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Sustainable forest management through natural mangrove regeneration on Pannikiang Island, South Sulawesi

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Abstract. Sustainable management of mangrove forests is determined by the ability of the forest to regenerate naturally. This study aims to determine the potential of natural stands and regeneration of mangrove forests on Pannikiang Island, Barru Regency. Determination of sample plots was done by Purposive Line Sampling plot technique. All plants in the observation transect were identified and classified based on the growth phase, namely seedlings, saplings, poles, and trees. The results showed that there were 20 species, consisting of 8 true mangroves, 5 supporting mangroves, and 7 species of mangrove associations. The estimated total volume of mangrove stands in the Pannikiang island area was $23,624.71 \leq 39,679.45 \leq 55,734.19$ m^3. The potential for natural regeneration of mangrove species on Pannikiang Island is determined by the highest Importance Value Index (IVI) from seedling to tree level. Mangrove natural regeneration with the highest IVI at all tree growth rates was dominated by the species of *Brugueira gymnorhiza, Rhizophora mucronata, Sonneratia alba,* and *Rhizophora stylosa*. These species can guarantee the survival of natural regeneration for mangrove communities on Pannikiang Island, while other species require intervention through artificial regeneration.

1. Introduction

Indonesia as an archipelago with a coastline of about 81,000 km has a very large coastal resources, both natural and non-biological natural resources [1]. One potential coastal ecosystem is a mangrove forest. The total area of mangrove forests in Indonesia of around 3.5 million hectares is the largest mangrove in the world exceeding Brazil (1.3 million ha), Nigeria (1.1 million ha) and Australia (0.97 ha) [2].

Mangrove forests spread almost in all coastal sea waters of Indonesia. The largest mangroves area were found in Papua about 1,350,600 ha (38%), Kalimantan 978,200 ha (28%), Sumatra 673,300 ha (19%) [2], and Sulawesi 329,443 ha [3]. In addition to these areas, mangroves also grow and develop well on beaches that have large and protected rivers [4].

Mangrove forests physically function as preventing coastal abrasion against ocean waves, and as trapping pollutants and waste [4,5], accelerating land expansion, preventing intrusion of salt water (salt intrusion) towards the land area [6], and managing organic waste [7,8]. In addition, mangroves community also have the capacity as a potential carbon sink [9,10]. Iksan et al. [11] stated that mangrove forest ecosystems are complex and dynamic, but unstable. Mangrove ecosystem, besides being filled with mangrove vegetation [11], is also a habitat for various animals and aquatic biota

[12,13]. The type of soil underneath includes saline young soil which has a high clay content with high base saturation and cation exchange capacity [14].

The magnitude of the role of mangroves for human life and the environment is not matched by efforts to preserve the mangrove area [15]. Currently, mangrove forests that are still in good conditions only exist in Papua Island, while in Sumatra, Java, Kalimantan, and Sulawesi, most have been damaged due to conversion into various purposes, including fish ponds, settlements, agriculture and industry [16,17]. Mangrove forest ecosystems that have been damaged are usually difficult to rejuvenate and require a long time to return to their original condition [18,19]. One of the factors supporting the success of mangrove forest management can be seen from the potential of natural stands and regeneration produced in the mangrove forest area [1,20].

Pannikiang Island, Barru Regency is one of the regions in South Sulawesi that still has a natural mangrove forest area. In the context of sustainable management of mangrove forests on Pannikiang Island, this study measured the potential of natural stands and regeneration in the mangrove forest area. The data obtained is used as a reference and consideration in implementing an appropriate silvicultural system.

2. Research methods

2.1. Study sites

This research was conducted from February to May 2018, in the mangrove forest area in Pannikiang Island, Barru Regency, South Sulawesi Province (Figure 1).

Figure 1. Research location and transect line on Pannikiang Island, Barru Regency

Pannikiang Island has very high diversity of mangrove species, because almost all parts of Pannikiang Island are overgrown by mangrove vegetation. Of the total area of 97.3 Ha, there are about 91.48 ha (94%) covered by mangrove vegetation.

2.2. Research procedure
Placement of the transect line was done purposively (*Purposive Line Sampling plots*), which 3 transects placed at the location that represents the mangrove community [21]. The transect was made perpendicular to the coastline 20 m wide, and within the transect line it was divided into several sample plots with a size of 20 m × 20 m continuously, while the length of the transect was adjusted to the thickness of the mangrove.

The sample plot with an area of 20 m × 20 m (A) was used to measure mature trees (tree diameter> 20 cm). Inside the 20 m × 20 m plot, it was further divided into 20 m x 10 m (B) subplots for the Pole level (young trees 10-20 cm in diameter), 10 m × 10 m subplots for the Stake level (regeneration with height ≥ 1.5 m to D < 10 cm), and 5 m × 5 m (D) sub-plots for seedlings (seedlings ranging from sprouts to as high as <1.5 m) [19, 20]. The shape and size of the plot can be seen in figure 2.

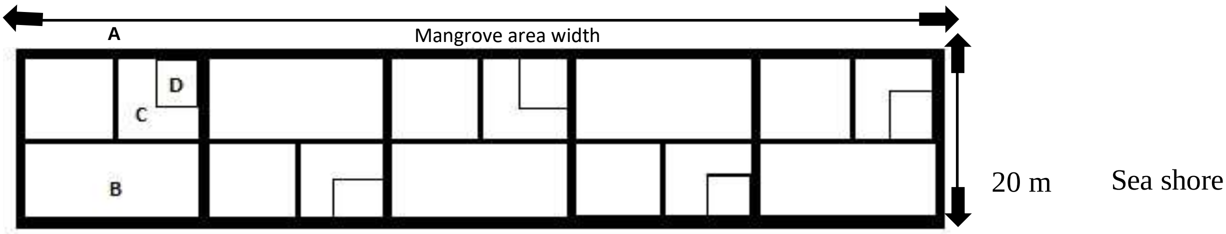

Figure 2. Sketch of research transects

Observation of mangrove plants in each sample plot was done by recording the species, the number of individuals of each species, and measuring height and diameter, while for seedlings only the number of individuals and their species was recorded.

2.3. Data analysis

2.3.1. Potential stand. The potential of mangrove stands was calculated from the volume of stands and number of trees per ha, with the following procedure: Area of Tree Base Area ($BA=m^2$) is calculated by the formula $BA = \frac{1}{4} \pi D^2$ and the volume of trees with the formula $V = \frac{1}{4} \pi D^2 T F$ ……………(1), where: π = constant (3.14); D = Diameter of Breast Height or 20 cm above buttresses (m); V = tree volume (m^3); T = tree height (m) and F = Tree shapes value (0.7).

Timber potential from all plots was calculated using the formula for estimating stand volume as follows:
Estimated total volume of timber

$$\overline{V} - t.S\overline{V} \leq \frac{\overline{V}}{pu} \leq \overline{v} + t.S\overline{V}$$ ……………………………………...(2)

2.3.2. Potential natural regeneration. The dominant potential of mangrove regeneration was assessed from the calculation of the Importance Value Index (IVI). IVI is a quantitative parameter that can be used to express the level of dominance (level of stand closure) of dominant species (the dominant one) in a plant community

For the stage of Saplings, pole and tree level, the formula is used IVI = RD + RF + RD, while for the seedling level the formula IVI = RD + RF [21] is used………………………………………….(3).
where: IVI = important value index (%)

RD = Relative Density (%)
RF = Relative Frequency (%)
RD = Relative Dominance (%)

3. Results and discussion

3.1. Results

3.1.1. Composition of mangrove plants. From the identification of mangrove species, as many as 20 species of mangrove plants were found, consisting of 8 true mangroves, 5 supporting mangroves, and 7 species of mangrove plant associations. The distribution of growth of each mangrove species in the three transects can be seen in table 1.

Table 1. The composition of mangrove plant species on Pannikiang Island, Barru Regency

Species	Transect I	Transect II	Transect III
True Mangroves:			
Sonneratia alba	v	v	v
Lumnitzera racemosa	v	_	_
Bruguiera gymnorhiza	v	v	v
Rhizophora mucronata	v	v	v
Rhizophora stylosa	v	v	v
Rhizophora appiculata	_	v	v
Ceriops tagal	_	_	v
Avicenia alba	_	_	v
Supporting Mangroves:			
Xylocarpus moluccensis	v	v	_
Aegiceras floridium	_	v	_
Osbornia octodonta	v	_	_
Heriteria littoralis	_	_	v
Excoecoria agallocha	v	v	v
Mangrove Associations:			
Leucaena leucocephala	v	v	v
Pongamia pinnata	v	_	v
Microcos crassifolia	_	v	v
Thespesia populnea	_	v	v
Derris trifolia	_	v	v
Terminalia catappa	_	_	v
Unknown species	v	_	_

Note: v = found, - = not found

The composition of mangrove plant species based on Basal Area (BA) calculations illustrates different variations for each species. Basal Area describes the percentage of the level of control of a species over the habitat where it grows. From the results of the study it is found that there are certain species that dominate the area of growth.

Mangrove species that had the highest BA in transect I were *Rhizophora mucronata* at 27.4% for all growth rates (trees, poles, saplings and seedlings) and *Bruguiera gymnorhiza* by 18.2%, and the lowest was *Sonneratia alba* 6.3%. In addition, mangrove association species in general have a low level of dominance ranging from 0.4% - 1.7%. In transect II, it was dominated by *Rhizophora mucronata* species with 54% followed by *Sonneratia alba* 22.3%, while supporting species only ranged from 0.03% - 0.6%. In transect III, it was controlled by *Sonneratia alba* by 52.9%, followed by *Rhizophora mucronata* and *Bruguiera gymnorhiza* respectively 16% and 12.2%, while mangrove associations ranged from 0.01% - 0.84%.

3.1.2. Population structure. The population structure of vegetation for all species in the mangrove forest area on Pannikiang Island is in accordance with figure 3, showing that the number of seedlings is far greater than the number of saplings, poles, and trees.

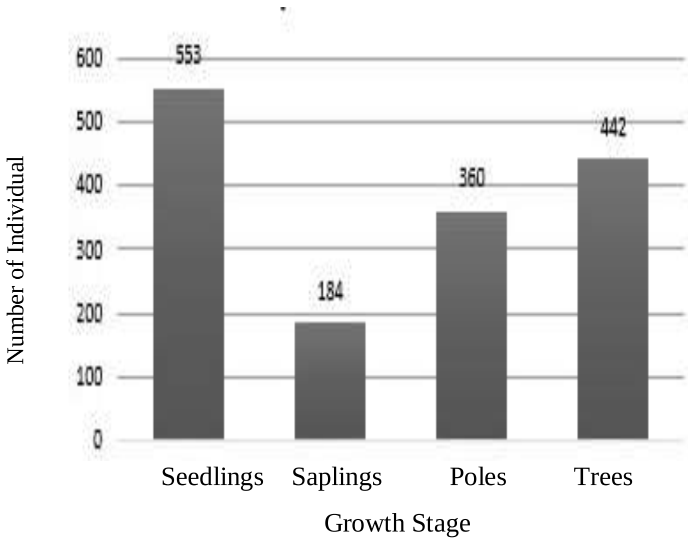

Figure 3. Structure of mangrove flora based on the stage of growth

As depicted in Figure 3 that at the seedling stage has more individuals than the other stages, indicating that regeneration can naturally take place on an ongoing basis. The number of pole and tree levels which are quite numerous can also be functioned as a natural source of seeds.

Of the 20 species of mangrove plants obtained, there are several species of mangroves that have an important role in the community and are part of a true mangrove group, namely: *Sonneratia alba, Brugueira gymnorhiza, Rhizophora mucronata, and Rhizophora stylosa*.

3.1.3. Potential of mangrove stand. To find out the potential of mangrove stands, it can be seen from two aspects, namely aspects of ecological and economic potential. Based on the calculation of stand volume (m^3), the average wood volume range of all species per plot was 17.34 m^3 and volume per hectare was 433.50 m^3 (table 2).

While the estimated total volume of stands in mangrove forests on Pannikiang Island, Barru Regency based on equation 2 amounted to $23,624.71 \leq 39,679.45 \leq 55,734.19$ m^3.

3.1.4. Natural regeneration. The potential of mangrove natural regeneration on Pannikiang Island is determined from the Important Value Index (IVI) based on equation3. The diagram of density, frequency, and dominance of all mangrove species for each growth phase are shown in Figures 4, 5, and 6.

Table 2. Tree volume of mangrove community in Pannikiang Island.

Species	Number of trees	Ṽ (m^3)	Ṽ/ha (m^3/ha)
Sonneratia alba	88	7.48	187.00
Lumnitzera racemosa	4	0.13	3.25
Bruguiera gymnorhiza	52	1.57	39.25
Rhizophora mucronata	165	2.77	69.25
Rhizophora stylosa	65	0.73	18.25
Rhizophora appiculata	17	0.30	7.50
Xylocarpus moluccensis	11	3.19	79.75
Osbornia octodonta	11	0.56	14.00
Heriteria littoralis	1	0.01	0.25
Excoecoria agallocha	15	0.33	8.25
Leucaena leucocephala	4	0.14	3.50
Microcos crassifolia	4	0.05	1.25
Thespesia populnea	4	0.05	1.25
Type X	1	0.03	0.75
All Species	442	17.34	433.50

Note, Ṽ = Average tree volume / plot, V / ha = Average volume per hectare (m^3/ha).

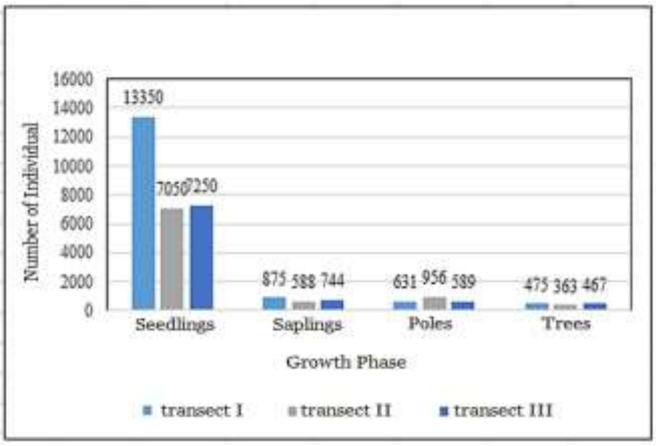

Figure 4. Diagram of species density at each growth phase

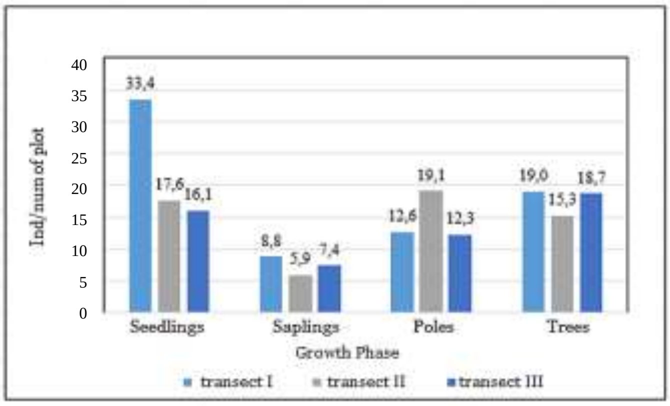

Figure 5. Diagram of species frequency at each growth phase

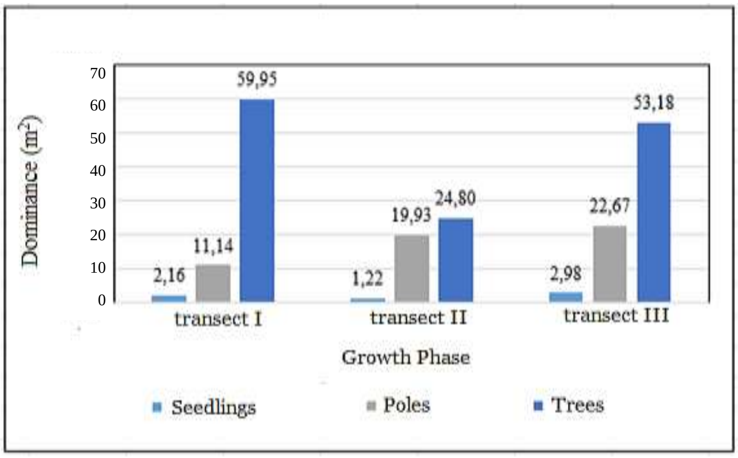

Figure 6. Diagram of species dominance at each growth phase

IVI values for each tree growth level are detailed as follows:

***Seedlings Stage*:**
The natural regeneration rate for the seedling phase is in accordance with the INP calculation presented in Figure 7.

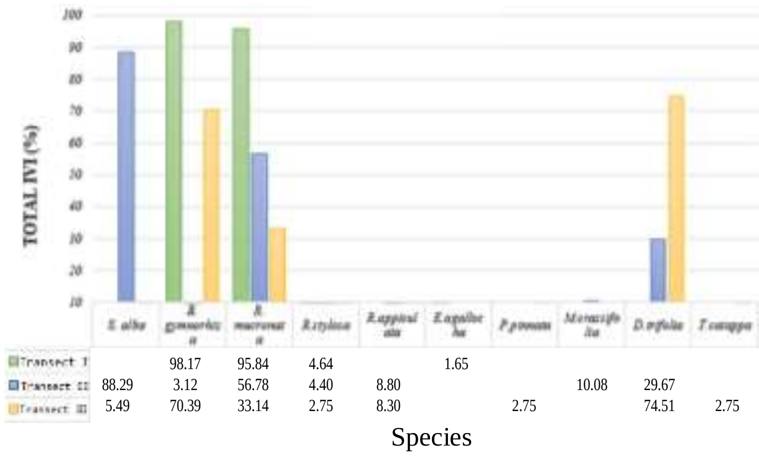

Figure 7. Diagram IVI for seedling level

Mangrove species at seedling stage were found as many as 10 species of mangroves, with a total of 553 individuals in the three research transects. If this value is converted to the per hectare area, the *Sonneratia alba* species has a density of 1,100 individuals/ha, *Brugueira gymnorizha* 3,067 individuals / ha, and *Rhizophora mucronata* 3200 individuals/ha.

In accordance with Decree of the Director General of Forestry No. 60 Kpts/DJ/I/1978 regarding mangrove forest management, it is stated that mangrove communities have normal natural regeneration if they have 1000 individual seedlings/ha.

Saplings Stage:
Mangrove species at the sapling level, found 13 mangrove species, with 184 individuals, the number of individuals at the sapling level is smaller than the number of individuals at the seedling level.

The results of the analysis of the relative density of mangroves at the sapling level showed that the highest relative density was the species of *Brugueira gymnorizha* and *Rhizophora mucronata*. While the lowest relative frequency is *Avicenia alba* type.

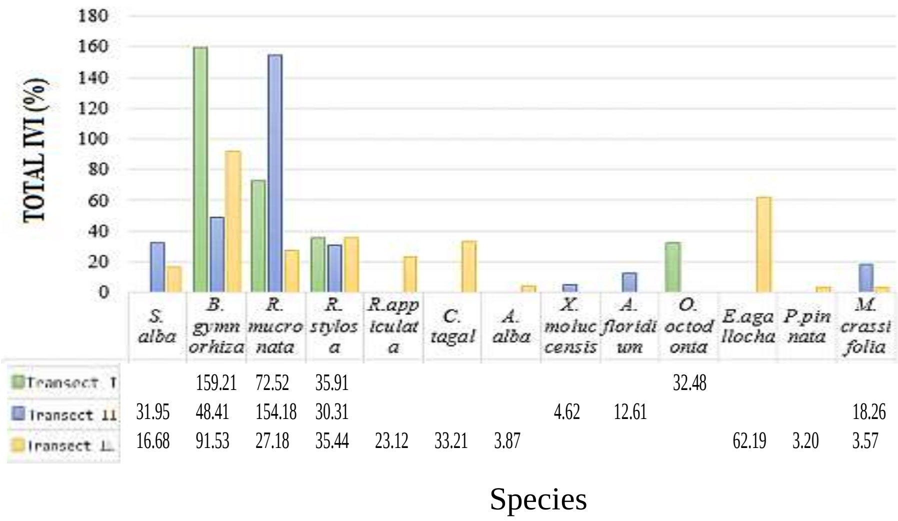

Figure 8. Diagram of Saplings IVI level

Pole Stage:

The natural regeneration rate for the pole phase shows the highest IVI for the species *Rhizophora stylosa*, *Rhizophora mucronata*, *Brugueira gymnorhiza* (Figure 9).

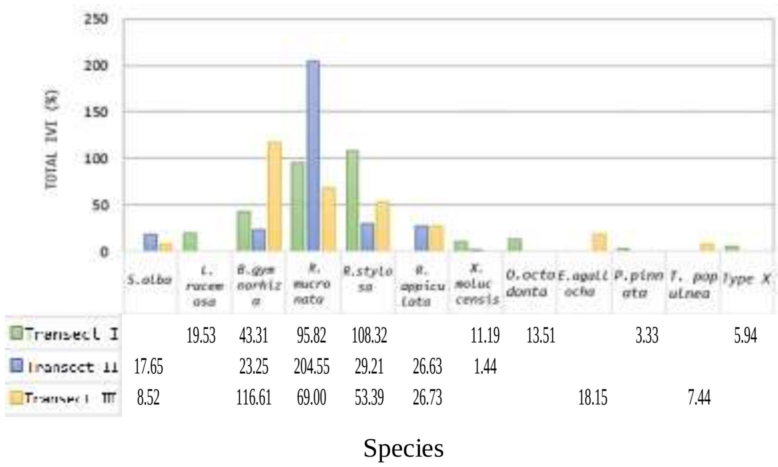

Figure 9. IVI diagram at Pole level

Mangrove species at the pole level, found 12 mangrove species, with a total of 360 individuals. The highest relative density of mangroves at pole level was obtained in species of *Rhizophora mucronata*, *Brugueira gymnorizha*, and *Rhizophora stylosa*.

Tree Stage:

Mangrove species at the tree stages, found as many as 14 mangrove species, with a total of 442 individuals, the number of individuals at the tree stage is greater than the number of individuals at the pole and sapling level. The highest relative densities are *Rhizophora mucronata*, *Sonneratia alba*, *Rhizophora stylosa*, and *Brugueira gymnorizha* (Figure 10).

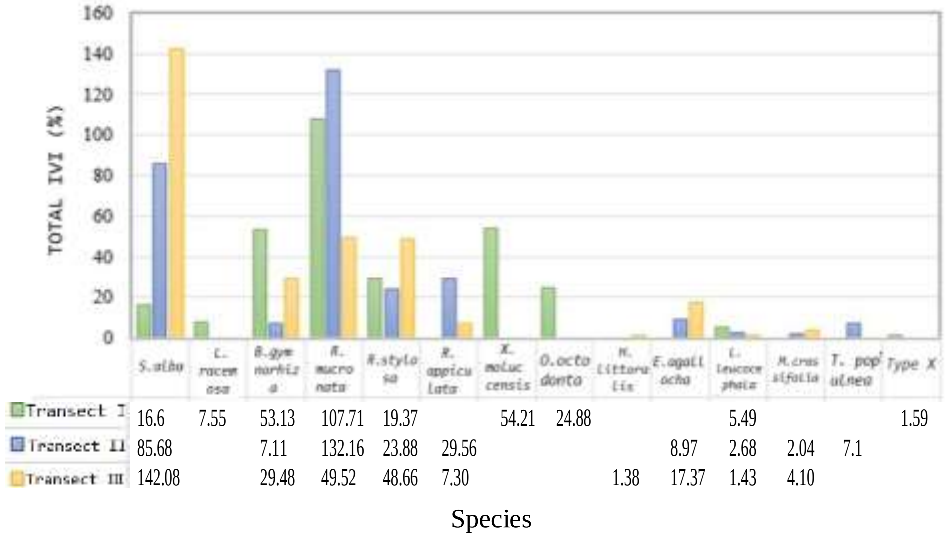

Figure 10. Diagram IVI of tree level

3.2. Discussion

3.2.1. Mangrove stand structure. Forest structure can change from time to time according to the environmental conditions in which it grows [22,25]. The quality of the habitat to grow itself is influenced by three things, namely soil fertility, climate, and biotic factors [26].

The spread of mangrove growth is influenced by the level of adaptation of each species to the environment in which it grows, including: sea tides, soil types, soil salinity, water salinity, and light [7,27,28]. Some mangrove species that can make natural regeneration successfully such as *Rhizophora* sp because it has long supporting roots and propagules, and some others must be intervened through artificial regeneration. Some intolerant species such as the genus Rhizophora, Avicennia and Sonneratia can grow well in open areas [8].

3.2.2. Population structure. In addition to the parent tree factors that determine the success of natural regeneration, the environmental factors in which they grow also have a major influence on the growth of mangrove seedlings. *Avicenia* sp and *Sonneratia* sp usually grow well in sandy soil conditions more than mud and are always inundated with sea water, whereas for *Rhizophora* sp and *Ceriops tagal* grow well in muddy soil conditions and frequency of inundation is lower [7,17]. Species of true mangrove flora play an important role in forming pure stands in the mangrove forest habitat [25].

From the research results it is known that *Brugueira gymnorhiza* and *Rhizophora mucronata* species have a good development, because the structure resembles J inverse with the number of individuals in the seedling phase is quite abundant. Both of these species can maintain the continuity of regeneration well, compared with some other true mangrove species whose development is difficult to predict because it has little rejuvenation at the level of seedlings and saplings [29].

3.2.3. Natural regeneration. The results of observations for the potential natural mangrove regeneration on Pannikiang Island found that the presence of mangroves on Pannikiang Island has an ecological role to maintain the existence of the surrounding environment.

The frequency distribution value of mangrove species is one of the parameters that can show the distribution pattern of plant species in the ecosystem [30,31]. The high value of the frequency of mangrove seedlings provides a guarantee of the continuity of mangrove forest regeneration in the future on the island of Pannikiang.

Basal area values for certain species in growing habitats are used to determine the level of control of dominant species [32]. If dominance is more concentrated in one particular species at a certain level of growth then the dominance index value will provide information about the level of control of the species over the habitat where it grows [15,18,19].

4. Conclusions

a) The number of mangrove species found on Pannikiang Island is 20 species, consisting of 8 true mangroves, 5 supporting mangroves, and 7 species of mangrove associations.
b) The estimated total stand volume per plot is 17.34 m^3 / 0.04 ha or 433.50 m^3 / ha, and the estimated total stand volume in mangrove forests on Pannikiang Island is around 23,624.71 ≤ 39,679.45 ≤ 55,734,19 m^3.
c) The potential for mangrove natural regeneration on Pannikiang Island is dominated by *Brugueira gymnorhiza, Rhizophora mucronata, Sonneratia alba, and Rhizophora stylosa*. These species can guarantee the survival of natural regeneration for mangrove communities on Pannikiang Island, while other species require intervention through artificial regeneration.

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