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Species composition and stand structure of *Shorea stenoptera* Burck in the Forest Area with Special Purposes (KHDTK) Haurbentes, Indonesia

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Abstract. *The importance of preventing* Shorea stenoptera *in restoring sustainable forest management to maintain the existence of forests in the future, the reduction due to deforestation causes a decrease in land conventions.* S. stenoptera *Burck is a forest species native to Borneo, Sumatra, Thailand, and Malaysia. IUCN declared this species in the category of Near Threatened. This study aims to analyze the species composition, stand structure, and natural regeneration of* S. stenoptera *Burck and identify the biophysics effect on the regeneration performance of* S. stenoptera *in KHDTK Haurbentes. This research method uses vegetation analysis by constructing five observation areas. The results showed that* S. stenoptera *dominated at each growth stage. The stand structure shows an inverted J-curve. This indicates that the stands of* S. stenoptera *have turned into natural forest. The decrease in density followed the increase in diameter class, so* S. stenoptera *regeneration showed normal regeneration. Biophysical aspects such as slope and elevation affect the growth of* S. stenoptera *by observing the characteristics of the analysis adjusted statistically.*

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INTRODUCTION

The importance of *Shorea stenoptera* prevention in restoring sustainable forest management to maintain forest existence in the future. Indonesia has the largest forest area only Indonesia has the largest forest area which is only located in Papua and Kalimantan, with the dominance of the Dipterocarpaceae Family. The Dipterocarpaceae Family has a high commercial value (Forest Watch Indonesia 2001). *S. stenoptera* Burck, also known as Tengkawang, is one of the large-fruited species of the Dipterocarpaceae Family, an endemic species found in Borneo, Sumatra, Thailand, and Malaysia (Riska and Manurung 2018). Tengkawang seeds and fruits are processed as raw materials in the food, cosmetic, and medicinal industries. Ecologically, Tengkawang is useful as a guardian of ecosystem balance (Maharani et al. 2013). The existence of Tengkawang is declining because of uncontrolled logging activities, making it difficult to find. The IUCN designated Tengkawang as Endangered in 1998 and Nearly Threatened in 2019, with its natural habitat decreasing by 30–50% in Kalimantan (Randi et al. 2019).

The Forest Area with Special Purposes (KHDTK) Haurbentes is a forest area managed by the Forest Research and Development Center that introduces forestry tree species, such as Dipterocarpaceae, and research locations based on the Minister of Forestry Decree No. 288/KPTS-II/2003 (KLHK 2014). KHDTK Haurbentes has a strategic role as a seed and genetic resource for Dipterocarpaceae species, particularly *Shorea* species. Some Dipterocarpaceae introductions in KHDTK Haurbentes have been successful, making them suitable options for the development of Industrial Forest Plantations (Erizilina 2016). The growth performance of Dipterocarpaceae species in KHDTK Haurbentes was satisfactory, providing it as an Identified Seedling Stand from to 2006–2011 (Putri and Sudrajat 2017).

Research related to the composition, structure, and regeneration of *S. stenoptera* is limited, considering the various benefits of *S. stenoptera*. Therefore, the behavior of this adaptation needs to be studied through natural regeneration growth. Biophysical aspects such as topography and climate significantly influence natural regeneration. Optimal growth is supported by suitable environmental conditions (microclimate), which increases its survival ability. Therefore, it is important to conduct research on the composition and structure of *S. stenoptera* stands and their biophysical effects (Pamoengkas and Erizilina 2019). This study aimed to analyze the composition of the species and the structure of the *S. stenoptera* Burck stand in the KHDTK Haurbentes, and to identify the biophysical aspects of the natural regeneration growth of *S. stenoptera* Burck in the KHDTK Haurbentes.

MATERIAL AND METHODS

Study Area

The research was conducted in January 2022 on plots of *S. stenoptera* in the KHDTK Haurbentes, Curug Village, Jasinga, and Bogor, Indonesia. KHDTK Haurbentes is located at 6'32'–6'33' south latitude and 106'26' east longitude, with a forest management unit. The topography of the location is slightly wavy with contour patterns, a slope of 15–20% and an altitude of 250 m asl. The type of climate is tropical rain with an average rainfall of 3,000–4,000 mm/year, red-yellow podzolic soil types, and several types of yellow-brown latosols with claystone parent material (Puslitbanghut 2018). A map of the KHDTK Haurbentes area is presented in Figure 1, and the study area is presented in Figure 2.

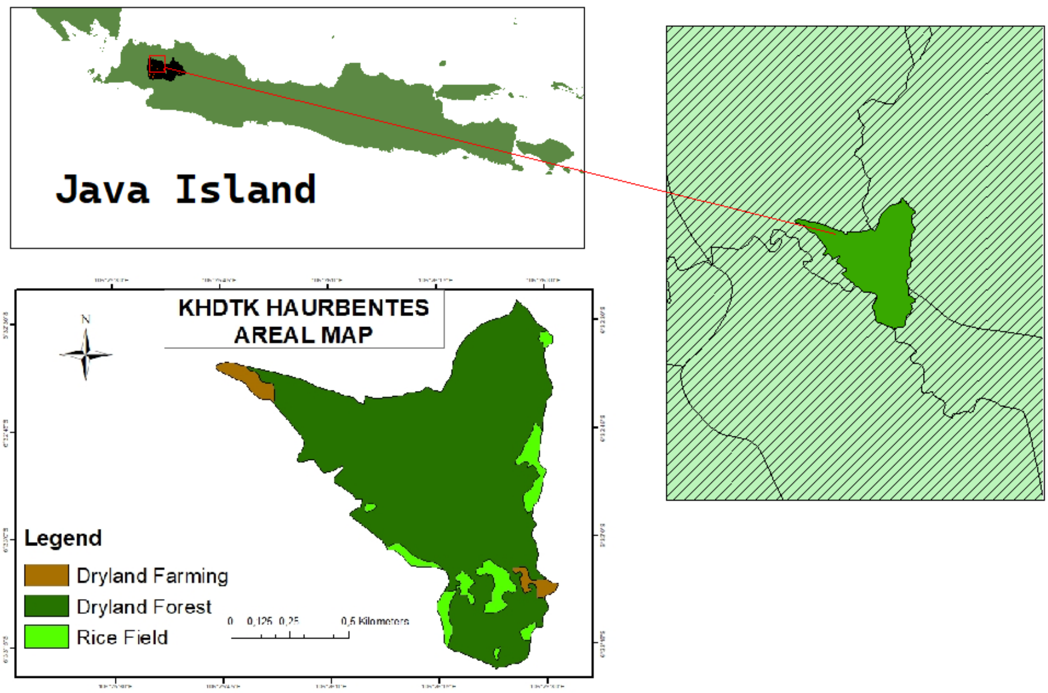

Figure 1 KHDTK Haurbentes areal map (Puslitbanghut 2018)

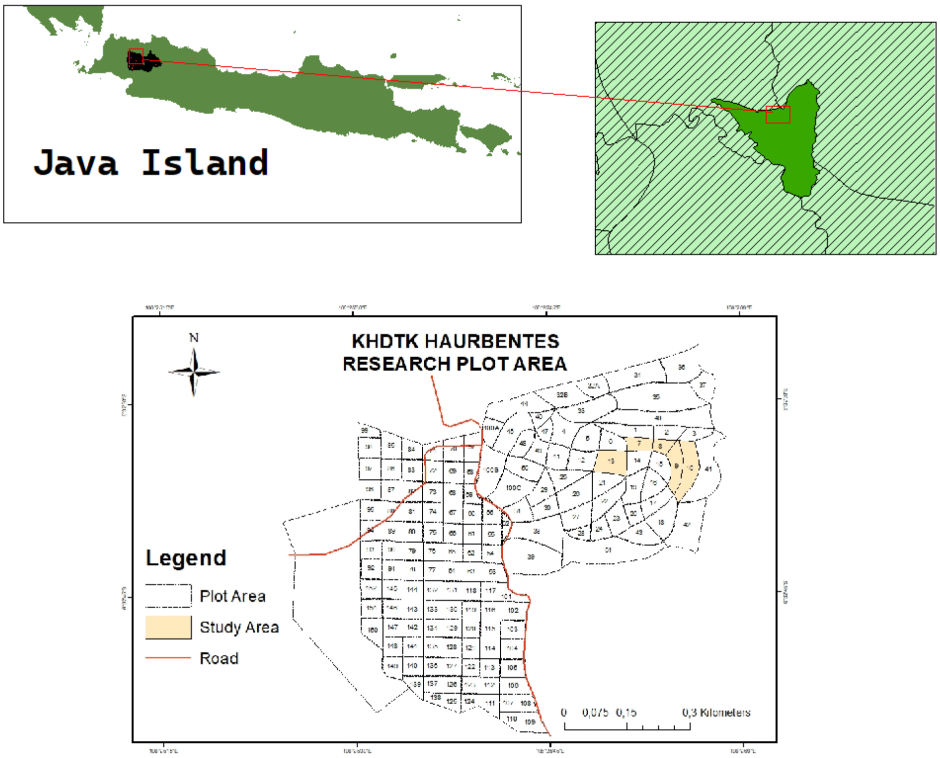

Figure 2 KHDTK Haurbentes research plot area with study area

Data Collection

Data were collected through plot development, measurement of species composition and stand structure, collection of biophysical data, and literature review. Data were collected in *S. stenoptera*-dominated plots, specifically plots 7, 8, 9, 10, and 13 (Figure 2). Vegetation data were collected using the plot-path method through purposive sampling. Each plot had a 20 m × 60 m sample plot for the collection of seedlings, stands, saplings, and trees. The plots were divided into three 20 m × 20 m subplots.

The plots were 20 × 20 m in size to assess the stage of the trees. Subplots of 10 × 10 m were used to assess the stage of the poles, 5 × 5 m were used to assess the stage of saplings, and 2 × 2 m were used to assess the stage of seedlings for a total of 15 plots (Figure 3). Data collection for seedlings and saplings included only the species and number of individuals. In contrast, the data for poles and trees were diameter, total height, height without branches, tree coordinates (x, y), crown curve, crown radius, and crown.

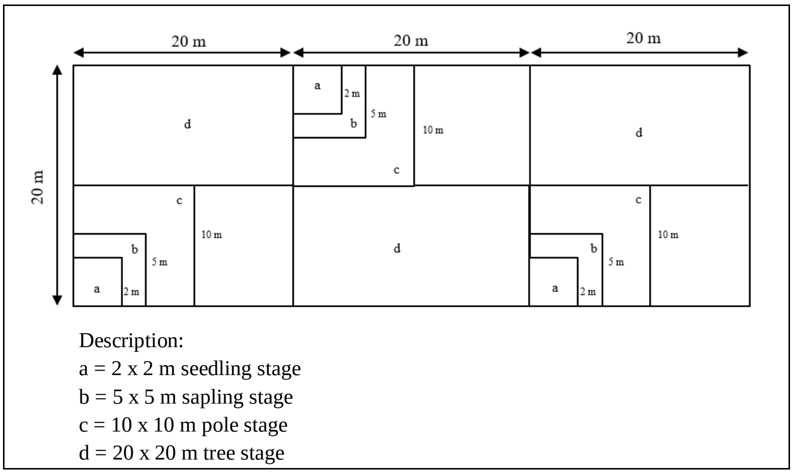

Figure 3 Design plot of study area with terraced lines

The biophysical data collected included temperature, humidity, slope, elevation, humus thickness, and organic matter. Temperature and humidity data were collected in the plots in the morning, afternoon, and evening. Slope was measured using a slope aid (inclinometer). The elevation in the plots was measured using GPS. The thickness of humus and organic matter was determined using a ruler at five points per plot. A design plot of humus thickness and organic matter content is presented in Figure 4.

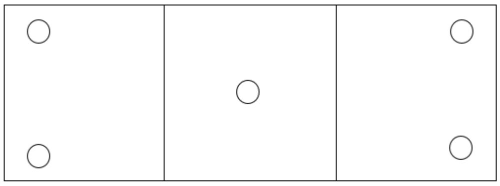

Figure 4 Design plot for measure humus thickness and organic matter

Data Analysis Method

Vegetation Analysis

The Importance Value Index (IVI) was used to analyze a specific type's dominance within a particular community. According to (Misra 1980), the IVI calculation formula used is:

$$\text{Density (D)} = \frac{\text{number of individuals of a species (n)}}{\text{area of the sample plot (ha)}}$$

$$\text{Relative Density (RD)} = \frac{\text{density of a species (N/ha)}}{\text{density of all species (N/ha)}} \times 100\%$$

$$\text{Frequency (F)} = \frac{\text{number of plots found of a species}}{\text{number of all plots}}$$

$$\text{Relative Frequency (RF)} = \frac{\text{frequency of a species}}{\text{frequency of all species}} \times 100\%$$

$$\text{Dominance (Do)} = \frac{\text{number of basal area of a species } (m^2)}{\text{area of the sample plot (ha)}}$$

$$\text{Relative Dominance (RDo)} = \frac{\text{dominance of a species } (m^2\text{/ha})}{\text{dominance of all species } (m^2\text{/ha})} \times 100\%$$

IVI (%) = RD + RF (for seedling and sapling level)

IVI (%) = RD + RF + RDo (for poles and tree level)

Species Diversity Index

The species diversity index (H') was calculated using the Shannon diversity formula (Magurran 1988) as follows:

$$H' = -\sum_{I=1}^{S} p_i \ln p_i \, ; p_i = \frac{n_i}{N}$$

Where:
ni = density value of species i
N = total density

There are three criteria for the analysis of the species diversity index: a value of H' < 2 is categorized as low, 2 < H' < 3 is categorized as moderate, and H' > 3 is categorized as high (Magurran 1988).

Species Evenness Index

The species evenness index (E) indicates the level of evenness of the individuals per species. If the value of E is closer to 1, the evenness value is high (Magurran 1988). The value of E was calculated using the following formula:

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

Where:
H' = species diversity index
S = total number of species

There are three criteria in the analysis of the species evenness index: a value of E < 0.3 indicates a low category; a value of 0.3 < E < 0.6 indicates a moderate category; and E > 0.6 indicates a high category.

Species Dominance Index

The species dominance index (C) shows the concentration or dominance of a certain species in an area using a systematic formula (Misra 1980) as follows:

$$C = \sum_{i=1}^{n} \left(\frac{n_i}{N}\right)^2$$

Where:
ni = density value of species i
N = total density

If the value of the species dominance index is close to 1, it can be said that a stand is dominated by only one species, meaning that there has been a clustering of plant species. However, if the value of C is close to 0, then there is no dominance of one species in a stand.

Species Richness Index

The species richness index (Dmg) indicates the number of species in a given area. The formula for calculating the species richness index from Margalef was as follows:

$$Dmg = \frac{S-1}{ln\ (N)}$$

Where:
S = total number of species
N = total number of individuals

There are three criteria for analyzing the species richness index: Dmg < 3.5 is considered low, 3.5 < Dmg < 5.0 is considered moderate, and Dmg > 5.0 is considered high (Magurran 1988).

Stands Horizontal Structure

The stand structure was designed using the relationship between the diameter class and breast height (cm) with tree density (number of trees per hectare). The tree density is on the y-axis, whereas the diameter class is on the x-axis.

Stands Vertical Structure (Canopy Stratification)

Canopy stratification was formed in a stand profile diagram depicting the stand projection from the top (canopy projection on the forest floor) and the stand projection from the side. The creation of the stand profile diagram used the SExI-FS 2.1.0 application. The data required were the diameter, total height, free branch height, tree coordinate point (x, y), crown curve, depth, and crown radius.

RESULTS AND DISCUSSION

Species Composition

Species composition refers to the presence of different tree species in a forest (Nyoman and Thamrin 2014). From a silvicultural perspective, species composition aimed to examine the presence of both the main species and new species found in the observation plot to analyze the condition of natural regeneration. The composition of the research plot showed high to low density at the seedling-to-tree level. IVI values are used in conservation programs where species with low IVI values are prioritized for conservation, and species with high IVI values require monitoring management (Neelo et al. 2015). The IVI consists of three main categories of species; thus, the relative density of the relative frequency and the relative basal area of the IVI gives a true sense of the dominance of the species relative to its population (Kaushal and Baishya 2021). The overall individual densities are listed in Table 1.

Table 1 Density in each planting plot in KHDTK Haurbentes

Planting date (year)	**Plot No.**	**Density (N/ha)**			
		Seedling	**Sapling**	**Pole**	**Tree**
1940 (82 years)	7	15,833	6,400	33	150
	8	12,500	4,933	33	117
	9	14,167	3,867	100	108
	10	12,500	4,267	167	100
	13	13,333	3,200	100	142
Total		68,333	22,667	433	617

Table 1 shows that, at the nursery level, the highest density was found in each plot. The dominant species in each plot was *S. stenoptera* Burck at the seedling, pole, sapling, and tree levels with densities of 12,500 n/ha (plots 7 and 10), 5733 n/ha (plot 7), 16 7 n/ha (plot 10), and 150 n/ha (plot 7). Forest ecosystem management is classified as mildly unsuitable, so the density experiences an imbalance in forest sustainability. According to the Regulation of the Conservation of Living Natural Resources and Ecosystems No. 12 about guidance for recovery ecosystem in Nature Conservation Area, there are several natural regeneration of ≥ 1,000 n/ha climax species that are widely distributed evenly in the stand, including in the sieve category (Perdirjen 2015). Efforts can be made to maintain the natural succession of stands by providing continuous protection and ecosystem rehabilitation so that changes are very large and strong, which will affect the system.

Table 2 shows that the values of the species diversity index (H') in various plots were low. The species diversity index indicates the stability of a community structure (Hidayat 2018). Low H' values indicate less stable species diversity. This may be due to climate variability and high levels of natural disturbance, which are important factors that control species diversity in tropical forests (Sahu et al. 2016). The H’ values in the moderate category indicated a stable species diversity. High diversity indicates a very stable and complex community owing to the high interactions between species (Fajri and Supartini 2015). The evenness index (E) value was high in plot 13 at all growth levels. High E values indicate that species diversity in the community is becoming more stable. The species diversity value was directly proportional to the evenness index (Kuswandi et al. 2015).

Table 2 Species diversity index (H'), species evenness index (E), species richness index (Dmg), and species dominance index (C) in various observation plots at KHDTK Haurbentes

Plot No.	Growth level	H’	E	Dmg	C
7	Seedling	0.73 (L)	0.53 (M)	1.02 (L)	0.64
	Sapling	0.33 (L)	0.48 (M)	0.26 (L)	0.81
	Pole	0.00 (L)	0.00 (L)	0.00 (L)	1.00
	Tree	0.00 (L)	0.00 (L)	0.00 (L)	1.00
8	Seedling	0.95 (L)	0.69 (H)	1.11 (L)	0.49
	Sapling	1.24 (L)	0.60 (M)	1.94 (L)	0.45
	Pole	0.00 (L)	0.00 (L)	0.00 (L)	1.00
	Tree	0.00 (L)	0.00 (L)	0.00 (L)	1.00
9	Seedling	0.55 (L)	0.79 (H)	0.35 (L)	0.64
	Sapling	1.43 (L)	0.69 (H)	2.08 (L)	0.37
	Pole	0.00 (L)	0.00 (L)	0.00 (L)	1.00
	Tree	0.27 (L)	0.39 (M)	0.00 (L)	0.86
10	Seedling	0.00 (L)	0.00 (L)	0.00 (L)	1.00
	Sapling	1.45 (L)	0.70 (H)	2.02 (L)	0.36
	Pole	0.00 (L)	0.00 (L)	0.00 (L)	1.00
	Tree	0.00 (L)	0.00 (L)	0.00 (L)	1.00
13	Seedling	1.08 (L)	0.99 (H)	0.72 (L)	0.34
	Sapling	0.76 (L)	0.69 (H)	0.63 (L)	0.53
	Pole	0.64 (L)	0.92 (H)	0.91 (L)	0.56
	Tree	0.47 (L)	0.67 (H)	0.39 (L)	0.71

H': Species diversity index, E: species evenness index, Dmg: species richness index, C: species dominance index, L: Low, M: Medium, H: High

The higher the E value, the higher is the H' value. E values in other plots were in the moderate to high category, but H' values were low, indicating lower tree species diversity in managed stands compared to unmanaged or natural stands due to the initial effects of the intervention (Awasthi et al. 2015). One example is the stacking level in plot 7 with a medium E but low H'. This condition is possible because of environmental imbalances that are unsuitable for plant growth (Kuswandi et al. 2015). Furthermore, other species were found at the tree level in plots 9 *S. mecistopteryx* and 13 *S. pinanga*. Based on this research, the main species of *S. stenoptera* grew large due to exposure to environmental stabilization, so the physical aspects underwent significant changes due to abiotic factors such as wind from the main plots of *S. mecistopteryx* plots 16 and *S. pinanga* plots 11 and 12 spread and grew in plots 9 and 13; therefore, the physical changes of the species experienced an imbalance.

The richness index (Dmg) values in the various observation plots were low. The low Dmg value was caused by the same species being planted in the plots, *S. stenoptera*, which was planted in 1940. Some differences were found in the number of seedlings and saplings, such as *Anisoptera marginata*, *S. mecistopteryx*, *S. pinanga*, *S. palembanica*, and *S. leprosula*. This is thought to be caused by abiotic environmental factors (abiotic) including wind, air, soil, water, and sun exposure to temperature. The Biotic Factor occurs because it is touched by living things, such as animals, plants (destroyers), and human behavior. The dominance index value (C) in the observation plot was 1 for the level of seedlings in plot 10 and poles to tree level in plots 7, 8, and 10. The species with an index value of C 1 were *S. stenoptera*. The C index value was close to 0 at the seedling level in plot 13 with a value of 0.34, while at the sapling level in plot 10 with a value of 0.36 the evenness index (Dharmawan et al. 2021).

Stands Structure of *Shorea stenoptera* Burck in KHDTK Haurbentes

The results of the vegetation analysis of the observation plots showed a distribution of the number of trees based on diameter. The diameter distribution of the trees can be identified by obtaining information related to the stand structure. Stand structure can be distinguished based on age class composition, and even-aged and uneven-aged stands. Plots 7, 8, 9, 10, and 13 are examples of even-aged stands where tree planting was performed simultaneously. Even-aged stands are characterized by the largest distribution of tree numbers in the diameter class obtained from the stand average, and the diameter of the trees in the class above or below is less (Wahyudi 2013). Information related to the distribution of the number of trees based on their density and diameter distribution is presented in Figure 5.

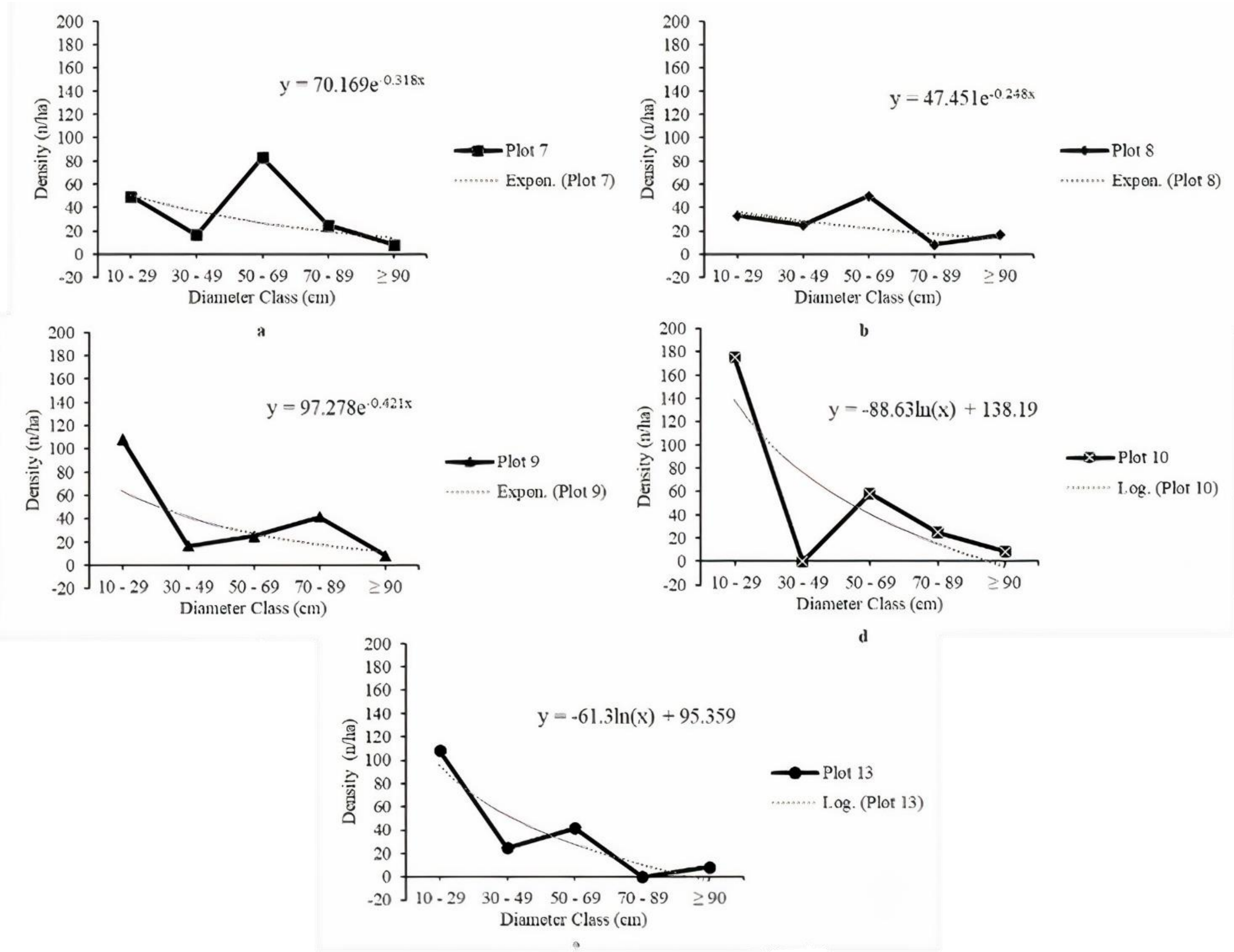

Figure 5 *S. stenoptera* diameter distribution on each plot in KHDTK Haurbentes of (a) plot 7, (b) plot 8, (c) plot 9, (d) plot 10, (e) plot 13

Figure 6 shows the diameter distribution in each plot forming a “J” shaped curve. Plots 7, 8, and 9 show negative exponential values, indicating a resemblance to a natural forest. However, plots 10 and 13 do not resemble a reversed J-shaped curve with negative logarithmic values. A stand structure with a reversed J-shaped curve indicates a balanced condition with uneven-aged stands as the composition of the stand for the next rotation (Pamoengkas et al. 2019). A natural forest is an uneven-aged forest with a typical pattern of species and diameter class distribution dominated by trees of a small diameter class and young age (Osmaston 1968). However, this was quite different in the observation plots because they were initially plantation forests. It was shown in the distribution that there was still an increase in density in the diameter class of 50–69 cm (plots 7, 8, 10, and 13) and diameter class of 70–89 cm (plot 9).

Thus, in the relatively long period since the planting year (1940), there was a gradual change in the shape of the plantation forest to the form of a natural forest. The diameter class of 10–29 cm was quite high, indicating regeneration that had reached the level of pole growth, and young trees replaced the above diameter class. However, some plots, such as Plots 7 and 8, had small values in the diameter class of 10–29 cm. Growth inhibition by small trees is suspected to be due to the presence of adult trees, so the growing space is reduced, such as the closure of the canopy by adult trees (Erizilina 2016).

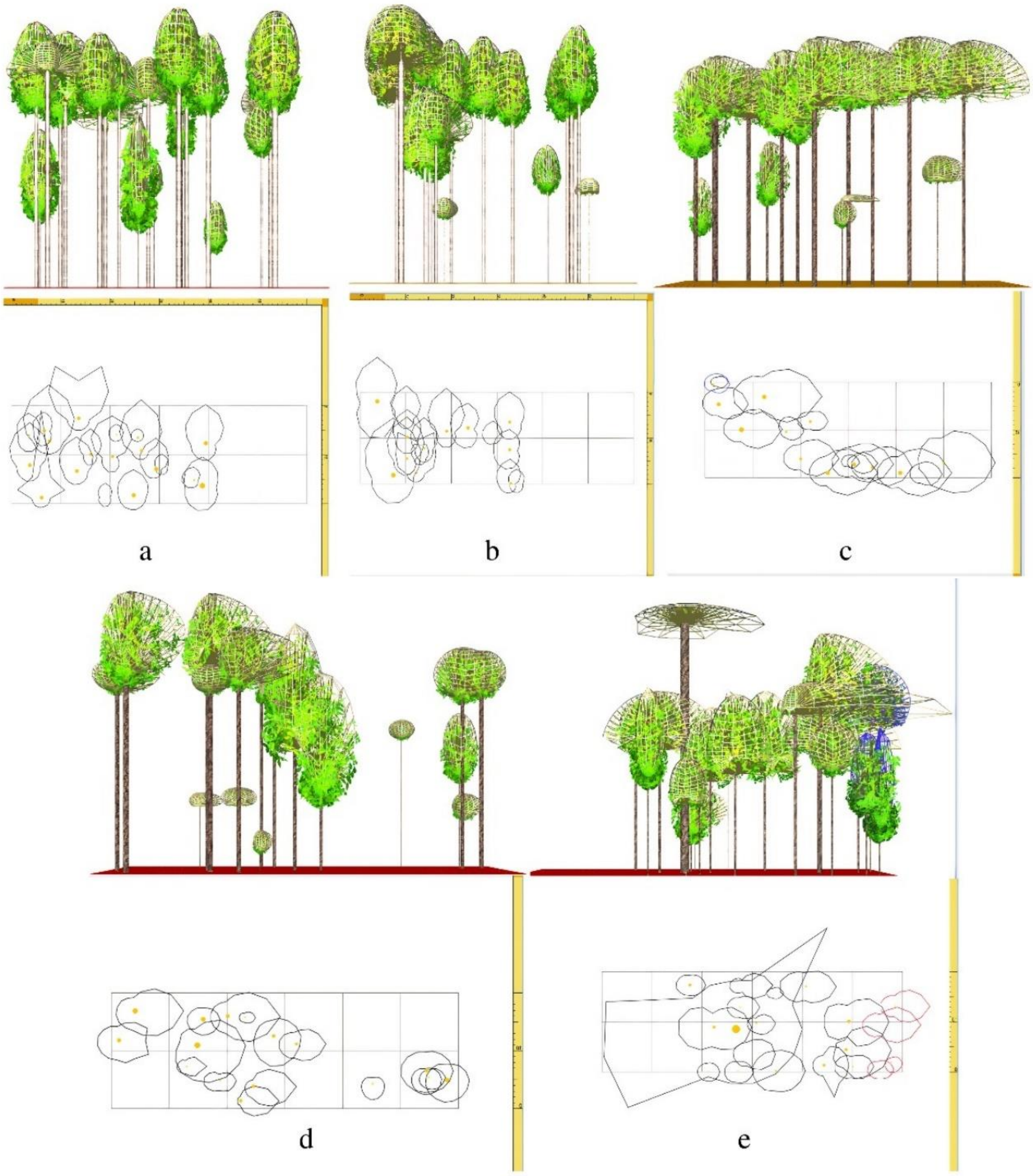

Figure 6 *S. stenoptera* canopy cover profile on each plot. (a) plot 7, (b) plot 8, (c) plot 9, (d) plot 10, (e) plot 13, the black line is *S. stenoptera*, the blue line is *S. mecistopteryx*, and the red line is *S. Pinanga*

The crown cover in five plots in the same planting year (1940) showed differences in crown strata in some plots. A uniform header layer was not found across all tiles. Stratification of the stand was divided into five strata classes, consisting of stratum A with the highest tree layer with a total height of more than 30 m, stratum B with a total height of 20–30 m, stratum C with a total height of 4–20 m. m, stratum D with a total height of 1–4 m, and stratum E, the lowest layer below 1 m (Septiawan et al. 2017). The condition of the non-uniform canopy indicates a change caused by environmental factors. The natural rejuvenation applied at KHDTK

Haurbentes was carried out by allowing abandoned plantation forests to become natural forest conditions. Rejuvenation has an optimal impact on natural rejuvenation in the observation plots. Supportive growth conditions increase plant regeneration; therefore, it is necessary to review regeneration conditions to ensure sustainability (Chaubey and Sharma 2013). The stands in each plot were dominated by *S. stenoptera* Burck in strata A, B, and C at the level of the pole up to the tree. Other species were found at the tree level, such as *S. mecistopteryx* in plot 9 and at the stand and tree level, *S. pinanga* in plot 13.

The Influence of Bio-Physical Aspects on the *Shorea stenoptera* Burck Growth

Information regarding the biophysical conditions at KHDTK Haurbentes in the observation plots is quite good because field conditions have been adjusted to normal availability, and inhibiting factors such as biotic and abiotic factors have been improved, which is adjusted to existing data for *S. stenoptera* Burck growth biophysical conditions in each plot, as presented in Tables 3 and 4.

Table 3 Physical conditions in each plot of *S. stenoptera* Burck plants

Plot	Temperature (℃)	Humidity (%)	Slope (^{0})	Elevation (masl)
7	25	91	13 (C)	239
8	26	81	16 (C)	253
9	27	81	14 (C)	247
10	26	81	7 (AC)	221
13	26	88.3	19 (C)	256

AC: Somewhat steep, C: Steep (Zuidam 1983)

Table 4 Average thickness of humus and organic matter in each plot of observation of *S. stenoptera* Burck

Plot	Humus thickness (cm)	Organic matter thickness (cm)
7	8.80	7.16
8	6.46	4.54
9	7.06	5.40
10	4.54	5.54
13	6.62	10.6

Table 4 shows that *S. stenoptera* Burck is suitable because it grows at temperature, humidity, moderate to steep slopes, and altitudes ranging from to 221–256 masl so, the suitability of the table above is able to balance with abiotic factors in the field, suitable for the observation of humus thickness and thickness of organic matter so that each plot has been passed within normal limits. Tengkawang (S. *stenoptera* Burck) grows well at an altitude of 0–1300 masl in steep and hilly areas, with climate conditions of type A and B rainfall and optimal temperature of 25–30 ℃. *Shorea* spp. are semi-tolerant, meaning they require sun exposure during the seedling and sapling stages (Fambayun 2014). Plot 13, with its relatively high slope, also provided a high evenness index. In line with the research of Fajri and Supartini (2015), high evenness values were obtained on steep slopes because the distribution of species in the plot was even. The results showed that *S. stenoptera* was suitable for growing in KHDTK Haurbentes; therefore, regeneration was carried out for the next cycle to preserve the species.

Soil conditions such as humus, organic matter, groundwater availability, humus, and soil organisms were important factors for growth in looking at the soil quality for the growth of seedlings. The soil types in the KHDTK Haurbentes consisted of red-yellow podzolic and yellow-brown latosols with clay soil parent material. These soil types have slow permeability, good drainage, acidic pH (pH 4.6), organic matter, nitrogen, and a decreasing C/N ratio from top to bottom (Puslitbanghut 2018). Soils with a clay texture tend to be finer, with a larger surface area in the ability to hold and provide high-nutrient elements (Hardjowigeno 2010). With these soil conditions, the growth of *S. stenoptera* Burck was well supported.

Table 4 is related to the humus thickness measured on the plant plot ranging from 4.54–8.8 cm, with the organic matter thickness ranging from 4.54–0.6 cm. This thickness supported the regeneration of *S. stenoptera* by the dominance index value of the species at various growth levels approaching 1, and the evenness of *S. stenoptera* and others was widely distributed with moderate to high index values. Humus and organic matter are available materials, and active weathering processes in the soil cycle support sustainable plant growth. Humus productivity supports the addition of organic matter to the soil layer. Leaves and branches falling to the soil layer were naturally pruned to increase the organic matter content. Generally, *Shorea* spp. grow in nutrient-poor locations and dense soil conditions. The semitropical nature of this type made it less fertile. Therefore, the presence of organic matter and humus can result in optimal plant productivity (Fambayun 2014).

CONCLUSION

The stand composition has high to low density, successively from seedlings to trees. All plots in the study area were dominated by *S. stenoptera.* The structure of the *S. stenoptera plant stand* showed a transition to that of the natural forest, as seen in the inverted J-shaped curve (in plots 7, 8, and 9). These results are suitable and satisfactory for the surrounding environment to support better natural regeneration in the next cycle. Biophysical aspects such as temperature, humidity, slope, elevation, humus layer thickness, and organic matter thickness have a positive effect on optimal growth and increase productivity to produce maximum research. Thus, analysis of species composition, stand structure, and natural regeneration of S. stenoptera stands, as well as identification of the effect of biophysical aspects on the performance of natural regeneration of S. stenoptera, proved to be mutually compatible with the environment.

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