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Floristic diversity of dipterocarpaceae in the Sungai Harapan Protected Forest, Batam Island, Indonesia

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ABSTRACT
The Dipterocarpaceae family plays an important role as a dominant component of lowland tropical rainforest ecosystems, particularly within the Sunda Shelf region, such as Batam Island, Indonesia. However, these species are increasingly threatened by anthropogenic activities, including deforestation and land-use conversion, underscoring the need for conservation efforts supported by scientific data. This study aimed to identify species of the Dipterocarpaceae family, analyze the Important Value Index (IVI), and determine species diversity and evenness. The research was conducted using an exploratory survey method with Systematic Sampling with Random Start across an area of 1.74 ha within the 87 ha Special Block Protected Forest. Primary data were collected from different growth stages, including seedlings, saplings, poles, and trees, along with measurements of temperature and humidity. Data were analyzed qualitatively and quantitatively using the IVI, Shannon–Wiener diversity index, and evenness index. The results recorded 20 species across 6 genera (Cotylelobium, Dipterocarpus, Dryobalanops, Hopea, Shorea, and Vatica) from 44 plots, totaling 590 individuals. The number of individuals consisted of 228 seedlings, 172 saplings, 77 poles, and 113 trees. The highest IVI values were observed in *Hopea beccariana* Burck at the seedling (52.40%) and sapling (55.40%) stages, while *Shorea curtisii* Dyer ex King ssp. *S. curtisii* dominated the pole (103.68%) and tree (93.06%) stages. Shannon–Wiener diversity index values ranged from 1.81 to 2.05, indicating moderate diversity across all growth stages. Evenness index values ranged from 0.67 to 0.86, indicating high species evenness.
Keyword: Batam Island, Conservation Ecology, Dipterocarpaceae, Important Value Index (IVI), Species Diversity

1. Introduction

Floristic composition is a fundamental component of vegetation ecology, describing the identity, composition, and distribution of plant species within a community. Floristic studies provide essential information on species diversity, community structure, and ecological relationships, thereby serving as a scientific basis for biodiversity conservation, forest management, and ecosystem restoration. In tropical forests, floristic inventories are particularly important for identifying species composition and evaluating the conservation status of ecologically significant plant groups, such as the Dipterocarpaceae, which dominate many Southeast Asian lowland rainforests [1,2].

Lowland tropical rainforest ecosystems support high levels of biodiversity and provide ecosystem services that are fundamental to ecological stability, carbon storage, biodiversity conservation, and the regulation of regional climate and hydrological processes. Sumatra and Kalimantan serve as centers of Dipterocarpaceae diversity, characterized by forest compositions dominated by Dipterocarpaceae in the upper canopy; these natural forests also exhibit high productivity [3,4].

Indonesia is home to approximately 230 species of Dipterocarpaceae, with around 112 species and 8 genera found in Sumatra [6]. As a global center of Dipterocarpaceae diversity, the Sunda Shelf region (comprising Sumatra, Kalimantan, the Malay Peninsula, and surrounding islands) hosts 13 of the 22 known Dipterocarpaceae genera. About 30 species across six genera are found in the Riau Islands, while approximately 10 species from four genera occur on Batam Island. Although species richness on Batam Island is lower than in Sumatra, the Sungai Harapan Protection Forest serves as a natural habitat for Dipterocarpaceae species [5].

Dipterocarps contribute significantly to above-ground biomass, carbon storage, and hydrological regulation, while also helping to prevent landslides. Their broad canopies and irregular mass fruiting events make these forests vital natural habitats and food sources for a wide range of animals, including mammals, birds, and insects. Dipterocarp conservation is considered an "umbrella" strategy for tropical forest conservation [7]. Due to their high commercial value, dipterocarp timber plays a role in balancing ecological needs with local communities' economic interests [8]. Taxonomic perspectives underscore the importance of dipterocarp conservation in maintaining the ecological benefits of tropical forests [9].

Dipterocarp forests in Indonesia are undergoing degradation and deforestation driven by forest conversion, infrastructure development, illegal logging, and fragmentation, all of which alter tropical forest structure [10,11]. This situation is also evident on Batam Island, where industrial development and urban expansion have led to forest fragmentation and habitat loss. These factors have led to a decline in dipterocarp populations and hindered natural regeneration, underscoring the need for long-term conservation efforts and sustainable forest management [12].

In Riau Islands Province, the Sungai Harapan Protection Forest is one of the natural habitats supporting native species on Batam Island [13]. The Sungai Harapan Protection Forest also remains one of the few natural habitats for Dipterocarpaceae species on Batam Island. To support in-situ conservation, part of this protected forest was designated as a Special Block Arboretum covering approximately 87 ha [14]. According to [15], the main functions of Protected Forests include regulating hydrological systems, preventing soil erosion, maintaining soil fertility, and supporting long-term environmental sustainability. Protected forests are legally designated to maintain ecosystem integrity through hydrological regulation, soil conservation, erosion control, and biodiversity protection [14]. Consequently, the conservation value of the Sungai Harapan Protected Forest has become increasingly important for preserving the remaining dipterocarp populations on Batam Island.

Previous studies conducted in the Riau Islands have mainly focused on vegetation inventories and floristic composition [5,6]. More recently, studies in the remnant dipterocarp forests of Batam have described stand composition and forest structure [16]. However, information concerning the diversity and ecological characteristics of Dipterocarpaceae communities within the Special Block Arboretum of the Sungai Harapan Protected Forest remains limited. This lack of scientific information constrains evidence-based conservation planning and sustainable forest management for one of the few remaining dipterocarp habitats in the Riau Islands.

To address this knowledge gap, the present study investigates the diversity and ecological characteristics of Dipterocarpaceae species in the Special Block Arboretum of the Sungai Harapan Protected Forest, Batam Island. Specifically, this study aims to identify species composition, evaluate species diversity, and characterize the ecological condition of dipterocarp communities. The findings are expected to provide baseline information for long-term biodiversity monitoring, strengthen conservation planning, and support sustainable management of protected forests in the Riau Islands, thereby contributing to the long-term conservation of Indonesia's remaining dipterocarp forests.

2. Methods

2.1. Study Area and Research Period

The study was conducted in the Sungai Harapan Protected Forest Special Blocks Arboretum, Sekupang District, Batam City, Riau Islands Province, Indonesia. The research site was located at coordinates 103°58'3.096" E and 1°5'16.233" N, covering approximately 87 hectares. The study is being conducted from December 2025 to March 2026.

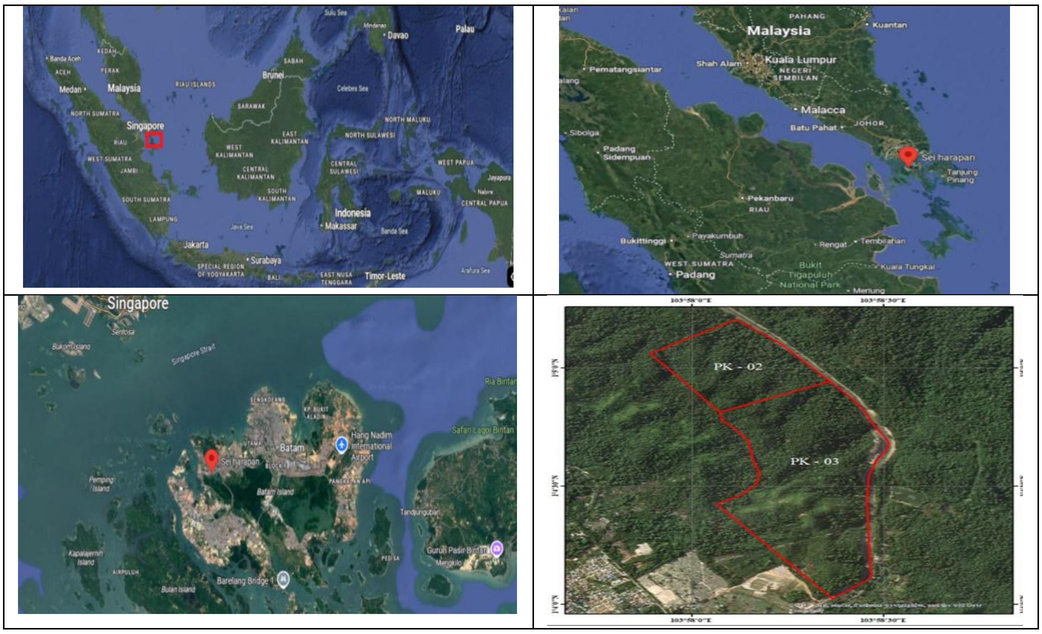

Figure 1. Research location map

2.2. Tools and Materials

The tools and materials used in this study included a tree identification guide for the Dipterocarpaceae family, GPS, a laptop, a camera, a measuring tape, a Haga altimeter, a diameter tape (phi-band), a compass, writing instruments, binoculars, a machete, rope, and data recording sheets.

2.3. Research Method

This research employed a field survey method. Vegetation analysis conducted in the heterogeneous natural forest yielded data on species composition, ecosystem structure, biodiversity, and species evenness [17]. Along the designated transect lines within the arboretum block of the Sungai Harapan protected forest area, vegetation data, including species, number of individuals, tree diameter, and basal area, were collected to calculate the Importance Value Index (IVI), diversity index, and evenness index [18]. This analysis is widely used to evaluate the structure and biodiversity of forest ecosystems [19]. In addition to the primary data, secondary data on environmental conditions, such as soil type, soil pH, temperature, and humidity at the research site, were collected from various literature sources.

2.4. Plot Design and Sampling Plot

Data collection was conducted using plots based on a systematic sampling method with a random start. A sampling intensity of 2% of the 87-hectare area was applied, resulting in a total sampled area of approximately 1.74 hectares. This level of sampling intensity is typically used to assess forest vegetation diversity, specifically to determine species composition, rather than for a comprehensive inventory [17]. A total of 44 sample plots were distributed across the study area to capture the presence of the target species, namely the Dipterocarpaceae family [18]. The sample plots were square-shaped, with dimensions of 2 m × 2 m (seedlings), 5 m × 5 m (saplings), 10 m × 10 m (poles), and 20 m × 20 m (trees) [19].

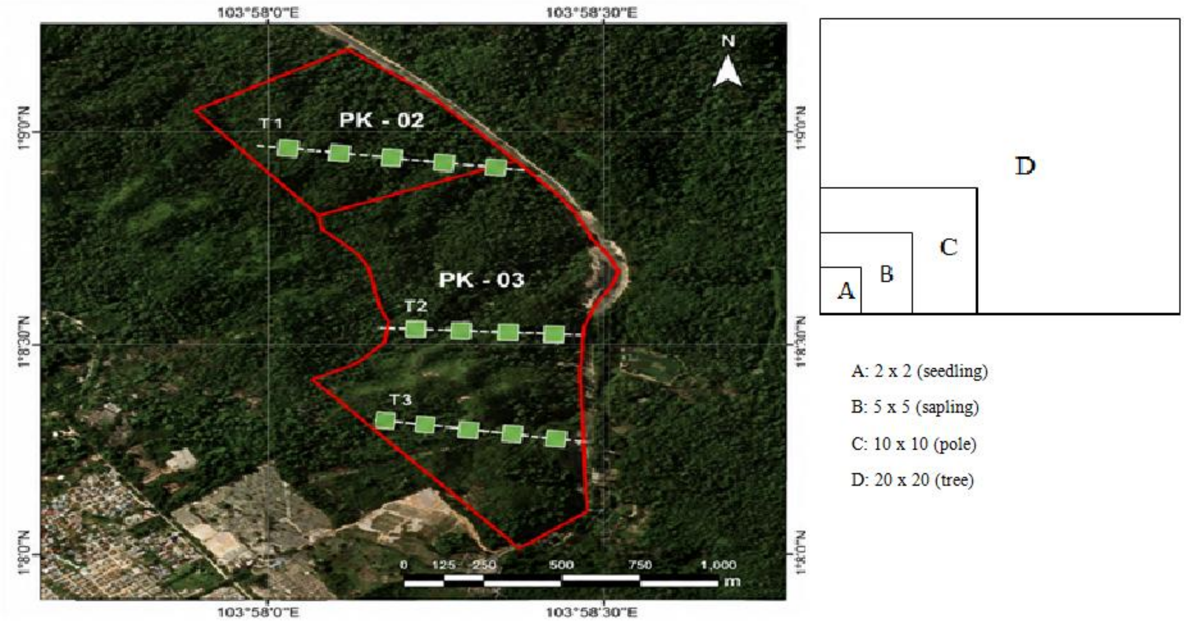

Figure 2. Plot Design and Sampling Plot

2.5. Data Analysis

The Importance Value Index (IVI) is calculated using the following formulas:

$$\text{IVI} = \text{RD} + \text{RF (seedlings and saplings)} \tag{1}$$

$$\text{IVI} = \text{RD} + \text{RF} + \text{RDo (trees and poles)} \tag{2}$$

Where:
RD = Relative Density
RF = Relative Frequency
RDo = Relative Dominance

$$\text{Density (D)} = \frac{\text{Number of individuals of a species}}{\text{Sample plot area}} \tag{3}$$

$$\text{Relative Density (RD)} = \frac{\text{Density of species}}{\text{Total Density of all species}} \times 100\% \tag{4}$$

$$\text{Frequency (F)} = \frac{\text{Number of plots where a species is found}}{\text{Total number of observation plots}} \tag{5}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of species}}{\text{Total Frequency of all species}} \times 100\% \tag{6}$$

$$\text{Dominance (Do)} = \frac{\text{Total basal area of a species}}{\text{Observation area}} \tag{7}$$

$$\text{Dominance Relative (RDo)} = \frac{\text{Dominance of species}}{\text{Total dominance of all species}} \times 100\% \tag{8}$$

2.5.1. Species Diversity Index

Species diversity is a widely used ecological indicator for evaluating community structure and ecosystem resilience, accounting for species richness and relative abundance. Higher species diversity is associated with greater resilience and better environmental quality [20].

In this study, species diversity was quantified using the Shannon–Wiener diversity index (H′), which combines species richness and species abundance into a single measure. The species diversity index (H’) is determined using the Shannon–Wiener formula [21]:

$$\text{H}' = -\Sigma(\frac{\text{ni}}{\text{N}}\ln(\frac{\text{ni}}{\text{N}}) \tag{9}$$

where
H′ : Shannon–Wiener diversity index,
n_i : number of individuals of species i, and
N : total number of individuals.
The diversity categories are classified as follows: $H' \leq 1.0$ (low), $1.0 < H' \leq 3.0$ (moderate), and $H' > 3.0$ (high).

2.5.2. Species Evenness Index

Species evenness measures the uniformity of the distribution of individuals among species within a community. High evenness indicates that species have relatively similar abundances, whereas low evenness suggests that one or a few species dominate the community. Therefore, the evenness index provides complementary information to species diversity by describing the balance of species composition [19]. The species evenness index (E) is determined using the formula:

$$E = \frac{H'}{\ln(S)} \tag{10}$$

where:
E : species evenness index,
H' : species diversity index, and
S : number of species.
The criteria are as follows: $E \leq 0.4$ (low), $0.4 < E \leq 0.6$ (moderate), and $E > 0.6$ (high).

3. Results and Discussion

3.1. Biophysical Conditions

Batam Island lies near the equator (approximately 1° N) and has a humid tropical climate that supports the development of lowland tropical rainforests and their associated biodiversity. According to [22], the city experiences warm temperatures year-round, with high humidity and abundant annual rainfall, creating favorable conditions for tropical forest vegetation. The average annual air temperature ranges from 24–35 °C, relative humidity ranges from 73–96%, and annual rainfall is approximately 2,600 mm.

Although Batam receives abundant solar radiation due to its equatorial location, the relatively low light intensity recorded in the study area was primarily due to the dense, multi-layered forest canopy, which reduced light penetration to the forest floor. Such shaded conditions are characteristic of intact lowland tropical forests and are generally favorable for the regeneration of many Dipterocarpaceae species during their early growth stages.

According to [22], the average monthly air temperature in 2024 ranged from 27.0 to 28.9°C, while the average relative humidity ranged from 79.0% to 86.6%. Microclimatic factors, including canopy cover, topography, and the timing of field measurements, influence temperature and humidity at the study site. Favorable environmental conditions support the growth and regeneration of Dipterocarpaceae. High air humidity is a characteristic feature of lowland tropical forests and plays a vital role in maintaining the microclimate and biodiversity.

The soil pH in the Sungai Harapan Protection Forest is 4.3, indicating highly acidic conditions; this aligns with the general soil characteristics of Batam Island, where Ultisols dominate, with pH below 5 due to leaching processes driven by rainfall in a wet tropical climate. Acidic soils are common in tropical lowland forests. They are generally suitable for many native tree species, including members of the Dipterocarpaceae, which have adapted to nutrient-poor and acidic environments [23].

3.2. Identification of Dipterocarpaceae Species

Based on the results of the study conducted in the Sungai Harapan Protected Forest, Special Block of the Batam Arboretum, Riau Islands Province, a total of 20 species belonging to the Dipterocarpaceae family were identified from 44 observation plots. A total of 590 individuals were recorded across six genera: *Cotylelobium, Dipterocarpus, Dryobalanops, Hopea, Shorea*, and *Vatica*. The plant species belonging to the Dipterocarpaceae family were presented in Table 1.

Table 1. Plant species of the Dipterocarpaceae family in the Sungai Harapan Protected Forest, Special Block of the Batam Arboretum, Riau Islands Province.

No	Local Name	Genus	Scientific Name	Seeding	Sapling	Pole	Tree
1	Merawan	*Hopea*	*Hopea beccariana* Burck	74	53	16	19
2	Meranti Seraya	*Shorea*	*Shorea curtisii* Dyer ex King	20	36	26	36
3	Resak Rawa	*Vatica*	*Vatica pauciflora* (Korth.) Blume	59	24	5	11
4	Merawan	*Hopea*	*Hopea mengarawan* Miq	14	21	6	8
5	Keruin Chogan	*Dipterocarpus*	*Dipterocarpus rigidus* Ridl.	23	10	7	12
6	Resak Daun Runcing	*Vatica*	*Vatica cuspidata* Ridl	20	10	3	8
7	Keruing Buah	*Dipterocarpus*	*Dipterocarpus elongatus* Korth.	7	4	2	9
8	Balau	*Shorea*	*Shorea falcifera* Dyer ex Brandis	5	2	0	4
9	Meranti Tembaga	*Shorea*	*Shorea leprosula* Miq	1	1	8	0
10	Meranti Batu	*Shorea*	*Shorea johorensis* Foxw	0	2	4	0
11	Giam	*Cotylelobium*	*Cotylelobium melanoxylon* (Hook.f.) Pierre	0	3	0	0
12	Kapur	*Dryobalanops*	*Dryobalanops aromatica* C.F.Gaertn.	0	3	0	0
13	Meranti Bunga	*Shorea*	*Shorea ovalis* Korth	0	1	0	2
14	Keruing	*Dipterocarpus*	*Dipterocarpus grandiflorus* (Blanco) Blanco	1	1	0	0
15	Meranti Rambai	*Shorea*	*Shorea accuminata* Dyer	1	0	0	1
16	Meranti Sabut	*Shorea*	*Shorea parvifolia* Dyer *ssp.velutinata* P.S.Ashton	0	0	0	2
17	Meranti Bukit	*Shorea*	*Shorea platyclados* Slooten ex Foxw	1	1	0	0
18	Meranti Sabut	*Shorea*	*Shorea parvifolia* Dyer *ssp.parvifolia*	0	0	0	1
19	Meranti	*Shorea*	*Shorea selanica* (Valmont)	1	0	0	0
20	Resak	*Vatica*	*Vatica lowii* King	1	0	0	0
		Sub Total		228	172	77	113
		Total			590		

Based on Table 1, it was known that the total number of species from the Dipterocarpaceae family in the Sungai Harapan Protected Forest, Special Block of the Batam Arboretum, consists of 20 species with a total of 590 individuals from six genera. These species exhibit various growth stages, including seedlings, saplings, poles, and trees. The most dominant species was *Hopea beccariana* Burck with 182 individuals, followed by Shorea curtisii Dyer ex King with 108 individuals, and the third most abundant species was *Vatica pauciflora* (Korth.) Blume with 99 individuals. These three species were found at all growth stages, namely seedlings, saplings, poles, and trees. The lowest number of individuals from the Dipterocarpaceae family was recorded for *Shorea selanica* (Valmont) and *Vatica lowii* King, each represented by only one seedling.

3.3. Important Value Index (IVI)

Based on the IVI calculations for the Dipterocarpaceae family in the research plots, which were classified by growth stage (seedlings, saplings, poles, and trees), the results are presented sequentially in the tables below.

Table 2. IVI at the seedling level.

No	Species	RD(%)	RF (%)	IVI (%)
1	*H. beccariana*	32.46	20	52.46
2	*V. pauciflora*	25.88	15	40.88
3	*S. curtisii*	8.77	15	23.77
4	*H. mengarawan*	6.14	12.50	18.64
5	*D. rigidus*	10.09	7.50	17.59
6	*V. cuspidata*	8.77	7.50	16.27
7	*D. elongatus*.	3.07	5	8.07
8	*S falcifera*	2.19	2.50	4.69
9	*D. grandifloras*	0.44	2.50	2.94

10	*S. acuminate*	0.44	2.50	2.94
11	*S. leprosula*	0.44	2.50	2.94
12	*S. platyclados*	0.44	2.50	2.94
13	*S. selanica*	0.44	2.50	2.94
14	*V. lowii*	0.44	2.50	2.94
Total		100	100	200

The seedling level, H. beccariana, had the highest IVI value (52.46%), followed by *V. pauciflora* (40.88%), *S. curtisii* (23.77%), *H. mengarawan* (18.64%), and *D. rigidus* (17.59%). The species with the highest IVI value at the seedling level in the study area was *H. beccariana* (Merawan), which was the most frequently found species because this group produces abundant fruits during fruiting seasons and its seeds germinate easily on the forest floor [24].

H. beccariana was also found throughout all research areas, indicating that this species has strong adaptability within lowland forest ecosystems. The small seeds and the elongated shape of the seeds enable widespread dispersal, extending well beyond the immediate vicinity of the parent tree. The dominance of Hopea species is supported by [24], who stated that Hopea seedlings are capable of growing under the shade of other trees, unlike species from the genus Dipterocarpus. Based on field observations, Hopea grew well, particularly at the mature seedling stage, in both open habitats and shaded conditions. This phenomenon was also observed in *S. curtisii, V. pauciflora*, and *V. cuspidata*. This finding differs from the study conducted in the Pulau Weh Nature Tourism Park, Aceh, Indonesia, which identified two species from the Dipterocarpaceae family. At the seedling stage, the most dominant species was *D. hasseltii*, followed by S. sumatrana, with IVI values of 94.62% and 105.38%, respectively [25].

Table 3. IVI at the sapling level.

No	Species	RD(%)	RF (%)	IVI (%)
1	*H.beccariana*	30.81	24.59	55.40
2	*S. curtisii*	20.93	18.03	38.96
3	*V. pauciflora*	13.95	11.48	25.43
4	*H. mengarawan*	12.21	13.11	25.32
5	*V. cuspidata*	5.81	9.84	15.65
6	*D. rigidus.*	5.81	6.56	12.37
7	*D. elongatus.*	2.33	3.28	5.60
8	*C. melanoxylon*	1.74	1.64	3.38
9	*D. aromatica.*	1.74	1.64	3.38
10	*S. falcifera*	1.16	1.64	2.80
11	*S. johorensis*	1.16	1.64	2.80
12	*D. grandifloras*	0.58	1.64	2.22
13	*S. leprosula*	0.58	1.64	2.22
14	*S. ovalis*	0.58	1.64	2.22
15	*S. platyclados*	0.58	1.64	2.22
Total		100	100	200

H. beccariana had the highest IVI at 55.40%, followed by *S. curtisii* (38.96%), *V. pauciflora* (25.43%), H. *mengarawan* (25.32%), and *V. cuspidata* (15.65%). In 2018, seed and wild seedling collection activities were conducted in the Sungai Harapan Protected Forest during the flowering season. This activity was carried out as one of the in situ conservation strategies for species native to Batam. Two of these species were *H. beccariana* and *S. curtisii*. However, the IVI values at both the seedling and sapling stages showed that *S. curtisii* and *H. beccariana* had the highest IVI values among the species in the study area, indicating their high dominance.

A study conducted in the Hemanq Beniung Customary Forest, West Kalimantan, showed different results at the sapling stage, where *Knema elmerii* was the dominant species with an IVI of 18.15%. At the tree stage, one of the dominant species was *Dipterocarpus tempehes* from the Dipterocarpaceae family, with an IVI value of 19.23% [26]. However, research conducted in the natural Dipterocarpaceae forests of southern Vietnam showed similarity in the dominant genus, namely Hopea, particularly Hopea odorata. It was stated that the genus Hopea has shade tolerance during its early growth stages, allowing seeds and seedlings to survive under dense forest canopies [27].

Table 4. IVI at the pole level.

No	Species	RD(%)	RF (%)	RDo (%)	IVI (%)
1	*S. curtisii*	33.77	34.15	35.76	103.68
2	*H. beccariana*	20.78	19.51	18.97	59.26
3	*D. rigidus.*	9.09	14.63	8.07	31.80
4	*V. pauciflora*	6.49	9.76	8.66	24.91
5	*S. leprosula*	10.39	2.44	10.99	23.81
6	*H. mengarawan*	7.79	7.32	5.90	21.01
7	*V. cuspidata*	3.90	7.32	3.39	14.60
8	*S. johorensis*	5.19	2.44	5.49	13.13
9	*D. elongatus.*	2.60	2.44	2.77	7.81
Total		100	100	100	300

At the pole level, the highest IVI value was recorded for *S. curtisii* (103.68%), followed by *H. beccariana* (59.26%), *D. rigidus* (31.80%), *V. pauciflora* (24.91%), and *S. leprosula* (23.81%). *S. leprosula* and *S. johorensis* were only found at the seedling, sapling, and pole level, but were absent at the tree stage. The limited abundance of these species on Batam Island is suspected to result from historical exploitation. The fragmentation of forests on Batam Island was not only a consequence of rapid urbanization and industrial expansion but is also associated with historical logging, land conversion, and recurrent forest fires, all of which have contributed to the decline of suitable habitats for *Rubroshorea curtisii*.

This disturbance results in changes to forest structure and habitat fragmentation, and affects the natural regeneration of Dipterocarpaceae, particularly species characterized by irregular flowering patterns and limited seed dispersal. Forest loss is driven by land-use change and the exploitation of natural forests [28]. Furthermore, fragmentation and reduced connectivity between forest areas lead to a loss of biodiversity in tropical forests [21].

Despite anthropogenic pressures from urban development, the lowland tropical forest on Tiban Hill, Batam Island, supports a population of R. *curtisii*. This highlights the conservation value of the remaining protected forest for native species [16]. These observations highlight the importance of conserving the Sungai Harapan Protected Forest to maintain biodiversity and ensure the long-term persistence of Dipterocarpaceae populations.

In addition, Batam Island naturally experiences strong winds that frequently cause mature trees to fall, potentially damaging younger growth stages, such as seedlings, saplings, and poles. Such disturbances affect not only the survival of *Shorea* spp. but also tree species within the forest ecosystem. The fall of mature trees creates canopy gaps that may damage surrounding young individuals while simultaneously accelerating the growth of pioneer species, as increased light intensity and nutrient availability in the affected area [29].

A study in the Sungai Harapan Protected Forest, Batam, showed different dominant species within Peninsular Malaysia at the pole stage, namely D. rigidus with an IVI of 52.80%, followed by *Calophyllum pulcherrimum* with an IVI of 35.55% [30]. Based on the study in the Gunung Semahung Protected Forest, the species with the highest IVI at the pole stage was *Shorea acuminatissima* (yellow meranti) with a value of 19.59 [31]. These findings are similar to those of the present study, in which the most dominant genus at the pole stage was S. curtisii, with an IVI of 103.68%. The similarity in dominant genera indicates that Shorea possesses strong ecological adaptation and high competitiveness in tropical lowland forests. In contrast, differences in dominant species are likely influenced by variations in habitat conditions, stand structure, and the distribution of parent trees across study sites.

Table 5. IVI at the tree level.

No	Species	RD(%)	RF (%)	RDo (%)	IVI (%)
1	*S. curtisii*	31.86	30.43	34.76	97.06
2	*H. beccariana*	16.81	17.39	14.11	48.31
3	*D. rigidus*	10.62	10.87	22.26	43.75
4	*V. pauciflora*	9.73	9.78	4.24	23.76
5	*V. cuspidata*	7.08	8.70	5.81	21.59
6	*H. mengarawan*	7.08	8.70	4.51	20.29
7	*D. elongatus.*	7.96	4.35	6.93	19.24
8	*S. falcifera*	3.54	3.26	3.83	10.63
9	*S. velutinata*	1.77	2.17	1.49	5.43
10	*S. ovalis*	1.77	2.17	1.37	5.31
11	*S. parvifolia*	0.88	1.09	0.41	2.38
12	*S. acuminata*	0.88	1.09	0.28	2.26
Total		100	100	100	300

Table 5 shows the IVI values at the tree level in the Sungai Harapan Protected Forest. *S. curtisii* had the highest IVI value at 97.06%, followed by *H. beccariana* (48.31%), *D. rigidus* (43.75%), *V. pauciflora* (23.76%), and *V. cuspidata* (21.59%). The species identified at the tree stage in the Sungai Harapan Protected Forest are native Dipterocarpaceae species of Batam. The species with the lowest IVI value was Shorea, with an IVI of 2.26%, and it was found only in one observation plot with a diameter of 26 cm. A tree is considered healthy or in normal condition when it can perform its physiological functions optimally. Conversely, a tree is considered unhealthy when it exhibits structural damage, either affecting the entire tree or specific parts of its structure [32].

S. curtisii was considered a key species in the dynamics of hilly Dipterocarpaceae forests. The sampling plots, predominantly located in hilly areas, confirmed the dominance of S. curtisii at the tree stage in these upland regions. *S. curtisii* had the highest IVI value of 138.01% at elevations ranging from 60–115 meters above sea level [33]. A study conducted in the Sungai Harapan Protected Forest, Batam, found different dominant species at the tree stage, namely D.rigidus with an IVI of 67.22%, followed by *Sloetia elongata* (35.34%) and *S. curtisii* (14.17%) [16].

3.4. Shannon–Wiener Diversity Index

Based on the calculation results of the Shannon–Wiener Diversity Index for the Dipterocarpaceae family in the Sungai Harapan Protected Forest Special Block, the values are presented in Table 6.

Table 6. Shannon–Wiener Diversity Index.

No	Growth Stage	Diversity Index	Category
1	Seedling	1.81	Moderate
2	Sapling	2.00	Moderate
3	Pole	1.90	Moderate
4	Tree	2.05	Moderate

The dominant structure and composition of the Sungai Harapan Protected Forest Special Block varied across growth stages. At the tree stage, there were 113 individuals from 12 species, dominated by *S.curtisii, H. beccariana, D. rigidus, V. pauciflora,* and *V. cuspidata*. At the pole stage, 77 individuals from 9 species were recorded, dominated by *S. curtisii, H. beccariana, D. rigidus, V. pauciflora,* and *H. mengarawan*. At the sapling stage, 172 individuals from 15 species were recorded, dominated by *H. beccariana, S. curtisii, V. pauciflora, H. mengarawan,* and *D. rigidus*. Meanwhile, at the seedling stage, 228 individuals from 14 species were recorded, dominated by *H beccariana, V pauciflora, D. rigidus, S. curtisii,* and *V. cuspidata*.

The biodiversity index values at the seedling, sapling, pole, and tree stages were 1.83, 2.03, 1.90, and 2.05, respectively. All Dipterocarpaceae growth structures in the Sungai Harapan Protected Forest Special Block Batam were classified as having moderate diversity levels. Overall, all structural levels showed relatively similar values. This similarity indicates a relatively stable diversity condition within the Sungai Harapan Protected Forest Special Block.

The Dipterocarpaceae biodiversity index in the Sungai Harapan Protected Forest can be considered high, as the tree-stage value of 2.05 was obtained from a single family distributed from riverbanks to hilly areas. If vegetation analysis were conducted across all plant families, it is possible that the biodiversity index of the Sungai Harapan Protected Forest would exceed 2.05. A study in Taman Negara, Pahang, measured biodiversity in lowland Dipterocarpaceae forests and identified 43 families and 104 genera, yielding a biodiversity index of 4.84, which was categorized as high [34].

One of the most dominant tree species identified was *S. curtisii* and *H. beccariana*, which were commonly found in hilly areas. *V. pauciflora* and a small number of *H. mengarawan* were frequently encountered along riverbanks and watercourses. In one observation plot located near the river, *D. elongatus* was found growing in clusters, with one tree reaching a diameter of 60 cm. In the dry hilly areas, D. rigidus was identified in several sample plots; this species dominates the dryland habitat, with diameters approaching 100 cm.

The seedling stage has the lowest diversity index among all growth stages. This condition was attributed to the last mass flowering event occurring in 2018, after which no mass flowering of Dipterocarpaceae species was observed until the time of this study. Based on field observations, *S. curtisii* showed strong dominance at the tree stage but did not exhibit a similar pattern at the seedling stage. This phenomenon indicates disturbances in the species' natural regeneration process within its habitat. One of the main factors limiting the natural regeneration of S. curtisii is competition, particularly with species from other families that are better adapted to environmental changes. Pioneer tree species from the families Euphorbiaceae and Moraceae, as well as understory vegetation such as *Dicranopteris linearis*, often dominate the forest floor after fire events, thereby inhibiting the growth and development of S. curtisii seedlings [35]. S.curtisii produces relatively few seeds in the natural forest [24].

In certain areas of the Sungai Harapan Protected Forest Special Block, Batam, *S. curtisii* was identified as one of the species that survived the major forest fire event in 2015. Following a forest fire, land cover shifts to be dominated by pioneer species and vegetation capable of rapid growth and colonization, such as D. linearis, within the forest understory. However, these conditions are unfavorable for the regeneration of S. curtisii, a climax species [35]. According to [16], *S. curtisii* is still found in the remnant lowland dipterocarp forest of Bukit Tiban, Batam Island, despite past disturbances. This indicates that, even after fires and habitat disturbances altered the forest composition, the remaining dipterocarp population holds the potential for natural forest regeneration and long-term ecosystem recovery. Dipterocarps are native plants that sustain tropical forest biodiversity [33].

S. curtisii seedlings exhibit higher survival rates in canopy gaps compared to those growing under a closed canopy [34]. However, these findings did not account for topographic factors or distance from the parent tree. Field observations indicate that *S. curtisii* planted in open areas tends to show better growth than that planted under canopy shade. Naturally, *S. curtisii* grows in hilly environments and produces small seeds, a trait that facilitates dispersal over a wider area and prevents seeds from accumulating solely around the parent tree.

Among the saplings, those belonging to the genus Hopea were the most frequently encountered. At the saplings stage, *H. beccariana* (merawan) was most commonly found, as this species produces abundant seeds that germinate readily on the forest floor during the fruiting season. *H. beccariana* was also found throughout the study area, demonstrating its strong adaptability to the forest ecosystem. The dominance of Hopea species is due to the need for shade for growth [24]. However, field observations indicate that Hopea can grow well, especially at the sapling stage, in both open and shaded habitats. Species distribution and abundance were influenced by local environmental conditions, including humidity, temperature, elevation, and soil fertility; these factors determine habitat suitability and support species growth [36].

The second most dominant sapling species was V. *pauciflora*; this species was found growing in clusters in areas far from water sources. Newly emerged seedlings with 4 leaves were frequently observed, with up to 20 per 2 × 2 m plot. *V. pauciflora produces* "geluk" type fruits with imperfect wings, which facilitate seed dispersal through water. Along riverbanks, V. *pauciflora* was distributed evenly, reflecting an ecological adaptation. Observations also indicate that V. *pauciflora* seeds were frequently eaten by caterpillars, thus inhibiting germination. At the pole stage, V. *pauciflora* has reached reproductive maturity, contributing to the abundance of seedlings observed at the study site [37].

In addition to the vegetation analysis, several species not included in the sample plots were identified along the paths connecting the observation plots. Species recorded during the exploratory survey *include Shorea dasyphylla, Shorea guiso, Cotylelobium lanceolatum, Dryobalanops lanceolata, Dryobalanops oblongifolia,* *Dipterocarpus kerii, Dipterocarpus lowii, Dipterocarpus intricatus, Dipterocarpus zeylanicus, Dipterocarpus chartaceus, Dipterocarpus gracilis, Hopea gregaria, Hopea odorata, Hopea nutans, Hopea helferii, Shorea mecistopteryx, Shorea blumutensis, Shorea materialis, Shorea platyclados, Shorea platycarpa, Anisoptera marginata, Anisoptera costata, Anisoptera laevis,* and *Vatica rassak.*

3.5. Species Evenness Index

All growth stages exhibit values greater than 0.6, which are categorized as high. This indicates that the distribution of species across the observation plots was relatively even. The species evenness index was presented in Table 7.

Table 7. Species Evenness Index

No	Growth Stage	Evenness Index	Category
1	Seedling	0.67	High
2	Sapling	0.73	High
3	Pole	0.86	High
4	Tree	0.83	High

The Sungai Harapan protected forest ecosystem encompasses a range of ecological niches, including open forests, freshwater swamps, and hilly landscapes. These differences may contribute to a low species evenness index within individual observation plots. However, in this study, the evenness index tended to approach the maximum value, indicating that species distribution and abundance were relatively uniform across all observation plots. This condition was influenced by the selection of observation plots that were evenly distributed across each ecological niche. Species evenness was determined by the uniform distribution of species across observation plots and was inversely related to species dominance [38]. Higher evenness values indicate a more even species distribution and lower dominance by certain species [38,39].

4. Conclusion

The study on the identification of the diversity of the Dipterocarpaceae family in the Sungai Harapan Protected Forest Arboretum, Batam, Riau Islands Province, successfully identified 20 species from six genera: Cotylelobium, Dipterocarpus, Dryobalanops, Hopea, Shorea, and Vatica, with a total of 590 individuals recorded at the seedling, sapling, pole, and tree stages. The species with the highest IVI at the seedling level was *H. beccariana*, followed by *S.curtisii,* and *V. pauciflora*. At the sapling level, the dominant species based on IVI *were H. beccariana, S. curtisii,* and *V. pauciflora*. At the pole stage, the dominant species were *S. curtisii*, *H. beccariana*, and *D. rigidus*. Meanwhile, at the tree stage, the dominant species were *S. curtisii, H. beccariana,* and *D. rigidus*. All species recorded at the tree stage were native species. The Shannon–Wiener diversity index of the Dipterocarpaceae family was categorized as moderate, while the species evenness index was categorized as high. Species evenness is determined by the uniform distribution of species across observation plots and is inversely related to species dominance. Higher evenness values indicate a more even species distribution and lower dominance by certain species.

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