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Structure and Composition of Tree Vegetation in the High Conservation Value Area of Oil Palm Plantations

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ABSTRACT

The expansion of oil palm plantations is considered a major factor in the decline of tropical forest areas, and negatively impacting biodiversity, especially tree vegetation. This study aimed to identify tree vegetation types and the structure and composition of trees in two oil palm companies, namely PTPN IV and PTPN III. Identification of forest areas was performed by collecting data from the plantations, and processed tree species data using the quadrat method and calculated using the Shannon-Wiener and Simpson's diversity indices. Results showed that tree species with the highest Importance Value Index is Koompasia excels with a percentage of 92.95%, Shorea sp (56.7%), and Koompasia malaccensis (69.32%). Based on tree height, stratum A (>30 m) dominated in PTPN IV with 840 individual/ha, while in PTPN III-1 stratum B (20-30 m) dominated with 330 individual/ha. There were 600 individual/ha in PTPN IV with diameter class of 10-29 cm, 250 individual/ha with diameter class of 30-49 cm in PTPN III-1, and 220 individual/ha with 30-49 cm diameter in PTPN III-2. The highest Shannon-Wiener diversity index (2.148) was found in PTPN III-2, and the highest Simpson's dominance index (0.187) was found in PTPN IV. An inverted "J"-shaped curve indicated that the forest area had a good stand structure, with more small-diameter trees than large-diameter ones.

1. INTRODUCTION

Palm oil has made a significant contribution to Indonesia's economy through the plantation sector. In 2020, palm oil exports reached a remarkable figure of US$16,943,095,000, providing employment opportunities, particularly in rural areas, driving economic growth, and strengthening regional infrastructure. The rapid growth of the palm oil plantation industry over the past decade has led to extensive expansion and opening of large plantation areas throughout Indonesia. However, in North Sumatra Province, which is one of the regions with the second-largest plantation area on the island of Sumatra after Riau, this expansion poses problems for areas with high conservation value (HCV). The HCV areas play a crucial role in maintaining ecosystem balance and biodiversity, especially in tree vegetation, including local and endemic species typical of North Sumatra. The reduction in the number of HCV areas is a serious threat for the sustainability of biodiversity and tropical forest ecosystems in the region (Nahlunnisa *et al*., 2022).

To preserve biodiversity and promote sustainable oil palm plantation management, standards such as the RSPO (Roundtable on Sustainable Palm Oil) and ISPO (Indonesian Sustainable Palm Oil) are established (Dharmawan *et al*., 2019). RSPO and ISPO certifications require the management of HCV areas as a key parameter, recognizing their crucial role in maintaining ecosystem balance and biodiversity in oil palm plantations (Pareira, 2023).

One crucial aspect that needs to be understood and considered in HCV area management is the structure and composition of vegetation, especially related to tree habitus vegetation types. However, research on the structure and composition of vegetation in HCV areas in plantation regions, particularly in North Sumatra Province, is limited. Yet, this research is essential because the presence of tree vegetation in HCV areas can positively impact ecosystem balance on a broader scale and enhance biodiversity, especially plant diversity in HCV areas.

The role of vegetation in ecosystems is highly complex and diverse, involving the regulation of atmospheric carbon and oxygen cycles, improvement of soil quality through physical, chemical, and biological properties, as well as the regulation of groundwater. Despite the positive impact of vegetation, its effects can vary depending on its structure and composition (Wu *et al*., 2020). Therefore, the analysis of the structure and composition of vegetation, especially tree habitus and local species typical of North Sumatra Province, is crucial to understanding their impact on maintaining ecosystem balance and biodiversity in HCV areas of oil palm plantations (Santosa, 2017).

The management of HCV areas in oil palm plantations is becoming increasingly important, considering the strategic potential of these areas in preserving endemic flora and fauna and serving as habitats for various protected species (Nahlunnisa *et al*., 2022). Additionally, HCV areas play a vital role in maintaining ecosystem sustainability and preserving abundant natural resources.

The significance of research on the structure and composition of vegetation in HCV areas in plantation regions not only contributes to sustainable oil palm plantation management but also provides crucial information for nature conservation and climate change mitigation efforts. As efficient carbon absorbers, tropical forest areas, including HCV areas, contribute to mitigating greenhouse gas emissions and reducing the impact of global warming (Nahlunnisa *et al*., 2022). Furthermore, this research can deepen understanding of biodiversity and plant ecology, particularly among endemic species in North Sumatra Province. Information about tree vegetation types in HCV areas can serve as a foundation for designing more effective conservation and restoration strategies to ensure environmental sustainability.

The expansion of oil palm plantations in North Sumatra Province has indeed had positive impacts on economic growth and increased employment opportunities (Mulyana *et al*., 2019). However, on the flip side, the reduction in the extent of HCV areas due to the expansion of oil palm plantations poses challenges in preserving biodiversity and ecosystem balance in the region. Therefore, research on the structure and composition of vegetation in HCV areas of oil palm plantations in North Sumatra Province holds broad and profound significance. The research findings are expected to provide policy recommendations and practical steps to maintain the sustainability of tropical forest ecosystems, nature conservation, and environmentally conscious and sustainable oil palm plantation management. Understanding the impact of oil palm plantation expansion on HCV areas and biodiversity is a shared responsibility among all relevant parties, including the government, plantation industries, local communities, and conservation institutions. Through comprehensive and evidence-based research, it is hoped that appropriate policies and actions can be implemented to ensure that economic growth and development align with the preservation of the environment and biodiversity, which are valuable assets for North Sumatra Province and future generations.

By gaining a deeper understanding of the structure and composition of vegetation in HCV areas of oil palm plantations in North Sumatra Province, this research is expected to make a significant contribution to conservation efforts and biodiversity. This information will serve as a basis for policy-making and concrete actions to preserve valuable HCV areas and promote environmentally conscious and sustainable management of oil palm plantations (Yanuarsyah, 2018). This research, therefore, aims to identify the total area of HCV, the types of tree vegetation found in the HCV areas, and the structure and composition of trees within the HCV areas in several oil palm plantation companies in the North Sumatra province.

2. MATERIALS AND METHODS

The research was conducted in several oil palm plantations located in the Northern Sumatra region, specifically focusing in PTPN IV Unit Bah Jambi and PTPN III Unit Sei Baruhur. These plantations were selected due to their accessibility and representative characteristics of oil palm cultivation in the region. The Bah Jambi plantation was located in the Jawa Maraja Bah Jambi District, Simalungun Regency, North Sumatra. Geographically, Bah Jambi plantation was situated between 2°52'30" - 3°0'0" N and 99°4'30" - 99°15'0" E with a total area of 8,127.30 ha, consisting of 9 divisions for oil palm cultivation, a nursery site, a factory, and waste ponds. The HCV area covers a total of 38 ha, located in division 3 Bah Jambi. The average rainfall was 213 mm in 2017, and the land slope ranges from 2% to 8% (PTPN IV, 2017).

Sei Baruhur plantation, was located in District Labuhan Batu 2, North Sumatra. Geographically, it was situated at 1°38'11.38″ N, 100°26'34.30″ E. It had an area of 6,060.27 ha, consisting of 8 divisions of oil palm plantations. The total area of the HCV zone was 25 ha, located in Division 2, Blocks H10 and I10 of Sei Baruhur. This HCV area was divided by the provincial highway. It had an average rainfall of 215 mm in 2017 and a land slope of 5 – 10%.

2.1. Identification of HCV Areas

The method used in this research is a survey method. This survey involved observations and measurements to identify HCV Areas in Oil Palm Plantations, determine the types of trees in the HCV Areas, and measure the parameters of vegetation structure and composition. The research was conducted in HCV Areas of several Oil Palm Plantations in North Sumatra Province, such as PTPN IV Unit Bah Jambi and PTPN III Unit Sei Baruhur. This study involved collecting data from 4 plots in each oil palm plantation, with each plot measuring 20 × 20 m (Figure 1). The identification of HCV areas in the plantation area was carried out by collecting information from related plantation companies and the total area of HCV within the oil palm plantation area. HCV areas related to biodiversity, especially those with tree vegetation, were selected for the identification of tree species and analysis of vegetation structure and composition. The identified tree species in the HCV areas was classified into strata based the diameter measured at breast height of an adult. Each tree species is identified, counted, and measured for diameter at breast height (DBH), total height, and branch-free height for trees with a diameter ≥ 20 cm.

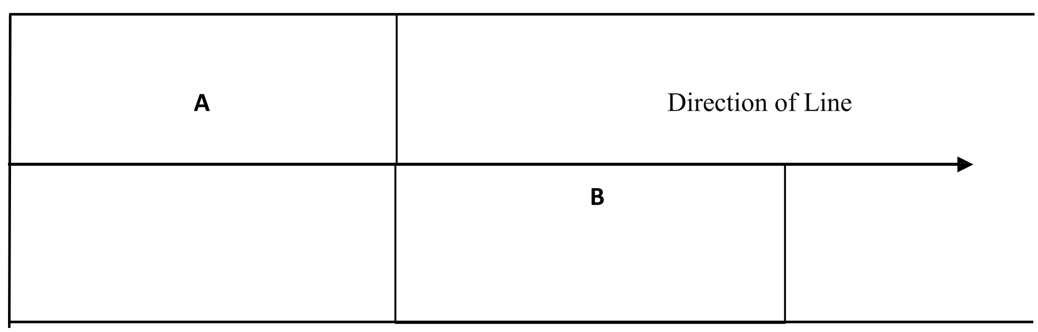

Figure 1. Sample plot for vegetation measurement

The data obtained were then entered into a Tally sheet measurement as shown in the provided table. Measurement parameters for vegetation structure and composition, including number of species, local species name, species name, diameter of total height (m), branch-free height (m), and species description. A study of the structure and composition of plant species is necessary to understand the variation or diversity of species at both individual and population levels, which supports conservation activities. The data obtained are processed using the quadrat method. Calculation parameters include density, relative density, frequency, relative frequency, dominance, relative dominance, Shannon index, and Simpson index. The results of this analysis are interpreted descriptively, related to the management and conservation of HCV areas. With this procedure, it is expected to gain a comprehensive understanding of the structure and composition of vegetation and biodiversity in the HCV areas of oil palm plantations under study.

2.2. Observation Parameters

Some parameters were used to evaluate the HCV state including tree density (K), relative tree density (KR), frequency (F), relative frequency (FR), dominance (D), relative dominance (DR), and importance index value (IIV). Tree density is defined as the number of individual tree per measurement plot. Frequency is the number of each species found in all sample plots. Dominance is the basal area of trees or the area of canopy cover of each species found in the plot. The term relative refers to the parameter value per total value, expressed as a percentage and is calculated as follows:

$$\text{KR} = \frac{K\ particular}{K\ Total} \times 100\% \quad (1)$$

$$\text{FR} = \frac{F\ particular}{F\ Total} \times 100\% \quad (2)$$

$$\text{DR} = \frac{D\ particular}{D\ Total} \times 100\% \quad (3)$$

$$\text{IVI} = \text{KR} + \text{FR} + \text{DR} \quad (4)$$

Tree diversity index is evaluated using the Shannon-Wiener index (*H*') and Simpson index (D) as the following:

$$H' = -\sum \frac{n_i}{N} \log \frac{n_i}{N} \quad (5)$$

$$D = \sum Pi^2 = \sum \left(\frac{ni}{N}\right)^2 \quad (6)$$

where n_i = number of individuals in one species, and *N* = total number of individuals of all species found.

The value of Shannon-Wiener index (*H*') ranges from 1.5 – 3.5. The higher the *H*' value, the higher the diversity value. While, the value of Simpson's diversity index (*D*) ranges from 0 – 1. A value of 0 indicates a homogeneous community, while a value of 1 indicates high diversity (Rozak *et al*., 2020).

3. RESULTS AND DISCUSSION

3.1. Stand Composition of Bah Jambi

Table 1 shows the stand composition in the HCV area of the Bah Jambi. Importance parameters related to stand composition include stand density, frequency, and dominance, as well as importance value index. The importance value index (IVI) of a species illustrates its dominance level within a community compared to other species. Species with the highest IVI are more likely to sustain growth and conservation.

Table 1. List of tree species in the HCV area of PTPN IV Unit Bah Jambi

No	Tree species	Local Name	K	KR	F	FR	D	DR	IVI
1	*Shorea sp*	Keruing	60	25.00	1.00	15.00	0.0015	5.53	55.53
2	*Spathodea campanulata*	Kupang	50	20.80	1.00	15.00	0.0012	4.42	50.22
3	*Alstonia scholaris*	Pule	50	20.80	0.50	12.50	0.0006	0.22	33.52
4	*Tectona grandis*	Jati	50	20.80	0.50	12.50	0.0010	3.69	36.99
5	*Arenga pinnata*	Aren	10	4.10	0.50	12.50	0.0003	1.10	17.70
6	*Koompasia excels*	Kempas	10	4.10	0.25	6.20	0.0224	82.65	92.95
7	*Canangium* sp	Kenanga	10	4.10	0.25	6.20	0.0001	0.36	10.66
	Total		240	100	4.00	100	0.0271	100	297.57

Note: K = Density (stems/ha); KR = Relative Density (%); F = Frequency; FR = Relative Frequency (%); D = Dominance (m^2/ha); DR = Dominance Relative (%); IVI = Importance Value Index (%)

Table 1 provides valuable information regarding the structure and composition of tree species in the HCV area of PTPN IV Unit Bah Jambi. The research results indicate that the species *Koompasia excels* has the highest Importance Value Index (IVI) at 92.95%, signifying its dominant presence in the HCV area. In contrast, *Canangium sp* shows the lowest IVI at 10.66%, indicating that this species is less commonly found in the HCV area of PTPN IV Bah Jambi. The variation in IVI among these tree species indicates significant diversity in their presence and importance in the HCV area. *Shorea sp* stands out as the most abundant species with 60 individuals per hectare, while *Arenga pinnata*, *Koompasia excels*, and *Canangium sp* are the least encountered, each with only 10 individuals per hectare. These differences may be attributed to factors such as environmental preferences, habitat sustainability, and ecological interactions among plant species.

The structure and composition of tree species in the HCV area are closely related to the ecosystem functions of the forest. The diversity of tree species supports various crucial ecological processes, such as nutrient cycles, water circulation, carbon storage, and maintaining overall ecosystem balance and biodiversity (Usmadi *et al*., 2022). The presence of certain species with low density, frequency, and dominance can pose challenges to long-term ecosystem balance. Additionally, the results from Table 1 also indicate that some species may face constraints in their growth processes, particularly related to environmental factors such as soil conditions and elevation. These factors can influence the distribution and sustainability of tree species in the HCV area, making it essential to understand and consider them in conservation and management efforts. The development of HCV in oil palm plantations in North Sumatra Province, such as PTPN IV Unit Bah Jambi and PTPN III Unit Sei Baruhur, aims to preserve biodiversity and prioritize high environmental values. HCV focuses on protecting the habitats of native flora and fauna, maintaining crucial ecological functions, and ensuring the long-term sustainability of the ecosystems surrounding the plantations. Moreover, this reflects the companies' commitment to responsible and sustainable management practices, enhancing their reputation in environmental sustainability.

3.2. Stand Composition of Sei Baruhur-1

Table 2 presents information on tree strata types in the HCV area of PTPN III unit Sei Baruhur-1. The research results indicate that *Shorea sp* has the highest IVI with a percentage of 56.7%. Meanwhile, *Syzygium sp* has the lowest IVI value, which is only 11.56%. In the HCV area of PTPN III unit Sei Baruhur-1, three tree species are most commonly found, with a quantity of 30 individuals per hectare: *Hopea mengarawan*, *Macaranga denticulata*, and *Cryptocarya crassenevia*. On the other hand, some tree species have the lowest quantity, only 10 individuals per hectare, including *Guazuma ulmifolia*, *Swietenia macrophylla*, and *Syzygium sp*.

The explanation provided by (Kusmana & Susanti, 2015) about the dominance of a plant species is highly relevant in the context of this research. The ability of a plant species to utilize available resources in its environment will influence how much that species dominates the HCV area (Mulyana *et al*., 2019). The dominance of a particular tree species can be influenced by its competitiveness in obtaining sunlight, water, nutrients, and other environmental factors. In the context of forest conservation and management, understanding the dominance of tree species and the overall vegetation composition is crucial. This information provides insight into biodiversity and the ecosystem dynamics of the HCV area. This understanding can be used to design sustainable management strategies, including conservation efforts to protect less dominant tree species so they can continue to play a role in the ecosystem. By delving deeper into the ecology and interactions among tree species in the HCV area, forest managers can take appropriate steps to preserve biodiversity and maintain a balanced and sustainable forest ecosystem in PTPN III unit Sei Baruhur-1 and the entire North Sumatra region.

Table 2. List of tree species in the HCV area of PTPN III Unit Sei Baruhur-1

No	Tree species	Local name	K	KR	F	FR	D	DR	IVI
1	*Guazuma ulmifolia*	Cempaka	10	6.20	0.50	9.50	0.0008	26.66	42.36
2	*Hopea mengarawan*	Meranti	30	18.70	1.00	19.00	0.0004	13.33	51.03
3	*Shorea sp*	Keruing	20	12.50	0.75	14.20	0.0009	30.00	56.70
4	*Macaranga denticulata*	Tapak Dewa	30	18.70	0.75	14.20	0.0002	6.66	40.06
5	*Swietenia macrophylla*	Mahogany	10	6.20	0.50	9.50	0.0002	6.66	22.36
6	*Crptocarya crassenervia*	Kayu Kuning	30	18.70	0.75	14.20	0.0001	3.33	36.23
7	*Syzygium* sp	Jambu	10	6.20	0.25	4.70	0.000002	0.66	11.56
8	*Artocarpus elasticus*	Sukun	20	12.50	0.75	14.20	0.0004	13.33	40.03
Total			160	100	5.25	100	0.003002	100	300.33

Note: K = Density (stems/ha); KR = Relative Density (%); F = Frequency; FR = Relative Frequency (%); D = Dominance (m²/ha); DR = Dominance Relative (%); IVI = Importance Value Index (%)

3.3. Stand Composition of Sei Baruhur-2

Table 3 presents information on the tree strata found in the HCV area of PTPN III Unit Sei Baruhur-2. The research results indicate that the highest importance value index (IVI) is found in the *Koompassia malaccensis* species, with a percentage of 69.32%. Meanwhile, the *Cryptocarya crassenervia* species has the lowest IVI value, which is only 17.32%. *Shorea sp* and *Macaranga denticulata* are the two most frequently found tree species in this HCV area, with a

Table 3. Tree species in the HCV area of PTPN III Unit Sei Baruhur-2.

No	Tree species	Local name	K	KR	F	FR	D	DR	IVI
1	*Guazuma ulmifolia*	Cempaka	10	7.10	0.50	9.50	0.0011	20.00	36.60
2	*Hopea mengarawan*	Meranti	10	7.10	0.50	9.50	0.0003	5.45	22.05
3	*Shorea sp.*	Keruing	30	21.40	0.75	14.20	0.0004	7.27	42.87
4	*Macaranga denticulata*	Tapak Dewa	30	21.40	1.00	19.00	0.0002	3.63	44.03
5	*Swietenia macrophylla*	Mahogany	10	7.10	0.50	9.50	0.0002	3.63	20.23
6	*Crptocarya crassenervia*	Kayu Kuning	10	7.10	0.50	9.50	0.00004	0.72	17.32
7	*Syzygium sp.*	Jambu	20	14.20	0.50	9.50	0.00004	0.72	24.42
8	*Artocarpus elasticus*	Sukun	10	7.10	0.50	9.50	0.0004	7.27	23.87
9	*Koompasia malaccensis*	Kempas	10	7.10	0.50	9.50	0.0029	52.72	69.32
	Total		140	100	5,25	100	0.00558	100	300.71

Note: K = Density (stems/ha); KR = Relative Density (%); F = Frequency; FR = Relative Frequency (%); D = Dominance (m²/ha); DR = Dominance Relative (%); IVI = Importance Value Index (%)

total of 30 individuals per hectare. On the other hand, there are several tree species with the lowest numbers, only 10 individuals per hectare, namely *Guazuma ulmifolia*, *Hopea mengarawan*, *Swietenia macrophylla*, *Cryptocarya crassenervia*, *Artocarpus elasticus*, and *Koompasia malaccensis*.

From the research results at the three locations, it is evident that there is one species dominating the HCV area, namely the *Shorea sp* species. The dominance of this species indicates its ability to adapt well to various research locations. This aligns with other research (Tsigos & Chrousos, 1994) stating that species dominating in various research locations demonstrate broad adaptability. Research (Heriyanto *et al.*, 2020) also states that lowland forests (secondary forests) are dominated by species from the *Dipterocarpaceae* family, such as meranti (*Shorea sp*). This information provides insights into the biodiversity and community structure of vegetation in the HCV area of PTPN III Unit Sei Baruhur-2. The dominance of specific tree species, such as *Shorea sp*, can be a crucial consideration in planning the management and conservation of this HCV area. By understanding this community structure, forest managers can design more effective management strategies to preserve biodiversity and sustain the forest ecosystem in the entire North Sumatra region.

3.4. Vertical Stand Structure

Vertical stand structure (crown stratification) of trees refers to all types that connect tree density with height classes of trees. (Kusmana & Susanti, 2015) divides forest strata into Stratum A (> 30 m), B (20-30 m), C (4-20 m), D (1-4 m), and E (0-1 m). Figure 1 shows the vertical tree structure diagram (tree height) in the HCV areas investigated in this research. The diagram illustrates the distribution of tree heights based on height strata classes, namely Class A (> 30 m), Class B (20-30 m), Class C (10-20 m), and no trees fall under Classes D and E because this study focuses only on tree habitus plants for all three HCV areas. From the diagram, it is evident that for HCV area of PTPN IV Unit Bah Jambi the highest number of trees is in class A (> 30 m), which represents the upper canopy layer. The number of trees then decreases in Class B (20-30 m) and Class C (10-20 m). The absence of trees in Classes D and E is due to the research focus on tree habitus plants, with no trees falling into these classes.

The presence of many trees in Class A (> 30 m) indicates that trees with a height of more than 30 meters dominate the HCV area of PTPN IV Unit Bah Jambi. Trees in the upper canopy layer have better access to sunlight and receive full light for photosynthesis processes (Zhang *et al*., 2011). This is consistent with previous research findings stating that upper canopy layer in tropical forests can receive sunlight optimally, making the energy transfer process in photosynthesis more efficient compared to trees in the middle or lower layers (Miller *et al*., 2021). Thus, the vertical tree structure diagram in the HCV area of PTPN IV Unit Bah Jambi provides an overview of tree height distribution in that area. This information can offer insights into the high diversity of trees and the condition of canopy layers in the HCV area of oil palm plantations. By understanding the vertical tree structure in the HCV area, plantation managers can plan appropriate measures to maintain ecosystem sustainability and maximize biodiversity potential in that area.

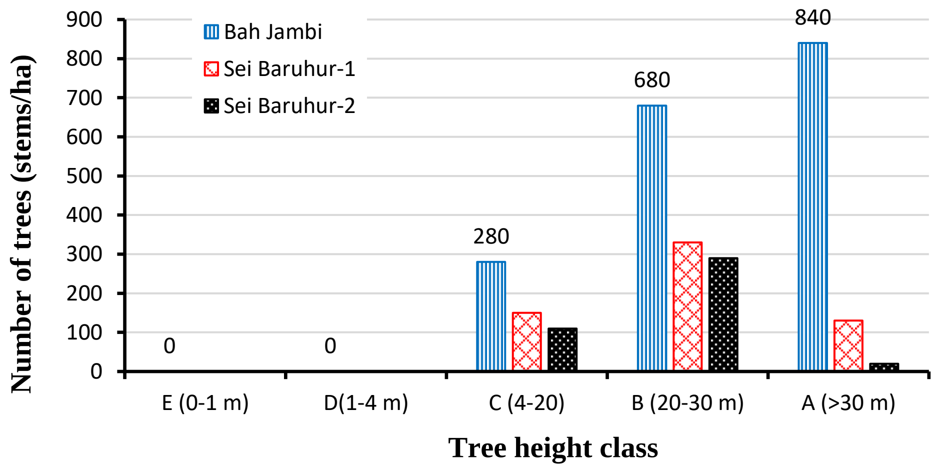

Figure 1. Vertical tree structure diagram (tree height) of the three HCV areas: Bah Jambi, Sei Baruhur-1, and Sei Baruhur-2

The vertical tree structure diagram in the HCV area of PTPN III Sei Baruhur-1 slightly differ compare to that of Bah Jambi. According to the diagram, the most abundant trees are found in the height class of 20-30 m, which falls under stratum B. This is followed by strata C and A, while no trees fall into strata D and E, as the research focuses on tree habitus plants. The height and canopy width of trees play a crucial role in photosynthesis processes, influencing the tree's ability to harness solar energy. Canopy trees in the topmost layer (stratum A) have better access to sunlight, receiving full light for efficient photosynthetic energy transfer compared to trees in the middle or lower canopy layers (Wulandari, 2011). On the other hand, vegetation with very low importance values may be due to limited distribution and small canopy cover, resulting in a relatively small impact on the ecosystem and can be disregarded in biodiversity and ecosystem function analyses (Cardinale *et al*., 2011). The information from this vertical tree structure diagram provides insights into the distribution of tree heights and vegetation composition in the HCV area of PTPN III Sei Baruhur-1. This understanding can assist forest managers in planning appropriate measures to maintain ecosystem sustainability, maximize economic benefits from oil palm plantations, and preserve biodiversity and environmental functions essential for North Sumatra and the global environment. The horizontal structure of forest vegetation can be depicted by connecting the density of individuals per hectare with diameter classes of individual plant stems (Harms *et al*., 2001). In Figure 5, this approach will be explained in more detail.

From Figure 1, it can be also observed the vertical tree structure (tree height) observed in the HCV area of PTPN III Unit Sei Baruhur-2. Here, the structure is similar to that of Sei Baruhur-1 where trees with the height 20 – 30 m, belonging to stratum B, dominate the structure. Subsequently, followed by strata C and A, while none of the trees reach strata D and E in this study because the research only measured plants with a tree habit. Figure 1 also shows that only a few trees are able to reach stratum A. This proves that reaching stratum A requires a relatively long time and involves high competition among trees in the high class. Factors such as nutrient availability, soil water, and light intensity become key factors influencing whether a tree can reach stratum A or not (Sirami *et al*., 2016). This vertical tree structure provides an overview of the distribution of tree height in the HCV area of PTPN III Unit Sei Baruhur-2. Trees with a height of more than 30 m are the most commonly found group of trees in this area. This structure reflects the differences in tree height in various strata, which in turn reflects the level of growth and competition among trees in the area. This study has important implications for the management and conservation of the HCV area of PTPN III Unit Sei Baruhur-2. Information about the vertical tree structure can help forest managers identify dominant tree species and understand interactions among trees in the forest ecosystem. Furthermore, an understanding of the vertical structure can serve as a basis for planning forest maintenance and rehabilitation activities to ensure the sustainability of a balanced ecosystem. With a better understanding of the vertical tree structure, forest managers can take appropriate steps to preserve biodiversity and the valuable forest ecosystem in the HCV area of PTPN III Unit Sei Baruhur-2. Protecting and preserving trees that reach stratum A can be a focus of conservation efforts to maintain the balance of the ecosystem and forest sustainability in the North Sumatra region. Thus, the information from this study can contribute to more effective and sustainable forest management efforts.

3.5. Horizontal Stand Structure

Horizontal vegetation structure can be revealed through calculations of tree density and its relationship with tree diameter distribution (Atkins *et al*., 2023). Furthermore, the horizontal forest structure can also be understood through tree distribution based on diameter classes in various land-use types (Mitchell *et al*., 2023). In the paper by Yosi *et al*. (2011), tree diameters are grouped into several classes: 10-29 cm, 30-49 cm, 50-69 cm, 70-89 cm, and >90 cm DBH. Figure 2 provides a more detailed explanation of horizontal vegetation structure in the studied area.

In the study of horizontal forest structure, tree density calculations are a crucial factor in understanding tree density in an area and its relationship with tree species composition and environmental conditions (Fan *et al*., 2019). This information can provide insights into how trees are distributed in the area and how this distribution affects biodiversity and the overall forest ecosystem. Additionally, the distribution of trees based on diameter classes offers more detailed information about vegetation community structure in various land-use types (Mienna *et al*., 2022). Grouping tree diameters into several classes allows an understanding of how trees of various sizes contribute to vegetation density in each class. This is important for understanding the distribution and composition of tree species and estimating the potential growth and regeneration of tree populations in the future. Figure 2 provides crucial information for forest managers and researchers in planning appropriate conservation and management strategies. Through comprehensive understanding the horizontal vegetation structure in the studied area, conservation and forest management efforts can be more targeted and have a positive impact on biodiversity and the overall forest ecosystem.

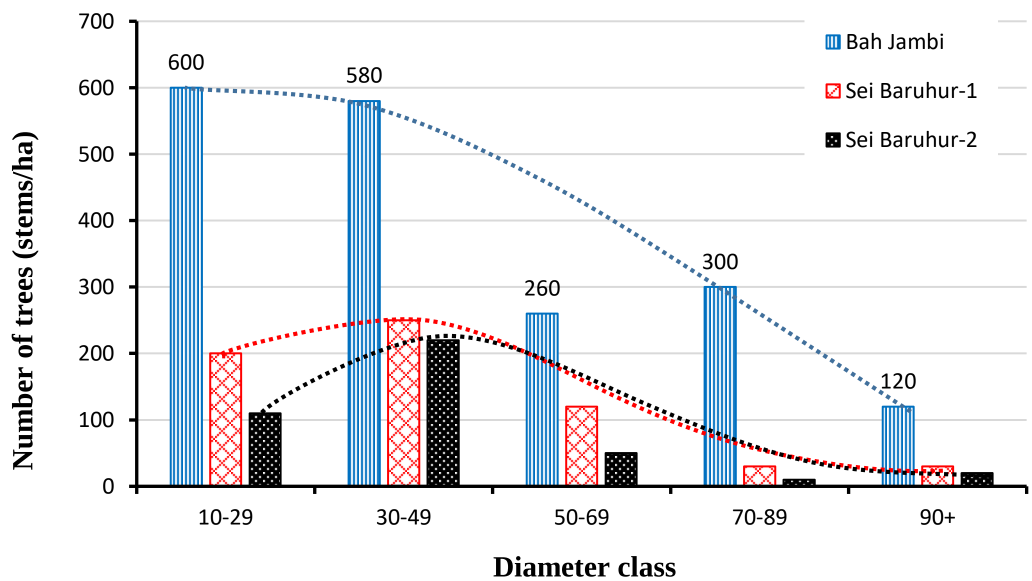

Figure 2. Horizontal tree structure diagram (tree diameter) of the three HCV areas: Bah Jambi, Sei Baruhur-1, and Sei Baruhur-2

In the HCV area of PTPN IV Unit Bah Jambi, the diameter of tree stands measured based on DBH using a measuring tape reveals several findings. The majority of trees were found in the diameter class of 10-29 cm, with a total of 600 trees, while the fewest trees were in the diameter class > 90 cm, with only 120 trees. The horizontal vegetation structure in this area tends to form an inverted "J" curve, indicating a well-functioning secondary succession process over time (Lopes *et al*., 2023). This finding illustrates the changes in tree composition and distribution in the HCV area of PTPN IV Unit Bah Jambi in line with ecosystem development and the influence of environmental factors.

The abundance of trees in the 10-29 cm diameter class indicates a good natural regeneration in the area, where young trees with smaller sizes are growing and developing healthily. Over time, some of these young trees will grow and reach larger sizes, becoming part of higher diameter classes. This reflects the essential process of secondary succession to maintain the sustainability of the forest ecosystem and biodiversity. On the other hand, the least number of trees in the > 90 cm diameter class suggests that larger-sized trees are relatively rare in the HCV area of PTPN IV Unit Bah Jambi. This may be influenced by factors such as natural selection, external pressures, and human activities. In the context of forest management and biodiversity conservation, understanding horizontal vegetation structure like this is crucial. Information about the distribution and composition of trees based on diameter size assists in planning and implementing appropriate actions to maintain the balance of the ecosystem and biodiversity in the HCV area of oil palm plantations. Thus, the results of this study provide a significant contribution to nature conservation efforts and sustainable forest management. Information about the horizontal vegetation structure of the forest in the HCV area of PTPN IV Unit Bah Jambi can serve as a basis for making informed policies to preserve biodiversity and the forest ecosystem, valuable assets for North Sumatra Province and future generations.

By understanding the horizontal structure of forest vegetation, forest managers can take appropriate steps to preserve biodiversity and maintain a balanced and sustainable forest ecosystem in PTPN III Unit Sei Baruhur-1 and the North Sumatra region as a whole. Figure 2 also provides a clear and easily understandable visualization of horizontal vegetation structure, making this information a robust foundation for decision-making in sustainable forest management. In the HCV area of PTPN III Unit Sei Baruhur-1, the diameter of tree stands can be observed from the measurements of DBH using a tape measure. Based on Figure 2, it was found that the most abundant trees fall into the diameter class of 30-49 cm, with a total of 250 trees. Meanwhile, the least number of trees was found in the diameter classes of 70-89 cm and > 90 cm, each with only 30 trees. Research (O'Hara, 2002) states that the tree population in this study area is evolving towards a balanced uneven-aged forest. This can be observed from the distribution pattern of the number of tree individuals based on diameter classes. The larger the diameter of the tree, the fewer individuals there are. This phenomenon can occur because larger-diameter trees take longer to grow and reach their size, resulting in fewer individuals compared to smaller-diameter trees.

This distribution pattern reflects a balanced and sustainable structure in the tree population of the HCV area of PTPN III Unit Sei Baruhur-1. A balanced population is crucial for maintaining biodiversity and ecosystem stability. With various diameter sizes of trees, the forest can function as a diverse habitat for flora and fauna, as well as have the capacity for sustainable regeneration and growth.

The results of this study provide essential information for forest managers to plan management and conservation strategies for the HCV area of PTPN III Unit Sei Baruhur-1. Conservation efforts and protection of large-diameter trees need attention to ensure their continued contribution to the ecosystem, while also considering the growth and regeneration of smaller-diameter trees to maintain forest sustainability. Thus, the HCV area of PTPN III Unit Sei Baruhur-1 can continue to play a crucial role in biodiversity and environmental functions for the North Sumatra region and the entire ecosystem.

The tree stands found in the HCV area of PTPN III Unit Sei Baruhur-2 can be seen also in Figure 2. It presents a visual overview of the tree density distribution in the HCV area of PTPN III Sei Baruhur-1 based on stem diameter classes. On the horizontal axis, there are diameter classes grouped according to size ranges, such as 10-29 cm, 30-49 cm, 50-69 cm, 70-89 cm, and >90 cm. On the vertical axis, information about tree density (number of individuals per hectare) found in each diameter class is provided. By using this visualization, we can visually observe the pattern of tree distribution based on their diameter size. This pattern can offer clues about the vegetation community structure in the HCV area and illustrate how trees are distributed in specific diameter classes. The analysis of horizontal vegetation structure provides crucial information for understanding ecosystem dynamics, including regeneration rates, growth, and tree species composition in the HCV area. Additionally, this information can be used in sustainable forest management planning, including efforts for the conservation and protection of less dominant tree species to maintain their role in the ecosystem.

In the HCV area of PTPN III Unit Sei Baruhur, the study aimed to measure the tree diameter based on DBH (Diameter at Breast Height) using a tape measure. The research results indicate a varied distribution of trees based on diameter classes. The majority of trees were found in the 30-49 cm diameter class, with a total of 220 trees, while the 70-89 cm diameter class had the least, with only 10 trees. This observation suggests that the HCV Unit Sei Baruhur area exhibits a tree diameter distribution following a normal type. This finding aligns with previous research conducted by (Bismark *et al*., 2008), stating that as the tree diameter class increases, the population of trees decreases.

The lower density of trees with a diameter greater than 60 cm, compared to trees with smaller diameter classes, can be explained by competition among plants for growing space, light, and nutrients.

3.6. Simpon's Diversity Index and Shannon-Wiener Index

The results of the Shannon-Wiener diversity index calculation indicate that the HCV area in PTPN III Unit Sei Baruhur-2 has the highest value of 2.148, while the HCV area in PTPN IV Unit Bah Jambi has the lowest value, which is 1.770. Both values fall into the category of moderate diversity, indicating that the HCV areas in both locations have a relatively good level of biodiversity. According to the criteria proposed, if the Shannon-Wiener diversity index (H') is below 1, the diversity is considered low. If H' is between 1 and 3, the diversity is considered moderate, and if H' exceeds 3, the diversity is considered high. Furthermore, in the Simpson Dominance Index presented in Table 8, the HCV area of PTPN III Unit Sei Baruhur-2 has a value of 0.123, indicating a more evenly distributed dominance of tree species in this area. Meanwhile, the HCV area of PTPN IV Unit Bah Jambi has a value of 0.187, depicting a more concentrated dominance on one tree species. The highest dominance value is 1.0, indicating that a stand is dominated by a single tree species or there is a concentration on a single tree species. These results align with previous research stating that the Simpson index is used to determine the extent of concentration and spread of dominant tree species. If the dominance is more concentrated on one species, the dominance index value will increase, whereas if several dominant tree species dominate together, the dominance index value will be low. Tree species with the highest IVI have a greater chance of maintaining their growth and sustainability.

Table 6. Diversity index of tree vegetation in PTPN IV Bah Jambi, PTPN III Sei Baruhur-1, and PTPN III Sei Baruhur-2

Index	PTPN IV Bah Jambi	PTPN III Sei Baruhur-1	PTPN III Sei Baruhur-2
Simpson’s index	0.187	0.144	0,123
Shanon’s index (*H*’)	1.770	2.004	2,148

The calculation results of diversity and dominance indices provide important insights into the structure and composition of the HCV areas in PTPN III Unit Sei Baruhur-2 and PTPN IV Unit Bah Jambi. Moderate diversity and diverse dominance distribution in both locations indicate a good level of ecosystem balance and tree species diversity. This information can be valuable for conservation and forest management efforts, promoting sustainable agricultural practices in the North Sumatra region. Considering these analysis results, policy measures and concrete actions can be taken to ensure the sustainability and biodiversity of these valuable HCV areas.

3.7. Sustainable Management of HCV Areas

Both PTPN IV Bah Jambi and PTPN III Sei Baruhur have HCV areas. The sustainable management of HCV areas in oil palm plantations involves securing against illegal logging, monitoring wildlife hunting, redelineating the areas, restoring the areas to their original state, installing conservation information boards, and involving relevant government institutions such as the Conservation of Natural Resources Center (Balai Konservasi Sumber Daya Alam) and the Environmental Agency (Badan Lingkungan Hidup).

4. CONCLUSIONS

Based on the research In these two HCV areas, the forest stand structure tends to follow an inverted "J" curve pattern, indicating the distribution of trees across diameter classes. The larger the diameter of the stem, the fewer individuals of that tree species. In general, the HCV areas show a well-structured stand with tree distribution in each diameter class, where the number of trees in smaller diameter classes is higher than in larger diameter classes.

In measuring biodiversity, the Shannon-Wiener diversity index is used. PTPN III Unit Sei Baruhur-2 has the highest diversity index of 2.148, indicating a higher level of diversity in that area. Meanwhile, to measure the dominance of tree species, the Simpson dominance index is used. In the HCV area of PTPN III 2, the Simpson dominance index value is 0.123, indicating an evenly distributed dominance among dominant tree species.

These measurements provide important information about the diversity and dominance of tree species in the HCV areas. PTPN III Unit Sei Baruhur-2 shows higher diversity and evenly distributed dominance, indicating a good ecosystem balance. This means that the HCV area tends to support the growth and sustainability of various tree species. Therefore, the management of HCV areas in oil palm plantations needs to be continually maintained and improved to ensure the biodiversity and sustainability of forest ecosystems are well-preserved.

Further research on the factors influencing the structure and composition of tree species in the HCV area of PTPN IV Bah Jambi can provide deeper insights into the ecological complexity and challenges in preserving biodiversity in the region. With a better understanding of forest ecosystem dynamics, the management of the HCV area in oil palm plantations can be more directed and effective in maintaining environmental sustainability and biodiversity, which are distinctive features of North Sumatra Province.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest in relation to the research presented in this work.

AUTHOR CONTRIBUTIONS

Suratni Afrianti played a crucial role in this project by designing the research framework, collecting and analyzing data, and making significant contributions to manuscript writing. Enni Halimatussa'diyah Pakpahan was responsible for formulating the research methodology, collecting data, and providing critical insights into the research findings. Both actively participated in discussions and provided feedback on drafts to ensure the overall quality of the article.

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