Growth assessment of upper hill dipterocarp (*Shorea platyclados*) at the various slope in a rehabilitated landscape

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Abstract. Rehabilitation aims to improve landscape function while increasing its resilience to climate change. Gunung Dahu research forest is a rehabilitated hilly landscape that is planted with more than 25 dipterocarp species, including an upper hill dipterocarp tree of *Shorea platyclados* at various site conditions. This study aimed to assess the growth performance of *S. platyclados* at five sloping levels class of 0-8%, 8-15%, 15-25%, 25-45%, and >45%. Observed growth attributes were stem diameter, total height, basal area, Mean Annual Increment (MAI), and Leaf Area Index (LAI), and diameter. The results showed that sloping levels significantly affect the growth performance of the planted trees. The highest slope level (>45%) supported the highest average stem diameter and tree height (41.48 cm and 20.86 m). The sloping level of >45%, 25-45%, 15-25%, 8-15%, and 0-8% yield different value of average diameter which were 41.48 cm, 35.86 cm, 36.54 cm, 34.61 cm, and 31.23 cm, while the average height were 20.86 m, 19.78 m, 18.72 m, 18.84 m, 18.61 m respectively. Thus, the upper hill dipterocarp of *S. platyclados* is a prospective native tree species for rehabilitating hilly upland landscapes.

1. Introduction

The Dipterocarpaceae family in Indonesia has a high commercial value. However, the distribution and abundance of Dipterocarpaceae species in Indonesia are decreasing. This condition is due to the conversion of forest functions to other functions and also overexploitation. KLHK [1] stated that the net deforestation rate in 2018-2019 in Indonesia was 462,400 Ha, a slight increase compared with the previous year, namely in 2017-2018 of 439,400 Ha. In general, it can be said that the rate of deforestation has decreased. However, rehabilitation is needed to restore forest resources. Forest rehabilitation aims to improve land use and, at the same time, increase its resilience to climate change. For example, the Gunung Dahu Research Forest is hilly land that has been rehabilitated and planted with more than 25 species of Dipterocarpaceae, including hill meranti trees (*Shorea platyclados*) under various site conditions.

*S. platyclados* Slooten ex Endert is a commercial timber-producing tree from the Dipterocarpaceae family, with the trade name red meranti. This species grows in hills or mountains and is known locally as meranti bukit, meranti gunung and meranti tenam. Its distribution area includes Peninsular Malaysia, Sumatra, Kalimantan including Sarawak, Sabah, and Brunei [2]. In The International Union for the Conservation of Nature (IUCN) [3] Red List of Threatened Species, *S. platyclados* is categorized in an endangered status (Endangered A1cd ver 2.3) which is characterized by a population decline of at least
50% in the last ten years. Efforts to restore the amount of red meranti to a sustainable status against the backdrop of the high demand for timber and non-timber products, according to [4], red meranti has a demand of 75% in the commercial timber trade of medium to strong, durable grade. The high benefit of this species requires optimization of stand productivity.

The planting site characteristics can influence the increase in stand productivity. The planting site characteristics with the condition of the suitable slope will produce good and maximum growth [5]. Therefore, the slope is a factor that needs to be considered in planting activities. Furthermore, the slope is one of the factors that affect the growth attributes through their erosion potential that may affect the soil function as a growing medium [6]. *S. platyclados* in the Gunung Dahu Research Forest is planted at the elevation of 786-868 m above sea level with a slope of 0% - > 45%. This study aimed to assess the growth performance of *S. platyclados* at five sloping levels class of 0-8%, 8-15%, 15-25%, 25-45%, > 45%, and environmental conditions in the area of the Gunung Dahu Research Forest. Therefore, this study is expected to provide information on the growth data of *S. platyclados* on various slope classes as an initial recommendation for restoration efforts on hilly sloping land.

2. Materials and Methods

2.1. Study sites and materials

Data were collected in Plot 15, 20, 21 of the Gunung Dahu Research Forest, Leuwiliang District, Bogor Regency, West Java in February - March 2021. The plot was planted with *S. platyclados* at a spacing distance of 4 x 4 m. Within the studied plots, slope grouped into 5 classes, those were 0-8% flat category, 8-15% gentle category, 15-25% mild category, 25-45% steep category and > 45% very steep category [7]. Geographically, The Gunung Dahu Research Forest (HPGD) area is located at coordinates 06° 36' 30".06° 37' 00" SL and 106° 34' 00 "-06° 35' 30" EL. The HPGD area is located in Pabangbon Village, Leuwiliang District, Bogor Regency, West Java Province. HPGD has a rainfall of 2500-2700 mm year\(^{-1}\) and is located at an elevation of 550-900 m asl with hilly and steep topography. Soil types in HPGD are included in the latosol soil type reddish-brown [8]. According to [9], the climate type HPGD includes climate type B, with 80% relative humidity and an average temperature of 30°C.

2.2. Study design and measured parameters

Data were obtained in the form of primary and secondary data. Primary data (e.g. tree diameter, total tree height, slope and elevation) were obtained by direct measurements, while secondary data included information on planting year, general condition, air temperature and rainfall data). Growth parameters were measured as follow:

- **Tree diameter**: Tree diameter measurements were carried out at the height of 1.30 m above ground level [10].
- **Total tree height**: Total height and branch-free height were measured using a haga hypsometer [11].
- **Elevation**: Elevation data is taken using GPS by marking the position according to the location of the research plot.
- **Litter thickness**: Measurement of litter thickness is done using a ruler. Five replications were taken for each slope class, and then the data were averaged.
- **Leaf Area Index (LAI)**: [12] explained that LAI is the leaf area (projected on a flat plane) for each unit of land surface area covered by a tree canopy. LAI data were collected by using a hemispherical canopy photograph using a Fish-eye lens.

2.3. Data analysis

Calculations of average tree diameter and total height, branch-free height, annual average increment (MAI) of tree height and diameter, stand density, and Basel Area (BA) were processed using Microsoft Excel 2010 and SPSS (Statistical Product and Service Solutions) applications. Furthermore, the statistical test is used to analyze the Anova test and Duncan’s continued test. Leaf Area Index (LAI) data was done using the Hemiview 2.1 Canopy Analysis Software application.
3. Results and Discussion
The studied plots have different characteristics. These characteristics include plot size, planting year, elevation, spacing, number of trees, and stand density. The characteristics of the studied plots are shown in Table 1.

Table 1. Plot characteristics of *S. platyclados* stand.

| Plots | Area (Ha) | Planted year | Elevation (m asl) | Spacing | Number of trees | Stand Density (individual ha⁻¹) |
|-------|-----------|--------------|-------------------|---------|----------------|-------------------------------|
| 15    | 2.8       | 1999         | 863               | 4 x 4 m | 132            | 47.14                        |
| 20    | 2.4       | 1999         | 700               | 4 x 4 m | 271            | 112.92                       |
| 21    | 0.6       | 1999         | 733               | 4 x 4 m | 12             | 20                           |

Table 1 shows the characteristics of the studied plot. According to [13], the elevation in the range 700-1000 m asl is the optimal height for the growth of *S. platyclados*. The difference in stand area causes the number of trees in each stand to be different. Environmental conditions can affect the growth of a plant, including soil texture, spacing, stand density, litter thickness, and the value of LAI (Leaf Area Index). The environmental conditions of the research plots are shown in Table 2.

Table 2. Environmental conditions of the research plot.

| Plot | Slope classes | Soil texture | Number of trees | Average litter thickness (cm) | LAI |
|------|---------------|--------------|-----------------|-------------------------------|-----|
| 15   | Flat          | Sandy clay   | 1               | 7.16                          | 0.99|
|      | Gentle        | Sandy clay   | 23              | 5.66                          | 1.06|
|      | Mild          | Sandy clay   | 33              | 6.60                          | 0.95|
|      | Steep         | Sandy clay   | 75              | 4.66                          | 0.77|
| 20   | Flat          | Sandy loam   | 27              | 1.83                          | 1.04|
|      | Gentle        | Sandy loam   | 23              | 5.33                          | 1.42|
|      | Mild          | Sandy loam   | 18              | 4.66                          | 1.40|
|      | Steep         | Sandy loam   | 203             | 5.38                          | 1.09|
| 21   | Very steep    | Sandy loam   | 12              | 7.00                          | 2.00|

Litter is dead material on the soil surface which undergoes decomposition and mineralization. The components that include litter are leaves, twigs, small branches, bark, flowers and fruit [14]. Litter plays an important role on the forest floor surface because most of the return of nutrients to the forest floor comes from the litter. The litter will help increase the nutrient content in the soil and protect the soil from falling rainwater to reduce soil erosion. The highest average litter thickness on plot 15 with flat slope class, while the lowest average litter thickness on plot 20. The results of the average thickness of the litter from the two plots were inversely proportional to the research of [15], which states that the amount of litter produced is strongly influenced by the number of stand densities and the number of individual trees. Supposedly, the more individual trees in a stand, the greater the stand density, so that the high stand density will produce a high litter. Vice versa, a small stand density will produce less litter. This contradicitive result was probably due to litter movement from higher areas surrounding the site and gathered at the flat site at the studied plot.

A large number of trees in the slope class does not indicate a large litter thickness. Litter thickness is influenced by two factors: the movement of litter from and to another place due to surface runoff, types of plants in shedding their leaves, the rate at which the litter falls to the forest floor, and the rate of litter weathering [16, 15]. The high litter thickness in plot 15 with a flat slope is thought to be difficult to carry over by surface runoff because it is obstructed by shrubs in the slope class. According to [17], the quality
of organic matter determines the level of the litter role. Lower quality organic material will result in a longer decomposition rate, thus resulting in a thick accumulation of litter on the forest floor surface.

According to [18], Leaf Area Index is the leaf area (projected on a flat plane) for each unit of land surface area covered by a tree canopy. Based on the results of LAI calculations using the Hemiview application (Figure 1), the LAI value can be used as an indicator to show the capacity of plants when solar radiation is absorbed for photosynthesis. According to [19], the greater the LAI value will absorb more solar radiation plants use. Therefore, a vast canopy condition supports good growth because the photosynthesis process is optimal. The plant will have sufficient energy to carry out its physiological functions, which will support the tree to grow optimally [20].

![Figure 1. Canopy cover at different slope of the studied sites: (a) Flat (0-8%) on plot 15 (LAI value = 0.99), (b) Gentle (8-15%) on plot 20 (LAI value = 1.42), (c) Mild (15-25%) on plot 20 (LAI value = 1.40), (d) Steep (25-45%) on plot 20 (LAI value = 0.77), (e) Very steep on plot 21 (LAI value = 2.00).](image)

The results of S. platyclados growth measurements in various slope classes in Table 3 show that the largest mean diameter and height are found in the very steep slope class, namely 41.48 cm and 20.86 m. The very steep slope class has a reasonably high litter thickness so that the litter thickness is thought to be a factor in producing better tree diameter and height growth. The statement of [21] supports that the soil organic matter content is influenced by litter so that it can increase soil fertility which will affect plant growth.

| Slope class   | Basal Area (cm$^2$) | Average | Increment (MAI) |
|---------------|---------------------|---------|-----------------|
|               |                     | D (cm)  | TT (m)          | Diameter (cm year$^{-1}$) | Height (m year$^{-1}$) |
| Flat          | 765.76              | 31.23   | 18.61           | 1.42                      | 0.85                    |
| Sloping       | 940.29              | 34.61   | 18.84           | 1.57                      | 0.86                    |
| Mild          | 1047.85             | 36.54   | 16.72           | 1.66                      | 0.76                    |
| Steep         | 1009.64             | 35.86   | 19.78           | 1.63                      | 0.90                    |
| Very steep    | 1350.72             | 41.48   | 20.86           | 1.89                      | 0.95                    |
Denser stands will trigger competition between plants for nutrients. The absorption of nutrients by plants can be affected by spacing. According to [22], denser spacing provides more individuals in the stands, so nutrient competition between plants will be higher. Tree growth can be influenced by environmental factors such as the general characteristics of the stands, stand density, climatic factors and soil factors (physical, chemical and biological characteristics of the soil), and the applied silvicultural treatment [23].

Plant increment is the plant growth rate, both individual trees and stands per certain time unit, or the added value of plant growth dimensions such as diameter and height each year [24]. The average annual increment (MAI) of *S. platyclados* trees is presented in Table 3. The largest mean annual increments (diameter and height) in the very steep slope class are 1.89 cm year\(^{-1}\) and 0.95 m year\(^{-1}\). This is directly proportional to the average diameter and height. Based on the classification of growth velocity by [25], the growth rate of a tree species is divided into five classification classes based on stem diameter increments. The five classes are very fast (increment > 1.4 cm year\(^{-1}\)), fast (increment = 1.19-1.4 cm year\(^{-1}\)), normal (increment = 0.79-1.19 cm year\(^{-1}\)), rather slow (increment = 0.36-0.79 cm year\(^{-1}\)), and slow (increment <0.36 cm year\(^{-1}\)). Based on these references, it can be seen that the annual average diameter increment (MAI) in the very steep slope class is in the very fast category because it has an increment of more than 1.4 cm year\(^{-1}\). This is thought to be a factor of relatively moderate competition between plants so that the nutrients obtained for the trees are sufficient and the good adaptability of the tree to their environment. Competition between individuals to survive in obtaining water, nutrients, and light depends on each individual and species [26].

Tree growth is calculated as growth in the basal area (BA) [27]. BA reflects the dominance of the single stand growth in one area. The older stand will have a greater BA value. The value of BA will continue to increase with age [28]. The highest BA value presented in Table 4 is obtained in the very steep slope class, 1350.72 cm\(^2\). It could be caused by the condition of a wide canopy so that the photosynthesis process runs well. Canopy conditions greatly affect the photosynthetic ability of a tree, which also affects the growth of tree diameter and stand BA.

Figure 2 shows the boxplot of *S. platyclados* diameter distribution for various slope classes. The flat, steep, and very steep slopes have a diameter value distribution close to the normal distribution. The normal diameter distribution is characterized by a symmetrical data distribution seen from the tree diameter population in the middle value and will form a bell-shaped histogram graph. In the natural or non-even aged forest, the forest structure resembles an inverted J-shaped. In plantations or even-aged forests, the structure is a bell-shaped or normal distribution curve with the largest number of trees in the middle diameter range [29].
The distribution of normal diameter data indicates that these plants can grow well in their environment. This can be presumed due to differences in microsites due to height growth which is sensitive to differences in environmental quality [30]. Conversely, the distribution of diameter data that is not normal or more than the mean value indicates a lack of adaptation to the environment. There is competition between individual plants for survival. The studied plot was also known as a plot with mixed planting, in which *S. platyclados* planted together with others species such as *Pinus merkusii* and *S. pinanga*. There is competition between individual plants, affecting height growth at increasingly denser spacing [31]. The not-normal distribution was also suspected as the absence of silvicultural treatments such as pruning and thinning which were applied to the *S. platyclados* research plot. *Meranti* (*Shorea sp.*) is a light-demanding species when mature, thus requires light and will produce better growth if there is thinning treatment by removing adjacent trees.

Figure 2 shows the boxplot distribution of the total height of *S. platyclados* in various slope classes that represent a normal distribution. The distribution of the total normal height is indicated by a symmetrical data distribution seen from the tree diameter population, which is more spread out in the middle value. The distribution of total height in the sloping class has a total height value that is more spread out below the mean value, which means that trees with lower height are more often found in that slope class.

The significant effect of slope in affecting growth attributes of *S. platyclados* was measured to diameter, total height and LAI. The results showed that the slope factor did not significantly affect diameter but significantly affects the total tree height and LAI (Table 4).

**Table 4.** Duncan MRT results of slope effects to *S. platyclados* growth parameters.

| No. | Slope class | Diameter (cm) | Height (cm) | LAI     |
|-----|-------------|---------------|-------------|---------|
| 1   | Flat        | 31.23 ± 2.1a  | 18.61 ± 0.7ab | 1.013 ± 0.08ab |
| 2   | Gentle      | 34.61 ± 1.7a  | 18.84 ± 0.6bc | 1.240 ± 0.08b  |
| 3   | Mild        | 35.76 ± 1.6ab | 16.72 ± 0.5a  | 1.174 ± 0.08ab |
| 4   | Steep       | 35.86 ± 0.7ab | 19.78 ± 0.2bc | 0.929 ± 0.08a  |
| 5   | Very steep  | 41.48 ± 3.8b  | 20.86 ± 1.1c  | 2.005 ± 0.12c  |

Remarks: *The numbers in the same column followed by the same letter are not significantly different at the 5% test level (Duncan's multiple range test).*
This is different from the [32] study results that different slope classes will significantly affect tree diameter and height growth. It is due to the differences in tree species and tree species studied. For example, studied by [32] used Grevillea robusta, while our study used S. platyclados. Different tree types are also factors that result in differences in the slope factor of diameter and height growth [23].

Tree growth can be influenced by the adaptability of plants to environmental conditions and is related to the ability of these plants to absorb the nutrients available by these [26]. According to previous studies [33], research on one environmental factor, such as the difference in slope class, does not cause a significant difference in diameter and height growth. This is also supported by the statement of [34], which states that the slope class has no influence and a close relationship with plant height and diameter growth. All slope classes yield significantly different heights and LAI values. The very steep slope class has the largest average height, while the flat slope class has the lowest average height. The study determined that the very steep slope class supports optimal height growth. This is indicated by the high amount of litter in the very steep slope class, which helps the nutrient content in the soil and protects the soil from falling rainwater in order to reduce soil erosion. The very steep slopes also have the highest LAI values and created a shady stand. The wide canopy condition supports photosynthesis, which in turn will allow the tree to grow optimally.

4. Conclusion
The very steep slope class produces better growth than other classes with the largest average diameter and height, 41.48 cm and 20.86 m, respectively. The largest increment value for diameter and height were 1.89 cm year⁻¹ and 0.95 m year⁻¹, respectively. Slope class had a significant effect on height growth and LAI but had no significant effect on tree diameter. The environmental conditions of the Gunung Dahu Research Forest support the growth of Shorea platyclados which has an elevation in the range of 700-800 m asl. The hill meranti (S. platyclados) is a prospective plant species for rehabilitating hilly land in the highlands.

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