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CHAPTER 12

Dipterocarps and their conservation

MEEKIONG, K.[1]* and A. LATIFF[2]

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

[1] Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia.
[2] Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia.
***Corresponding author: aqmuzzammil@unimas.my**

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).

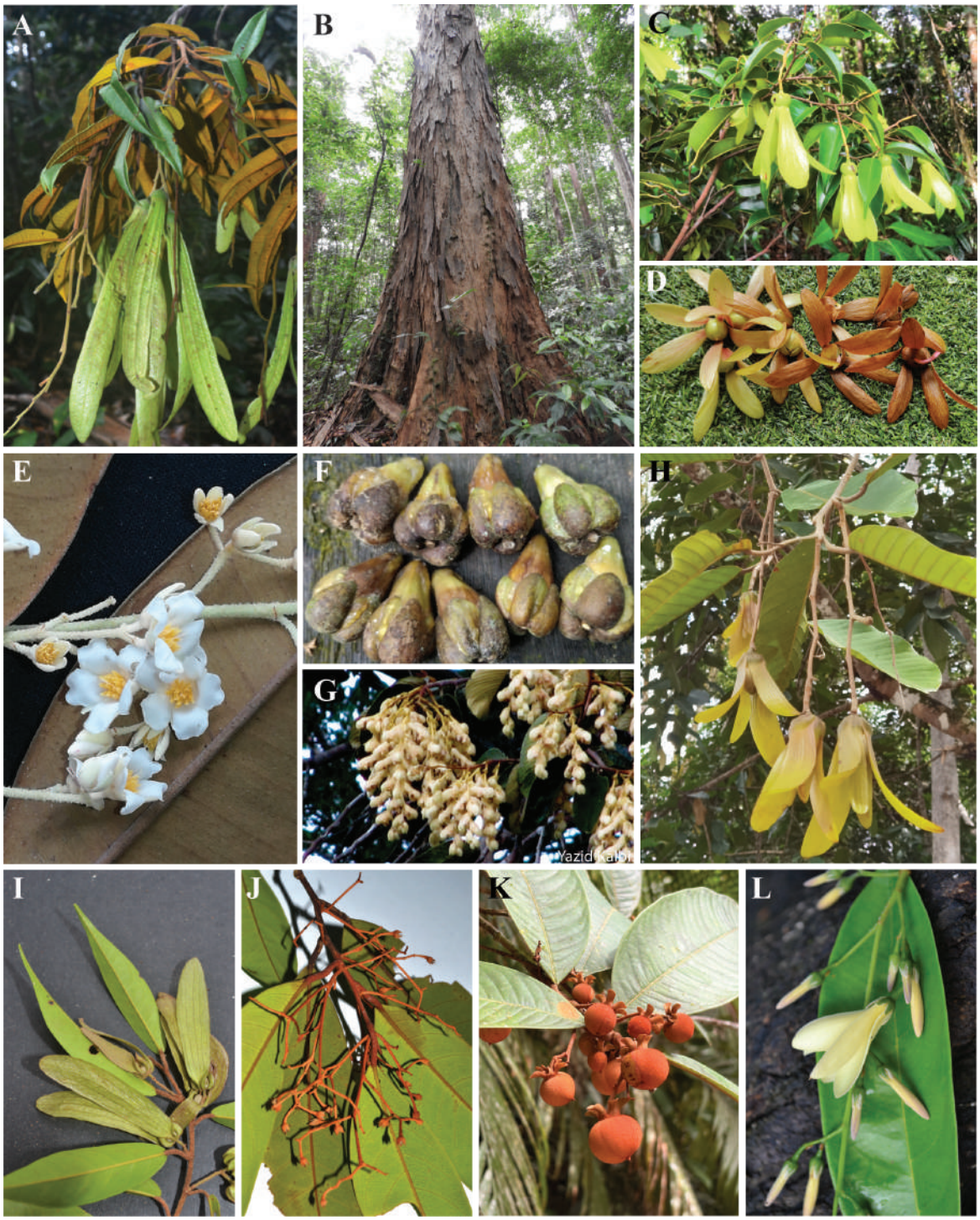

Figure 1. A. *Anisoptera grossivenia* Slooten , **B.** *Dryobalanops beccarii* Dyer, **C.** *D. aromatica* C.F. Gaertn., **D.** *D. fusca* Slooten, **E.** *Cotylelobium burckii* (F. Heim.) F. Heim., **F.** *Hopea pachycarpa* (Heim) Symington, **G.** *Anthoshorea ochracea* (Symington) P.S. Ashton & J. 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.

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