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# The characteristics of *Shorea macrophylla*'s habitat in Tane' Olen, Malinau District, North Kalimantan Province, Indonesia

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**Abstract.** *Fajri M, Pratiwi, Ruslim Y. 2020. The characteristics of* Shorea macrophylla*'s habitat in Tane' Olen, Malinau District, North Kalimantan Province, Indonesia. Biodiversitas 21: 3454-3462.* *Shorea macrophylla* is a tree species in Tane' Olen forest area. This study analyzed the soil's physical and chemical properties, topography, and microclimate of *S. macrophylla*'s habitat. A purposive method was used to select a sampling plot and to place the subplots. Soil was analyzed to determine the physical properties, i.e., texture, bulk density, porosity, and water content, and the chemical properties, i.e., pH, CEC, total N, organic C, C/N ratio, P, K , and Al saturation. Importance value index was determined for each tree species to know the species composition in the study site. Only the dominant species were presented. The soil at the study site had bulk density of 0.60-1.31 gram $cm^{3-1}$, porosity 50.60%-77.35%, water content 34.88%-95.37%, and soil texture sandy clay. The chemical properties of the soil were as follows: pH was 3.6-4.8, N 0.05%-0.19%, organic C 1.40%-3.65%, P 0.41-1.22 mg 100 $gr^{-1}$, K 58.68-232.55 mg 100 $gr^{-1}$, and Cation Exchange Capacity (CEC) 5.35-10.81 meg 100gr $^{-1}$. Slope ranged between 0 and 25%. The microclimate characteristics were as follows: temperature was 24-26.5°C, relative humidity 76-87%, and light intensity 145-750 Lm. Trees species with an IVI $\geq$ 10% were *S. macrophylla*, *Madhuca spectabilis*, *Myristica villosa* Warb, *Scorodocarpus borneensis*, *Eugenia* spp., *Palaquium* spp., *Macaranga triloba*, *Syzygium inophyllum* and *Shorea* sp. Positive associations were observed between *S. macropylla* and *S. borneensis*, *Eugenia* spp., *Palaquium* spp.. and *M. triloba*, and negative associations were observed between *S. macropylla* and *M. spectabilis*, *M. villosa* Warb, *S. inophyllum*, and *Shorea* sp. *S. macrophylla* grows on riversides with flat and gentle topography, acidic soil, and lower fertility but with suitable microclimate. This species can be recommended to be planted in degraded tropical forest areas but the microclimate and soil properties should be taken into account.

**Keywords:** Habitat, land characteristics, *Shorea macrophylla*

## INTRODUCTION

*Shorea macrophylla* is one of the fastest-growing climax tree species of the genera *Shorea* (Perumal et al. 2017). Local communities value this species as a source of timber and fruit (Randi et al. 2019). *S. macrophylla* is known locally in West Kalimantan as the *tengkawang tungkul* tree and has been cultivated by the Dayak and Malay communities (Fajri and Fernandes 2015). *S. macrophylla* grows in clusters in tropical rain forests with type A climate, on latosol soils at altitudes up to 500 m, on acidic soils (pH 4.6-4.9), and a cation-exchange capacity (CEC) of 16.25-19.40 (Istomo and Hidayati 2010). In Sarawak, Sabah, Brunei, and Kalimantan, this species is associated with sedimentary soils and is distributed evenly over riverbanks and areas with sloping or flat topography. It is rarely found on hills. (Randi et al. 2019; Utomo et al. 2018; Perumal et al. 2017).

The timber from *S. macrophylla* is commonly used for construction and to make veneer and plywood, musical instruments, furniture, and packing crates (Istomo and Hidayati 2010). The fruit, locally known as *tengkawang tungkul* (*Illipe*) nuts, is used as a raw material for soap and other cosmetics, a substitution for brown fat, and a source of vegetable fat (Maharani et al. 2016). The natural population of *tengkawang* is declining and is, at present, hard to find (Istomo and Hidayati 2010) because *S. macrophylla* is one of the most sought-after species in tropical forests. The exploitation of the species for its timber, combined with forest conversion to other uses, has resulted in *S. macrophylla* timber being difficult to find in the market (Rikando et al. 2019).

Tane' Olen is a forested area with a high environmental value preserved by the people of Setulang Village (Hutauruk et al. 2018a), a community that manages its forests based on the local wisdom and sustainable forest management practices (Fahrianoor et al. 2013; Kettle 2010), so the forest sustainability is maintained (Hutauruk et al. 2018). Forests are not only a place to live for them, but are also used as a source of food and medicine and economic, social, cultural, and spiritual functions (Merang et al. 2020; Matthew et al. 2018; Quedraogo et al. 2014).

*Shorea macrophylla's* habitat characteristics in secondary forest locations have been documented by Jaffar et al. (2018) and Perumal et al. (2017). Perumal et al. (2017) studied the relationship between soil fertility and the growth of *S. macrophylla* in enrichment plantings at Sampadi Forest Reserve, Lundu, Sarawak, and adjacent secondary forest. Jaffar et al. (2018) researched the effects of soil compaction and light intensity on the establishment and growth of *S. macrophylla* in riparian forests in Sungai Kayan Ulu Sungai, Serawak, Malaysia. The improvement of the company's management system, which is changing the way of harvesting using long cables during skidding activity, reduced the natural forest damage and could increase financial returns from natural forest concessions (Ruslim et al. 2016). The characteristics of *S. macrophylla* habitat in primary forest locations had not previously been studied. So, this study aimed to describe the characteristics of *S. macrophylla*'s habitat in primary forests by analyzing the physical and chemical properties of soil, the microclimate, topography, species associations, and vegetation. It is hoped that the results of this study will benefit conservation efforts of this species, especially on degraded land in the tropical rain forests of North Kalimantan, Indonesia.

## MATERIALS AND METHODS

### Study area

The study was carried out in Tane' Olen forest area, Setulang Village, Malinau District, North Kalimantan Province, Indonesia (3°25'0.86" N and 116°25'52.59" E). The location map is presented in Figure 1.

### Research procedure

A one-hectare research site was selected purposively and sampled using a square plot with a side length of 100 meters (Sari and Maharani 2016). Soil sampling was taken from purposively selected three sampling points, located on a ridge, a slope, and a valley (the ridge had the highest elevations and a 15-25% slope; the slope was located between the valley and ridge, and had an 8-15% slope; the valley was the lowest area and had a 0-8% slope) to ensure an accurate representation of the study site. At each sampling point, soil samples were taken at three depths: 0-20 cm, 20-40 cm, and 40-60 cm. Microclimate data (temperature, humidity, and light intensity) were collected at the same locations. The soil and microclimate data collection design is illustrated in Figure 2. Vegetation data were only collected for trees with a diameter at breast height (DBH) greater than 20.0 cm Each plot was divided into 25 subplots (20 m x 20 m). Within each subplot, the species were identified and DBH recorded for all trees (Widiyatno et al. 2017). Plot-making and field-data collection activities are presented in Figure 2, while sampling design is presented in Figures 3 and 4. Soil sample collection design and microclimate data are presented in Figures 3 and 4. Topography data collection design can be seen in Figure 4. The design of vegetation data collection can be seen in Figures 5.

### Data analyses

*Soil analyses*

Soil samples were analyzed for both physical and chemical properties (Kurnia et al. 2006; Eviati and Sulaeman 2009). Physical properties analyzed were texture, bulk density, porosity, and water content (using the Pipette method). Chemical properties analyzed were pH (using the electrode method), CEC (using the ammonium acetate pH 7 method), elements Al+++ and H+ (using the KCl method 1 N), total N elements (using the Kjeldahl method), organic C elements (using Walkley-Black method), C/N ratio (using arithmetic methods), elements $P_2O5$ and $K_2O$ (using Bray No I methods), and saturation Al (using arithmetic methods). Soil data analysis results from the soil laboratory were tabulated and analyzed descriptively and quantitatively.

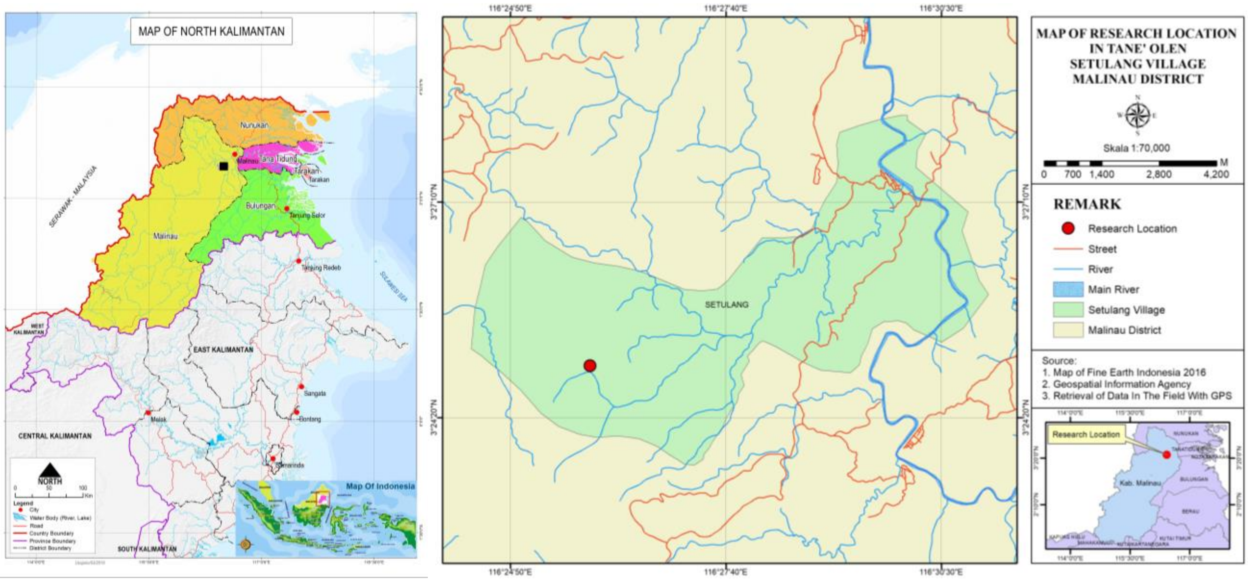

**Figure 1.** Location of the research in Tane' Olen (●), Setulang Village, Malinau District, North Kalimantan Province, Indonesia

**Figure 2**. A. Exploration, B. Research plot making, C. Soil sample collection, D. Tree inventory, E and F. Microclimate data collection

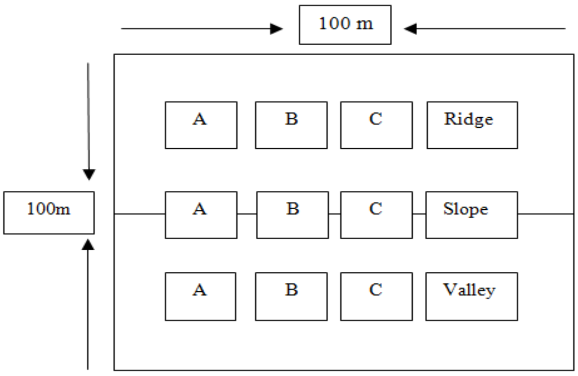

**Figure 3.** Soil and microclimate sample design. Note: A: lights intensity, B: temperature and area humidity, C: soil sampling, m: meter

*Analysis of topography*

The topographic analysis was done qualitatively to describe the topography suitable for *S. macrophylla*.

*Analysis of microclimate*

The analysis of microclimate was done qualitatively to provide information on microclimates characteristics suitable for *S. macrophylla*.

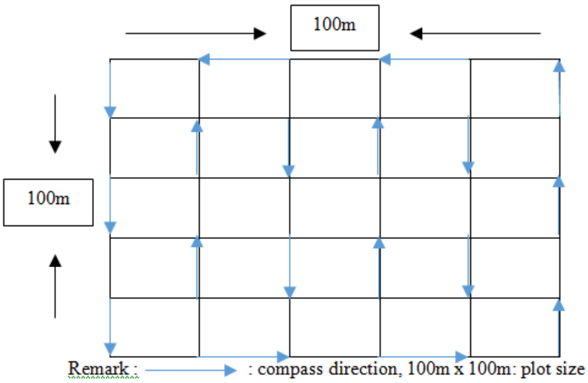

**Figure 4.** Plot design across contour line

*Importance Value Index*

According to Kacholi (2014), the Importance Value Index (IVI) is used in ecological studies to determine the ecological importance of a species in a particular ecosystem. IVI is also used to prioritize species conservation. Species with low IVI values require a higher conservation priority than those with high IVI, which is the dominant species. IVI value is a function of several characteristics, and calculated with this formula: IVI = relative density + relative frequency + relative dominance. IVI values were analyzed descriptively.

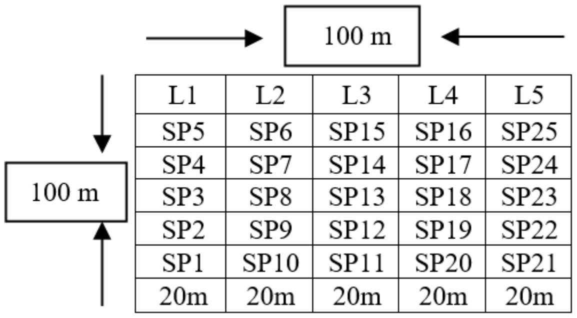

**Figure 5.** Design of plot and sub-plots for vegetation sampling. Note: L: lane, SP: subplot, 20m: distance between subplots, 100m x 100m: plot size, m: meter.

*Association of vegetation*

Associations between two tree species were analyzed using a series of 2x2 contingency tables (Mueller-Dombois and Ellenberg 1974). A more complete description is presented in Table 1.

Then, the data were tested with chi-square ($x^2$)

$$X^2 = \frac{(ad - bc)^2\ x\ N}{(a+b)(c+d)(a+c)(b+d)}$$

The association coefficient (C) values were determined as follows:

If ad $\geq$ bc, so $C = \frac{ad-bc}{(a+b)(b+d)}$

If bc > ad and d > a, so $C = \frac{ad-bc}{(a+b)(b+c)}$

If bc > ad and a > c, so $C = \frac{ad-bc}{(a+d)(c+d)}$

Positive or negative values of C indicate a positive or negative relationship between the two species. A positive relationship indicates that the association between trees is mutually beneficial to each other, while a negative value indicates that the association between trees harms one another.

**Table 1.** Contingency table form (Mueller-Dombois and Ellenberg 1974)

| **Species A**<br>**Species B** | + | - | |
|---|---|---|---|
| + | a | b | a + b |
| - | c | d | c + d |
| | a + c | b + d | N = a + b + c + d |

Note: a: number of plots containing species A and species B, b: number of plots containing only species A, but no species B, c: number of plots containing only species B, but no species A, d: number of plots containing neither species A nor species B, N: number of all plots.

## RESULTS AND DISCUSSION

### The soil's physical and chemical properties

The physical and chemical properties of soil properties in S. *macrophylla*'s habitat can be seen in Table 2. At the depth of 0-20 cm, the valley, slope, and ridge subplots had a low bulk density (0.60-1.05) (Table 2). According to Casanova et al. (2016) and Zeng et al. (2013), soil bulk density is influenced by external conditions and natural processes such as plant root growth and rainfall.

The soil porosity values in the valley, slope, and ridge subplots decreased with the increasing soil depth. The valley subplot had higher porosity value than the slope and ridge subplots. According to Darusman et al. (2019), the properties that affect soil porosity the most are bulk density and soil particle density; if the bulk density is low then the soil porosity will increase.

Water content in the ridge, slope, and valley decreased with the increasing soil depth. The water content in the ridge subplots was higher than the slope subplots because the water movement is faster in the slope subplots and the water settles in the lower area, i.e., the valley subplots, which resulted in a higher (95.37%) water content in the valley subplots than in the ridge and slope subplots. Jaffar et al. (2018) state that *S. macrophylla* plant roots can adapt to high water soil content. Moist soils stimulate *S. macrophylla* roots growth and development. According to Minasny and McBratney (2018), the availability of groundwater is an important component of water balance and the terrestrial biosphere cycle because it can affect evapotranspiration rates and support plant growth.

The results of the soil texture analysis can be seen in Table 3. The soil texture at the study site generally had a sand fraction of 45-65%, a clay fraction 35-55%, and a silt fraction 0-20% (Table 3). This means that the soil texture is sandy clay. According to Osman (2013), soil texture refers to the level of fineness or roughness created by the variously-sized soil particles.

Soil types are generally dominated by Ultisol (advanced development) soils, namely Typic Hapludults (Red-Yellow Podsolik) and Typic Paleudults (Yellow Podsolic). These soil types are typically found in lowland dipterocarp forests (Ohta and Effendi 1992).

Chemical soil characteristics of the study site are presented in Table 4. The soil at the study site was very acidic (pH = 4.1-4.8) (Table 4). According to Schroeder and Pumphrey (2013), acidic soils inhibit root and plant growth and increase Al levels in the soil. The CEC at the study site ranged from 5.3 to 10 meq/100 $g^{-1}$, indicating that the CEC was low. In general, the value of CEC is low in surface and subsurface soils of lowland dipterocarp forests (Perumal et al. 2017a).

Aluminum levels at the study site were high, especially in the slope and valley subplots, which indicated high soil toxicity. Al content in the soil decreased with the increasing organic matter because organic matter forms a strong bond with Al. According to Zaidey et al. (2010), Al is a major cause of soil acidity, and soils in lowland dipterocarp forests have high Al content.

Nitrogen levels at the study site ranged from 0.05% to 0.19% (low to very low). Sadeghi et al. (2016) also reported low total N levels in tropical rain forest soils. Nitrogen is important for plant growth (Omara et al. 2019), and N deficiency can inhibit plant growth (Mehata et al. 2019). According to Omara et al. (2019), the main sources of N are organic matter and rainfall/precipitation.

Organic C values were higher in the valley and slope subplots than in the ridge subplots. The steeper slopes in the ridge subplots are more prone to erosion, resulting in the leaching of organic C and other nutrients into the valley and slope subplots. According to Schlesinger and Bernhard (2013), carbon can be stored in the soil three times longer than in the atmosphere and is an indicator of soil microorganism abundance and diversity (Zhu and Zhu 2015). The presence of organic C in the soil spurs microorganism activity and thereby increases the rates of soil decomposition, P dissolution, N fixation, and other microorganism-dependent reactions.

Phosphate was calculated from $P_2O_5$, where the Phosphate content is very low (0.41-1.22 mg 100 gram$^{-1}$) (Table 4). According to Turner and Engelbrecht (2011), organic P plays an important role in maintaining P availability in lowland tropical rain forests. Phosphorus is essential for root development and plant growth (Abdissa et al. 2011). According to Carstensen, et al. (2018), P deficiency has a major impact on plant growth, development, and productivity.

Potassium values ranged from high (58.68-116.85 mg 100 gr$^{-1}$) in the valley and slope subplots to very high (120.34-232.55 mg 100 gr$^{-1}$) in the ridge subplots. According to Mouhamad et al. (2016), K is more abundant in the soil than other mineral elements. This element has an essential role in plant metabolism, growth, and yield. Potassium availability depends on soil properties (humidity, aeration, and temperature), soil treatment systems, and the dynamics of K. Therefore, the K exchange level varies among soils.

## Topography in the study area

According to Li and McCarty (2019), topographic features are key parameters that affect the nature of the soil at the earth's surface. Topographic features can affect organic matter; clay content; P, K, and Mg concentrations; and soil pH (Kumhalova et al. 2011).

The topography of the study site is moderately undulating with a slope of 0-25%. The subplot slopes range from flat to moderately steep. *S. macrophylla* was found primarily in flat to sloping areas with high environmental humidity, low ambient temperature, and abundant water, such as riverbanks. Jaffar et al. (2018) stated that the roots of the *S. macrophylla* are able to survive and grow in anaerobic waterlogged soils and is considered a flood-tolerant tree.

## Dominant trees at the study area

At the study site, *S. macrophylla* was the dominant tree species (Figure 5). Other tree species included *Madhuca spectabilis*, *Myristica villosa* Warb., *Scorodocarpus borneensis*, *Eugenia* spp., *Palaquium* spp., *Macaranga triloba*, *Syzygium inophyllum*, and *Shorea sp.* . *S. macrophylla* dominated the study site due to its fast germination process and high germination rate (Appanah and Turnbull 1998), its high growth rate (fastest of the genus *Shorea)*, and its status as a climax species along rivers (Perumal et al. 2017).

## Microclimate

Three microclimate factors were collected, i.e., temperature, humidity, and light intensity (see Table 6 for a more complete description). The temperature values at the study site were 24-26,5°C (Table 6). According to Ruchaemi (2013), the optimal temperature for plant assimilation is 25-30°C. Relative humidity values were high to very high, ranging from 76 to 87%. Lights intensity was very low to low, ranging from 7,25% (145 Lm) to 23.46% (469 Lm) due to dense canopy dominated by *S. macrophylla* which prevented light from reaching the forest floor. This low light intensity is consistent with the findings of Panjaitan et al. (2012), who found that the closed canopy only allowed a little sunlight to reach the forest floor. These conditions benefit *S. macrophylla* seedlings, which are sun intolerant.

**Table 2.** Physical properties of soil at the study site

| Location of soil | Depth (cm) | Bulk density (gram/cm³)* | Porosity (%)* | Water content (%) |
|---|---|---|---|---|
| Valley | 0-20 | 0.60 | 77.35 | 95.37 |
| | 20-40 | 1.13 | 57.32 | 40.04 |
| | 40-60 | 1.18 | 55.54 | 39.20 |
| Slope | 0-20 | 1.05 | 60.42 | 48.08 |
| | 20-40 | 1.31 | 50.60 | 41.42 |
| | 40-60 | 1.23 | 53.72 | 34.88 |
| Ridge | 0-20 | 0.83 | 68.75 | 61.68 |
| | 20-40 | 1.01 | 61.92 | 44.23 |
| | 40-60 | 1.20 | 54.66 | 35.53 |

Note: *Average score from three repetitions

**Table 3.** Soil texture at the study site

| Location of soil | Depth (cm) | Clay (%) | Sand (%) | Silt (%) | texture (USDA) |
|---|---|---|---|---|---|
| Valley | 0-20 | 33.70 | 50.90 | 15.40 | SCL |
| | 20-40 | 36.50 | 49.50 | 14.00 | SC |
| | 40-60 | 34.00 | 56.80 | 9.20 | SCL |
| Slope | 0-20 | 24.70 | 67.20 | 8.10 | SCL |
| | 20-40 | 27.30 | 63.10 | 9.60 | SCL |
| | 40-60 | 33.10 | 60.50 | 6.40 | SCL |
| Ridge | 0-20 | 37.80 | 54.60 | 7.60 | SC |
| | 20-40 | 37.40 | 46.40 | 16.20 | SC |
| | 40-60 | 40.70 | 48.00 | 11.30 | SC |

Note: Laboratory of soil test in B2P2EHD and Pusrehut, Mulawarman University

**Table 4.** Chemical characteristics of soil at the study site

| Location of soil | Depth (cm) | pH (1: 25) | | Cation exchange rates (meg 100gr$^{-1}$) | | | Organic content (%) | | Ratio | Mineral (Mg 100 gram$^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $H_2O$ | KCl | CEC | $Al3^+$ | $H^+$ | Tot. N. | Org C | C/N | $P_2O_5$ | $K_2O$ |
| Valley | 0-20 | 4.6 | 3.3 | 7.26 | 4.92 | 1.50 | 0.19 | 3.65 | 19 | 0.89 | 116.85 |
| | 20-40 | 4.6 | 3.4 | 7.25 | 5.56 | 1.08 | 0.12 | 2.65 | 22 | 0.73 | 73.30 |
| | 40-60 | 4.4 | 3.4 | 7.18 | 5.75 | 0.92 | 0.10 | 2.12 | 22 | 1.22 | 59.00 |
| Slope | 0-20 | 4.1 | 3.5 | 5.35 | 2.75 | 1.33 | 0.13 | 2.31 | 18 | 0.65 | 73.62 |
| | 20-40 | 4.7 | 3.5 | 5.30 | 3.50 | 0.92 | 0.07 | 1.54 | 22 | 0.65 | 58.68 |
| | 40-60 | 4.8 | 3.5 | 5.53 | 3.33 | 1.42 | 0.05 | 1.40 | 26 | 0.41 | 60.90 |
| Ridge | 0-20 | 4.4 | 3.0 | 10.81 | 7.25 | 2.75 | 0.09 | 3.46 | 39 | 2.35 | 120.34 |
| | 20-40 | 3.6 | 3.3 | 10.48 | 7.80 | 1.83 | 0.08 | 2.12 | 28 | 0.89 | 194.09 |
| | 40-60 | 4.4 | 3.4 | 10.37 | 6.83 | 2.58 | 0.09 | 1.54 | 17 | 0.65 | 232.55 |

Note: Laboratory of soil test in B2P2EHD and Pusrehut, Mulawarman University

**Table 5.** The importance value index of the dominant tree species at the study site

| Local name | Scientific Name | Family | Relative density (%) | Relative dominance (%) | Relative frequency (%) | Importance value index (%) |
|---|---|---|---|---|---|---|
| Tengkawang | *S. macropyilla* | Dipterocarpaceae | 7.69 | 15.35 | 5.0 | 28.04 |
| Kajen ase | *M. spectabilis* | Sapotaceae | 10.25 | 7.29 | 4.61 | 22.16 |
| Darah-darah | *M. villosa* | Myristicaceae | 7.45 | 4.79 | 5.0 | 17.25 |
| Bala seveny | *S. borneensis* | Olacaceae | 5.12 | 5.77 | 5.0 | 15.90 |
| Ubah | *Eugenia* spp. | Myrtaceae | 5.59 | 3.64 | 4.61 | 13.85 |
| Nyatok | *Palaquium* spp. | Sapotaceae | 4.42 | 3.70 | 4.61 | 12.74 |
| Beneva | *M. triloba* | Euphorbiaceae | 4.66 | 4.32 | 3.46 | 12.44 |
| Ehang | *S. inophyllum* | Myrtaceae | 5.36 | 3.14 | 3.84 | 12.35 |
| Kaze tenak | *Shorea* sp. | Dipterocarpaceae | 2.33 | 6.08 | 2.69 | 11.10 |

**Table 6.** Microclimate at the study site

| Location | Microclimate | Unit | Time | 1-st record | 2-nd record | 3-rd record | Average | Remark |
|---|---|---|---|---|---|---|---|---|
| 1. | Light intensity | Lm | Morning | 350 | 400 | 452 | 400.67 | Taken at 8.59 sunny conditions |
| 2. | Temperature | °c | Morning | 24 | 24.5 | 25 | 24.5 | |
| 3. | Relative humidity | % | Morning | 81 | 79 | 80 | 80 | |
| 1. | Lights intensity | Lm | Mid day | 750 | 450 | 207 | 469 | Taken at 12:02 sunny conditions |
| 2. | Temperature | °c | Mid day | 26.5 | 26 | 24.5 | 25.67 | |
| 3. | Relative humidity | % | Mid day | 76 | 79 | 81 | 78.67 | |
| 1. | Lights intensity | Lm | Afternoon | 369 | 237 | 145 | 250.33 | Taken at 16:30 sunny conditions |
| 2. | Temperature | °c | Afternoon | 25 | 24.5 | 23 | 24.17 | |
| 3. | Relative humidity | % | Afternoon | 84 | 85 | 87 | 85.33 | |

## Association with other trees

According to Saiz and Alados (2012), plant species association is a fundamental aspect of the ecology of plant communities. Analysis of plant species associations provides information on environmental heterogeneity, biotic interactions, and seed dispersal patterns. The results of the species association analysis and the association coefficient are presented in Table 7.

Table 7 shows the results of a series of 2x2 contingency tests between *S. macropylla* and each of the eight other dominant tree species. The calculated $X^2$ values were greatest between *S. macropylla* and *M. villosa* Warb, indicating that *S. macrophylla* had a strong but negative association with *M. villosa* Warb. According to Sofiah et al. (2013), species pairs do not always indicate positive relationships. Tree species with high populations are not always associated with another species. Likewise, low-population species are not necessarily negatively correlated with another species.

The association coefficient (C) was used as a parameter of the magnitude of the relationship between the eight species and *S. macropylla* and indicates positive or negative associations. Species that showed positive coefficients of association with *S. macropylla* were *S. borneensis, Eugenia* spp., *Palaquium* spp., and *M. triloba.* According to Windusari1 et al. (2011), positive associations indicate both species have the same requirement of environmental conditions; for example, wet conditions, high light intensity, or shade. *S. macropylla* showed a negative association with *M. spectabilis, M. villosa, S. inophyllum,* and *Shorea* sp. Negative associations indicate intolerance for cohabitation or the absence of a mutually beneficial relationship (Pratama et al. 2012).

**Figure 6**. A. Tree of *Shorea macrophylla* and B. Leaves of *S. macrophylla*

**Table 7.** Association of *S. macropylla* with other species.

| Species association | $X^2$ count | Assoc. species | C (+/-) |
|---|---|---|---|
| *S. macropylla* with *M. spectabilis* | 0.35 | - | 0.04 |
| *S. macropylla* with *M. villosa* | 6.82 | - | 0.29 |
| *S. macropylla* with *S. borneensis* | 0.04 | + | 0.04 |
| *S. macropylla* with *Eugenia* spp. | 0.37 | + | 0.11 |
| *S. macropylla* with *Palaquium* spp. | 0.37 | + | 0.11 |
| *S. macropylla* with *M. triloba* | 1.21 | + | 0.16 |
| *S. macropylla* with *S. inophyllum* | 3.23 | - | 0.29 |
| *S. macropylla* with *Shorea* sp. | 1.92 | - | 0.24 |

Note: $X^2$ tabulated value at 5% level: 3.841. $X^2$ tabulated value at 1% level: 6.35

## Direction of *S. macrophylla* plantation

At present, tropical forests are being degraded by anthropogenic activities such as timber extraction, agricultural cultivation, and the establishment of commercial plantations. This results in the conversion of forests into agricultural land and the fragmentation and degradation of tropical rain forests. Deforestation damages the environment by increasing light intensity and causing severe mineral soil erosion. In general, degraded forests can be divided into three categories: grasslands after burning, early-succession secondary forests, and commercially logged forests (Daisuke et al. 2013).

Planting native trees are considered to be an effective rehabilitation method for degraded tropical rain forests because native trees provide benefits such as timber, food, and medical products (Daisuke et al. 2013). According to Pratiwi et al. (2014), tropical forest rehabilitation is necessary to both meet the demand for timber and improve environmental conditions. One key to rehabilitation success is the understanding of the suitability of each growing site for each species being planted. One approach to determine the suitability of growing sites for each species is to identify each species' potential, identify locally superior species, and correlate this with species distribution data and growth requirements (Pratiwi et al. 2014).

*Shorea macrophylla* is a recommended species for replanting degraded tropical forest land, i.e., pastures after burning (Daisuke et al. 2013), early-succession secondary forests (Daisuke et al. 2013; Perumal et al. 2012), and commercially logged forests. In commercially logged forests, *S. macrophylla* can be planted using the line planting system or gap planting system. In early-succession secondary forests and pasture after burning, *S. macrophylla* requires pioneer plants to assist growth. *S. macrophylla* is a valuable tree species that have socio-economic and ecological benefits and is beneficial for reforestation and rehabilitation activities (Perumal et al. 2012; Perumal et al. 2015; Perumal et al. 2017a; Perumal et al. 2017b; Perumal et al. 2019).

This species is important for land rehabilitation activities because it plays a role in maintaining water quality, filtering out pollutants and deposits, and storing carbon (Utomo et al. 2018; You et al. 2015). Things that must be considered when planting *S. macrophylla* are the nutrient content in clay and the clay mineral composition. These two factors can be used to evaluate soil fertility. The growth of *S. macrophylla* is also significantly limited by the high light intensity in grasslands (*Imperata cylindrica*/ pastures after burning). *S. macropylla* grows well in habitats with low light intensity. In secondary forests and logged-over forests, the survival and growth of *S. macrophylla* are limited by soil compaction. This agrees with the results of this study, where fine sandy clay soils were found.

*Shorea macrophylla* grows on riversides with flat and gentle topography, acidic soil, and lower fertility, but with a suitable microclimate (temperature of 24-26,5°C, high humidity 76-87%, and a low light intensity 7,25-23.46%). This species can be recommended to be planted in degraded tropical forest areas if microclimatic factors and soil conditions are taken into account.

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