

Understanding the forest structure of a planted and natural mangrove forest: the case of Zamboanga Sibugay, Philippines

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Abstract. Mangrove reforestation has been widely implemented in the Philippines, yet limited information is available on the structural and compositional attributes of natural and planted mangrove forests in Zamboanga Sibugay. This study compared the stand structure, species composition, diversity, and regeneration patterns of natural and planted in selected mangrove forests in the province using the line-quadrat plot method. Results showed that the natural mangrove forest in Siay had higher species diversity, more balanced zonal distribution, and better regeneration structure than the planted mangrove forest in Naga. In contrast, the planted forest was characterized by lower diversity, the absence of seedlings, and dominance by *Rhizophora mucronata* Poir, indicating a simplified community structure influenced by species selection in reforestation activities. These findings suggest that natural mangrove stands exhibit greater structural complexity and regeneration capacity than planted stands. Therefore, mangrove restoration in Zamboanga Sibugay should prioritize site-suitable native species, natural recruitment, hydrological recovery, and long-term ecological monitoring to improve restoration effectiveness.

Keywords: mangrove community, mangrove management, stand biomass, stand structure.

Introduction. Mangroves are a disproportionately global provider of ecosystem services, consisting of above and below-ground carbon sinks, shoreline stabilization, wave and storm surge alleviation, fisheries support, nursery habitats, and coastal livelihoods (Mogeni 2025). This underlines the necessity of conservation and restoration as one of the priorities of mitigation and resilience in coastal climate (Food and Agriculture Organization of the United Nations, 2020). This is particularly important because mangroves are concentrated in tropical and subtropical regions that are highly vulnerable to climate change impacts (Friess et al., 2022). Among these tropical regions, Southeast (SE) Asia holds particular global significance as a biodiversity hotspot (Bhowmik et al., 2022). It also holds the largest potential mangrove ecosystem in the world (Spalding et al., 2010). Unfortunately, SE Asia has faced the largest loss of mangroves (Spalding & Leal 2021). The leading factor in most of these countries is the swift proliferation of the aquaculture ponds (Luo et al., 2022). In the Philippines, to mitigate the biodiversity loss, numerous mangrove planting and rehabilitation projects were initiated as part of its national and local policy that are driven by conservation and livelihood requirements of communities (Primavera & Esteban, 2008; Giri et al., 2011). However, studies highlight recurring issues such as planting in unsuitable areas, using fast-growing monocultures, overlooking local land and water conditions, and weak long-term monitoring (Primavera & Esteban, 2008; Friess et al., 2022).

Despite these challenges, mangrove reforestation projects have continued. In particular, Zamboanga Sibugay has long implemented this restoration effort and has successfully increased mangrove forest cover since 2006. This was largely through the efforts of organizations such as the Philippine Tropical Forest Conservation Foundation (PTFCF) and the Xavier Agricultural Extension Service Foundation (Monzon et al., 2016).

Nevertheless, even though these mangroves replanting succeeded, the mangroves are still at their developmental stage 10 years afterward (Monzon et al., 2016). Moreover, the province is home to the Sibugay Wetland Nature Reserve (SWNR), the Philippines' largest and most recent Ramsar site, where extensive natural mangrove forests coexist with rehabilitated planted stands. Nevertheless, the limited availability of site-specific and plot-level information on natural and planted mangrove stands constrains managers from reliably assessing whether reforestation efforts are restoring the structural attributes needed to support biodiversity conservation and the long-term delivery of ecosystem services (Friess et al., 2019). In response to this gap, the proposed study aims to evaluate and compare the floristic diversity, vegetation structure, and management conditions of natural and planted mangrove stands in Siay and Naga, Zamboanga Sibugay. This study also provides the first detailed structural comparison of mangrove stands in the province. By providing a paired and detailed structural comparison, this study contributes baseline information needed to assess mangrove restoration outcomes in the province.

Material and Method

Description of the study sites. The study was conducted in mangrove ecosystems of Barangay Laih, Siay, and Barangay Gubawang, Naga Zamboanga Sibugay (Figure 1). Barangay Laih, Siay is located at (7°44'12.8" N, 122°48'17.9" E), which represents a natural mangrove forest, and Barangay Gubawang located at (7°47'20.6" N, 122°42'15.2" E) represents a planted mangrove forest established through reforestation initiatives. Both ecosystems fall under type III climate, characterized by a relatively even distribution of annual rainfall. The natural mangrove site is situated within the Sibugay Wetland Nature Reserve, a Ramsar Wetland of International Importance (Site No. 2552) declared in 2024. The reserve covers ~175,551 ha across nine municipalities in the province, with mangrove forests accounting for about 8,000 ha of its extent (PIA, 2025). Siay mangrove forest (~2,800 ha) serves as both a conservation and ecotourism site. In contrast, the planted mangrove forest in Barangay Gubawang, Naga (~50 ha) was established through community-based reforestation to address coastal degradation and shoreline erosion and is designated coastal protection zone; however not a part of Sibugay Wetland Nature Reserve. Established over the past 20-30 years, these stands represent varying successional stages. These contrasting systems enable comparative assessment of structural and compositional attributes between natural and planted mangrove forests. However, this study acknowledges some limitations with regards to the number of sites representing both planted and natural forests. Only one natural site and one planted site were considered in the study. The findings may not be generalized to all natural and planted mangrove forests in the province. But the results provide site-specific baseline evidence on how the selected natural and planted stands differ in terms of floristic composition, vegetation structure, and stand condition.

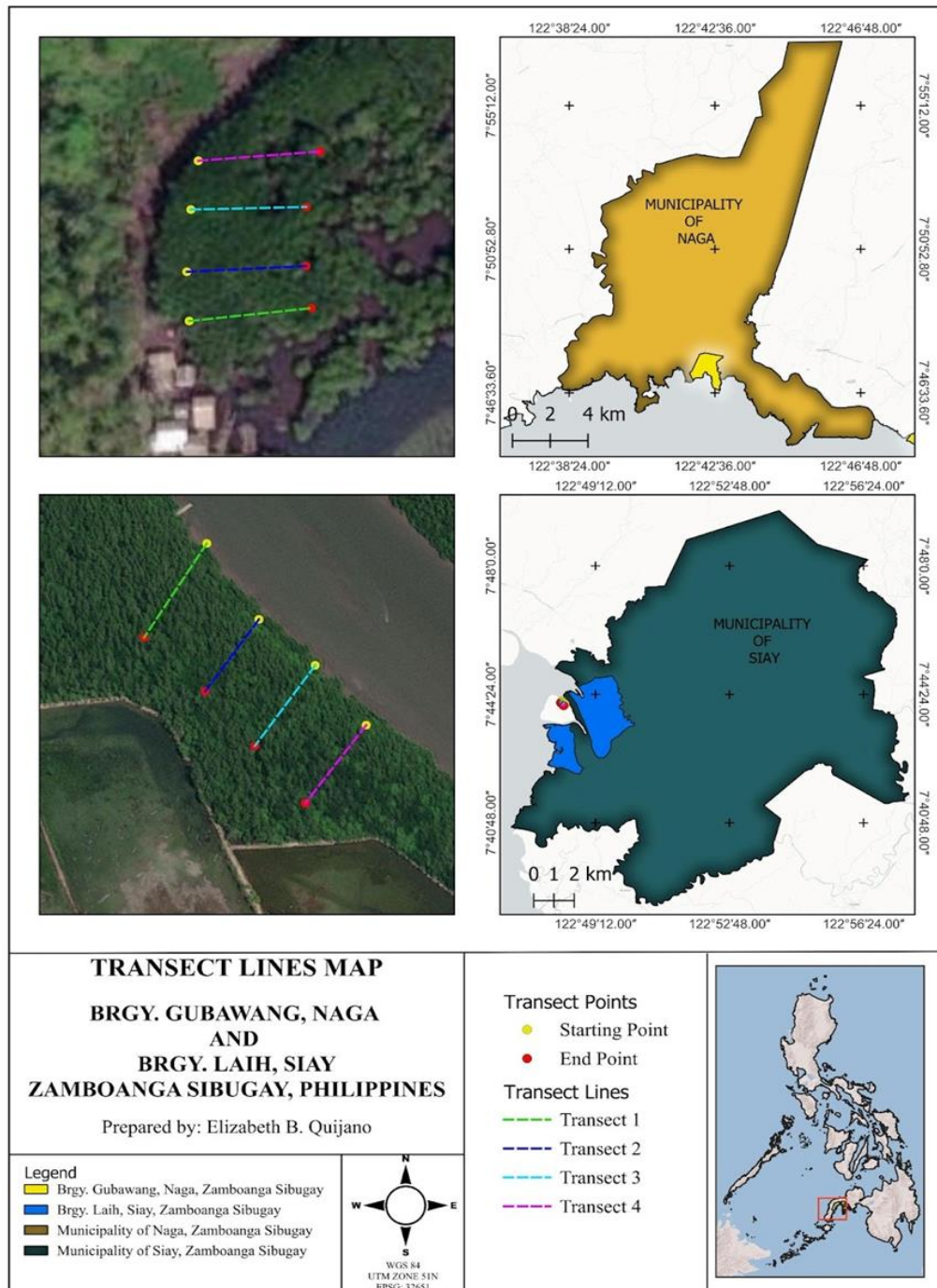


Figure 1. Geographic location of the two mangrove sampling sites in Siay and Naga, Zamboanga Sibugay, Philippines.

Field sampling and data collection. Field sampling was conducted from August to September 2025 in Siay and Naga, Zamboanga Sibugay, using a non-destructive line quadrat method to assess mangrove vegetation. Four 100 m transects per site were established perpendicular to the shoreline at 100 m intervals across each replicate transect to account for spatial heterogeneity. Each transect was further divided into landward, mid, and seaward zones. In each zone, three 10 x 10 m plots were systematically arranged (Figure 2). All mangrove individuals were identified and recorded for species composition, diameter at breast height (DBH), and height. Seedlings and saplings were counted, while only individuals with DBH ≥ 5 cm were measured for basal area analysis. For trees with prop roots, DBH was measured at 30 cm above the highest prop root. Trees with irregular stem forms were measured following the protocols of Pearson et al. (2005). Species

identification was made based on morphological and reproductive (if available) characteristics aided by the Handbook of Mangroves in the Philippines by Primavera (2004) and Digital Flora of the Philippines by Co's Digital Flora of the Philippines.

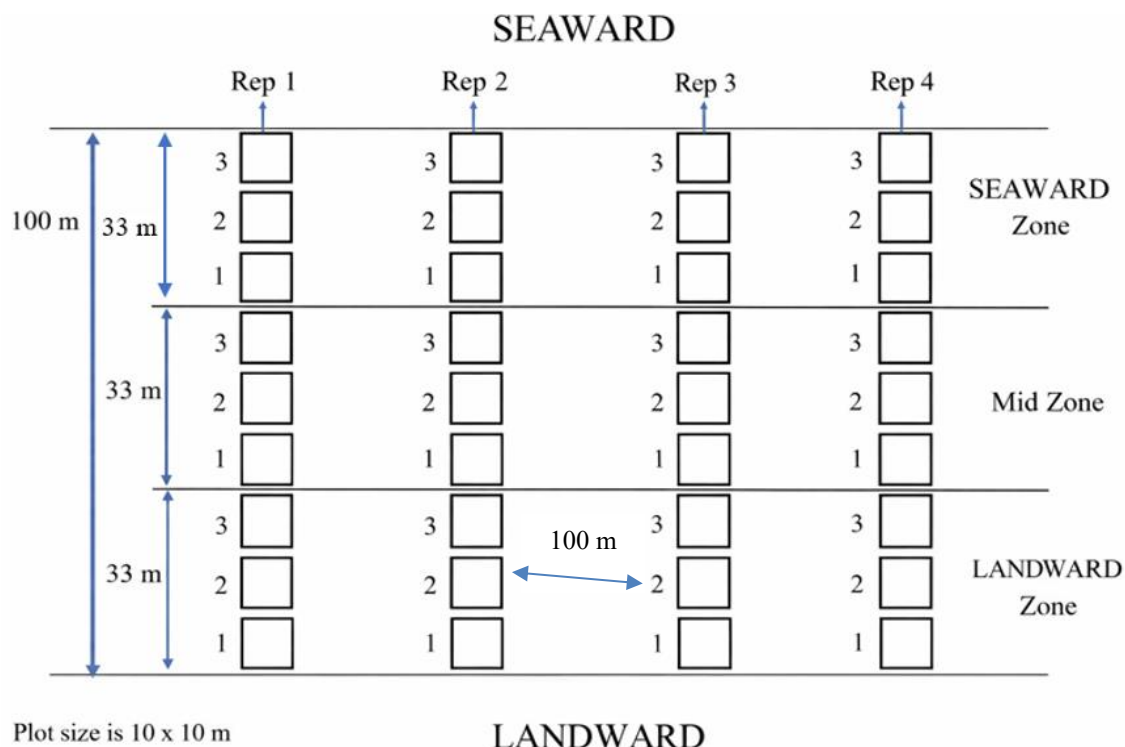


Figure 2. Forest assessment design using plot sampling per zone.

Data analysis. Jamovi (The jamovi project, 2019) and Microsoft Excel were used to compute descriptive statistics such as the counts, mean, median, frequency, and percent, as well as in incorporating raw data and graphing. Species diversity indices such as Shannon-Wiener (H'), Evenness (J'), and Dominance (D) were computed using Paleontological Statistics (PAST) software version 4.03 (Hammer et al., 2001). The interpretation of the species diversity indices is presented in Table 1. For the Shannon Diversity Index, the following formula was used (Shannon, 1948):

$$H' = \sum_{i=1}^S P_i \ln(P_i),$$

Where:

H' - the Shannon-Wiener Index of Diversity;

S - the number of species;

P_i - the proportion of the i species ($P_i = N_i/N$, N_i = amount of i species);

N_i - the total number of individuals of species i in the quadrat/sample;

N - the total number of individuals of all the species in the quadrat/sample.

For the Evenness index, this formula was used (Pielou, 1975; Krebs, 1989):

$$J = \frac{H'}{\ln(S)},$$

Where:

H' - the Diversity value;

S - the total number of species in the sample.

For Simpson's Dominance Index, which measures species dominance in a community (Simpson, 1949), the formula below was used:

$$D = \sum_{i=1}^S p_i^2,$$

Where:

D - the Simpson's dominance index;

pi - the proportion of individuals of species;

i and S - the total number of species.

It estimates the chance that two individuals randomly drawn from a sample are members of the same species. In simple terms, it tells how strongly one or a few species dominate a community.

Table 1

Diversity index and species evenness values and their interpretation

<i>Diversity(H')</i>		<i>Evenness (J)</i>		<i>Dominance (D)</i>	
<i>Values</i>	<i>Interpretation</i>	<i>Values</i>	<i>Interpretation</i>	<i>Values</i>	<i>Interpretation</i>
> 3.50	Very high	0.96-1.00	Balanced	0.75-1.00	Very high
3.00-3.49	High	0.76-0.95	Almost balanced	0.50-0.74	High
2.50-2.99	Moderate	0.51-0.75	Semi-balanced	0.25-0.49	Moderate
2.00-2.59	Low	0.26-0.50	Less balanced	0.15-0.24	Low
< 1.99	Very low	0.00-0.25	Unbalanced	< 0.14	Very low

Source: Napaldet, 2023.

The community structure was assessed using mangrove vegetation parameters such as density (stems ha⁻¹), basal area (m² ha⁻¹), relative density (RDen), relative frequency (RF), and relative dominance (RDom). All computations were based on formulas presented by Mueller-Dombois & Ellenberg (1974). Moreover, the Importance Value Index (IVI) for each species was also calculated by adding the relative density, relative dominance, and relative frequency. Relative density represents the abundance of a species in relation to the total number of individuals of all species. Whereas, relative dominance reflects the proportion of basal area a species occupies within the community. While relative frequency indicates how widely a species is distributed across sampling plots. By adding these measures, the IVI provides a comprehensive assessment of the ecological importance, structural influence, and competitive status of the species within the plant community. The interpretation of IVI was based on Aureo et al. (2020), where high IVI means that the species is abundant, widespread, and structurally significant in the community. Whereas, species with lower IVI means less dominant and have a smaller ecological role within the community. The formulas were presented below:

Relative density = (Number of individuals of a species / Total number of individuals of all species) × 100

Relative dominance = (Total basal area of species / Total basal area of all species) × 100

Relative frequency = (Frequency of a species / Frequency of all species) × 100

IVI = Relative density + Relative frequency + Relative dominance

Statistical analysis. Two independent samples t-test was the main statistical test used to examine the significant difference in the species diversity between a natural and planted mangrove forest. Species diversity was quantified using the Shannon Diversity Index (H') and Simpson's Dominance Index (D) for each zone within each transect. This results in a total of twelve diversity estimates per forest type. To further compare the diversity indices between forest types, the diversity permutation test was used. It is a non-parametric statistical method used to determine whether the difference in biodiversity between two or more groups is statistically significant by using random resampling (permutations) instead of relying on distributional assumptions. It tests not just the difference in Shannon H and dominance but also the species richness, abundance, and evenness. The significant

difference was defined at 5% alpha level ($p < 0.05$). In addition, the association between zonation and species distribution was determined through multivariate analysis using correspondence analysis. Statistical analyses were performed using Jamovi software.

Results and Discussion

Composition and vertical stratification of natural and planted mangrove forest.

Species composition differed slightly between the two studied mangrove forest types. The natural mangrove forest in Siay, Zamboanga Sibugay supported five species across four families, with Rhizophoraceae as the most represented family (three species), while Acanthaceae and Lythraceae were represented by one species each (Table 2). In contrast, the planted forest in Naga recorded four species from three families, including two species from Rhizophoraceae. Both forests shared three dominant species, such as *Sonneratia alba* Sm., *Rhizophora apiculata* Blume, and *Rhizophora mucronata* Poir. This finding is similar to the research in Zamboanga del Sur, by Mariano et al. (2019), in which only 7 species of true mangroves were detected in the natural forest and 5 in other forests. On the same note, Bitantos et al. (2017) also identified eight true mangrove species in the natural mangrove forest of Buug, Zamboanga Sibugay. These findings however run contrary to the findings of other studies in other parts of Mindanao Island, where higher numbers of mangrove species were reported. A study in Imelda, Dinagat Island recorded ten species (Canizares et al., 2016), and in Bacolod, Lanao del Norte eleven species can be observed (Benecario et al., 2016). While in Samar, Calipayan et al. (2024) found five species of mangroves in the natural forests and ten species of mangrove in the planted forests.

Table 2

Identified mangrove species in Zamboanga Sibugay and their conservation status

Family name	Species name	Local name	Distribution per site		Conservation status	
			Siay	Naga	IUCN Redlist	DAO 2017-11
Acanthaceae	<i>Avicennia marina</i>	Miapi		✓	LC	OWS
Lythraceae	<i>Sonneratia alba</i>	Pagatpat	✓	✓	LC	OWS
Meliaceae	<i>Xylocarpus granatum</i>	Tabigi	✓		LC	OWS
Rhizophoraceae	<i>Rhizophora apiculata</i>	Bakhaw lalaki	✓	✓	LC	OWS
Rhizophoraceae	<i>Rhizophora mucronata</i>	Bakhaw babae	✓	✓	LC	OWS
Rhizophoraceae	<i>Rhizophora stylosa</i>	Bakhaw bato	✓		LC	OWS

Note: Check mark (✓) means presence of the species in the area. LC- Least Concern, OWS- Other Wildlife Species

All recorded species for both forest types are listed as “Least Concern” by the International Union for Conservation of Nature (IUCN). This means that the identified mangrove species have relatively stable global populations. In addition, these species are categorized as “Other Wildlife Species” under the classification of DENR Administrative Order No. 2017-11. Therefore, these species were not recognized as threatened, endangered, or vulnerable at the national level. Nonetheless, the “Least Concern” classification does not reduce the conservation importance of these species, as global IUCN assessments may not fully reflect local or regional threats (International Union for Conservation of Nature, 2024). Despite their global abundance, mangrove species may still experience localized declines due to coastal development, aquaculture, pollution, illegal harvesting, and climate change impacts, particularly in areas with weak management and enforcement (Alongi, 2008; Friess et al., 2019).

Table 3

Growth types and stand structure composition of natural and planted mangrove forest in
Zamboanga Sibugay

Forest type (Location)	Growth stage	Mean height (m)	Mean DBH (cm)	Total count	Percent (%)
Natural (Siay)	Seedlings	< 1	1.11	16	2.1
	Saplings	~ 1-3	3.74	264	34.4
	Trees	> 3	10.6	489	63.6
	Total	-	8.05	769	100
Planted (Naga)	Seedlings	-	-	0	0
	Saplings	~ 1-3	4.33	34	6.9
	Trees	> 3	9.57	460	93.1
	Total	-	9.20	494	100

Note: Seedling-DBH < 2cm, Sapling-2cm≤DBH<5cm, Matured tree-DBH≥5cm (Yap et al., 2018).

The stand structure, which is a measure of natural recruitment and restoration success, is a significant variable of forest regeneration, maturity, and ecological stability, especially in mangrove ecosystems (Calipayan et al., 2024). Table 3 presents the structure composition of the two types of studied forests in Zamboanga Sibugay in terms of growth stage classification of seedlings, saplings, and trees based on the DBH classification of Yap et al. (2018). There were 769 individuals observed in the natural mangrove forest distributed among trees (63.6%), saplings (34.4%), and seedlings (2.1%). This finding depicts a natural regeneration in a natural forest, implying that the mangrove stand at Siay has a rather even age distribution. On the other hand, the planted forest in Naga revealed a different stand structure. The area is mostly covered with trees that comprise 93.1% of the overall 494 individuals counted. The proportion of saplings is only 6.9 percent, and none of the sampled plots had seedlings. Alongi (2014) argues that the lack of seedlings implies that there was no natural recruitment that is typical of mangrove planted stands where trees are usually planted simultaneously. In addition, trees within a planted forest were observed to have lower average DBH of 9.57 cm compared to 10.6 cm tree DBH in the natural forest (Table 3). This underscores an increased pre-eminence of trees occurring in the natural forest. The findings demonstrated that natural mangrove forest had a more balanced stand structure and reflects more natural recruitment and ecological stability than a planted mangrove forest (Alongi, 2014).

Horizontal distribution of species in natural and planted mangrove forest.

Assessing species distribution and spatial arrangement is also essential for managing mangrove forest health. Identifying key areas for growth and recruitment supports conservation, restoration, and sustainable coastal management. Table 4 presents the zonation patterns and soil characteristics of studied natural and planted mangrove forests in Zamboanga Sibugay. In the natural forest, the mid zone has the best soil texture of silt loam, which is characterized by having good water retention and fertility. Correspondingly, this zone has the most number of species (292 individuals). Specifically, *R. apiculata* dominate not just the mid zone but also the sea zone. This showed that mid zone and silt loam soil favors the growth of *R. apiculata*, followed by *S. alba* and *R. mucronata*. This is likely due to balanced tides and nutrient-rich sediments in this zone. *Rhizophora* species, particularly *R. apiculata* and *R. mucronata*, are well adapted to mid-intertidal zones where moderate inundation and fine-textured soils support stable anchorage and efficient nutrient absorption (Friess et al., 2022). Similarly, *S. alba* thrives in areas with regular tidal flushing and soft sediments, which facilitate gas exchange and reduce salinity stress (Tomlinson 2016). Generally, mid zones support higher diversity due to favorable physicochemical conditions (Raganas & Magcale-Macandog, 2020).

Table 4

Mangrove zonation and soil texture comparison in natural and planted forests

Forest type (Location)	Zonation	Species count	Percent (%)	Soil texture
Natural (Siay)	Land zone	220	28.61	Loamy Sandy
	Mid zone	292	37.97	Silt Loam
	Sea Zzone	257	33.42	Clay Loam
	Total	769	100	-
Planted (Naga)	Land zone	57	11.54	Sandy
	Mid zone	122	24.70	Sandy
	Sea zone	315	63.76	Loam
	Total	494	100	-

Moreover, the correspondence analysis (CA) ordination plot indicates that the mid-zone occupies a central position, which suggests that its species composition overlaps with both landward and seaward zones rather than being defined by a single dominant species (Figure 4). The sea zone was associated with *S. alba* trees and saplings, *Xylocarpus granatum* J.Koenig saplings, and *R. apiculata* saplings, which indicates their establishment and regeneration in the seaward portion of the natural forest. This is consistent with the adaptation of *Rhizophora* species to frequently inundated substrates through their prop root systems (Duke, 2006) although *X. granatum* is more commonly associated with middle to landward zones (Tomlinson, 2016).

In contrast, the land zone was associated mainly with *R. mucronata* across growth stages and *R. stylosa* saplings, suggesting active regeneration in the landward portion. Although *R. stylosa* is often reported in seaward to middle intertidal zones and *R. mucronata* in middle intertidal areas (Tomlinson, 2016), their occurrence may reflect local tidal, sediment, and substrate conditions. In Siay, the natural mangrove forest is co-managed by DENR, the LGU, and POs under the CBFM program. Local ordinances, mangrove-cutting restrictions, and Bantay-Dagat enforcement have helped maintain ecosystem integrity. This initiative supports more natural zonation patterns shaped by tidal and sediment conditions.

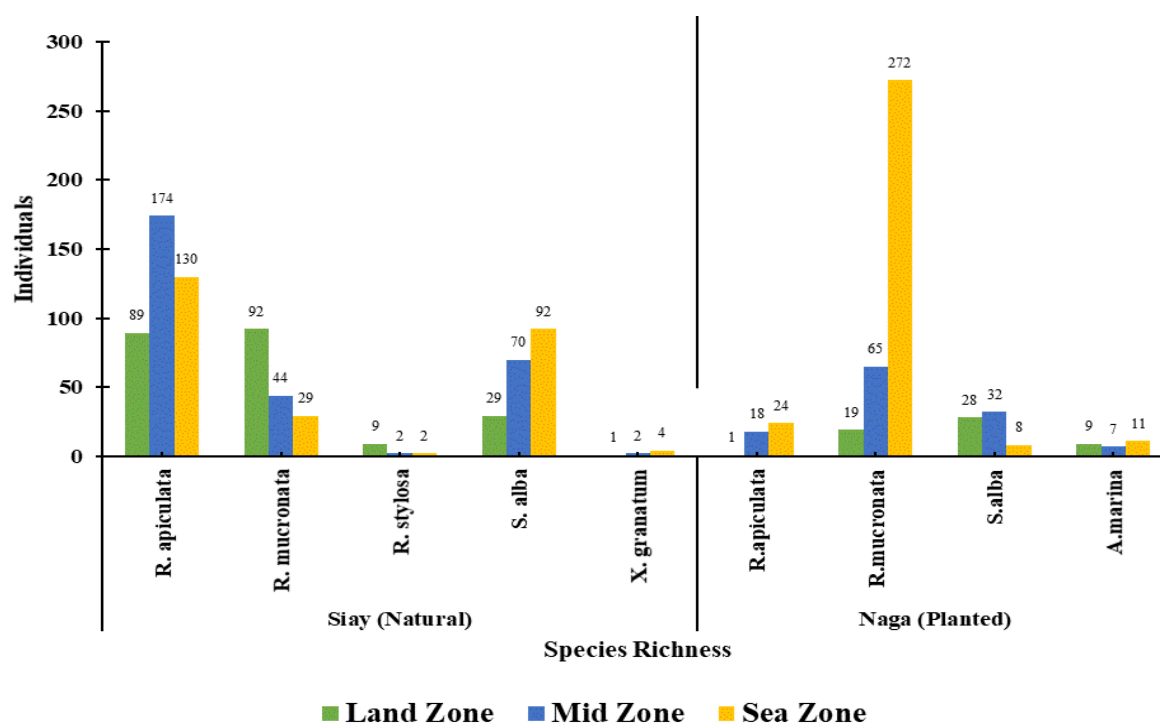


Figure 3. Zonal distribution of mangrove species in natural and planted forests.

Meanwhile, the planted mangrove forest in Naga displayed a different zonal-species abundance and soil texture pattern. The sea zone had the most species of 315 out of 494 individuals, and a notable loam soil texture. *R. mucronata* dominated this zone (272 individuals), which indicates that this zone possesses better moisture retention and nutrient availability supporting faster growth of this species. Olagoke et al. (2013) showed that *R. mucronata* grows well in areas that are degraded but still moist, especially when the soil is fine-textured like loam or clay. This highlights the species preference for soils that hold water and are influenced by tides. Similarly, Kathiresan & Bingham (2001) found that *R. mucronata* is usually located in seaward zones of mangrove forests, where conditions are salty, waterlogged, and have high moisture retention. In fact, *R. mucronata* dominated not just the mid-zone but the entire planted forest (399 individuals). This dominance was also reflected in the CA ordination plot, which showed a simplified and clustered species distribution pattern. *R. mucronata* and *S. alba* saplings were associated with the sea zone, which indicates their tolerance to salinity and regular tidal inundation. In contrast, *Avicennia marina* (Forssk.) Vierh. was positioned closer to the mid-zone. This reflects the broad ecological tolerance of the species across intertidal habitats with moderate salinity and tidal influence (Duke, 2006; Almahasheer et al., 2016). These patterns suggest that species distribution in the planted stand reflects both ecological tolerance and previous planting strategies (Lewis, 2005). Compared with the natural mangrove forest, the planted forest showed lower ecological complexity and less natural zonation. In Naga, mangrove management is mainly through periodic planting by the Philippine Coast Guard and local communities. However, key informants reported limited maintenance, illegal cutting, waste dumping, weak local ordinances, and low community awareness. These factors may have affected species establishment, survival, and the clustered structure of the planted forest.

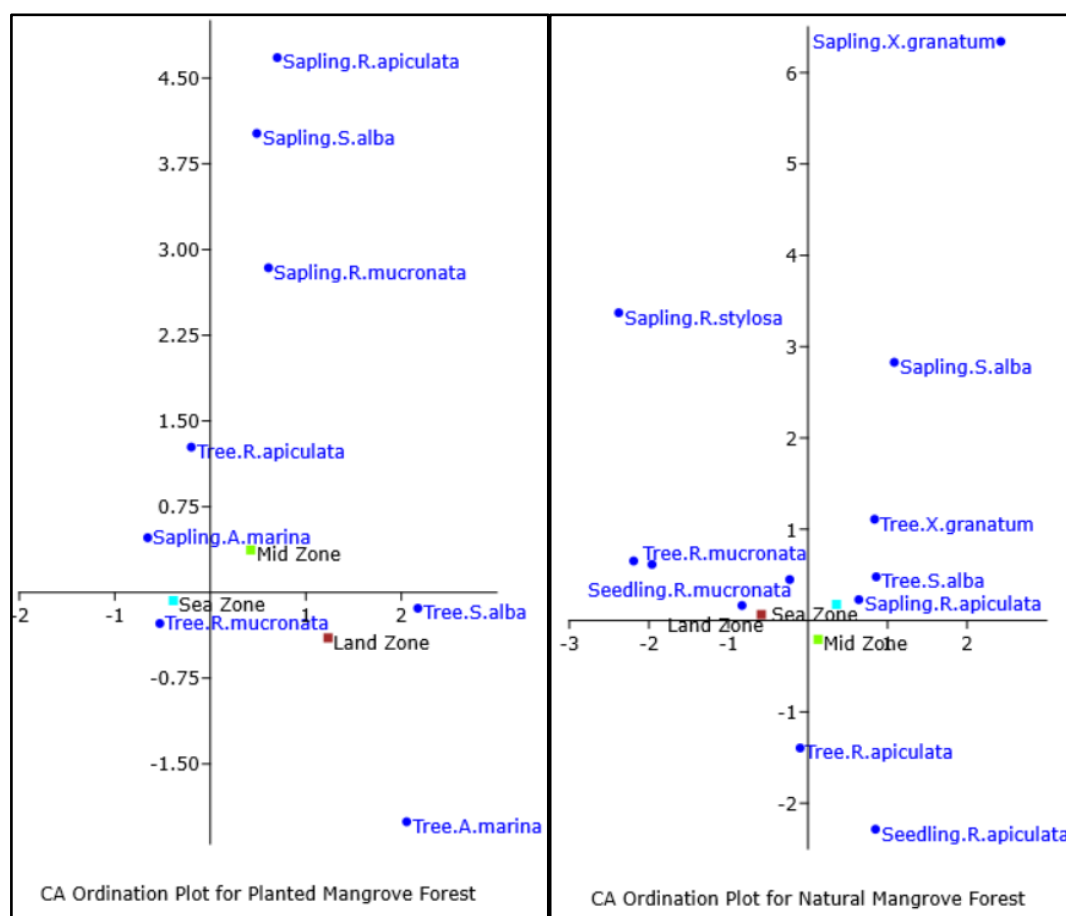


Figure 4. Correspondence Analysis (CA) Ordination Plot of Mangrove Species and Growth Stages (i.e., tree, sapling, seedling) across Zonation (color code: Brown- Land zone, Green- Mid zone, Aqua- Sea zone) in Natural and Planted Mangrove Forests

Clearly, zonation and soil texture differ with respect to species distribution and abundance. The studied natural forest exhibits higher soil texture in both land and mid zones as compared to the planted forest but showed lower soil texture in the sea zone. Moreover, the natural mangrove forest showed a more diverse and even species distribution across ecological zones, while the planted forest was characterized by species clustering and dominance of a few planted species. This suggests that restoration practices and species selection influence mangrove community structure and associated ecosystem functions.

Species diversity in natural and planted mangrove forest. The ecological stability plays a critical role in the management of mangrove forests, and is mainly measured using the species diversity. Table 4 presents the stand structure and ecological roles of the mangrove species at natural and planted forests in the province based on relative density, relative frequency, relative dominance, and Importance Value Index (IVI). The results indicate that *S. alba* has been identified as having the greatest ecological significance in the natural forest of Siay, as represented by the largest stand basal area ($26.19 \text{ m}^2 \text{ ha}^{-1}$) and importance value index (IVI) of 129.89. This ecological dominance indicated its major contribution to forest structure and biomass. It has been established that the *Sonneratia* species are valuable and sustainable in forest stress (Carlos et al., 2015; Baring & Cadiz 2024).

R. apiculata also showed ecological importance in the natural mangrove forest with an IVI of 98.06, which means that the species is widely distributed and thus undergoes stress tolerance and competitiveness (Isa & Suratman, 2021). On the contrary, *R. mucronata*, *R. stylosa*, and *X. granatum* had lower values of IVI, which restricts their ecological footprint. The difference in species composition between the natural forest in Siay and the planted forest in Naga may be linked to differences in management and community participation. In Siay, strong support from DENR, the LGU, and community-based organizations, together with local ordinances and enforcement, helps protect the mangrove forest and supports natural processes such as recruitment and propagule dispersal. This may have contributed to the higher species diversity and more balanced ecological structure of the natural forest.

Table 5

Stand structure and ecological importance of mangrove species in natural and planted forests

Forest type	Species name	Mean DBH	Stand BA ($\text{m}^2 \text{ ha}^{-1}$)	RDen	RF	RDom	IVI
SIAY (Natural)	<i>Rhizophora apiculata</i>	6.44	5.03	51.11	32.71	14.24	98.06
	<i>Rhizophora mucronata</i>	8.29	3.44	21.46	24.30	9.76	55.51
	<i>Rhizophora stylosa</i>	9.50	0.43	1.69	7.48	1.20	10.37
	<i>Sonneratia alba</i>	20.7	26.19	24.84	30.84	74.21	129.89
	<i>Xylocarpus granatum</i>	9.66	0.21	0.91	4.67	0.58	6.17
NAGA (Planted)	<i>Rhizophora apiculata</i>	10.9	1.32	8.70	20.78	7.20	36.68
	<i>Rhizophora mucronata</i>	9.54	7.89	72.06	40.26	43.04	155.37
	<i>Sonneratia alba</i>	20.9	8.56	13.77	25.97	46.68	86.42
	<i>Avicennia marina</i>	8.59	0.56	5.47	12.99	3.08	21.53

Note: Ave.DBH - Average Diameter at Breast Height (cm), BA - Basal Area (m^2), RDen - Relative Density, RF - Relative Frequency, RDom - Relative Dominance, IVI - Importance Value Index

Conversely, the planted mangrove forest in Naga was dominated by *R. mucronata* with an IVI of 155.37. This reflects the rehabilitation practices that favored this species (Batool et al., 2014; Villanueva et al., 2021). Although *S. alba*, *A. marina*, and *R. apiculata* had lower structural importance, they still contribute to sediment stabilization, succession, habitat support, and biomass development (Duke 2006; Komiyama et al., 2008; Usman et al., 2013). Specifically, *S. alba* dominates in terms of relative dominance (RDom) due to its large DBH among mangrove species. The findings revealed a clear disparity between the species-rich planted forest and the more balanced natural forest. It means that natural ecosystems of Zamboanga Sibugay sustain more diverse and richer mangrove

communities compared to the planted ones. Strengthening community awareness, maintenance, and diversified restoration strategies may improve the ecological condition and biodiversity of planted mangrove forests.

Table 5 further compares the ecological roles and diversity indices of the studied natural and planted mangrove forests. The analysis employed an independent t-test to examine the difference where normality was confirmed in the data, as well as the diversity permutation test. Based on the result of diversity analysis, the natural forest had a higher Shannon diversity index (1.131) than the planted forest (0.880), although both were classified as low-diversity communities (Napaldet, 2023). This result is similar to other works by Bitantos et al. (2017), Mariano et al. (2019), and Goloran (2020) in which they found that mangrove forests were not diverse. However, in low-diversity systems, natural forests demonstrate greater and more species-balance than planted ones. Their differences are also statistically significant according to the independent t test ($p = 0.027$) and Simpson index (1-D: natural 0.631 - planted 0.451). Dominance, evenness, and richness indices also demonstrated further difference between the two forest types based on the result of diversity permutation test. The decision to show that a small number of species dominate planted forests is supported by the fact that the higher dominance index (D) in the planted site (0.549 vs. 0.369) is high. It means that the planted mangrove forests are more likely to have a simplified structure of the community with a limited number of species prevailing in the environment. Generally, the finding indicated that the natural mangrove forest in Siay, Zamboanga Sibugay is relatively more diverse in species and balanced as compared to planted forests. This finding is consistent with Labutap et al. (2013), who indicated that they found a difference in the density and diversity of species in natural and planted mangrove forests in Sorsogon, Philippines.

Table 6

Comparative analysis of species diversity in natural and planted mangrove forests

<i>Species diversity index</i>	<i>Forest type</i>		<i>Independent t-test (P-value)</i>	<i>Diversity permutation test (P-value)</i>
	<i>Natural (Siay)</i>	<i>Planted (Naga)</i>		
Taxa S (Richness)	5	4	-	0.0031*
Individuals (Abundance)	769	494	-	<0.001*
Shannon (H')	1.131	0.880	0.027*	0.0001*
Dominance (D)	0.369	0.549	0.032*	0.0001*
Evenness (J)	0.620	0.603	-	0.4429
Simpson (1-D)	0.631	0.451	-	0.0001*

Note: asterisk (*) means significantly different at 5% significant level ($p < 0.05$). The computed diversity (Shannon) and dominance from 24 zones (12 per site) are normal ($p = 0.261$, $p = 166$).

To further visualize the species diversity per zone between the two studied forest types, a rarefaction analysis was performed using the Shannon diversity (Figure 5). In the natural mangrove forest of Siay, the curves showed relatively close plateau levels across zones, which indicates sufficient sampling and more balanced species diversity. The land zone showed the highest diversity, followed by the sea and mid zones. Whereas, in the planted mangrove forest of Naga, the rarefaction curves showed more uneven diversity patterns. The mid and land zones had higher diversity, while the sea zone showed a lower and slower-rising curve. This further confirmed the dominance of a few species in the area. Overall, the rarefaction analysis indicates that the natural forest maintains more balanced diversity across zones, whereas the planted forest shows uneven diversity influenced by planting practices and species selection. This is consistent with studies showing that planted mangrove forests are often dominated by fast-growing and easily established species such as *R. mucronata* (Osing et al., 2019; Irsadi et al., 2025).

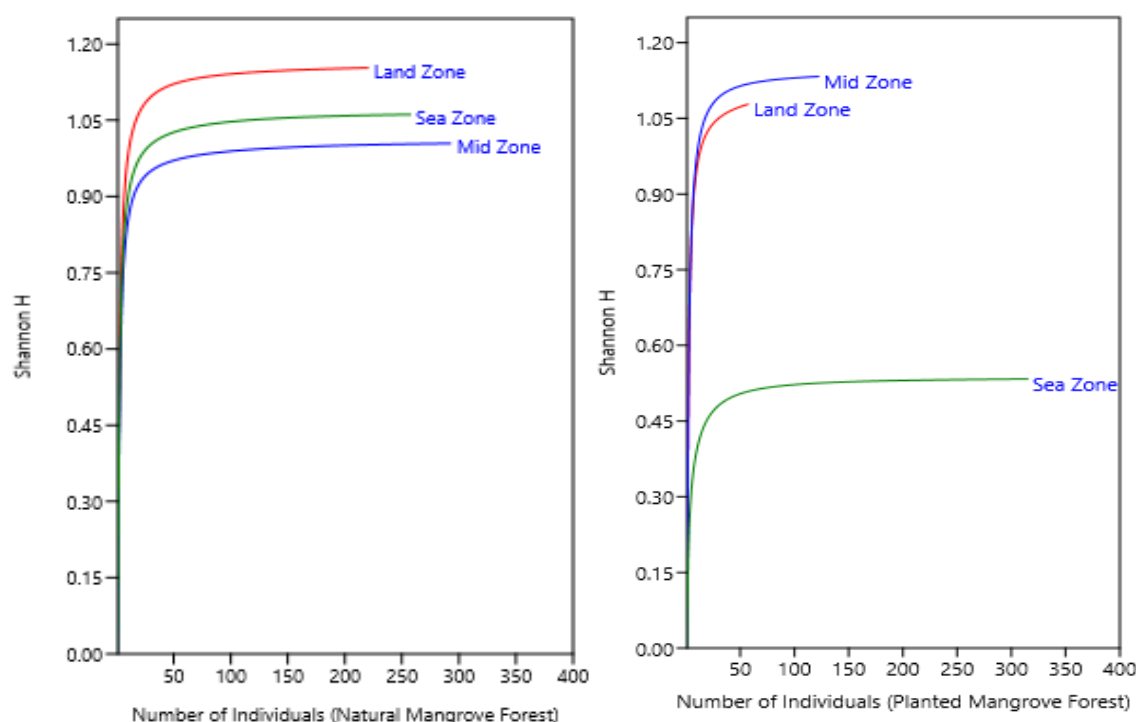


Figure 5. Individual rarefaction analysis using Shannon H index for both natural and planted mangrove forest.

Conclusions. The studied natural and planted mangrove forests in Zamboanga Sibugay exhibited distinct differences in forest structure, species composition, and regeneration capacity. The natural mangrove stands in Siay showed higher structural complexity, greater species diversity, and a more balanced regeneration pattern across seedlings, saplings, and mature trees. This condition was mainly associated with the dominance and successful regeneration of *Sonneratia alba*, particularly in the mid-zone. In contrast, the planted mangrove stand in Naga was characterized by lower species diversity and strong dominance of *Rhizophora mucronata*. The absence of seedlings indicates limited natural regeneration, which suggests reduced recruitment potential and lower ecological resilience. Site observations also indicate that the planted stand is exposed to management constraints, including waste accumulation, limited monitoring, and weaker enforcement. Thus, the studied natural mangrove stands exhibited higher structural complexity and regeneration capacity compared to the studied planted stand.

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Conflict of Interest. The authors declare that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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