a changing climate.

CONCLUSION

Climate change poses a systemic and escalating risk to Malaysia's agricultural sector. Rising temperatures, shifting rainfall patterns, and the increasing frequency of extreme weather events are already affecting crop productivity, livestock performance, and farm livelihoods across key agricultural subsectors (IPCC 2021; NRES 2024). Although the severity and nature of impacts vary among production systems and locations, the evidence clearly indicates that climate change threatens the long-term sustainability, resilience, and reliability of national food production. These challenges underscore the urgent need for targeted, sector-specific adaptation strategies to reduce vulnerability and strengthen resilience within Malaysia's agricultural sector. Effective adaptation is critical for safeguarding agricultural productivity, rural livelihoods, and national food security. In this regard, a combination of crop genetic improvement, enhanced water and crop management, climate-smart agriculture practices, and supportive institutional and policy frameworks forms the foundation of climate-resilient agricultural systems. While notable progress has been made in advancing adaptation efforts, continued investment in research, development, and innovation, capacity building, and policy integration remains essential to address emerging and future climate risks. By adopting integrated and location-appropriate adaptation strategies across major agricultural subsectors, Malaysia can enhance the resilience and sustainability of its agricultural systems and better position the sector to withstand the challenges of a changing climate.

REFERENCES

Applied Agricultural Resources Sdn. Bhd. n.d. Soil Management: Soil and Water Conservation Management. *AA Resources*. https://aarsb.com.my/soil-management-soil-and-water-conservation-management

Corley, R.H.V. and Tinker, P.B. 2015. The climate of the oil palm-growing regions. In *The Oil Palm. 5th Edition*, pp. 56–67. Chichester: Wiley-Blackwell.

FAO. 2017. *Water Management in Rice in Asia: Some Issues and Challenges*. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2019a. *Climate Change and Livestock*. Rome: Food and Agriculture Organization of the United Nations.

FAO. 2019b. *Climate-Smart Agriculture Sourcebook*. Rome: Food and Agriculture Organization of the United Nations.

Hosnan, M.A. 2014, May 14. GETAH - KLON 1 MALAYSIA? *Anim Agro Technology*. https://animhosnan.blogspot.com/2014/05/getah-klon-1-malaysia.html

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (Eds.). Cambridge: Cambridge University Press.

IPCC. 2021. *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, V. Masson-Delmotte, P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud *et al.* (Eds.). Cambridge: Cambridge University Press.

IPCC. 2022. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig *et al*. (Eds.). Cambridge: Cambridge University Press.

Liu, H., Wei, Y., Xia, S., Xie, W., Ren, D. and Rao, Y. 2025. Improvements in tolerance to heat stress in rice via molecular mechanisms and rice varieties. *Agriculture* 15(3): 318. https://doi.org/10.3390/agriculture15030318

Mohanty, S., Wassmann, R., Nelson, A., Moya, P. and Jagadish, S.V.K. 2013. *Rice and Climate Change: Significance for Food Security and Vulnerability. IRRI Discussion Paper Series No. 49*. Los Baños: International Rice Research Institute.

NRES. 2024. *Malaysia Fourth National Communication (NC4) to the United Nations Framework Convention on Climate Change*. Putrajaya: Ministry of Natural Resources and Environmental Sustainability.

Osman, R., Ramba, H. and Ling, A.S.C. 2017. Preliminary assessment on drought tolerance characteristics of some Malaysian cocoa planting materials, *Indonesian International Cocoa Symposium*, 18-21 October 2017, Grand Sahid Jaya, Jakarta.

Peng, S., Huang, J., Sheehy, J.E., Laza, R.C., Visperas, R.M., Zhong, X., Centeno, G.S., Khush, G.S. and Cassman, K.G. 2004. Rice yields decline with higher night temperature from global warming. *Proceedings of the National Academy of Sciences of the United States of America* 101(27): 9971–9975. https://doi.org/10.1073/pnas.0403720101

Rahutomo, S. 2016. BMP's for Facing Drought Stress on Oil Palm, *Field Clinic and Colloquium of the International Society of Oil Palm Agronomists (ISOPA)*, Marihat, Indonesia, 29 September 2016. https://agroklimatologippks.com/wp-content/uploads/2016/10/iopri-presentation-on-isopa-2016_rev01_may.pdf

Rohaizad, M., Zulkefly, S., Siti, N.A.A., Mohd Razi, I., Sarker Mohammad, R.K., Mohd Aswad, A.W. and Aizat Shamin, N. 2024. Physiological behavior of rubber plants (*Hevea brasiliensis*) to different soil moisture conditions. *Pertanika Journal of Science and Technology* 32(6): 2807–2826.

Schroth, G., Läderach, P., Martinez-Valle, A.I., Bunn, C. and Jassogne, L. 2016. Vulnerability to climate change of cocoa in West Africa: Patterns, opportunities and limits to adaptation. *Science of the Total Environment* 556: 231–241.

Tang, K.H.D. 2019. Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Science of the Total Environment* 650: 1858–1871. https://doi.org/10.1016/j.scitotenv.2016.03.024

The Stringer. 2021, July 17. Fungal infection can render rubber trees unable to produce much latex, posing damaging risks to smallholders, manufacturers. *The Stringer*. https://thestringer874585516.wordpress.com/2021/07/17/fungal-infection-can-render-rubber-trees-unable-to-produce-much-latex-posing-damaging-risks-to-smallholders-manufacturers

Vanegtern, B., Rogers, M. and Nelson, S. 2015. Black pod rot of cacao caused by *Phytophthora palmivora*. In *CTAHR Plant Disease Publication, PD-108*. Honolulu: College of Tropical Agriculture and Human Resources, University of Hawai‘i at Mānoa. https://www.ctahr.hawaii.edu/oc/freepubs/pdf/PD-108.pdf

Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A.M., Redona, E., Serraj, R., Singh, R.K. *et al*. Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. In *Advances in Agronomy, Vol. 101*, D.L. Sparks (Ed.), pp. 59–122. Burlington: Academic Press.

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