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Diameter growth performance and estimated carbon stock of *Shorea* spp. at KHDTK Haurbentes, Bogor

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Abstract. Shorea leprosula *Miq. and* Shorea selanica *(Lam.) Blume are fast-growing plants, and can be used as a rehabilitation plant. Plant adaptability can be seen from the growth in diameter. Furthermore, rehabilitation plants have the potential to store carbon stocks which can support Indonesia's Forestry And Other Land Use (FOLU) Net Sink 2030 program. This study aims to analyze diameter growth and estimate carbon stocks stored in 8-year-old* S. leprosula *and* S. selanica *species in unproductive forest area KHDTK Haurbentes, Bogor. Furthermore, the data collection of diameter was conducted by census, while carbon stock estimation used allometric equations. The diameter distribution of* S. leprosula *and* S. selanica *was normally distributed. The normal diameter distribution is defined as the highest number of frequencies around the mean value. The results of the normality test of* S. leprosula *and* S. selanica *have normal diameter distribution data, which indicate that these species have good adaptability in unproductive forest areas. Moreover, the incremental growth of* S. leprosula *diameter is 1,38 cm, while the diameter increment of* S. selanica *is 1,19 cm. The carbon stock of* S. leprosula *is 4,72 tons/ha while* S. selanica *is 8,32 tons/ha.* S. leprosula *and* S. selanica *have good adaptability. Thus, they can be used as plants to rehabilitate unproductive forests and store potential carbon stocks.*

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INTRODUCTION

Climate change is one of the most serious threats facing the world today. Climate change can be caused by internal natural processes as well as external forces or human actions, which continuously change the composition of the atmosphere and land use (Gernowo *et al.* 2012). Furthermore, the increase in carbon dioxide (CO_2) emissions is one of the causes of climate change which triggers global warming. Some experts suspect that the amount of CO_2 and greenhouse gases (GHG) is increasing day by day due to the increasing carbon emissions which humans produce from burning fossil fuels and forest degradation (Gernowo *et al.* 2012). Moreover, the conference of the parties (COP-26) held in Glasgow in 2021 revealed that the increase in global temperature needs to be limited to 1.5°C through halving world emissions by 2030 and achieving net zero emissions (NZE) by 2050. Meanwhile, the National program "Indonesia's FOLU (Forestry and other Land

Uses) Net Sink 2030" set in Presidential Regulation 98 of 2021 is intended to achieve net zero emissions in the forestry and land sector by 2030 of 140 million tons of CO_2.

Deforestation and forest degradation have a real impact on increasing greenhouse gases, climate change, and causing unproductive forest conditions. On the other hand, the existence of forests contributes to absorbing and storing carbon which affects GHG reduction, so forest and land rehabilitation efforts are needed to reduce deforestation and forest degradation (Jatmiko *et al.* 2012). Furthermore, Forest and Land Rehabilitation Activities (RHL) aim to restore forest and land conditions so that they can function normally and sustainably as a life support system. Rehabilitation activities require plants that grow fast and have a high degree of adaptability in order to grow optimally. It is important to know the measurement of growth performance to evaluate the types of plants which can grow optimally in the rehabilitation area. In addition, rehabilitated plants have the potential to store high carbon stocks. Long-lived woody trees can store more carbon than annual plants. Tree biomass and forest vegetation contain huge carbon stocks, which can maintain and balance the earth's carbon cycle (Yunita 2016).

Shorea leprosula Miq. and *Shorea selanica* (Lam.) Blume are fast-growing plant species and can store carbon reserves. *S. leprosula* is an endemic plant in Kalimantan which belongs to the Dipterocarpaceae family with a critically endangered status (Yulita and Kalima 2017). This species grows well in the open ground and has a high growth rate. This type produces resin which is known as damar, and it can be used as a medicinal ingredient (Yulita and Kalima 2017). *S. selanica* is an endemic plant in the Maluku Islands, which is endangered with critically endangered status. *S. selanica* can grow well in lowland forests with fertile soil and good drainage and on limestone hills (Hasnah 2014; Yulita and Kalima 2017).

Forest Area With Special Purpose/*Kawasan Hutan Dengan Tujuan Khusus* (KHDTK) Haurbentes is a forest area located in Jasinga District, Bogor Regency, West Java. The benefits of KHDTK Haurbentes are for research and development activities, education, training, and cultural and religious purposes (Suharti *et al.* 2005). Furthermore, KHDTK Haurbentes has rehabilitated unproductive forest areas that can increase carbon stocks by planting Dipterocarp species, including *Shorea leprosula* and *Shorea selanica,* in rehabilitation plots since 2014. The estimation of carbon stocks in this location has never been conducted. Therefore, study on diameter growth performance and estimation of carbon stocks of *Shorea leprosula* and *Shorea selanica* species is very important as an effort to monitor and evaluate diameter growth performances, as well as strengthen the carbon stock database which is generated in the rehabilitation plots. This study aims to analyze the diameter growth performance and estimate the carbon stock stored in *S. leprosula* and *S. selanica* species in the rehabilitation plot, KHDTK Haurbentes.

METHOD

Location and Period

This study was conducted in January 2022 on a rehabilitation plot of 10 species at KHDTK Haurbentes, Jasinga District, Bogor Regency. KHDTK Haurbentes administratively belongs to the Haurbentes Village, Jugala Jaya Village, and Wirajaya Village, Jasinga District, Bogor Regency. KHDTK Haurbentes is located at an altitude of ± 250 masl, and it geographically is located at 6º32'-6º33 South Latitude and 106º26 East Longitude.

Data Collection

Data collection on the Haurbentes KHDTK rehabilitation plot, especially on *S. leprosula* and *S. selanica* species, was conducted using the census method. The plot was originally an unproductive forest land. Then it was rehabilitated using 9 species of Dipterocarpaceae plants with a pathway system. The nine species include *Dipterocarpus grandiflorus*, *Shorea mecisopteryx*, *Vatica sumatrana*, *Hopea mengarawan*, *Shorea leprosula*, *Shorea stenoptera*, *Shorea pinanga*, *Shorea palembanica*,and *Shorea selanica*. To date, the rehabilitation plot for 9 species in KHDTK Haurbentes has never been conducted by silvicultural measures. The data were taken following the path which had been planted on 8 years old *S. leprosula* and *Shorea selanica* species.

Moreover, the width of the path was 1,5 meters, the spacing between plants in the path was 2,5 meters, and the distance between paths was 5 meters. The number of observation units was 84 plants consisting of 6 lines, with each line consisting of 14 plants of both *S. leprosula* and *S. selanica* species. In addition, the primary data taken were the number of individual living plants and the diameter at breast height. The primary data taken were the number of live plants and the diameter of the stands of *S. leprosula* and *S. selanica*. The diameter was measured at breast height using the phi band on each tree located in the research plot.

Data Analysis Method

Percentage of Living

The percentage of living can be obtained based on the total number of living individuals divided by the total number of individuals planted multiplied by 100%. Classification of a percentage of plant life in the study which was conducted by Gunawan *et al.* (2016) is divided into three: 1). Percentage of plant life <55 % is classified as a failure; 2) Percentage of plant life 55−76% is classified as quite successful; 3) Percentage of plant life >76%−100% classified as successful.

Average Tree Diameter and Mean Annual Increment (MAI)

The calculation of the average tree diameter can be conducted by dividing the total diameter of the observed trees (cm) by the number of individual trees observed. The mean annual increment is the average diameter increment that occurs over a certain period of time (per year) based on the Mean Annual Increment or MAI (Prodan 1968) formula.

$$\text{MAI} = \frac{Di}{T}$$

Note:
MAI = Mean annual increment (cm/year)
Di = Average tree diameter at age 1 (cm)
T = Age of tree at the time of observation (year)

Tree Diameter Class Division

The steps in the division of tree diameter classes in the distribution of frequency distribution are as follows (Sudarman, 2015): 1) Calculating the range by subtracting the largest diameter data value with the smallest data value; 2) Calculating the length of the class with the Struges formula: Class length = 1 + 3.33 log n (n = number of data); 3) The number of classes or the number of class intervals required to group data by dividing the range by the class length; 4) Class interval by compiling the initial number of lower and upper limits for the first to last class interval.

Making a Histogram Graph of Diameter Distribution and Data Normality Test

Making a histogram graph of diameter distribution used a normal curve on the IBM SPSS 25 application. The data normality test is a test by comparing the observed data (empirical data) with normally distributed data (theoretical data) which has the same average and standard deviation as the empirical data. Testing with the IBM SPSS 25 application used the Kolmogorov-Smirnov and Shapiro-Wilk test statistics at a significance level of 0,05 with the following hypothesis (Pamoengkas and Prasetia, 2014): a) H0: Empirical diameter distribution (measurement results) = Theoretical distribution (normal); b) H1: Empirical diameter distribution (measurement results) ≠ Theoretical distribution (normal). The decision rule or test criteria if significant (p ≤

0,05); then reject H0. Meanwhile, if it is not significant ($p > 0,05$), then accept H0, or it can be said that the data is normally distributed.

Aboveground Stand-level Biomass Calculation

The calculation of biomass used the average tree diameter in each path which was entered into the allometric equation according to the type of tree (Table 1).

Table 1 Allometric equations which are used

No.	Allometric Equation	Tree Type	Source
1	$B = 0{,}0726\ D^{2{,}378}$	*Shorea leprosula*	Krisnawati *et al.* (2012)
2	$B = 0{,}2291\ D^{2{,}31}$	*Shorea selanica*	Wulansih (2012)

Note: B: biomass weight (kg); D: diameter at breast height (cm)

Forest Carbon Estimation

The biomass value which is obtained from the calculation results can be used to estimate the potential for the carbon stored in forest vegetation. Carbon stock can be determined by using the carbon fraction of forest biomass, which is 0.47, or it can be said by multiplying forest biomass by the carbon fraction (IPCC 2006).

$$C = B \times 0{,}47$$

Note: C = Carbon (kg); B = biomass (kg/tree); 0,47 = carbon fraction

The calculation of carbon storage per hectare for carbon per tree which has been obtained, can use the following formula (BSN 2011).

$$C_n = \frac{C}{1.000} x \frac{10.000}{Lplot}$$

Note: C_n = carbon per hectare (ton/ha); C = carbon (kg); L_{plot} = plot area (m^2)

RESULTS AND DISCUSSION

General Condition of Observation Plots of *S. leprosula* and *S. selanica*

Environmental conditions greatly affect plant growth. This observation plot, which is an unproductive forest, began to be planted with Diptercarpaceae species, such as, *S. leprosula* and *S. selanica* in 2014. The growing conditions in the observation plot can be seen in Table 2. The growing conditions for *S. leprosula* and *S. selanica* in Table 2 refer to research data from Erizilina (2017) who conducted research in the same plot. The data in Table 2 shows that the stands in the observation plot were planted in 2014 so that they were 8 years old at the time of data collection.

Table 2 Conditions of the observation plots grow

Parameter	Description
Large	0,525 ha*
Year of planting	2014*
Temperature	28,97°C*
Humidity	81,74%*
Soil pH	5,4–5,8 (acid)*

*Erizilina research data (2017) on the same research plot

Generally, this 0,525 ha plant plot has uniform conditions. Furthermore, the soil at the research site is classified as acidic, with a soil pH ranging from 5,4 to 5,8. Soil types in KHDTK Haurbentes consist of three types of soil that are red-yellow podzolic, Regosol, and brown forest soil a(Center for Research and Development of Forests and Nature Conservation 2005). In addition, according to Sari *et al.* (2019), red-yellow podzolic soils have highly leached soil, there is an accumulation of clay with relatively heavy texture, lumpy structure, low permeability, low aggregate stability, low organic matter, low base saturation, and it is categorized as soil with relatively low fertility.

Growth Performance of *Shorea leprosula* and *Shorea selanica*

The growth performance of *S. leprosula* and *S. selanica* diameters can be seen based on the increment values and diameter distribution as follows.

Diameter Increment

The number of living individuals in a stand can be represented in the calculation of the percentage of living. Table 3 shows the percentage values of plant life of *S. leprosula* and *S. selanica*, respectively which are 83,33% and 87,80%. Based on the classification of a percentage of plant life in the study which was conducted by Gunawan *et al.* (2016), the percentage of plant life is high if it has a value in the range of 76% to 100%. The percentages of living of *S. leprosula* and *S. selanica* are high, which indicates that *S. leprosula* and *S. selanica* are able to grow in the rehabilitation area. In addition, it indicates that *S. leprosula* and *S. selanica* are able to adapt to the rehabilitation plot well and are in accordance with research which had conducted by Fajri (2020), which stated that dipterocarp species are able to adapt and have the highest percentage of living in the rehabilitation area.

Table 3 Percentage of living of *S. leprosula* dan *S.selanica*.

Type	Number of Plants (ind)		Total Plant (ind)	Percentage of Living (%)
	Life	Death		
S. leprosula	35	7	42	83,33
S. selanica	36	5	41	87,80

The diameter growth of *S. leprosula* and *S. selanica* stands can be determined by measuring the diameter increment or MAI (Mean Annual Increment). Table 4 shows the diameter growth of *S. leprosula* and *S. selanica*, which are 11,01 cm and 9,55 cm, respectively. Meanwhile, the increment (MAI) for *S. leprosula* is 1.38 cm, and *S. selanica* is 1,19 cm. Diameter increament of tree is a natural increase in tree diameter in a short time or periodically (Ruchaemi 2013). The value of the diameter increment of *S. leprosula* and *S. selanica* in this study was smaller when compared to Tirkaamiana's (2020) study, which has an average diameter of *S. leprosula* of 13 cm and a diameter increment of 2,08 cm at the age of 7 years. It can be due to the absence of maintenance or silvicultural techniques in the observation plots. Furthermore, according to a study which was conducted by Tirkaamiana (2020), intensive maintenance can significantly increase the growth of stand diameter increments. It is also in accordance with Ruchaemi's (2013) statement, which stated that silvicultural techniques, such as thinning, can increase the value of the diameter increment of the tree.

Table 4 Diameter growth of *S. leprosula* and *S. selanica*

Type	Age (year)	Diameter (cm)	
		Average	Increment (MAI)
S. leprosula	8	11,01	1,38
S. selanica	8	9,55	1,19

The value of the diameter increment of *S. leprosula* and *S. selanica* is greater when compared to Sholihah's (2020) study, which only has a value of 1,13 cm/year for the 21-year-old *S. selanica* species. In addition, the difference in this increment value can be due to the different ages of the plants during the study period. Moreover, according to Suhartati *et al.* (2013), a decrease in stand increment (MAI) can occur with increasing age of the plant, which can be caused by the stability of survival in these plants decreases while the size of the diameter of the tree continues to increase as the age of the tree increases.

Diameter Distribution

The *S. leprosula* and *S. selanica* plants which are found in the pathways in this rehabilitation plot are categorized as even-aged stand since they are planted at the same time. Figure 1 shows that the most common diameter distributions are found at a frequency of 2,88–6,20 cm and 6,20–9,52 cm with each number of 8 individuals. In addition, the frequency of diameter 22,80–26,12 cm is found only one individual. The distribution of the diameter of the species of *S. selanica* can be seen in Figure 2.

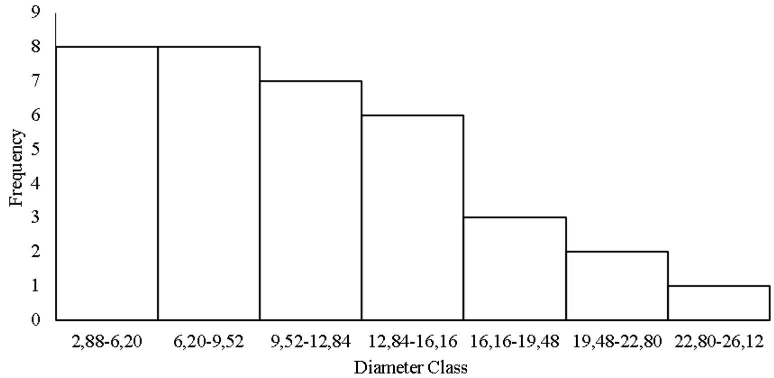


Figure 1 Frequency distribution of the diameter of *S. leprosula*

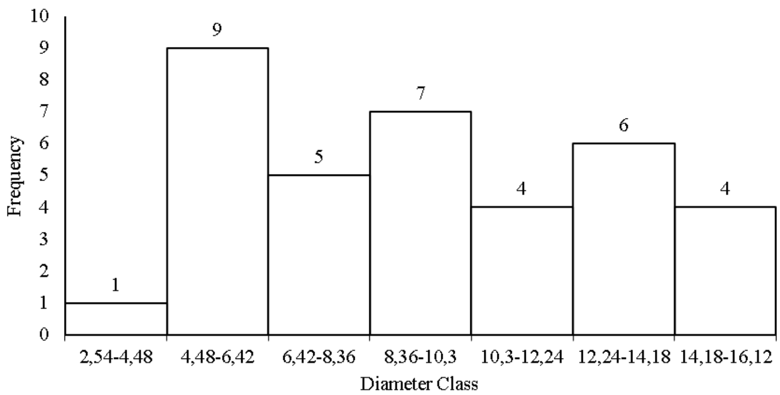
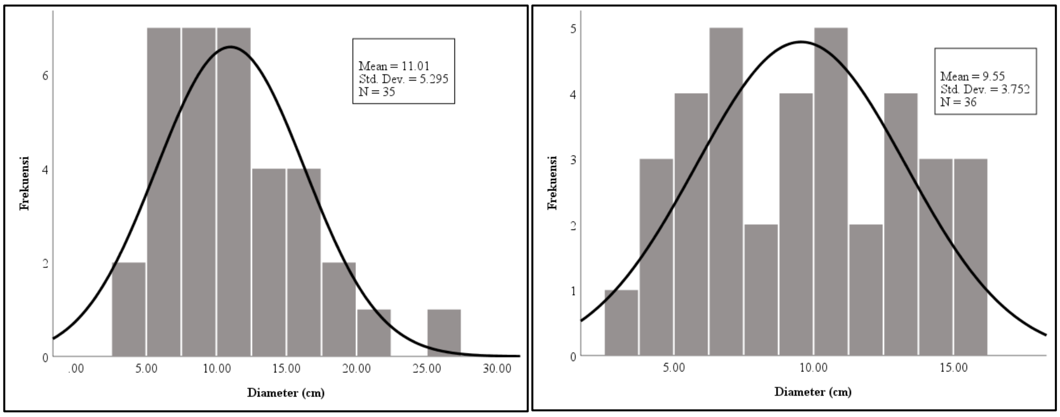


Figure 2 Frequency distribution of the diameter of *S. selanica*

The distribution of diameters in Figure 2 of *S. selanica* species is based on frequency distribution. Based on Figure 2, it can be seen that the most common diameter distribution is found at a frequency of 4,48–6,42 cm with a total of 9 individuals. Meanwhile, the frequency of diameter 2,54–4,48 cm is found in only one individual. The frequency distribution of the diameters of *S. leprosula* and *S. selanica* species can be known to spread normally by conducting a normality test.

Figure 3 shows that the distribution of diameters for both *S. leprosula* and *S. selanica* characterizes a normal distribution that is the highest frequency around the mean in the stands and decreases with diameter values that are smaller or larger than the mean value. It shows that the diameter visualized in the form of a graph indicates the shape of the diameter class distribution according to the shape of the normal distribution curve. This normal distribution curve can be said that the stands in the research plot are in normal and healthy conditions (Herianto 2017). Furthermore, it is in accordance with the results of research which had conducted by Pamoengkas and Prayogi (2011), which stated that even-aged stands tend to have more frequencies around the stand center value and decrease in frequency at smaller or larger diameter values so that they look like bells.



(A) (B)

Figure 3 Graph of diameter distribution and the normal curve: (A) *S. leprosula*; (B) *S. selanica*

The results of the data normality test by Kolmogorov-Smirnov and Shapiro-Wilk confirm that the diameter distribution data for the 8-year-old *S. leprosula* and *S. selanica* species have normal diameter distribution data (Table 5). Table 5 shows the result of the normality test of *S. leprosula* and *S. selanica* data that is accepting H0 or it can be said that this 8-year-old plant has normal diameter distribution data. It is because the significance value of Kolmogorov-Smirnov and Shapiro-Wilk for the types of *S. leprosula* and *S. selanica* is greater than 0,05, which means that the diameter distribution of the measurement results is the same as the theoretical or normal distribution.

Table 5 The results of the normality test of the data

Type	**p(K-S)**	**p(S-W)**	**Test Result**
S. leprosula	0,200	0,090	Accepted H_0 ($p > 0,05$)
S. selanica	0,174	0,220	Accepted H_0 ($p > 0,05$)

Furthermore, based on the results of the normality test, the species *S. leprosula* and *S. selanica* are able to adapt well to the rehabilitation plot of unproductive forest stands. It is in accordance with research conducted by Fajri (2020) and (Panjaitan *et al.* 2011), which stated that S. leprosula and S. selanica could adapt well to rehabilitation land, such as unproductive forest stands. Moreover, according to research which had conducted by Pamoengkas and Prasetia (2014), at a young age, the type of *S. leprosula* has not been able to grow well; however, when it reaches the age of 3 years and over, the growth of this plant is able to adapt to its environment well. The results of this study are also similar to those of Pamoengkas and Prasetia (2014), who explained that even-aged stand is planted as tree crowns of one stratum or, in other words, tree crowns which looked uniform.

The growth of *S. leprosula* and *S. selanica* is good even though maintenance is not conducted. The results of the research which had conducted by Hardjana and Suastati (2014) stated that silvicultural treatment in a stand could optimize plant growth in the stand. Furthermore, research which had conducted by Panjaitan (2016) stated that apart from maintenance, there are other factors which have a greater influence on the diameter growth of Shorea spp. compared to maintenance; such as light intensity, humidity, soil fertility, and suitability of plant species with environmental conditions.

Plant growth of *S. leprosula* and *S. selanica* can be influenced by environmental factors; such as crown closure. According to Manya (2017), *S. leprosula* and *S. selanica* are semi-tolerant species which at seedling or at a young age they need shelter, which is up to two years old or 1,5 m high or more, but after they mature enough, light is needed for further growth. Furthermore, the results of research which had conducted by Erizilina (2017) on the same research plot, the planting path of *S. leprosula* and *S. selanica* at 3,5 years old has open crown closure, but crown openness does not show a relationship or influence on plant growth. In addition, the research which had conducted by Pamoengkas and Prayogi (2011) stated that the response to the difference in the percentage of crown (canopy) cover does not show a certain relationship or tendencies in each diameter class. However, when the observation of the percentage of crown (canopy) cover is continued at 9 years of planting, there is a tendency that the lower the percentage of crown (canopy) cover is, thus, the larger the diameter.

Biomass and Carbon Stock of *S. leprosula* and *S. selanica*

Tree biomass of *S. leprosula* and *S. selanica* can be estimated using the allometric equation, $B = 0{,}0726\ D^{2{,}378}$ (*S. leprosula*) and $B = 0{,}2291\ D^{2{,}31}$ (*S. selanica*). Meanwhile carbon stock of *S. leprosula* and *S. selanica* using carbon stock $C = B \times 0{,}47$. The formula of both parameter can be seen in the methods. Table 6 shows that the biomass of *S. leprosula* is 1.054,06 kg/tree (the amount of tree biomass was calculated by summing the biomass of each tree within the plot) with a carbon stock of 4,72 tons/ha (the amount of carbon stock was calculated by summing the carbon of each tree within the plot and converted into per ha), while *S. selanica* has a biomass of 1.858,42 kg/tree (the amount of tree biomass was calculated by summing the biomass of each tree within the plot) with a carbon stock of 8,32 tons/ha (the amount of carbon stock was calculated by summing the carbon of each tree within the plot and converted into per hectare).

Table 6 Biomass and stored carbon of *S. leprosula* and *S. selanica*

Type	Tree Biomass (kg/tree)	Carbon Stock (ton/ha)
S. leprosula	1.054,06[a]	4,72
S. selanica	1.858,42[b]	8,32

Note: the plot area = 1.050 m^2; a (number of trees) = 35 trees; b (number of trees) = 36 trees

Furthermore, research which had conducted by Yunita (2016) estimated carbon stocks of 10-year-old *S. leprosula* stands in natural forests in silin areas have a higher carbon stock yield of 65,21 tons/ha. It is presumably due to differences in diameter, plant age, and intensive land management. According to research which had conducted by Nuranisa *et al.* (2020), the factors which cause differences in the carbon stock of a stand include differences in stand age, soil fertility, and land management methods. Table 6 shows that the greater the biomass of *S. leprosula* and *S. selanica*, the greater the carbon stock. This study is in accordance with a study which had conducted by Komul *et al.* (2016) which explained that the higher the growth of vegetation or above-ground biomass, the higher the stored carbon stock.

Data on carbon stocks of *S. leprosula* (4,72 tons/ha) and *S. selanica* (8,32 tons/ha) in KHDTK Haurbentes is able to strengthen the database on the achievement of Indonesia's FOLU Net Sink 2030. According to the Decree of the Minister of Environment and Forestry of the Republic of Indonesia Number SK.168/MENLHK/PKTL/PLA.1/2/2022 concerning Indonesia's Forestry And Other Land Use (FOLU) Net Sink 2030, the area within the zone, even though the forest condition is no longer productive, must still be maintained as a forest area as an effort to realize the 2030 FOLU Net Sink program. Moreover, biomass and carbon stored in *S. leprosula* and *S. selanica* species in this unproductive forest stand rehabilitation plot can support the FOLU Net Sink 2030 program that is as a step to reduce greenhouse gas emissions since, in this study, *S. leprosula* and *S. selanica* can adapt to unproductive forest stands and can store carbon stocks well. In addition, according to research which had conducted by Yunita (2016), the carbon stock stored in the form of biomass in meranti stands continues to increase along with the age of the stand so that it can increase the productivity of the forest's ability to reduce CO_2 emissions in the atmosphere and store it as carbon stock.

CONCLUSION

The diameter growth of 8-year-old *S. leprosula* and *S. selanica* species planted in the unproductive forest rehabilitation plot line has normal diameter growth distribution. Moreover, the incremental growth of *S. leprosula* diameter is 1,38 cm, and the diameter increment of *S. selanica* is 1,19 cm. The carbon stock of *S. leprosula* is 4,72 tons/ha, and *S. selanica* is 8,32 tons/ha. In addition, *S. leprosula* and *S. selanica* have good adaptability so that they can be used as plants to rehabilitate unproductive forests and store potential carbon stocks.

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