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Conserving dipterocarps biodiversity in remnant forests of small islands in Batam Island, Indonesia

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Abstract. *Susilowati A, Wijaya K, Mawazin, Rachmat HH, Lismayati Y, Kurniawan H, Ginting IM. 2024. Conserving dipterocarps biodiversity in remnant forests of small islands in Batam Island, Indonesia. Biodiversitas 25: 726-733.* The protected forest of Sei Harapan is a remnant forest in Batam Island, the Riau Islands Province, Indonesia and one of the *keruing* (*Dipterocarpus* spp.) habitats on Sumatra Island. Illegal logging for its wood and land degradation have significantly reduced the *keruing* population. The objective of this research was to assess the diversity of *keruing* species and floristic composition in the Sei Harapan Protected Forest. This study employed a vegetation analysis method using purposive sampling with plotted lines and the transect placement based on the *keruing* position. The research revealed more than 70 species, three of which were Dipterocarpaceae species, including *Vatica pauciflora*, *Shorea curtisii*, and *Dipterocarpus rigidus*. *D. rigidus* had the highest IVI at the sapling (52.80%) and pole (67.22%). However, *D. rigidus* ranked 13th in the seedling stage, with an IVI of 5.79%. The diversity index was high at the seedling stage (3.73), moderate at sapling (2.25), pole (2.76), and tree stage (2.89). The evenness index was high at all growth stages, with values of 0.94 (seedling), 0.98 (sapling), 0.91 (pole), and 0.81 (tree). The richness index at the seedling, pole, and tree stage were categorized as high, with values of 10.40, 5.39, and 7.09, respectively, whereas the richness index at the sapling stage was moderate at 3.51. The study finding pointed out that the existence of Sei Harapan remnant forest requires to be preserved considering its essential function for preserving high economic value tree species, especially Dipterocarp. The comprehensive conservation effort for dipterocarps species, is crucial considering the research findings revealed a problem of continuity of species regeneration and the emergence of new pioneer species as the consequence of anthropogenic disturbance.

Keywords: *Dipterocarpus rigidus*, diversity, floristic composition, habitat

INTRODUCTION

Small islands play a vital role in conserving tree biodiversity, particularly within the context of the climate change scenario. As isolated ecosystems, small islands often serve as unique and crucial refuges for various plant species (Jose et al. 2021), fostering higher species endemism and diversity (Thomas et al. 2020), and facilitating genetic exchange between populations and promoting adaptability to changing environmental conditions (Meyer et al. 2019; Costa et al. 2022). However, despite their ecological significance, small islands are vulnerable to anthropogenic activities such as illegal logging and land degradation (Solórzano-García et al. 2021), putting their rich tree biodiversity at risk. Therefore, concerted efforts towards effective conservation measures are urgently needed to protect the remnant forests on these small islands, preserving not only their endemic species but also the broader tree biodiversity that is integral to mitigating the impacts of climate change on terrestrial ecosystems.

Significant landscape changes have impacted biodiversity and ecological processes, particularly in highly diversified ecosystems such as tropical forests (Barlow et al. 2016). As a result, remaining tropical forests are becoming increasingly isolated, persisting on smaller, irregular patches with larger edge effects (Laurance et al. 2006; Arroyo-Rodríguez et al. 2013). Despite their small size, remnant forests play an essential function in the recovery of post-disturbance forest ecosystems (Wu et al. 2022). This is because remnant trees may assist in the immediate recovery of disturbed areas by providing seeds that are necessary for forest regeneration, recruiting seedlings, and promoting landscape connectedness. Remnant ecosystem is also crucial for preserving native species (Kowarik and Lippe 2017) and has the highest concentration of endangered species in a single environment (Soga et al. 2013). Therefore, efforts to protect and evaluate the existence of remaining ecosystem are critical as a source of species conservation.

Dipterocarpus, also known locally as *keruing* is a commercial wood and resin producer genus (Dewi and Supartini 2017), and the third largest genus in the Dipterocarpaceae (Ashton 1988; Khan et al. 2020). There are 38 species of *keruing* known to be found in Indonesia, particularly on the islands of Sumatra and Kalimantan (Kartawinata 1983). The IUCN Redlist currently reports that 15 *Dipterocarpus* species out of 61 recognized species are undergoing a population decline. Several previous studies (Rugayah et al. 2017; Robiansyah 2017; Rachmat et al. 2018) showed that damaged habitat and illegal wood exploitation have threatened *keruing* sustainability. Furthermore, a longer flowering season (Harrison et al. 2005, Shivaprasad et al. 2017), and specific habitat (Purwaningsih 2004; Shivaprasad et al. 2017) have the potential to decrease *keruing* populations. The declining population of *Dipterocarpus* species requires rapid conservation efforts.

Batam Island is a natural habitat for several Dipterocarpaceae species. The existence of Dipterocarpaceae species on this island has been widely reported, including by Subiakto and Rachmat (2015), Susilowati et al. (2020), Subiakto et al. (2016) and Susilowati et al. (2023) including *Dipterocarpus rigidus*. Although recent study evidence indicates that this species still persists its natural habitat (Susilowati et al. 2023), the IUCN Red List classifies *D. rigidus* as Critically Endangered (Rachmat et al. 2020) and is listed in Appendix I CITES, implying that the trade of this species is prohibited. It also indicates that various types of disturbances have resulted in a significant decrease in *D. rigidus* population, posing a serious threat to its long-term viability. Illegal logging for timber and habitat conversion have been suggested to be major factors contributing to its population decline, particularly in Indonesia (Rachmat et al. 2020; Susilowati et al. 2020). These threats are expected to continue as the need of timber products for housing rises as human population increases.

The Sei Harapan protected forest, which is part of the city of Batam, is one remaining forest in Batam and natural habitat for many Dipterocarpaceae species, including *D. rigidus.* According to Batam Municipality in Figures (2023), the Sei Harapan region is located in the Sekupang District, Batam Island, with an area of 673,7 ha. The Sei Harapan protected forest, as well as several other protected forests on Batam Island, have been subjected to a variety of disturbances, including forest fires, human interference, and land conversion into residential and commercial districts (Yuliastrin 2016). This anthropogenic disturbance has an impact not only on tree diversity, population structure, and forest regeneration, but it also threatens protected forest areas and the biodiversity they represent. A thorough understanding of existing vegetation is important for management to ensure the continued existence of a plant species through natural regeneration, therefore the purposes of this study were to assess the diversity of *keruing* species and floristic composition in the Sei Harapan protected forest. The information on the floristic diversity in Sei Harapan can provide guidance for scientific management and conservation planning of remaining trees, particularly *keruing* species.

MATERIALS AND METHODS

Study area and period

This study was carried out in the Sei Harapan protected forest in Batam Island. This area administratively is located in Sekupang Sub-district, Batam City, Riau Islands Province, Indonesia. Sei Harapan Forest is a protected forest (*Hutan Lindung*) surrounded by residential areas and is one of few remaining protected forests in Batam City. The study site is a lowland tropical forest with elevation of 5 m asl. It has a minimum temperature of 22.4 to 23.3°C and a maximum temperature of 31.6 to 34.2°C. Meanwhile, humidity levels at the research site ranged from 78 to 86%. Monthly rainfall ranges from 77.1 to 368.9 mm^3, with the least and greatest number of rainy days being 6 and 26, respectively. The Sei Harapan protected forest not only provides habitat for numerous species of flora and fauna, but it also provides clean water for the neighboring population. A reservoir on the outer edge of this forested region serves as a supply of clean water. As a result, the Sei Harapan protected forest area is particularly significant not only for the ecosystem, but also for the livelihoods of the neighboring population. According to the official Batam City website and existing data, the Sei Harapan protected forest was only 673,7 ha in size. In 2019, the Sei Harapan protected forest experienced a fire that burned approximately ± 40 ha of the forest.

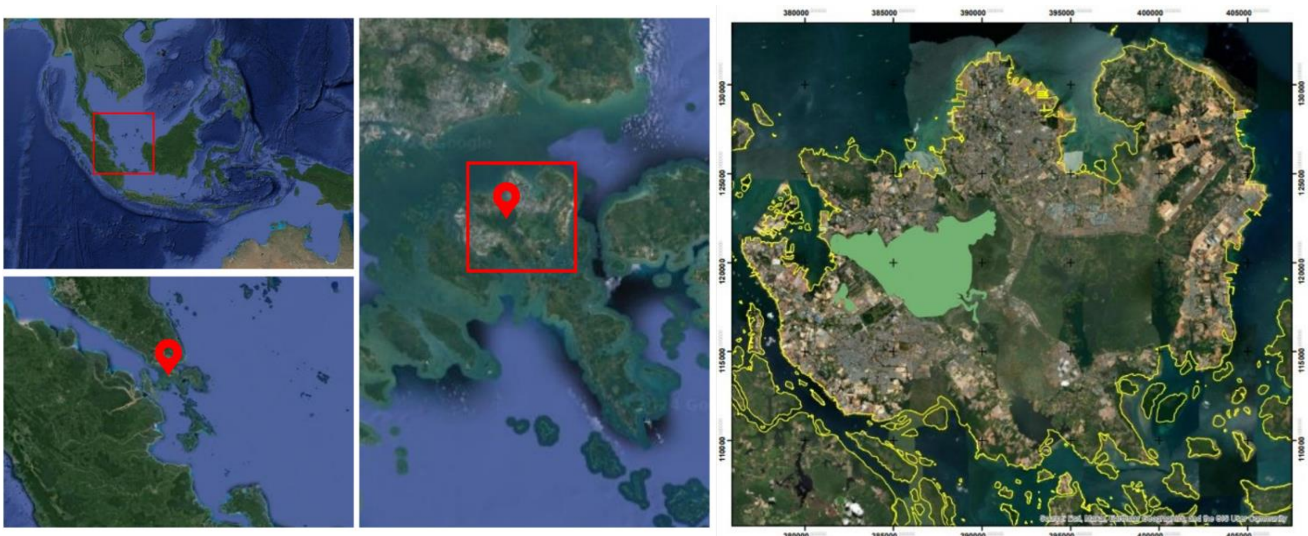

Figure 1. Research location in Sei Harapan Protected Forest, Batam Island, Riau Islands Province, Indonesia

Data collection

The sampling for the population study was carried out using the point center method to record the parent trees followed by establishing 20 quadrant plots of 10 × 10 m. The neighboring areas of this quadrat were then observed for the presence of the target species. If at least one individual of *D. rigidus* was detected, a neighboring 10 × 10 m quadrat was added to the initial quadrat. Quadrats were added repeatedly until no additional plots contained target species. In each of the quadrat plots, samples of all individual trees were collected. The field survey was conducted at the flowering times, making it easy to determine the mature trees. The trees at the flowering stage were considered the parents. The seedlings and saplings located around the parent trees and whose height has not reached the upper canopy layer were considered the offspring.

The species name and number of individuals were recorded. The vegetation was categorized into four growth stages, namely seedlings (height <1.5 m), saplings (height > .5 m and diameter at breast height/dbh <10 cm), poles (10 cm<dbh<20 cm and trees (dbh >20 cm). For poles and trees, dbh was recorded to obtain basal area values. Unidentified species were collected their specimens and stored in a herbarium for later identification.

Data analysis

The importance value index (IVI) was calculated to determine the species composition at the research area. Curtis and McIntosh (1950) and Phillips (1959), developed the IVI by adding up the relative estimates of density, frequency, and basal area. Relative density was calculated by dividing the number of individuals in a species by the total number of individuals in all species as follows:

$$\text{Relative Density} = \frac{Total\ number\ of\ individual\ species}{Total\ number\ of\ all\ individual\ of\ species} \times 100\%$$

Relative frequency was determined by the number of plots in which a species can be found. Relative frequency indicates how frequently a species appears in observation plots, and relative frequency can also determine the ratio of a species' frequency to all species observed at the research location. The following formula was used to compute relative frequency.

$$\text{Relative Frequency} = \frac{Frequency\ of\ respective\ species}{Frequency\ of\ all\ species} \times 100\%$$

Relative basal area (RBA) was computed for the tree stage using the dbh value. When employing dbh values, RBA is determined not only by the number of individuals, but also by the size of the stems recorded for each individual. As a result, stem width can have a substantial impact on the basal area value. The following formula was used to calculate relative basal area:

$$Relative\ Basal\ Area = \frac{Basal\ area\ of\ species}{Basal\ area\ of\ all\ species} \times 100\%$$

The important value index was calculated as follow:

$IVI = RD + RF$ (seedling and sapling)

$IVI = RD + RF + RBA$ (pole and tree)

This study also assessed several ecological indices, including the species diversity index, species evenness index, and species richness index, in addition to assessing species dominance factors at the research location. The Shannon Wienner index (H') is used to determine the species diversity index. The Shannon Wienner Index is a measure of the portion of a species' coverage in the total number of samples (Turkis and Elmas 2018). The Shannon-Wienner diversity index (H') can be calculated using the Odum (1971) formula, which is as follows:

$$(H') = -\sum_{i=1}^{s} Pi \ln Pi$$

Where: H' is the species diversity index and S is the total number of species. The Pi value is a comparison or proportion of the number of individuals found in a species (ni) to the total number of individuals found. Species evenness index is derived using a formula based on Odum (1971), specifically the following formula:

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

Where: E represents the evenness index and H' represents the species diversity value. The species evenness value ranges from 0 to 1 in which value close to 0 indicates species evenness is poor, while value close to 1 indicates high evenness. In addition to the diversity and evenness indices, the species richness index is examined in this study. The species richness index is determined by comparing the number of species discovered to the total number of individuals found across all species. The species richness index was calculated using the following formula, which is based on Margalef (1958):

$$R = S - \frac{1}{Ln\ (N)}$$

Where: R is Margalef index, S is the total number of species recorded at the research site, and N is the total number of individuals from all species. Wardhana et al. (2022) divide the species richness index value into three categories: high if the value obtained is greater than four (R >4), moderate if the value obtained is between 2.4 and four (2.5>R>4), and low if the value obtained is less than 2.5 (R<2.5).

RESULTS AND DISCUSSION

Floristic composition in Sei Harapan protection forest

Based on the findings of the study, the *D. rigidus* was quite prominent in the Sei Harapan protected forest, where it can be found at three growth stages, namely seedling, pole, and tree. *D. rigidus* dominated the pole and tree stages and had the highest IVI with 52.80 and 67.22%, respectively. However, at the seedling stage, *D. rigidus* ranked 13 and had low IVI with 5.79% (Table 1).

Table 1. Ten tree species with the highest IVI at the seedling, sapling, pole, and tree stages in the Sei Harapan protected forest, Batam Islands, Riau Islands Province, Indonesia

Rank	Species	RD (%)	RF (%)	RBA (%)	IVI (%)
Seedling					
	Gironniera nervosa Planch.	6.13	5.63		11.77
	Calophyllum pulcherrimum Wall. ex Choisy	5.52	4.93		10.45
	Sloetia elongata (Miq.) Koord.	4.91	4.93		9.84
	Gironniera parvifolia Planch.	4.29	4.93		9.22
	Coffea sp.	3.68	4.23		7.91
	Pternandra echinata Jack	3.07	3.52		6.59
	Canarium apertum H.J.Lam	3.68	2.82		6.50
	Palaquium burckii H.J.Lam	3.68	2.82		6.50
	Santiria laevigata Blume	3.68	2.82		6.50
	Syzygium syzygioides (Miq.) Merr. & L.M.Perry	3.68	2.82		6.50
	Dipterocarpus rigidus Ridl.	3.68	2.11		5.79
Sapling					
	Calophyllum pulcherrimum Wall. ex Choisy	15.38	16.67		32.05
	Garcinia parvifolia (MIq.) Miq.	15.38	16.67		32.05
	Shorea curtisii (Dyer ex King) P.S.Ashton & J.Heck.	15.38	8.33		23.72
	Coffea sp.	7.69	8.33		16.03
	Kibatalia maingayi (Hook.f.) Woodson	7.69	8.33		16.03
	Litsea firma (Blume) Hook.f.	7.69	8.33		16.03
	Rhodamnia cinerea Jack	7.69	8.33		16.03
	Syzygium syzygioides (Miq.) Merr. & L.M.Perry	7.69	8.33		16.03
	Syzygium urceolatum subsp. *palembanicum* (Miq.) P.S.Ashton	7.69	8.33		16.03
	Vatica pauciflora (Korth.) Blume	7.69	8.33		16.03
Pole					
	Dipterocarpus rigidus Ridl.	19.51	9.38	23.91	52.80
	Calophyllum pulcherrimum Wall. ex Choisy	12.20	12.50	10.85	35.55
	Litsea firma (Blume) Hook.f.	9.76	6.25	8.96	24.97
	Shorea curtisii (Dyer ex King) P.S.Ashton & J.Heck.	7.32	9.38	5.08	21.77
	Maasia glauca (Hassk.) Mols, Kessler & Rogstad	4.88	6.25	6.41	17.54
	Coffea sp.	4.88	3.13	6.41	14.41
	Alangium ridleyi King	4.88	6.25	3.16	14.29
	Calophyllum canum Hook.f. ex T.Anderson	4.88	6.25	3.16	14.29
	Carallia brachiata (Lour.) Merr.	2.44	3.13	3.81	9.37
	Sterculia foetida L.	2.44	3.13	3.81	9.37
Tree					
	Dipterocarpus rigidus Ridl.	23.97	9.59	33.67	67.22
	Sloetia elongata (Miq.) Koord.	17.36	8.22	9.76	35.34
	Shorea curtisii (Dyer ex King) P.S.Ashton & J.Heck.	4.13	6.85	3.19	14.17
	Porterandia anisophylla (Jack ex Roxb.) Ridl.	4.96	5.48	3.03	13.46
	Palaquium burckii H.J.Lam	4.96	4.11	3.45	12.52
	Endospermum diadenum (Miq.) Airy Shaw	2.48	4.11	4.71	11.30
	Calophyllum pulcherrimum Wall. ex Choisy	4.13	4.11	2.54	10.78
	Dyera costulata (Miq.) Hook.f.	1.65	2.74	6.28	10.67
	Pternandra echinata Jack	3.31	4.11	2.18	9.59
	Kibatalia maingayi (Hook.f.) Woodson	3.31	4.11	1.13	8.54

Note: RD: Relative Density; RF: Relative Frequency, RBA: Relative Basal Area; IVI: Important Index Value

Dipterocarpus rigidus grows and distributes naturally in lowland tropical forests at altitudes of less than 200 m asl as reported by Brearley et al. (2007), who discovered *D. rigidus* growing in hilly forest areas at an elevation of around 150 m asl in Central Kalimantan. Meanwhile, previous studies reported *D. rigidus* grows naturally at low altitudes (100 m asl) in Riau and Batam Island (Subiakto et al. 2016; Susilowati et al. 2023). This species is a large-size tree with cylindrical trunk and is distinguished by a yellowish-green crown when viewed from below (Subiakto et al. 2016).

The study's findings indicate that there is an imbalance between the population of *D. rigidus* at the juvenile stages and those at pole and tree stages. At the seedling stage, 163 individuals from 54 species were identified, however, only 6 individuals of *D. rigidus* were recorded. This species was found at the seedling stage but not at the sapling stage. Several biotic and abiotic factors may cause the low presence at the juvenile stages. Anthropogenic factors are regarded to be the most important elements in disrupting the stability of the *keruing* population at the location of the study. In 2019, fire occurred at the research site and is thought to have killed many trees, opening the canopy that provides shade and dramatically increasing the light intensity. The high light intensity is considered to accelerate the growth of shrubs and understory plants, preventing seeds from many species, including *D. rigidus*, from contacting the ground and eventually failing to germinate, despite the old trees producing seeds. Forest fires in 2019 opened up the canopy, preventing a large number of seedlings from surviving and growing into saplings in the next stage. Susilowati et al. (2020) reported that by reducing light intensity by up to 75%, *D. rigidus* attained a relatively high survival rate of 88.9% in shaded seedling beds. Based on this, it is suggested that *D. rigidus* prefers low light intensity during the juvenile stages. A similar phenomena was observed in the Idgaon Dipterocarp forest in Bangladesh *D. turbinatus* is disappearing at the sapling stage as a result of anthropogenic disturbance and natural regeneration. *Dipterocarpus* totally relies on regeneration through seed. Consequently, on disturbed area the seedlings will be out competed by the species that can regenerate vegetatively (Biswas and Misbahuzzaman 2008). This situation is becoming severe as residential areas expand into forest regions, converting the forest into degraded areas with undesirable vegetation. Susilowati et al. (2021) reported that the population of all *Dipterocarpus* species have declined due to anthropogenic pressure on forests for various activities such as agriculture and illegal logging, as well as their preferences for specific microsites and biological reproductive characteristics.

Aside from ecological variables, the characteristics of *keruing* fruit, which are attractive to a variety of animals, are likely to have influenced the low quantity of seedlings at the research location. Naturally, *keruing* fruit is frequently devoured by forest animals and has the nutrients that animals require. Thus, when it falls on the forest floor, the *keruing* fruit is generally eaten by animals before it has a chance to germinate. Previous research has found that *keruing* fruit is palatable by animals such as birds, monkeys, and wild boar, limiting its germination rate on the forest floor (Iku et al. 2017; Heriyanto and Bismark 2014; Denny and Susilo 2019). Still linked to seed characteristics, *keruing* seed has short viability period since it is a recalcitrant seed. Because suitable environmental conditions are required for seeds to germinate, falling fruit will fail to develop into seedlings in unfavorable environmental conditions. There were also unfavorable environmental conditions at the research site, where there were many bushes and vegetation that prevented the seeds from reaching the soil, resulting in diminished viability and failure to germinate. This is caused by an open canopy, which increases the amount of light that enters the forest floor and stimulates the growth of diverse shrubs and understory plants. The relatively high temperature at the research site aggravates the condition of falling seeds, causing them to dry up before germinating. According to O'Brien et al. (2013), the formation of Dipterocarpaceae seeds is very vulnerable to rare rainfall due to their recalcitrant characteristics, making the seeds fail to survive the dry season (Romadini et al. 2022), which is further exacerbated by high predation of seeds by animals.

In contrast to the species composition at the seedling and sapling stages, the results showed that *D. rigidus* dominated the pole and tree stages. The abundance of *D. rigidus* at the pole and tree stages at the research site suggests that the Sei Harapan protected forest is a natural habitat for *keruing*, and that this species predominates over others. The numerous adult individuals provide a supply of seeds that enable natural regeneration prior to various habitat disturbances that limit natural regeneration and change the stability of the vegetation composition therein. The existence of a large number of adult *D. rigidus* individuals also suggests that environmental conditions at the research site are stable, with disturbances occurring when *D. rigidus* matures, produces flowers and fruit, and produces seeds, but no adequate natural regeneration occurs. Although no reference that specifically states how old *D. rigidus* is until it reaches the mature stage, individuals that are estimated to grow at a relatively uniform age (including the adult category) provide an indication that growth from the seedling stage to becoming an adult individual is proceeding well. This lends credence to the argument that the anthropogenic disturbance occurred recently.

Aside from *D. rigidus*, the research results suggest that other Dipterocarp species dominated the area of study. *Shorea curtisii* and *Vatica pauciflora*, two other dipterocarps species studied, had the highest IVI at all growth stages. *S. curtisii*, like *D. rigidus*, had three growth stages, however unlike *D. rigidus*, it did not have a seedling stage. *S. curtisii* was discovered consistently at the sapling, pole, and tree stages, with IVI values of 23.72, 21.77, and 14.17%, respectively. Unlike the other two species, *Vatica pauciflora* was only discovered at the sapling stage, with an IVI of 16.03% (Table 1).

Gironniera nervosa had the highest IVI value throughout the seedling stage, followed by *Calophyllum pulcherrimum* and *Sloetia elongata*, with 11.7, 10.45, and 9.48%, respectively. At the sapling stage, *C. pulcherrimum* had the highest IVI, followed by *Garcinia parvifolia* and *S. curtisii*, which had IVI of 32.05, 32.05, and 23.72%, respectively. The two species with the highest IVI in the previous growth stage were not found at this stage. A similar occurrence happened at the pole stage, where *G. parvifolia* and *S. curtisii* were replaced at the top by *D. rigidus* and *Litsea firma*. In sequence, the three species that obtained the highest IVI values at the pole stage were *D. rigidus* (52.80%), *C. pulcherrimum* (35.55%), and *L. firm*a (24.97%). Meanwhile, at the tree stage, *D. rigidus* was again recorded to have obtained the highest IVI value, followed by two other species, namely *Sloetia elongata* and *S. curtisii* with IVI values of 67.22%, 35.34% and 14.17% respectively (Table 1). At the pole stage, the three species with the greatest IVI were *D. rigidus* (52.80%), *C. pulcherrimum* (35.55%), and *L. firm* (24.97%). Meanwhile, *D. rigidus* had the greatest IVI at the tree stage, followed by *Sloetia elongate* and *S. curtisii*, with IVI of 67.22, 35.34, and 14.17%, respectively (Table 1). Overall, the majority of species discovered have fluctuating populations at each growth stage which might be related to environmental conditions. Individuals unable to withstand unfavorable environmental conditions are likely to have decreased in number. Forest structure and dynamics in natural forests, according to Ghalandarayeshi et al. (2017), are the outcome of an enormous factor and processes triggered by disturbance regimes throughout space and time. Chiteculo and Surovy (2018) highlighted that environmental conditions, species interactions, and human involvement over time can all contribute to forest structure and dynamics.

Ecological index in Sei Harapan protection forest

Ecological index analysis is notable for its ability to describe how complex diversity is produced in an ecosystem, which can be assessed using three separate components: diversity value, species evenness value, and species richness value. The study's findings indicate that the Sei Harapan protected forest had variable levels of diversity, evenness, and species richness at each growth stage (Figure 1).

According to Figure 2, the species diversity index (H') in the Sei Harapan protected forest ranged from 2.25 to 3.73. The seedling stage had the highest diversity index, with 3.73, which is classified as high. Meanwhile, the sapling level had the lowest species diversity index, which is classified as medium (H'=2.25) (Figure 2). Several variables are known to contribute to the high species variety during the seedling stage, but open land conditions due to anthropogenic disturbances are thought to be the most important. This is supposed to have stimulated the growth of diverse seeds on the forest floor, allowing the seeds to expand and flourish. Susilowati et al. (2021) found that species diversity at the seedling level in a natural habitat of *keruing* in North Sumatra Province was low, which is thought to be due to the high density of the tree canopy, which prevents light from entering the forest floor and inhibits the growth of juvenile individuals.

Apart from having a dominantly moderate diversity index, analysis of the species evenness index showed that the level of evenness tended to be high at all stages of growth (Figure 1). The evenness index closer to 1 indicates that the majority of species at all stages of growth have a fairly even population of individuals. The results showed that the highest evenness index was obtained at the sapling stage (E=0.98), while the lowest evenness index was obtained at the tree stage (E=0.81). High species evenness can be an indicator of ecosystem stability, where an even number among species will minimize the tendency of a species to dominate the ecosystem. Several researchers have also stated that plant evenness and diversity are strongly correlated with the stability of the associated community, demonstrating that a high level of diversity leads to higher use of complementary resources through complementary niches (de Mazancourt et al. 2013; Loreau and De Mazancourt et al. 2013). Despite being damaged in the past, the research location, which has the status of a protected forest, has a diverse plant species composition with a consistent number of individuals. This subsequently affects the evenness of the species within it, resulting in a high evenness index. Susilowati et al. (2021) discovered the same result in their research, meaning that the evenness of species and the increase in plant communities are controlled by varied natural forest components and a constant number of individuals.

In terms of richness, the highest species richness index (R) was obtained at the seedling stage, namely 10.40, which is classified as high. Meanwhile, the sapling stage had the lowest richness index, with a value of only 3.51 and falling into the medium category (Figure 2). Species richness is strongly related to the number of species observed in an environment, suggesting that the research area had a high diversity of species. Tilk et al. (2017) suggested that habitat heterogeneity affects species richness, stating that changes in the richness and diversity of tree and seedling species can be connected with habitat heterogeneity, which is reflected by environmental conditions and soil characteristics. Regardless of the scale of the disturbance experienced by the Sei Harapan protected forest, the ecological index, which has a rather high value, demonstrates quite good resilience. Although the data reveal rather decent stability, conservation efforts and species enrichment at the research site are strongly encouraged to assist in the establishment of a more complex ecosystem.

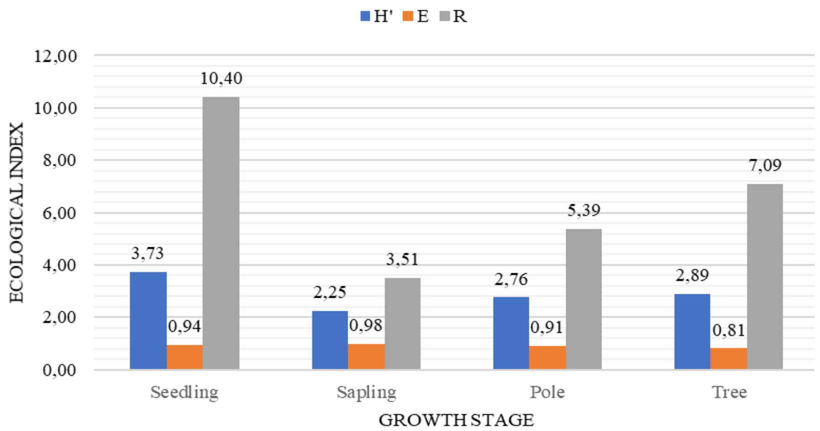

Figure 2. Ecological index of tree species in the Sei Harapan protected forest area, Batam Island, Riau Islands Province, Indonesia

In conclusion, the existence of the remaining Sei Harapan forest is very important in maintaining the existence of dipterocarps in anthropogenically disturbed areas in Batam. Although the research findings indicated that the genera *Dipterocarpus*, *Shorea*, and *Vatica* remain at this area, anthropogenic disturbances have impacted their natural regeneration. Forest fires and other anthropogenic disturbances allowed the canopy openness, resulting in the disappearance of *S. curtisii*, *V. pauciflora* (at seedling stage), and *D. rigidus* (at sapling stage), as well as the new recruitment of pioneer species. The emergence of pioneer species that are more adaptive to canopy openness also needs concerns due to possibility of disrupting the natural ecosystem structure. To maintain the existence of species with high commercial value, such as Dipterocarpacea, and return forests to their original structure, a comprehensive program such as native species planting is required that guarantees and maintains the natural regeneration of native species, particularly dipterocarps, while maintaining the current trend of regeneration for the understorey species that are required.

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