Mangrove Growth After Five Years of Restoration on Former Fish Pond Land with Planting and Enrichment Patterns in Berbak-Sembilang National Park

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Abstract. One of the biggest mangrove regions on the South Sumatra coast is Berbak-Sembilang National Park. Fish ponds have replaced the mangroves in this location. The purpose of this study is to compare the growth of mangroves following restoration with novel planting and enrichment strategies. Both total height and canopy height were measured, and the results were subsequently subjected to descriptive analysis. With an average of 137 individuals/ha, *Rhizophora mucronata* had the best species density under the new planting pattern, according to the results. With an average of 39 individuals/ha, *Ceriops decandra* exhibited the highest species density in the enrichment pattern. The *Rhizophora* genus performed better in the new planting location, whereas the *Ceriops* genus grew better in the enrichment area, according to total height and canopy height. Growth improved when the new planting pattern was restored, and species diversity increased when the enrichment planting design was used.

Keywords: Berbak-Sembilang national park, mangrove restoration, mangrove density and growth, planting and enrichment pattern, rhizophora mucronata

1 Introduction

Mangroves provide ecosystem services that have been declining extensively in tropical regions. For coastal communities in particular, mangrove ecosystems play a highly strategic role,

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ecologically, socially, and economically [1] [2]. With increasing human activity in coastal areas and rising demand for land, the existence and function of mangrove ecosystems are increasingly threatened. Currently, mangrove forests along Indonesia's coast have suffered serious damage due to human activities, particularly fish and shrimp farming. To mitigate mangrove loss, rehabilitation has become a top priority on the conservation agenda [3].

One of the biggest mangrove ecosystems in Western Indonesia is located in South Sumatra's Berbak-Sembilang National Park (TNBS). Numerous human activities have caused the mangrove environment in this area to deteriorate [4]. Aquaculture ponds have been created from mangrove forests [5]. The South Sumatra Nature Conservation National Park (TNBS) has been restoring mangroves on old fish farms in the Barong River since 2014, working with Sriwijaya University and JICA-RECA (Japan). Four models are used to carry out the restoration: enrichment planting, new planting, aided natural regeneration, and natural regeneration.

The adequacy of environmental circumstances and each mangrove species' tolerance limitations determines the success of mangrove rehabilitation [6]. Mangrove regeneration in former aquaculture ponds may be impacted by a number of interconnected factors [7]. Many experts have spent the last few decades studying mangrove growth through the use of novel planting techniques [8] [3]. [9] However, research on mangrove growth and survival in enrichment planting regions is still comparatively rare [10]. Comparing mangrove growth following restoration with new planting patterns and enrichment is the goal of this study.

2 Methods

2.1 Research location and sampling

This study was performed at Berbak-Sembilang National Park, located along the shore of Banyuasin Regency, South Sumatra Province (**Figure 1**). The area is 202,896.31 hectares, as per the Minister of Forestry Decree No. 95/Kpts-II/2003, dated March 19, 2003. Dense mangrove cover encompasses roughly 44,206.53 ha, moderate mangrove cover spans 28,545.16 ha, and sparse mangrove cover extends over 10,695.10 ha [11]. Data collection occurred at five stations: stations 1, 2, and 3 representing the new planting pattern **(Figure 2A**), and stations 4 and 5 representing the enrichment planting pattern (**Figure 2B**). Data measured included total height, and canopy height (**Figure 3**).

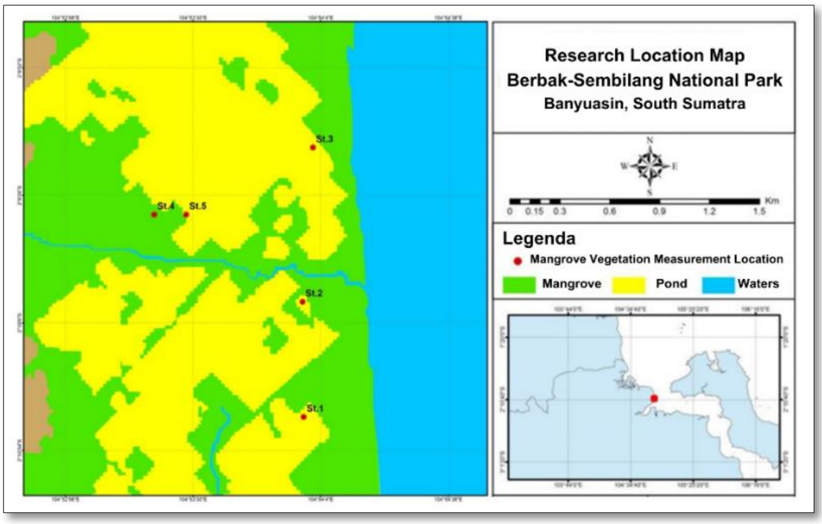

Fig. 1. Berbak-Sembilang national park mangrove restoration site.

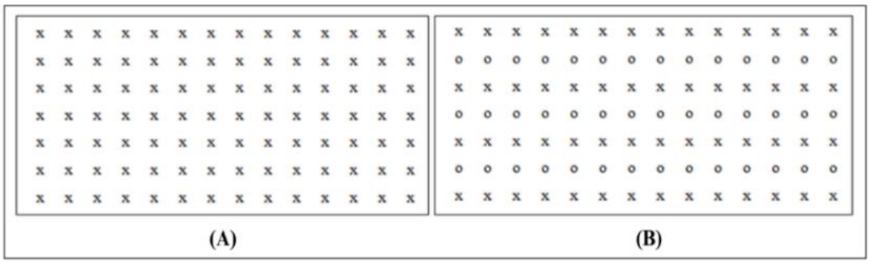

Fig. 2. Illustration of mangrove restoration (A) new planting pattern (x): mangroves planted; (b) enrichment planting pattern (x): mangroves planted (o): mangroves growing naturally.

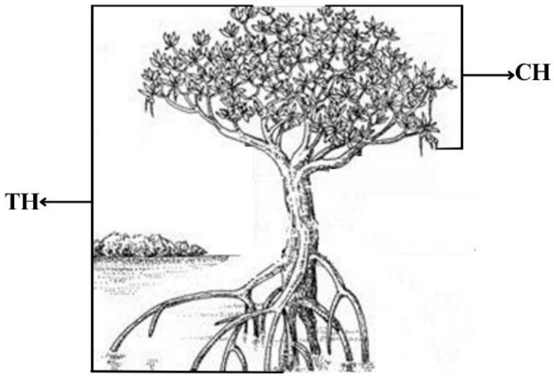

Fig. 3. Illustration of mangrove growth measurement (TH : Total Height; CH : Canopy Height)

3 Result and discussion

3.1 Mangrove composition

In general, ten mangrove species were found. The mangrove species found at the planting pattern stations and enrichment pattern stations are shown in **Table 1**. The planting pattern focuses more on rehabilitation or reforestation, prioritizing species with high growth rates and high survival rates. On the other hand, the enrichment pattern focuses more on increasing mangrove species diversity. At the enrichment site, the native species were *Avicennia marina* and *Avicennia alba* then enriched with the species in **Table 1**.

Table 1. Mangrove species found in new planting patterns and enrichment planting.

No	Mangrove species	Restoration Pattern	
		New planting	Enrichment planting
1.	*Avicennia corniculatum*	-	+
2.	*Bruguiera cylindrica*	-	+
3.	*Bruguiera gymnorrhiza*	+	-
4.	*Bruguiera sexangula*	-	+
5.	*Ceriops decandra*	+	+
6.	*Ceriops tagal*	+	+
7.	*Kandelia candel*	+	-
8.	*Rhizophora apiculata*	+	+
9.	*Rhizophora mucronata*	+	+
10.	*Xylocarpus granatum*	-	+

Noted: + : found, - : not found

This new planting pattern is used for the rehabilitation and reforestation of degraded areas by selecting fast-growing mangrove species with high survival rates. In contrast, the enrichment pattern focuses on increasing mangrove biodiversity. In the enrichment area, *Avicennia marina* and *Avicennia alba* are the dominant natural species, which are then enriched with other species (Table 1). Four mangrove species *Ceriops decandra, Ceriops tagal, Rhizophora apiculata,* and *Rhizophora mucronata* are planted in both patterns, all from the Rhizophoraceae family, which have important ecological benefits [5], Generally used as a material in regional scale river basin (DAS) rehabilitation efforts [12].

3.2 Post-restoration mangrove density between planting and enrichment patterns

In general, the mangrove individuals found at the planting pattern stations were dominated by the *Rhizophora mucronata* species (**Table 2** and **Figure 4**). Station I had a total species density of 192 (ind/ha), station II had a total value of 404 (ind/ha), and station III had a total species density of 93 (ind/ha). The average species density of individual mangroves by planting pattern is presented in **Figure 4**.

The restoration region, including the new planting pattern (stations 1, 2, and 3) is situated in the central zone, whilst the enrichment pattern is positioned in the sea zone (stations 4 and 5). *Rhizophora mucronata* is a mangrove species that thrives in intertidal and muddy zones. [13] that exhibits superior growth in the midward zone relative to the seaward zone. This midward restoration zone has moderate salt levels and a moderate frequency of flooding. Prior research has demonstrated that *Rhizophora mucronata* exhibits a strong capacity for adaptation to inundation and mild salinity conditions [14].

Table 2. Average density based on the new planting pattern.

Stations	Mangrove species	Mangrove density (ind/ha)
1	*Rhizophora apiculata*	21
	Rhizophora mucronata	171
	Total	192
2	*Rhizophora apiculata*	173
	Rhizophora mucronata	196
	Bruguiera gymnorrhiza	12
	Ceriops decandra	17
	Ceriops tagal	5
	Kandelia candel	1
	Total	404
3	*Rhizophora apiculata*	50
	Rhizophora mucronata	43
	Total	93

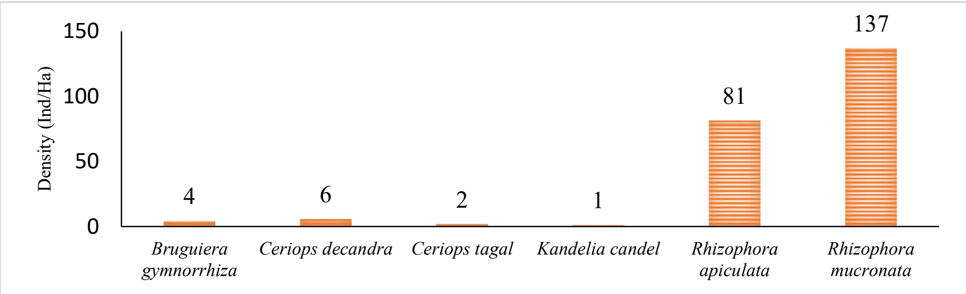

Fig. 4. Average density of each species

In Indonesia, *Rhizophora mucronata* is one of the main mangrove species recommended for the restoration of degraded mangrove areas [8]. [9] showed that *Rhizophora mucronata* has a high level of adaptation and survival on highly eroded coastlines within the mangrove restoration area. This species is also widespread, easy to grow, and produces abundant seeds [15]. These conditions make *Rhizophora mucronata* an important plant in coastal rehabilitation.

In general, mangrove individuals at the enrichment pattern stations were dominated by *Ceriops decandra.* Station II had a higher species density than Station V, at 199 individuals/ha. Station IV had a lower species density, at 70 individuals/ha. *Ceriops decandra* exhibited very high densities within the enrichment planting zone (Table 3 and Figure 5). As one of five recognized species within the genus Ceriops (*Ceriops decandra, Ceriops tagal, Ceriops australis, Ceriops* *decandra*, and *Ceriops zippeliana*), this species is commonly found throughout tropical and subtropical coastal habitats. Interestingly, *Ceriops decandra* exhibited a higher survival rate in the enrichment pattern compared to other species. Typically, *Ceriops decandra* is considered an inner mangrove species with a relatively limited distribution and is often found growing in the intertidal zone with other members of the *Rhizophoraceae* family [16].

Table 3. Average density based on the enrichment planting pattern.

Stations	Mangrove species	Mangrove density (ind/ha)
4	*Bruguiera sexangula*	15
	Ceriops decandra	37
	Rhizophora mucronata	18
	Total	70
5	*Avicennia corniculatum*	4
	Bruguiera cylindrica	22
	Bruguiera sexangula	10
	Ceriops decandra	42
	Ceriops tagal	34
	Rhizophora apiculata	44
	Rhizophora mucronata	35
	Xylocarpus granatum	8
	Total	199

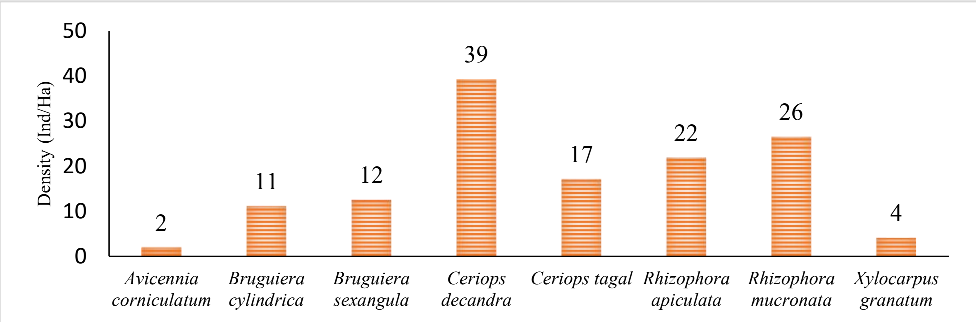

Fig. 5. Average density of each species

A significant distinction between the enrichment pattern regions (stations 4 and 5) and the new planting pattern areas (stations 1, 2, and 3) is the existence of canopy cover. Enrichment zones were characterized by the presence of natural mangrove species, including *Avicennia marina* and *Avicennia alba*, while the planting pattern sites were predominantly exposed and devoid of canopy cover. According to [17] canopy gaps substantially affect the dynamics of mangrove ecosystems by modifying stand structure and species mix. The optimal shade level during the first growth (nurse) period is deemed a crucial element in mangrove regeneration and horticulture initiatives [13]. Canopy gaps that create suitable regeneration circumstances can significantly contribute to the recruitment and enhancement of the existing mangrove community [17] [18].

In contrast to the new planting pattern regions, Ceriops decandra exhibited superior development alongside the indigenous mangrove species Avicennia marina and *Avicennia alba* in the enrichment pattern zones (stations 4 and 5), relative to other *Rhizophoraceae* species. [19] articulated that several coexisting species within the same family frequently demonstrate divergent establishing methods, which subsequently influence their local and worldwide ranges, along with species-specific dynamics within mangrove ecosystems. According to [20] Ceriops species commence root development more swiftly than *Rhizophora* during the initial establishment phase in Kenyan mangrove forests, however *Rhizophora* generally exhibits more rapid root growth in later stages. [21] Furthermore, it was underscored that root formation in mangroves is significantly affected by light conditions during the establishing period.

3.3 Post-restoration mangrove growth between planting and enrichment patterns

Comparison of mangrove growth in terms of total height and canopy height (*Ceriops decandra, Ceriops tagal, Rhizophora apiculata,* and *Rhizophora mucronata*, found in both planting pattern locations) is shown in **Figures 6 and 7**. In terms of total height and canopy height, rhe Ceriops genus exhibited superior performance in the enrichment site, whereas the *Rhizophora* genus thrived more effectively in the new planting site.

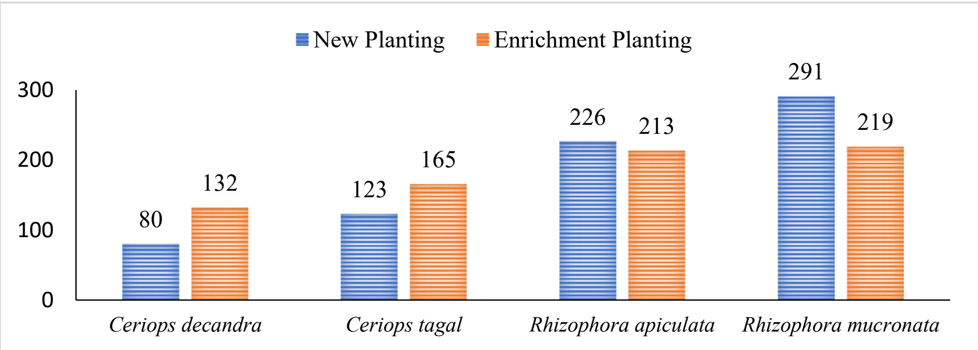

Fig. 6. Total height comparison

Each mangrove species possesses specific tolerance limits to various environmental factors, and the interaction of these factors collectively influences their actual growth in both natural habitats and restored areas [22]. Successful mangrove establishment necessitates that seedlings are adequately suited to the environmental conditions of the planting location. Our findings suggest that mangrove species adapted to regions with dynamic water circulation demonstrate enhanced growth performance. These results align with [19] *Ceriops* propagules are more susceptible to dehydration and necessitate swifter establishment compared to *Rhizophora* propagules, rendering them less appropriate for extended dissemination.

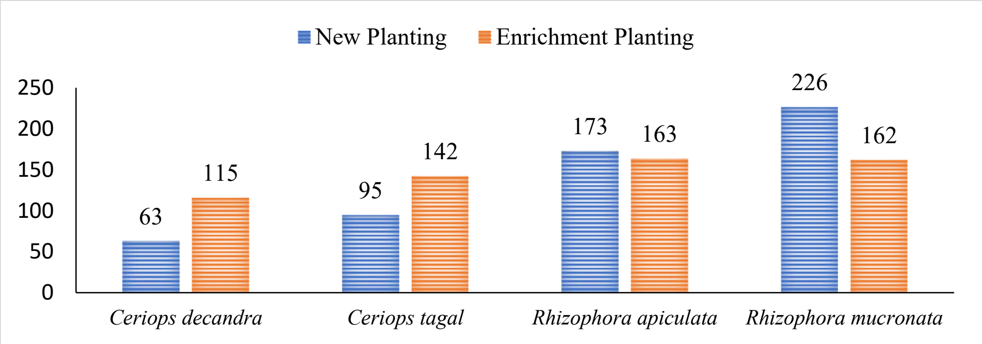

Fig. 7. Canopy height comparison

Additional investigations have demonstrated that *Rhizophora* can exhibit substantial yearly growth during rehabilitation efforts. Two-year-old *Rhizophora* species. attained a height of 92.22 cm for infants, 146.01 cm for three-year-olds, 239.35 cm for four-year-olds, and 255.53 cm for five-year-olds [23]. Mangrove rehabilitation in Vietnam also reported that *Rhizophora apiculata* planted and aged 3 years can reach a height of 187.7 cm [24].

Figure 6 and 7 also suggests that mangroves in newly planted, open areas where there is minimal competition tended to exhibit better growth compared to those in enrichment zones. The rapid growth traits of certain mangrove species enable them to quickly establish themselves in open environments and potentially coexist with native mangrove species over the long term [10]. In contrast, growth in enrichment areas is more constrained, primarily due to competition with existing native mangrove vegetation. These results emphasize the importance of selecting mangrove species and planting patterns to suit the environmental conditions in the rehabilitation area. Enrichment planting patterns can support the growth of certain species, such as *Ceriops*, which are shade-tolerant and exhibit relatively high canopy cover. However, it's important to emphasize that new planting locations provide better opportunities for fast-growing, light-demanding species, such as *Rhizophora*. Mangrove rehabilitation takes into account not only the adaptability and growth performance of each species, but also ecological interactions such as competition and light availability [25]. The availability of light is very important to support the increase in stem height, base area, and leaf area [10]. Therefore, integration between ecological suitability assessment and planting pattern design is very important to increase the success and sustainability of mangrove restoration activities.

4 Conclusion

Rhizophora mucronata exhibited the highest species density in the novel planting configuration, averaging 137 individuals per hectare. Ceriops decandra exhibited the highest species density in the enrichment plan, averaging 39 individuals per hectare. Regarding total height and canopy height, the Ceriops genus exhibited superior growth in the enrichment location, but the *Rhizophora* genus thrived more effectively in the new planting site. The restoration employing the new planting pattern yielded enhanced growth, whilst the enriched planting design produced greater species diversity. *Rhizophora mucronata* had the highest density and optimal growth among all species.

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