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Analysis of vegetation and plant diversity in high conservation value areas in oil palm plantations

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Abstract

The expansion of oil palm plantations is often rumored to impact the destruction of forests and other ecosystems with high conservation value (HCV). This study aimed to analyze the vegetation and plant diversity in the HCV area of oil palm plantations. The research was conducted on an oil palm plantation in Seruyan District, Central Kalimantan Province, Indonesia with an HCV area of 5,379 ha. The research was carried out using the grid transect method on various types of vegetation, divided into four plots: seedlings, saplings, poles, and trees. Parameters observed included the number of species, the number of individuals, and the level of plant diversity. The results showed that the research location had good vegetation and plant diversity in the HCV area. There were 25 plant species from 17 families with a total of 355 plants. The number of species found in the seedling plots was 11 species (6 families) with a total of 38 plants; in the sapling plots was 16 species (12 families) with a total of 159 plants; in the pole plots was 14 species (11 families) with a total of 43 plants, and in the tree plots was 13 species (10 families) 115 plants. There was variation in the number of species and families in each plot. The overall plant diversity index was low. The diversity index of plants in the plots of seedlings, saplings, poles, and trees (and the average) was in the low category.

Keywords

Diversity; HCV; Oil Palm; Plantation; Vegetation

Introduction

Palm oil is a leading commodity in Indonesia, covering approximately 14.99 million hectares (ha) in 2022. This figure reflects a 2.49 percent increase compared to the previous year (1). Currently, the palm oil industry is Indonesia's largest contributor to foreign exchange. The contribution of the Indonesian palm oil industry to the national economy is significant and far reaching, encompassing employment, increasing people's welfare, regional development, technology transfer, and investment inflows (2–4). Additionally, the industry has adopted the concept of a circular economy to mitigate its environmental footprint and enhance resource efficiency (5–7).

However, as the palm oil industry in Indonesia continues to grow, the expansion of oil palm plantations directly impacts deforestation (8). The expansion of oil palm plantations is frequently linked to the destruction of forests and other ecosystems with high conservation value, or HCV (9-10). The expansion of oil palm plantations leads to the loss of extensive forested areas, deforestation, soil erosion, biodiversity loss, alterations in ecological landscapes, shifts in land use cover, and environmental issues (11-13). Moreover, deforestation negatively impacts indigenous tribes and local communities that rely on the forest for their livelihoods, limiting their access to natural resources and jeopardizing the sustainability of their culture and traditions (14–16).

Hence it is imperative for the government and relevant stakeholders to implement sustainable and environmentally responsible policies in the management of the palm oil industry. This is essential to minimize its adverse effects on the environment and society (16-17).

Oil palm plantations can result in the loss of endangered species of flora and fauna, followed by an ecological imbalance (18–20). The loss of forests and natural habitats causes climate change because of the reduction in CO_2 absorption capacity (21-22). The loss of tall plants is another factor in climate change, as they maintain a moderate temperature in tropical areas by their canopy (23). Large land clearing for various human interests also affects soil quality and the microclimate in the region (24-26). All of these factors ultimately have an impact on the level of global climate change, which significantly disrupts environmental conditions (27-29).

Based on the above facts, it is important to manage the expansion of oil palm plantations appropriately (30-31). The integration of sustainable principles in the planning and operation of agricultural practices is a key aspect of maintaining a sustainable environment and the active participation of governmental bodies, companies, communities, and environmental NGOs is required to achieve this goal (32-34). Implementation of sustainable and innovative technologies, such as the use of advanced technology in land management, irrigation, environmental monitoring, and palm kernel sorting, is also necessary to reduce the negative impacts of plantations (35-37). This effort is an integral part of economic, social, and ecological relationships to minimize damage (38,39). By adopting a sustainable approach to planning and operating, oil palm plantations can contribute positively to the economy without compromising the preservation of the environment and biodiversity which are very valuable (40-42). This study aimed to analyze vegetation and plant diversity in high conservation value areas within a 15-year-old oil palm plantation.

Materials and Methods

Study Site and Time

The study was conducted on an oil palm plantation in Seruyan District, Central Kalimantan Province, Indonesia, covering a HCV area of 5,379 ha (Fig. 1). The study lasted for 12 months, from September 2021 to November 2022. The topography of the study site consisted of flat (0–4%) to undulating (4–12%) land, with undulating terrain predominately located in the north and east. The majority of the area comprised undulating to flat alluvial plains bisected by a river. The elevation in the area ranges from around 5 – 30 meters, and during the rainy season, most of the low-lying areas were susceptible to flooding.

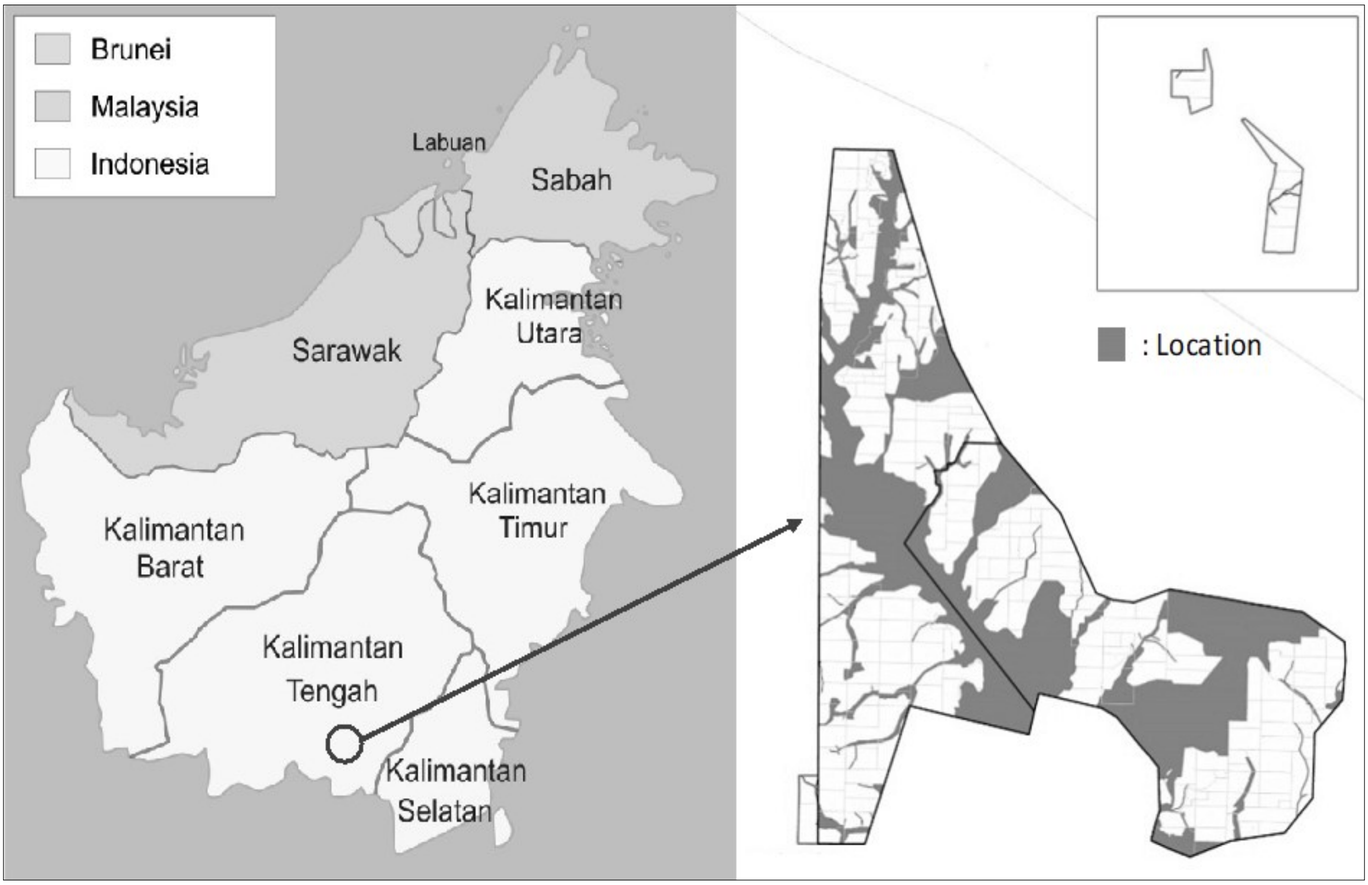

Fig. 1. The Site Map of Oil Palm Plantations, Central Kalimantan

Data Collection Methods

This research employed a descriptive quantitative approach, focusing on vegetation analysis using the grid transect method on various ecosystems/vegetation types. The objective was to gather data on vegetation composition and structure. The quadrat transect method, as the chosen research technique, involved selecting the research site through purposive sampling and dividing it into four predetermined observation points (stations). The square size for each station was determined based on plant habitus, namely: seedling plot (2 x 2 m^2), sapling plot (5 x 5 m^2), pole plot (10 x 10 m^2) and tree plot (20 x 20 m^2) (Fig. 2).

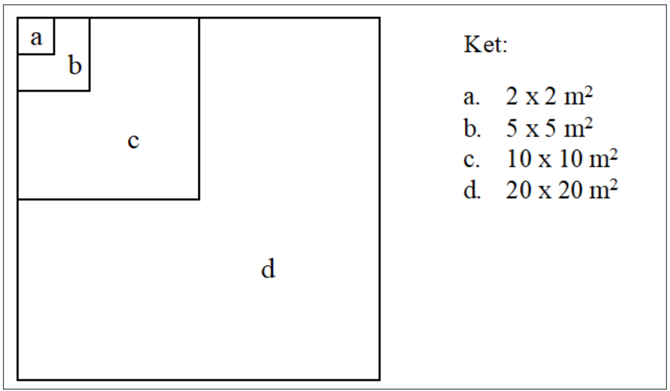

Fig. 2. Research Sampling Sketch

The plant diversity levels in this study were categorized as follows:

1. Seedlings are saplings starting to germinate to a height of less than 1.5 m
2. Saplings are saplings with a height of ≥ 1.5 m and a diameter of < 10 cm.
3. Poles are saplings with a diameter of 10 cm to <20 cm
4. Trees are mature trees with a diameter of ≥ 20 cm

The sample plots were placed systematically by making each transect to the north, south, west, and east. Each observation station was placed in as many as four quadratic transects. To facilitate data collection, each plant observed in every plot was labelled. Individual data within each plot at every observed station were recorded on the observation sheet. Subsequently, the number of individuals per species in each square was calculated to determine the importance value of each. Plant species obtained were documented using a photo camera, and identification was conducteddirectly by using an identification book. The observed research parameters included the number of species, the number of individuals, and the level of plant diversity.

Data analysis

Data analysis was carried out qualitatively and quantitatively. Qualitative analysis was carried to describe the types of plants (herbs, shrubs, poles, and trees). Quantitative analysis amied to assess the diversity value and plant vegetation structure. Plant vegetation assessment involved parameters like density, frequency, dominance, important value index (IVI), and Diversity Index.

Density

Density represents the number of individuals of each species in the sample plot. To facilitate the process of density analysis, AD notation is often used. The ratio of the density of a species to the density of all species expressed in percent is called relative density (RD). The density of plant species and the relative density of species can be calculated by the following equation:

$$\text{Absolute Density (AD)} = \frac{\text{Number of a Species}}{\text{Total Area Sampled}}$$

$$\text{Relative Density (RD)} = \frac{\text{Density of a Species}}{\text{Total Density of all Species}} x\ 100\%$$

Frequency

Frequency is the number of occurrences of each species found in all sample plots. Frequency is the intensity of the discovery of a species of organism in observing the presence of organisms in an ecosystem community. The species frequency and species relative frequency can be calculated using the following equation:

$$\text{Absolute Frequency (AF)} = \frac{\text{Area of Plots in which a Species Occurs}}{\text{Total Area Sampled}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{Frequency of a Species}}{\text{Total Frequency of all Species}} x\ 100\%$$

Dominance

Dominance is the basal area of the tree or the crown cover area of each species found in the plot. Dominance can also be called the cover area. Coverage area is the proportion between the area covered by plant species and the total area of the habitat. The species dominance and species relative dominance can be calculated by the following equation:

$$\text{Absolute Dominance (AD)} = \frac{\text{Total Basal Area of a Species}}{\text{Total Area Sampled}}$$

$$\text{Relative Dominance (RDO)} = \frac{\text{Dominance of a Species}}{\text{Total Dominance of all Species}} x\ 100\%$$

Importance Value Index

The importance value index (IVI) is a quantitative parameter that can indicate the species that predominate at the study site. The important value index is calculated using the following equation:

$$\text{Importance Value Index (IVI) of Herbs/Seedling} = \text{Relative Density (\%)} + \text{Relative Frequency(\%)}$$

$$\text{Importance Value Index (IVI) of Samplin, Pole, \& } Tree = \text{Relative Density (\%)} + \text{Relative Frequency (\%)} + \text{Relative Dominance (\%)}$$

Diversity Index

After obtaining the results of the Importance Value Index (IVI) for each type, the diversity index of each plant species is sought. The diversity of a plant community can be determined using the Shannon-Wiener (Ĥ) information theory, which aims to measure the level of regularity and irregularity in a system. The diversity index is determined using the formula:

$$\hat{H} = \sum pi \ln pi$$

Note: Ĥ= Shannon-Wiener diversity index, *pi* = the proportion of the entire community made up of species , Ln = natural logarithm

High species diversity indicates a community has high complexity because the species interactions in that community are very high. The results obtained can then be categorized into three groups:

1. If Ĥ < 1, then the diversity index is categorized as Low
2. If Ĥ 1 < Ĥ < 3, then the diversity index is categorized as Medium
3. If Ĥ > 3, then the diversity index is categorized as High

The collected data were tabulated and processed. Subsequently, the data were analyzed using qualitative descriptive analysis, which includes the calculation of density, frequency, dominance, important value index, and species diversity index.

Results

Plant Species

The results revealed the presence of 25 plant species in the study area, representing 17 families with a total of 355 plants. The distribution across different developmental stages included 11 species (from 6 families) with a total of 38 plants in seedling plots, 16 species (from 12 families) with 159 plants in sapling plots, 14 species (from 11 families) with 43 plants in pole plots, and 13 species (from 10 families) with 115 plants in tree plots (Table 1). According to Table 1, the sapling level exhibited the highest dominance among the four plant levels. This can be attributed to the faster growth of saplings, facilitated by their robust stems and efficient root systems, enabling better absorption of nutrients and water from the soil. Additionally, saplings possess more leaves, facilitating enhanced photosynthesis and promoting taller and more substantial growth.

The *Myrtaceae* family was with the highest number

Table 1. The types and numbers of plants found in the sampling plots

Species	Indonesian names	Families	Number of Plants in Plots				
			1*	2*	3*	4*	Total
Aporusa sp.	*Hampuak*	*Phyllanthaceae*	-	1	2	-	3
Calophyllum hosei Ridley	*Bintangur*	*Guttiferae*	-	-	-	1	1
Calophyllum sp.	*Penaga*	*Clusiaceae*	5	6	-	2	13
Canarium sp.	*Pantis*	*Burseraceae*	-	-	1	-	1
Combretocarpus rotundatus Miq.	*Tumih*	*Anisophylleaceae*	-	-	3	7	10
Cratoxylon arborescens Vahl.	*Geronggang*	*Hypericaceae*	-	-	5	17	22
Diospyros seudomalabarica Desr.	*Kayu Arang*	*Ebenaceae*	-	1	-	-	1
Garcinia sp.	*Manggis Hutan*	*Clusiaceae*	1	-	-	-	1
Garcinia xanthochymus Hook.	*Asam Kemanjing*	*Clusiaceae*	-	2	1	-	3
Gordonia sp.	*Pelampang*	*Theaceae*	4	19	1	-	24
Horsfieldia glabra Warb.	*Kumpang*	*Myristicaceae*	-	1	6	9	16
Lithocarpus bancanus Scheff.	*Pampaning*	*Fagaceae*	-	2	3	1	6
Macaranga gigantea Mull.	*Mahang*	*Euphorbiaceae*	-	1	-	-	1
Melulaeca cajuputi Sub Sp. Cajuputi	*Galam*	*Myrtaceae*	-	-	1	-	1
Pternandra coerulescens Jack.	*Pasolan*	*Melastomataceae*	4	40	1	-	45
Rhodamnia cinerea Jack.	*Rasak*	*Myrtaceae*	-	-	1	20	21
Rothmannia sp.	*Kopi-Kopi*	*Gardenieae*	-	7	-	-	7
Shorea balangeran Korth.	*Belangeran*	*Dipterocarpaceae*	2	5	6	37	50
Stemonurus scorpiodes Becc.	*Bedaru*	*Stemonuraceae*	2	27	-	2	31
Syzygium antisepticum Blume	*Galam Tikus*	*Myrtaceae*	3	3	-	1	7
Syzygium sp	*Ubar Putih*	*Myrtaceae*	5	12	3	16	36

Syzygium tawahense Korth	*Ubar Merah*	*Myrtaceae*	8	29	9	1	47
Syzygium zeylanicum Linn	*Nasi-Nasi*	*Myrtaceae*	3	-	-	-	3
Tristaniopsis obovata Benn	*Pelawan*	*Myrtaceae*	1	3	-	-	4
Xylopia malayana Hook.f. & Thomson	*Jangkang*	*Annonaceae*	-	-	-	1	1

Note: **1*** = Seedling plots, **2*** = Sapling plots, **3*** = Pole plots, **4*** = Tree plots

of plants. Identified species from the this family included *Melulaeca cajuputri, Syzygium antisepticum Blume*., *Syzygium* sp., *Syzygium tawahense* Korth., *Syzygium zeylanicum* Linn., and *Tristaniopsis obovate*. While the most commonly found species was *Shorea bangeran* from the *Belangeran* family. *Shorea bangeran,* locally known as Bangeran, thrives in peatlands and can grow up to 20-25 meters, with a branch-free stem reaching 15 meters. Balangeran is known as a pioneer species capable of forming initial conditions for degraded peatlands due to its good adaptability. The second most common species was *Syzygium tawahense* Korth. from the *Myrtaceae* family, which is endemic to Kalimantan.

Importance Value Index (IVI)

The IVI of plant species in HCV is one of the important parameters, indicating the role of plant species and the stability of the ecosystem in the HCV region. The existence of plant species in this setting demonstrates their adaptability and tolerance to the environment. The higher the IVI value of a species, the greater its mastery over the HCV. Certain species can dominate an HCV community by effectively securing the majority of available resources compared to other species.

According to Figure 3, in the seedling plots, *Syzygium tawahense* Korth. exhibited the highest IVI value (113.4%), followed by *Calophyllum* sp. (49.5%), *Pternandra coerulescens* Jack. (21.4%), and then other species. The IVI value is the sum of the RD, RF, and RDO values. Therefore, a high IVI value suggests highRD, RF, and RDO values. *Syzygium tawahense* Korth. demonstrated higher RD (38.1%) and RF (54.2%) compared to other species in the community. *Calophyllum* sp. also displayed elevated RD (18.6%) and RF (17.7%). *Semonurus scorpiodes* occupied the third highest percentage in RD value (9.3%).

In the sapling plots, the highest IVI was observed in *Pternandra coerulescens* Jack. (58.5%), followed by *Stemonurus scorpiodes* Becc. (46.6%), and *Syzygium tawahense* Korth. (44.4%). *Pternandra coerulescens* Jack. also displayed the highest RD (13.9%) and RF (25.5%) values, followed by *Semonurus scorpiodes* (12.5% and 17.0%), *Syzygium tawahense* Korth. (11.5% and 18.2%) along with other plant species. The highest RDO values were were recoreded for *Pternandra coerulescens* Jack. (19.5%) and *Syzygium* sp. (17.8%), followed by *Stemonurus scorpiodes* Becc. (17.1%) and other plants (Fig. 3).

In the pole plots, the highest IVI value was found in *Syzygium tawahense* Korth. (58.2%), followed by *Horsfieldia glabra* Warb.(38.3%), *Shorea balangeran* Korth. (37.3%) along with other plants. *Syzygium tawahense* Korth. and *Horsfieldia glabra* Warb. exhibited high RD (14.5%, 9.6%), RF (20.9%, 14.0%), and RDO (22.8%, 14.7%) values. *Shorea balangeran* Korth.displayed relatively high RF (14.0%) and RDO (16.2%) values. Notably, the RD value of *Lithocarpus bancanus* Scheff. (14.5%) was also higher than *Horsfieldia glabra* Warb. (9.6%). In the tree plots, the highest IVI was found in *Shorea balangeran* Korth. (110.4%), surpassing *Rhodamnia cinerea* Jack. (41.5%) and Syzygium sp. (3.9%). Both *Shorea balangeran* Korth. and *Rhodamnia cinerea*

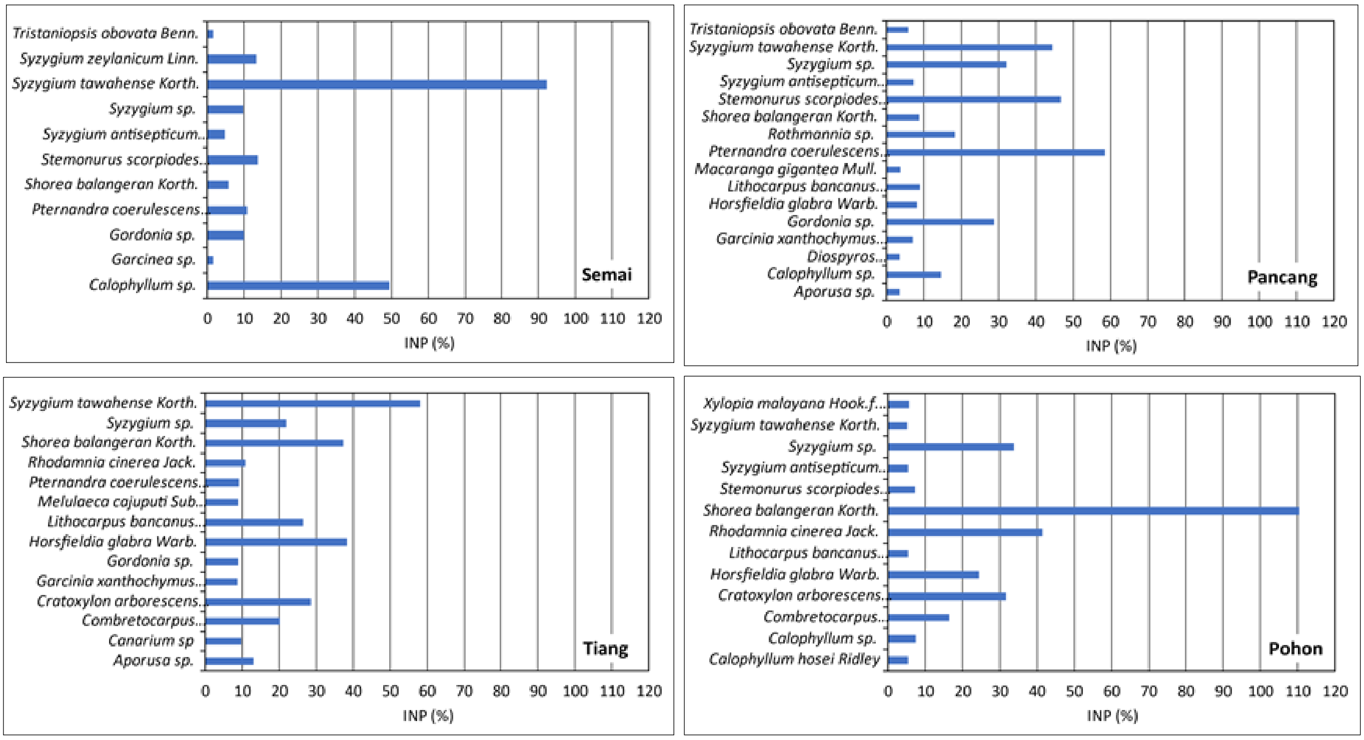

Fig. 3. The Importance Value Index (IVI) based on sampling plots.

Jack. exhibited high RD (19.0%, 11.7%), RF (32.2%, 17.4%), and RDO (59.2%, 12.3%) values. *Shorea balangeran* Korth. had a higher RD value (19.0%) compared to *Rhodamnia cinerea* Jack. (11.7%).

Based on the Fig. 4, Overall, the highest IVI was found in *Shorea balangeran* Korth. (76.9%), followed by *Pternandra coerulescens* Jack. (20.9%), *Rhodamnia cinerea* Jack. (23.6%), *Syzygium* sp. (23.7%), and *Syzygium tawahense* Korth. (20.6%). Notably, *Syzygium tawahense* Korth. had the highest IVI in seedling and pole plots, showcasing its adaptability across different plot types.

Diversity Index (Ĥ)

The diversity index of a plant community in HCV areas relies on the count of species and individuals of each type, offering a measure for expressing community structure. Species Diversity is a valuable metric for assessing community stability and monitoring changes over time. It can be useful for monitoring the impacts of human activities such as habitat degradation, pollution, and climate change. Two main factors in evaluating the diversity index are the number of different species present in an area (species richness) and the balance of the number of these species (species evenness). A higher diversity index value indicates a more diverse and stable ecosystem with more species richness and species evenness distribution. The Diversity Index is an important tool for HCV management because it provides a quantitative measure of the state of an ecosystem. It aids in identifying areas of critical importance for biodiversity conservation.

Based on the Table 2 , the plant diversity index in the HCV at the study site was classified into the low category (Ĥ = 0.96). The index value of plant diversity in the plots of seedlings, saplings, poles, and trees was also low. This low diversity index indicated that the HCV in the study area was dominated by several species that dominated the HCV community. As reported in the IVI study, these species are *Syzygium tawahense* Korth., *Pternandra coerulescens* Jack., and *Shorea balangeran* Korth (Fig. 5). The reasons behind the dominance of these species are further discussed in the following section.

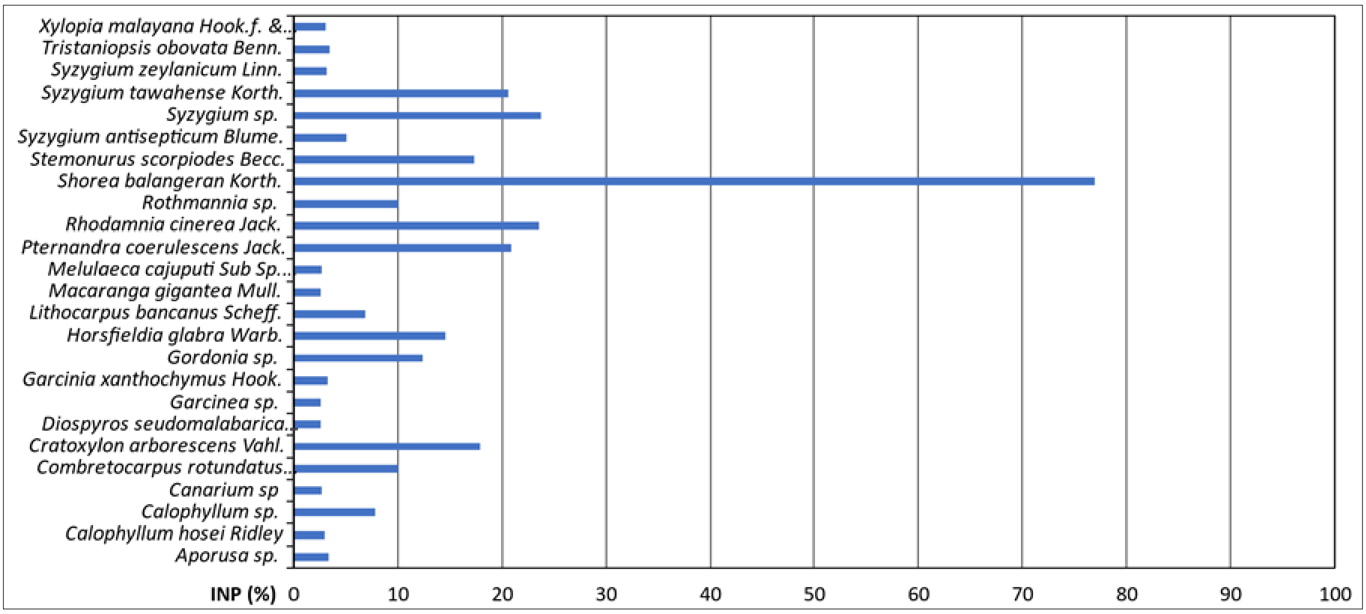

Fig. 4. The overall Important Value Index (IVI) of HCV at the study site

Discussion

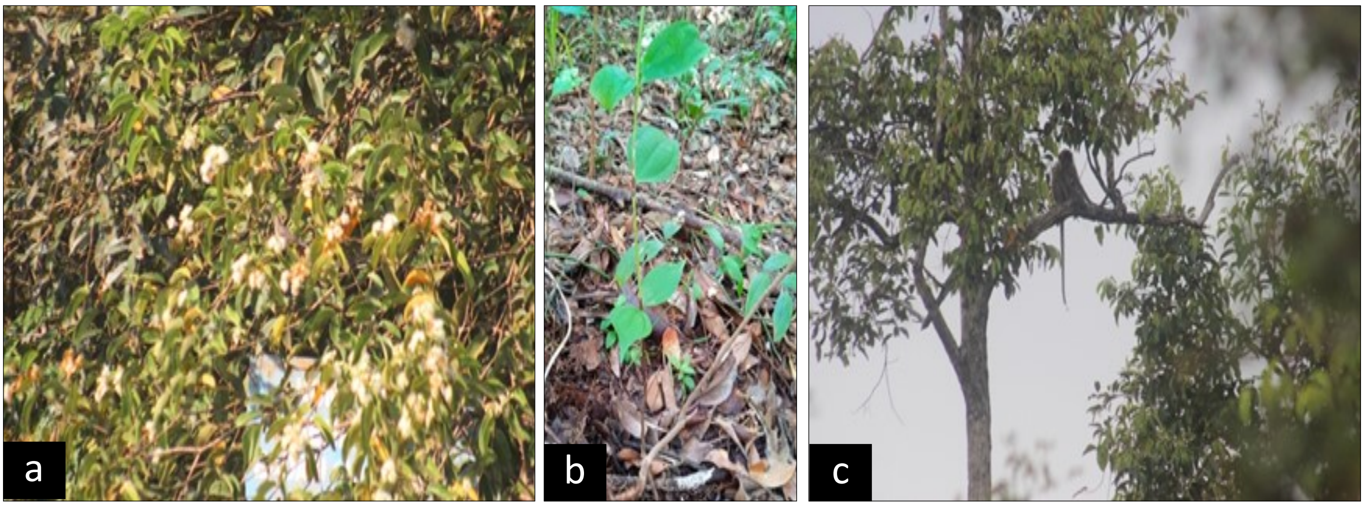

Fig. 5. Syzygium tawahense Korth. (**a**), Pternandra coerulescens Jack. (**b**), dan Shorea balangeran Korth. (**c**)

The dominant species in the area are *Syzygium tawahense* Korth., *Pternandra coerulescens* Jack., and *Shorea balangeran* Korth., as indicated by the study results. *Syzigium* is a genus within the *Myrtaceae* family, boasting around 1200 to 1800 species. *Syzygium tawahense* Korth. is reported to be an endemic plant in Kalimantan, known by various Indonesian names such as Lunoh-lunoh, Obah, Obah bukit, Obah merah, Obar, and Sulang-sulang (43, 44) An inventory at Gunung Baung Purwodadi Natural Tourism Mountain found *Syzygium tawahense* Korth. to be the dominant species at the seedling and understorey levels (45, 46). Similarly, in Lembonah Forest (East Kalimantan), an inventory at the pole level reported domination by *Polyalthia rumphii*, *Alseodaphne* sp., and *Syzygium tawahense* Korth. Interestingly, *Syzygium tawahense* Korth. thrives in undisturbed mixed dipterocarp forests up to 1000 m asl, on sandy and alluvial soils near rivers and streams (43).

Pternandra coerulescens Jack. identified as one of the plants with a high Importance Value Index (IVI) in the study, contrasts with the findings in a separate study conducted in the Riparian Kahala River area (47). In the latter study, *Pternandra coerulescens* Jack. was among the less frequently encountered plant types. This plant is known by various local names such as *Benaun, loho, bisalu, puloh, sari-sari, dulang-dulang, kalomnayng, sireh-sireh* and *ubah meskala*, *Ladek*, *Meransi*, *Mempuyang*, and *Kayu Jame*. *Pternandra coerulescens* Jack. naturally thrives in mixed dipterocarp heath forests at an altitude of 900 m, encompassing swamp forests and peat swamps (48). The genus is widely distributed, stretching from tropical China (Hainan Island), represented by *Pternandra coerulescens* Jack. across the Malay Peninsula (including Singapore), extending to Borneo, tropical Australia, and New Guinea (49). The species frequently encountered in these forests are present in the Pangkor Selatan Forest Reserve, located in Perak, Peninsular Malaysia (50). In the Australian Arnhem Coast Bioregion, both *Pternandra coerulescens* Jack. and *Sticherus flabellatus* var. *compactus* have been observed and documented to be commonly found in association with riparian vine forests and drainage systems (51).

Shorea balangeran Korth. has the Indonesian names *Angi, Ensurut, Marijang, Sepetir, Sindur, Tampar antu, Tampar hantu.* According to the research (52), the results of an inventory in the Sultan Adam Mandiangin Forest Park (South Kalimantan) reported that *Shorea balangeran* Korth. is the dominant plant species. At a different location, namely in the Mount Soka Customary Forest in Landak District, West Kalimantan, (53) has reported that there were at least 23 types of tree vegetation consisting of 13 families (741 individual trees), with the largest tree vegetation still belonging to the *Shorea* genus, namely *Shorea pinanga* Scheff (Engkabang Bukit). *Shorea balangeran* Korth. at the research site can grow well because it is based on the habitat and ecological conditions, namely in secondary forest, undisturbed mixed dipterocarp forest, and heath forest reaching a height of 100 m asl. This plant is reported to have good regeneration ability in peat forests, mainly due to the dispersal of its seeds by the wind. *S. balangeran* is among the plants with promising potential as a source of endophytic fungi (54). *Shorea balangeran* Korth. is a member of the *Diptero-carpaceae* family, naturally distributed in Indonesia, and adapted to a diverse range of ecological conditions, including peat swamps and heath forests (55).

Apart from this, several factors can cause a low Biodiversity Index (BI) in a particular ecosystem or HCV, namely as follows:

1. Habitat Loss and Fragmentation

Biodiversity Index (IB) is an important parameter for assessing the level of biodiversity in an ecosystem or a specific region. IB can be influenced by various factors, and one of the factors that can lead to low IB in an ecosystem is habitat loss and fragmentation (56–58). Habitat degradation is a serious problem caused by human activities, such as large-scale deforestation for logging purposes, urbanization converting land into urban areas, and land-use changes for agriculture or industry (59, 60). These activities result in the loss or reduction of natural habitats for animals and plants, leading to fragmentation (61).

When habitats become fragmented, populations of various species become separated and iso-lated, making genetic exchange between different populations difficult. As a result, species that cannot adapt to these changes tend to experience a decline in their population or even face the risk of extinction (62). Moreover, the reduction in habitat area can cause certain species to lose their homes and sources of food, which in turn dramatically impacts global habitat loss and fragmentation (63). Consequently, the number of species in a particular area may decrease, leading to a lower IB. Preserving natural habitats and managing areas sustainably becomes crucial to protect biodiversity and maintain ecosystem balance (64). Gradual conservation efforts focusing on habitat restoration, protected area conservation, and sustainable land management are essential steps in preserving life on Earth (65).

2. Invasive Species

Invasive species refers to non-native species introduced into an ecosystem that is not their natural habitat. The presence of invasive species can exert significant negative impacts on the existing ecosystem (66). Typically possessing rapid reproductive and growth abilities, invasive species can outcompete and outpace slower-developing native species (67). Their aggressive competition for resources such as food, water, and nesting sites often results in a decline in the abundance and diversity of native species, sometimes leading to changes in biomass (68). This disruption in food chains and species interactions can cause drastic alterations in ecosystem structure, population decline, and even the extinction of native species (69). Additionally, natural disasters have also been reported to impact the low biodiversity (70).

The presence of invasive species can also cause economic, social, agricultural, ecological, and environmental losses (71). Some invasive species can damage crops, forests, or gardens, reducing the productivity and income of farmers (72). To address the issue of invasive species and preserve biodiversity, appropriate conservation measures must be taken. Strict monitoring and prevention are necessary to avoid the introduction of new invasive species into a region. If invasive species are already present, control and eradication measures can be implemented to mitigate their impacts. Errors in species identification have been reported to hinder conservation management and delay the detection of invasive species (73). Moreover, it is important to raise public awareness about the significance of protecting and conserving biodiversity to maintain a balanced and sustainable ecosystem. Livestock grazing has been reported to contribute to the management of multifunctional floodplains (74).

3. Pollution

High levels of pollution in an ecosystem can have serious negative impacts on the lives of organisms within it (75). Pollution can take the form of air, water, or soil pollution, caused by various human activities such as industries, motor vehicles, agriculture, electronic waste, and domestic waste (76). For example, air pollution can contain toxic particles or hazardous chemical compounds such as carbon monoxide, nitrogen dioxide, and sulfur dioxide. Inhalation of these particles by living beings can lead to respiratory disturbances, irritation of the eyes, nose, and throat, as well as chronic respiratory diseases (77). Water pollution, such as the uncontrolled discharge of industrial or domestic waste, can contain toxic substances and contaminate water bodies, threatening the biodiversity dependent on that water (78,79). It has also been reported that lower biodiversity and dominance in polluted sites are interpreted as negative consequen-ces of metal pollution (80).

The impacts of pollution are not only felt by the organisms directly exposed but also affect the food chain and the ecosystem as a whole, including marine litter pollution (81). Some species sensitive to pollution may be replaced by species that are more tolerant to the polluted environment, leading to an overall decline in biodiversity. Therefore, efforts to prevent and control pollution become crucial in preserving biodiversity and ecosystem health. Regulation and enforcement of environmental policies by government officials need to be strengthened to limit pollution from potential sources that may damage the ecosystem (82). Strategies are also required to reduce the release of chemicals into the environment and mitigate their potential impacts (83). Moreover, awareness and public participation in maintaining cleanliness and environmental conservation are also key to addressing pollution issues and preserving biodiversity for a sustainable future.

4. Overexploitation

Overexploitation occurs when humans excessively harvest a species or remove key ecosystem components uncontrollably. This can lead to a drastic decline in the population of a species or even extinction. One example of overexploitation is the excessive harvesting of natural resources such as fish, forests, and medicinal plants. For instance, overfishing can cause a significant decrease in the population of certain fish species, disrupting the marine food chain and ecosystem balance (84). Overexploitation and uncontrolled tree cutting for the timber industry or agricultural land conversion can result in habitat destruction and a reduction in the number of plant and animal species residing in it.

To address the issue of overexploitation and preserve biodiversity, it is crucial to implement sustainable resource management policies. Additionally, raising public awareness about the importance of conserving natural resources and protecting wildlife species is essential to achieve a sustainable balance between humans and their environment by equipping the necessary resources and equipment (85). Preserving microhabitat corridors can also be an efficient strategy to integrate forestry activities and biodiversity conservation (86). In transformative national planning efforts, it is important to address institutional constraints and empower stakeholders to create innovative solutions (87).

5. Global Climate Change

Global climate change, caused by human activities such as increased greenhouse gas emissions, leads to changes in temperature, rainfall patterns, and other environmental factors in various regions (88,89). Extreme temperature changes and fluctuations in rainfall patterns can cause shifts in the life cycles and behaviors of various species due to their sensitivity to climate change (90,91). Global climate change and disruptions in agriculture have also been reported to affect changes in freshwater biodiversity (92). Some species may become unable to adapt to the new conditions and eventually experience population decline or even extinction. Moreover, climate change can cause future shifts in the geographical distribution of certain species (93). Some species may move towards areas more suitable for the new climate, while others may not be able to disperse and become trapped in regions that no longer meet their needs. The impacts of climate change leading to biodiversity loss can weaken ecosystem functions and services, potentially causing environmental crises worldwide (94). If climate change is not controlled, around 20% and 32% of endemic species on land and in the sea are at risk of extinction. However, with appropriate climate actions, the risk can be reduced by more than tenfold (95).

To address the issue of climate change and preserve biodiversity, mitigation and adaptation efforts are necessary (96). It is essential to understand the causes and impacts of climate change on biodiversity, and mitigation involves measures to reduce greenhouse gas emissions to slow down the rate of global climate change (97). Meanwhile, adaptation involves actions to cope with the unavoidable impacts of climate change. An agroecological approach and prioritizing sustainable agriculture are needed to preserve biodiversity, accelerate innovation, and benefit science and society at large (98). Protecting and restoring habitats, integrating agriculture, sustainable natural resource management, and increasing awareness of the importance of environmental conservation are crucial steps to maintain biodiversity and ecosystem balance amidst ongoing climate change challenges (99).

It is essential to address the above factors and take steps for biodiversity conservation management to maintain healthy and stable ecosystems in HCVs. It can be done with efforts such as habitat restoration, control of invasive species, pollution reduction, and sustainable natural resource management.

Conclusion

This research underscores the presence of well-preserved vegetation and plant diversity in areas of high conservation value. A total of 25 plant species from 17 families, comprising 355 plants, were identified. The distribution across different developmental stages included 11 species (6 families) with 38 plants in seedling plots, 16 species (12 families) with 159 plants in sapling plots, 14 species (11 families) with 43 plants in pole plots, and 13 species (10 families) with 115 plants in tree plots. Despite variation in the number of species and families in each plot, the overall plant diversity index remained low. The diversity index of plants in the plots of seedlings, saplings, poles, and trees (and the average) was in the low category ($\hat{H}$ = 0.96).

Several species exhibited the highest IVI were found in the seedling plots, including *Syzygium tawahense* Korth. (113.4%), *Calophyllum* sp. (49.5%), and *Pternandra coerulescens* Jack. (21.4%). In the sapling plots, the highest IVI was found in *Pternandra coerulescens* Jack.(58.5%), *Semonurus scorpiodes* (46.6%), and *Syzygium tawahense* Korth. (44.4%). In the pole plots, the highest IVI was found in *Syzygium tawahense* Korth. (58.2%), *Horsfieldia glabra* Warb. (38.3%), and *Shorea balangeran* Korth. (37.3%). In the tree plots, the highest IVI was found in *Shorea balangeran* Korth. (110.4%), *Rhodamnia cinerea* Jack. (41.5%), and *Syzygium* sp. (3.9%). The overall IVI was highest in *Shorea balangeran* Korth. (76.9%), followed by *Pternandra coerulescens* Jack. (20.9%), and *Rhodamnia cinerea* Jack. (23.6%). Some of these plants demonstrate the capacity to accumulate nutrients, suggesting their potential utility in environmental conservation and restoration management, particularly in phytoremediation or cleaning up contaminated environments.

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Authors contributions

Conceptualization, EDN, ARS, BJP, H; methodology, EDN, ARS, BJP, H; and S; validation, EDN, ARS, and S; formal analysis, EDN, ARS, RJ, and S; investigation, EDN, ARS, S, and H; SW; resources, EDN, SW; data curation, EDN, ARS, RJ, S, MD; writing—original draft preparation, S, RJ, and HUA; writing—review and editing, ARS, S, and RJ; supervision, BJP, and H; project administration, EDN, RJ, and S; funding acquisition, EDN. All authors have read and agreed to the published version of the manuscript.

Compliance with ethical standards

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