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Floristic Diversity of Mangrove Restoration Area: A Case Study in Pasar Rawa, North Sumatra

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ABSTRACT

Mangrove forests are important ecosystems. However, land conversion and degradation have destroyed a significant area of mangrove. Mangrove restoration employing native species has been performed in several degraded areas, including some North Sumatra regions. However, information regarding floristic diversity in monoculture restoration areas is still limited. This research aims to analyze the floristic diversity in the mangrove restoration area, which is dominated by *Soneratia alba* species in Pasar Rawa Village, North Sumatra. The plotted path approach was employed for vegetation analysis in a 3-ha area in Pasar Rawa. The findings revealed that 8 (eight) species were found in the *S. alba* restoration area. The highest Important Value Index (IVI) in the seedling stage was found in *Acanthus ilicifolius*, while at the sapling and tree stages, *S. alba* was the highest. The highest diversity index was obtained at the sapling stage, which was 1.46 (medium), and the lowest was obtained at the tree stages, which were 0.26 (low). The result showed a new recruitment of seedlings in the research location, although the species diversity value is still lower. The appearance of new species, particularly pioneer species, in the research area indicates that natural succession processes are currently taking place.

1. Introduction

Mangrove forests are distinctive and crucial wetland ecosystems on the coast due to being situated in the zone of transition between the sea and the land. This intertidal forest is known to be very productive and has a unique diversity of aquatic and terrestrial biodiversity (Ledheng et al. 2022; Malik et al. 2015). Mangrove forests support millions of people worldwide and contribute significantly to their well-being and survival by preventing coastal erosion and natural disasters such as tsunamis, providing food, construction supplies, firewood, and improving water quality by filtering waterborne pollutants (Huxham et al. 2017; Zu Ermgassen et al. 2021). Mangroves, also known as blue carbon, are more efficient than other ecosystems at absorbing organic carbon (Bryan-Brown et al. 2020; Lovelock and Duarte 2019). As a result, mangrove areas are prioritized in climate change and mitigation efforts (Duncan et al. 2016; Locatelli et al. 2014).

Despite their complex ecological services, mangroves are not defenseless to the decreased land area that results from various causes. Globally, mangrove forests have decreased from around 225,000 km^2 to around 137,000 km^2 from the 1970s to 2014 (Friess et al. 2019). Large-scale deforestation and land conversion have also occurred in mangrove forests, especially in Southeast Asia (Hamilton and Casey 2016; Richard and Friess 2016), where logging and land conversion for ponds are the most significant threats (Rahman et al. 2013). The reduction in mangrove areas has had an adverse effect on coastal communities' livelihoods. It has resulted in a decrease in coastal protection, which has led to the loss of life, property, and infrastructure due to extreme events, increased social conflict, increased greenhouse gas emissions, decreased carbon sequestration capacity, decreased nutrient cycles and fisheries yields, and reduced another ecosystem (Romañach et al. 2018; Sievers et al. 2019).

Mangrove restoration and rehabilitation are currently high on the agenda for non-government organizations (NGOs) and many governments responding to the widespread degradation of mangroves and growing awareness of harmful environmental and socioeconomic effects (Duncan et al. 2016; Ilman et al. 2016). Several restoration and rehabilitation programs have been introduced in recent decades to recover degraded ecosystem services and biodiversity (Barnuevo et al. 2017; Su et al. 2021). North Sumatra has a wide distribution of mangrove ecosystems and is generally found in several districts, including Asahan, Langkat, Deli Serdang, Tanjung Balai, Nias, Serdang Berdagai and Labuhan Batu (Basyuni et al. 2015). Land conversion occurred in the Langkat Regency, one of the mangrove ecosystems in North Sumatra. Between 1990 and 2015, 34,742.12 ha of mangrove land was changed to 16,765.96 ha (Basyuni et al. 2015).

Although the level of attention on mangrove restoration has increased (Friess et al. 2020), many restoration efforts were previously deemed to have failed (Hai et al. 2020). One of several factors that can contribute to this demise is the implementation of inappropriate species for the restoration area (Lopez-Portillo et al. 2017; Oh et al. 2017). Therefore, the utilization of local species is being considered for restoration and the success of the restoration program. Various regions have implemented restoration initiatives utilizing local species through the application of a monoculture system (Budiadi et al. 2020; O'Connel et al. 2022; Pimple et al. 2022), and several have been found in the North Sumatra Region, one of which in Pasar Rawa Village, North Sumatra.

The success of mangrove restoration efforts can be evaluated by assessing the diversity of flora in the restored area. The dimensions of individual trees in a mangrove forest substantially impact ecosystem function, carbon cycling, and other biogeochemical processes. The structural characteristics of mangroves are extremely important in terms of production and carbon sequestration capability (Sreelekshmi et al. 2020). Prior to the implementation of forest management programs, floristic surveys were carried out to ascertain the status and distribution patterns of specific species. As known, tree diversity is the main factor of biodiversity at the taxon and entire forest levels, as well as the functional composition of trees, forest structure, temperature, and soil. The diversity of tree species and functional diversity (variance in functional attribute values) are both essential (Ampoorter et al. 2020). Information on floristic diversity is also important for people surrounding forests for future utilization and awareness for conservation efforts (Duryat et al. 2023). The data on species diversity after restoration projects at Pasar Rawa have yet to be obtained. This information is vital because it is one of the aspects that impacts the success of restoration efforts and the future utilization of mangroves by the communities. Thus, this research was conducted to analyze the floristic diversity in the mangrove restoration area, which is dominated by *Soneratia alba* species in Pasar Rawa Village, North Sumatra.

2. Materials and Methods

2.1. Research Location

The research was conducted in the *S. alba* restoration area in Pasar Rawa Village, Langkat Regency, North Sumatra (**Fig. 1**), from May to August 2022. The research location was a riverside that receives the influence of sea tides. The research location has a substrate in the form of mud, which is quite deep (52.33 cm) and sticky (Sari et al. 2023). The *S. alba* restoration area is quite far from the sea (23 km) and has an area of approximately ± 3 ha.

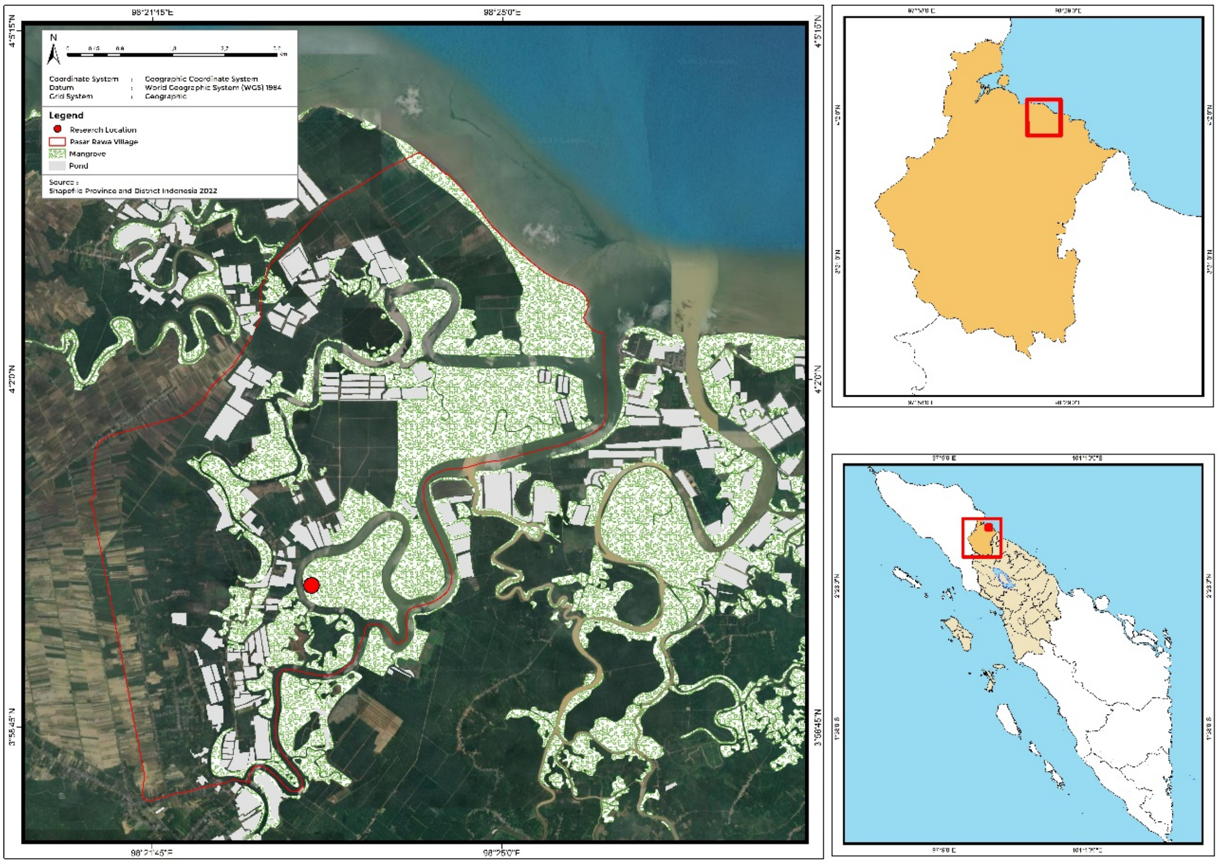

Fig. 1. Research site for *S. alba* species in Pasar Rawa Village.

2.2. Data Collecting and Analysis

Plot placement was completed following mapping procedures utilizing satellite data and direct surveys of the area used for *S. alba* restoration. The plots and transects are determined using satellite images and direct mapping in the field. The species outside the plot differ and do not constitute the restoration area. The vegetation analysis approach employing the plotted path method with a distance of 50 m between transects was used for data collection. On the transect, 10 × 10 m^2 plots were made to observe individuals at tree level (diameter breast height > 10 cm), with a distance of 10 m between plots. In plots measuring 10 × 10 m^2, subplots measuring 5 × 5 m^2 were made to observe individuals at the sapling level (2–10 cm in diameter), and plots measuring 2 × 2 m^2 were used to observe individuals at the seedling stage (diameter < 2 cm with a height of not more than 1.5 m). Diameter breast high (DBH) was assessed as primary data, along with species information and the number of individuals found. The latest botanical classifications were used to identify the species.

Data analysis was performed to get an important values index (IVI) according to Yuliana et al. (2019), which was utilized to measure biological success and dominance observed in the study. The IVI is the sum of relative density, relative frequency, and relative basal area. The following equations were used to calculate such parameters.

2.3. Floristic Diversity

The number of individual trees per unit area is determined as density, whereas the density of a species compared to the overall density of all species in an area is referred to as relative density (RD). Both parameters were calculated using Equation 1 and Equation 2.

$$Density\ (individual/ha) = \frac{Number\ of\ individuals\ of\ a\ species\ (individual)}{Total\ number\ of\ plots\ studied \times area\ of\ plot\ (ha)} \quad (1)$$

$$Relative\ density\ of\ a\ species\ (\%) = \frac{The\ density\ of\ a\ species\ (individual/ha)}{Density\ of\ all\ species\ (individual/ha)} \times 100\% \quad (2)$$

The dispersion of species in a community is measured by frequency, estimated as the proportion of sampling units in which a particular species was discovered using Equation 3.

$$Frequency = \frac{Number\ of\ plots\ in\ which\ species\ occur}{Total\ number\ of\ plots\ sampled} \quad (3)$$

The relative frequency (RF) of a species is its frequency compared to the overall frequency of all species in the community and was calculated using Equation 4.

$$Relative\ frequency\ (\%) = \frac{Frequency\ of\ a\ species}{Frequency\ of\ all\ species} \times 100\% \quad (4)$$

The basal area is the horizontal area occupied by a species' stem and indicates a species' dominance, whereas the relative basal area (RBA) is the comparison between the basal area of species and the basal area of all species. Both parameters were calculated using Equation 5 and Equation 6.

$$Basal\ area\ (cm^2) = A = \pi d^2/4 \quad (5)$$

$$Relative\ basal\ area\ (\%) = \frac{Basal\ area\ of\ a\ species}{Basal\ area\ of\ all\ species} \times 100\% \quad (6)$$

where π is a constant value of 3.14 and d is the diameter breast high (DBH).

The IVI is calculated by adding the RD, RF, and RBA at the tree stage. For the seedling and sapling stages, IVI was calculated by adding RD and RF, whereas at the tree stage, IVI was obtained by summing RD, RF, and RBA. The IVI is calculated using Equation 7 and Equation 8.

$$IVI\ (\%)\ for\ seedling\ and\ sapling = RD\ (\%) + RF\ (\%) \quad (7)$$

$$IVI\ (\%)\ for\ tree = RD\ (\%) + RF\ (\%) + RBA\ (\%) \quad (8)$$

2.4. Floristic Diversity

The diversity index value and species evenness index value were obtained using the Shannon-Wienner Diversity Index (H') and the Shannon-Wienner evenness Index (E) and species richness according to Yuliana et al. (2019) and Daly et al. (2018) Equation 9 is used to calculate the value.

$$H' = -\sum_{i=1}^{s} Pi\ ln\ pi \quad (9)$$

where H' is the Shanon-Wiener diversity index and ni is the individual size of the i-th species, $Pi = ni/N$. Additionally, N is the total amount of individuals identified at the research site from all species. This study also calculated the evenness values with the following Equation 10.

$$E = \frac{H'}{\log ni - \log ns} \tag{10}$$

where E is the species evenness index and H' is the species diversity index value. Meanwhile, S represents the total number of species discovered in the study area. The results of species evenness calculations can be classified into three categories: low if E is < 0.5, moderate if $E < 0.5 < E$ 0.6, and high if $E > 0.6$. Equation 11 was used to compute the species richness using the Margalef Index (D).

$$D = (S\text{-}1)/\ln N \tag{11}$$

where S is the total number of species and N is the total number of individuals.

3. Results and Discussion

3.1. Floristic Composition in Research Area

Mangroves are a distinct ecological network of halophytic vegetation, trees, and shrubs that emerge throughout the tidal zones in subtropical and tropical coastlines (Bai et al. 2020). Many studies regarding the relationship between plant productivity and diversity have revealed that species diversity has a reliable and beneficial influence on plant productivity (Fraser et al. 2015; Poorter et al. 2015). It indicates that the presence of species in an ecosystem is essential, particularly in terms of plant productivity in ecosystems, including restoration regions. The existence of species in the restoration area can be used as an indicator of the attainment of the restoration program. According to the research findings, the *S. alba* restoration area has a floristic composition that varies in IVI for each species (**Table 1**).

Table 1. The important value index of species in the *S. alba* restoration area in Pasar Rawa Village, Langkat Regency, North Sumatra

Growth stage	Species	Family	RD (%)	RF (%)	RBA (%)	IVI (%)
Seedling	*Acrostichum aureum*	Pteridaceae	17.60	15.09		32.69
	Acanthus ilicifolius	Acanthaceae	42.80	32.08		74.88
	Nypa fruticans	Arecaceae	0.40	1.89		2.29
	Finlaysonia obovata	Apocynaceae	1.60	1.89		3.49
	Rhizophopra apiculata	Rhizophoraceae	10.40	26.42		36.82
	Schyphiphora hydrophylacea	Rubiaceae	3.60	9.43		13.03
	Sonneratia alba	Lythraceae	23.60	13.21		36.81
Sapling	*Excoecaria agallocha*	Euphorbiaceae	9.30	21.31		30.61
	Rhizophopra apiculata	Rhizophoraceae	25.58	26.23		51.81
	Schyphiphora hydrophylacea	Rubiaceae	24.42	13.11		37.53
	Sonneratia alba	Lythraceae	40.70	39.34		80.04
Tree	*Rhizophopra apiculata*	Rhizophoraceae	1.22	3.23	0.39	4.83
	Schyphiphora hydrophylacea	Rubiaceae	4.88	9.68	2.23	16.79
	Sonneratia alba	Lythraceae	93.90	87.10	97.38	278.38

Notes: RD (relative density), RF (relative frequency), RBA (relative basal area), and IVI (important value index).

Table 1 shows that after 8 years of reforestation with *S. alba* species, 7 new species from 7 genera were discovered at the reforestation site. Six species were discovered in the seedling stages, three in the sapling stages, and two in the tree stages. The recruitment of new species increases the diversity of the research area. The appearance of new species has a substantial impact on the acquisition of diversity values in research areas. The research site's environmental characteristics have played a significant role in the emergence of numerous species (Fichtner et al. 2018). As a species specifically planted in restoration programs, *S. alba,* did not dominate at all growth stages. At the seedling, *S. alba* obtained an IVI of 36.81, where the IVI was below that of *A, ilicifolius,* and *R. apiculata*, each of which obtained an IVI of 74.88 and 36.82. However, at the sapling and tree stages, *S. alba* was discovered to be the species with the highest IVI, where this species obtained IVI of 80.04% and 278.38%, respectively.

Several factors would have contributed to *S. alba* seedlings not succeeding in becoming the dominant species in the study area. *S.alba* started flowering and fruiting at 3–4 years and requires open conditions for growth and can be discovered more frequently in gaps than in understory vegetation (Jenoh et al. 2016). *R. apiculata* and *A. neriifolius*, on the other hand, are less tolerant. As a result, the two types exhibit significant IVI at the seedling stage. On the other hand, an open canopy could increase the abundance of *S. alba*, while some minor gaps may hinder light-requiring species from forming and flourishing in other inland zones. Changing disturbance regimes and regeneration strategies (for example, light needs) under the dominant canopy may assist in keeping the existing species composition in each vegetative zone (Sahana et al. 2022). Winata et al. (2017) additionally stated that *S. alba* regenerates slowly under monoculture reforestation. The findings of the study revealed that no *S. alba* regeneration was discovered under the stands at the age of 8 years. Furthermore, Azman et al. (2021) discovered that propagule predation was the main mechanism regulating natural regeneration in these densely planted sites. The predominant faunal component of this stand is sesarmid crabs, which play a significant role in litter degradation and propagule predation (Balke et al. 2013). Propagule predation was more intensive under closed canopies, lowering resource competition in dense stands by regulating natural regeneration (Pimple et al. 2022). Propagule predators prefer dense canopies over openings in the canopy. Thinning is required for thinning to open the canopy, minimize competition, improving natural regeneration, reproductive maturity, and overall structural development.

The discovery of *N. fruticans* and several other new species at the research site was interesting. *N. fruticans* is known to be found behind mangrove forest formations, with habitats along rivers influenced by sea tides. Nipah's natural habitat has a salt concentration of 1 in 9 ppm, a soil type described as muddy and rich in alluvial muck, clay, and humus, and a pH range of 5. Nipah is also renowned as a pioneer with a high level of adaptability. *A. ilicifolius* was also discovered in the restoration area and quickly established as the dominant species during the seedling stage. *A. ilicifolius* is a type of emergent aquatic plant. Mangrove areas are in estuary waters downstream of rivers and estuaries from various waste/pollutants from various human activities. The presence of this species at restoration sites is attributable to the presence of a habitat suited for this species. The dense canopy of the research area also allows this species to survive and become the dominant species within the seedling stage. The research area is far from the sea, with relatively stable characteristics such as muddy substrates and slower currents, resulting in the emergence of multiple new species.

Mangrove vegetation growth is tightly tied to water body properties such as soil type (mud, sand, or peat), direct wave action, salt levels, and tidal impacts. Tidal events have a significant impact on the vegetation that creates in mangrove ecosystems. Tides that last a certain amount of time assist in the spread of seeds in a mangrove ecosystem. Balke et al. (2013) stated that the phenomenon is likely that the variability of the coastal physical environment and the compatibility of time with biota are the key mechanisms that explain the failure and success of seed formation in open tidal areas and mangrove margins. The findings of this study indicate that despite the research site being a monospecies (*S. alba*) restoration area, the emergence of 7 new species is very promising for the establishment of succession in the restoration area.

3.2. Species Diversity

In particular ecosystems, species composition may influence the plant structure and composition (Susilowati et al. 2021; Zulkarnaen et al. 2023). According to Wang et al. (2020), species diversity can reflect the resilience of plant ecosystems. Three components were calculated to assess species diversity. The findings revealed that species diversity in the research area resulted in varied values (**Table 2**).

Table 2. Diversity index, evenness index, and species dominance in the *S. alba* restoration area in Pasar Rawa Village, Langkat Regency, North Sumatra

Growth stage	H'	Category	E	Category	D	Category	Number of species
Tree	0.26	Low	0.24	Low	0.88	High	3
Sapling	1.28	Moderate	0.92	High	0.30	Moderate	4
Seedling	1.46	Moderate	0.70	High	0.28	Low	7

Notes: H' = Shannon-Wienner diversity index, E = Shannon-Wienner evenness index, and D = species richness.

The results showed that the acquisition of diversity values tended to decrease with increasing growth stages (**Table 2**). Even though it produces a trend of decreasing values, the diversity of species at the seedling stage, which is classified as moderate (Daly et al. 2018), indicated that heterogeneous ecosystems are starting to form from restoration programs that apply monoculture systems. The emergence of various species other than those planted in the restoration area has significantly impacted the acquisition of diversity values in that location. Environmental factors that support are thought to be most responsible for the emergence of various species in the research location at the juvenile stages. This is supported by Fichtner et al. (2018) and Forrester and Bauhus (2016), who argue that plant facilities depend on a collection of plants and environmental factors that significantly affect their diversity and productivity. The emergence of new species such as *A. aureum*, *A. ilicifolius*, *N. fruticans*, *F. obovata*, *E. agallocha*, *R. apiculata*, and *S. hydrophylacea* indicates that a natural succession process is occurring in the study area, with the emergence of pioneer species with a wide range of habitat tolerance. Several factors that contribute to the emergence of this type in the research area include seed size and nature (i.e., lightness and floatability), as well as root development because it was discovered that seeds germinate when they are covered by soil after being deposited by tidal currents.

The high number of seedlings and the initial growth process of foreign seeds trapped in the restoration area are thought to have caused fluctuations in the diversity value, which decreased as the growth stage. Areas that tend to be open with little canopy cover have contributed to the high intensity of light at the study site to support the growth of seedlings and undergrowth. In addition, the limited ability to grow and develop in various seedling species causes premature death, so it is not found at the adult growth stage. Attacks by marine biotas, such as mollusks and crustaceans that attack plant seeds and high tides, are thought to have reduced the number of individuals that grow and fail to reach the mature stage.

Species evenness, in addition to species diversity, can impact ecosystem stability. If there is a significant difference in the number of individuals of each species in a community, it has low evenness and vice versa (Susilowati et al. 2021). Contrary to the diversity index, the findings indicated that the sapling stage had the greatest evenness, which was 0.92, and the tree stage had the lowest uniformity, which was only 0.24 (**Table 2**). A high species evenness value at the sapling level (almost close to 1) indicates a tendency for individual populations of a species in that location. The high evenness value obtained also indicates a tendency for a species to dominate the ecosystem at the study site. *S. alba* species planted simultaneously in the restoration area have formed a community of individuals with uniform ages. As a result, most individuals that grow up have uniform sizes, allowing them to be identified at the sapling stage and forming uniformity within the community. Evenness is considered uniform or maximum when every species possesses an equal number of individuals.

4. Conclusions

The *S. alba* restoration area comprised 8 (eight) species of mangroves. At the seedling stage, *A. ilicifolius* had the highest IVI. However, at the sapling and tree stage, *S. alba* had the highest. The diversity indices show that the sapling stage had the highest diversity (1.46) and belonged to the medium category, while the tree stage had the lowest diversity (0.26). The appearance of new species, particularly pioneer species, in the research area indicates that natural succession processes are currently taking place. Regular monitoring of the research area is required to evaluate changes in vegetation and zoning.

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