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Diversity, stand structure, biomass and carbon storage potential of natural and planted Mangrove Forests in Samar, Philippines

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Abstract

Samar is one of the provinces in the Philippines with the most extensive remaining mangrove forest. However, information on ecology and carbon sequestration capacity is limited. Thus, this study aims to assess the species diversity, community structure, and carbon stock in the natural and planted mangrove stands in Zumarraga, Samar. The transect-line method was used to collect vegetation analysis and diversity data, while biomass estimation used an allometric equation. Fifteen sampling plots of 10 m x 10 m were established in each sampling site, representing the seaward, middleward, and landward zones. The species composition of these areas consists of 11 species belonging to 5 families. Biodiversity indices indicated very low species diversity for both types of mangrove forests. *Avicennia marina* was the most important species, with an importance value (IVI) of 168.55% (natural stand) and 75.61% (planted stand). The total carbon stock was 71.97 t C ha^{-1} in the natural stand and 391.44 t C ha^{-1} in the planted stand. Overall, even if both mangrove stands have very low species diversity, their ability to store and sequester carbon cannot be undermined, as evident in the biomass and carbon stock values. Thus, sustainable management strategies and efforts should be made to protect this naturally grown and planted mangrove ecosystem.

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Introduction

Mangrove forests are coastal wetland ecosystems considered one of Earth's most highly productive ecosystems, contributing various functions and services to surrounding coastal areas (Van Oudenhoven *et al.,* 2015). It provides many useful human products, such as charcoal, medicines, and building materials (Barbier *et al.,* 2011). Moreover, mangroves aid in regulating floods, erosion, and saltwater intrusion (Camacho *et al.,* 2020) and as a buffer for coastal communities against storms and typhoons (Polidoro *et al.,* 2010). Aside from that, this habitat also provides food and livelihood for coastal residents (Gevaña *et al.,* 2018). Furthermore, mangroves play an important role in the health of coastal ecosystems. Their intricate root network stabilizes sediments and enhances water clarity, providing a perfect home for many marine organisms (Arceo-Carranza *et al.,* 2021).

Recently, blue carbon ecosystems like mangroves have received international attention as a valuable tool for mitigating the impacts of climate change. This coastal ecosystem is rich in biodiversity and one of the world's most significant carbon sinks, trapping and storing a remarkable amount of carbon within its dense root systems and forest soils (Alongi, 2014; Howard *et al.,* 2014). Since the carbon trapped in the soil is difficult to decompose, this allows the stored carbon to stay in the soil for a long time, further emphasizing its vital importance in moderating the global climate (Castillo and Breva, 2012). Mangroves can hold up to 1023 t C ha^{-1} and five times more organic carbon than rainforests (Donato *et al.,* 2011; Kaufman *et al.,* 2018). Previous studies have emphasized that the bulk of this carbon is stored belowground, particularly in soil and roots (Donato *et al.,* 2011).

Despite their importance, mangrove forests face numerous threats and challenges. Anthropogenic activities such as urbanization (Marchio *et al.,* 2016), aquaculture (Primavera, 2006; Garcia *et al.,* 2014), and overexploitation (McLeod and Sam, 2006) have led to the widespread degradation of mangrove habitats. Climate change also poses a significant risk to mangroves with rising sea levels and increased frequency and intensity of storms (Gilman *et al.,* 2008; Abino *et al.,* 2014a). Globally, it is estimated that mangrove forests lost at a rate of 2.74% in 1996-2007 and 1.58% in 2007-2016 (Hagger *et al.,* 2022). Brander *et al.* (2012) forecast a decline from 6,042 to 2,082 ha for the mangrove forests in Southeast Asia between 2000 to 2050. According to Gevaña *et al.* (2018), the country's mangrove forest cover is estimated at 356,000 ha with a decadal deforestation rate of 0.5%. The main drivers of this huge loss are various anthropogenic activities, including deforestation, land conversion for agriculture, aquaculture, and coastal development (Primavera *et al.*, 2004; Garcia *et al.,* 2014).

The western part of Samar has a relatively long coastline, extending over 300 km (Abino *et al.,* 2014a). Its mangrove forests constitute 7% of the total mangrove area of the country (FMB, 2011). As one of the provinces in the Philippines with the most extensive remaining mangroves, its biomass carbon sequestration and storage potential is also expected to be huge. However, there is limited information on Samar's natural and planted mangrove stands' composition, structure, and carbon storage potential. Hence, this study provides information on the diversity, structural complexity, and carbon storage potential of mangroves in the province. The objectives of the present study were to (i) identify mangrove species composition and diversity, (ii) determine the mangrove community structure, and (iii) evaluate the biomass and carbon stock concentration. The data collected from this study provides more comprehensive information for properly implementing mangrove conservation programs and developing local-specific climate change mitigation strategies.

Materials and methods

Description of the sites

This study was conducted in the natural and planted mangrove forests on the municipal island of Zumarraga, Samar (Fig. 1). The planted stand is located at the coastal village of Pangdan (11° 37' 55" North and 124° 50' 55" East), while the natural stand is located at Botaera (11° 39' 52" North and 124° 50' 26" East). The biophysical conditions of both mangrove forests were relatively similar. These two sampling sites receive tidal inundation regularly and have a sandy-muddy soil type. The coastal town is characterized by having no dry season and a pronounced rainfall from December to February. The mean annual precipitation (MAP) is 1755 mm (Province of Samar, 2023). Both sampling sites were selected based on accessibility and safety when going to and from the mangrove forest.

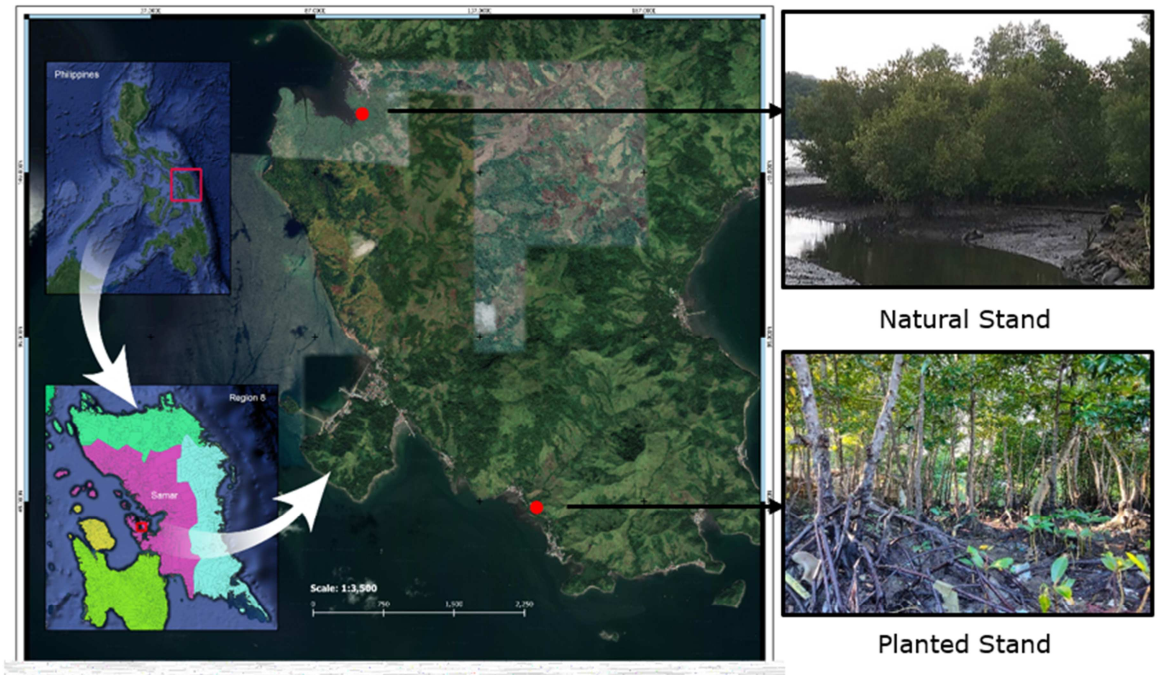

Fig. 1. Location of Zumarraga, Samar, Philippines, and photographs of the natural and planted stands.

Sampling method

The transect-line method was used to assess the natural and planted mangrove forests of Zumarraga, Samar. Five transects were established perpendicular to the shore. The adjacent transects were typically >50 m apart, depending on the dominant zonation pattern. Three 10 x 10 m plots were established along the transect line, which characterized the mangrove forest's landward, middleward, and seaward zones. These plots were systematically selected and spaced out to cover the different zones.

All trees with a diameter breast height (DBH) of 2.5cm and above were identified and counted within the sampled plot. DBH was measured at 130cm above the ground for relatively straight trees. If the observed tree has a forked stem below 130cm, individual branches were treated as separate stems. DBH was measured 30cm above the highest prop root for *Rhizophora* species and 30cm above the buttress of a *Bruguiera* species (Kairo *et al.,* 2002). The DBH was measured using a measuring tape. Tree height (m) was also estimated and recorded.

All the seedlings and saplings inside the plot were identified and counted. Saplings are trees with a diameter of less than 4cm and a height greater than 1 meter, while seedlings are trees with a height of less than 1 meter (Deguit *et al.,* 2004). Identification of the mangrove species was based on the nomenclature of Primavera *et al.* (2004) and Primavera (2009). A field guide was used to facilitate a better understanding of the morphological features of mangroves and easier taxon identification. In this study, only true mangrove species were recorded and measured. The conservation status of the species was also determined based on the International Union for Conservation of Nature (IUCN, 2022).

Data Analysis

Stands structure and diversity

The community structure was determined from the mangrove characteristics, which include density (stems ha^{-1}), basal area (m^2 ha^{-1}), relative density (RDen), relative frequency (RF), and relative dominance (RDom). The importance value (IVI) was also computed to determine which species have the highest structural importance in a particular mangrove community. The IVI was calculated by adding relative density, relative frequency, and relative dominance. The Shannon-Wiener index was used to estimate species diversity, and Pielou's evenness index was used to calculate the species evenness.

Determination of biomass and carbon stock

The tree biomass was calculated using the allometric equations formulated by Komiyama *et al.* (2005) for Southeast Asian mangroves. These equations estimate the whole weight of a tree from a regression that relates biomass to non-destructive growth parameters derived from DBH. The total biomass was calculated by summing up all the aboveground biomass (AGB) and belowground biomass (BGB) data from each tree.

The allometric equations for mangroves were as follows:

$$AGB = 0.251\ \rho\ D^{2.46}$$

$$BGB = 0.199\ \rho^{0.899}\ D^{2.22}$$

Where:

AGB = aboveground biomass

BGB = belowground biomass

ρ: wood density in gcm^{-3}

D: diameter at breast height (cm)

The AGB and BGB were converted to carbon stock by multiplying 0.48 and 0.39 as the conversion factors (Kaufmann *et al.,* 2016) using the following equations:

Aboveground carbon stock = AGB × 0.48

Belowground carbon stock = BGB × 0.39

The global wood density database data was used to determine the wood density for each mangrove species (Zanne *et al.,* 2009).

Results and discussion

Species Composition

A total of 129 individual trees representing 11 mangrove species were identified at the two sampling sites. The current list comprises three species belonging to the Rhizophoraceae family, two in Lythraceae, four under the Acanthaceae family, and one species each for Myrtaceae and Primulaceae (Table 1). In the natural stand, there were 38 individual trees counted, belonging to five mangrove species, which include *Avicennia alba*, *Avicennia officinalis*, *Avicennia marina*, *Avicennia rumphiana*, and *Rhizophora stylosa* (Fig. 2). On the other hand, there were 91 individual trees counted in the planted stand, representing ten mangrove species, namely: *A. marina*, *A. officinalis*, *A. alba*, *R. stylosa*, *Rhizophora apiculata*, *Sonneratia alba*, *Sonneratia caseolaris*, *Osbornia octodonta*, *Aegiceras floridum*, and *Ceriops decandra*.

Table 1. Mangrove species identified in the different sampling sites. (✓) indicated the presence of species; (-) indicated the absence of species.

Mangrove Species	Family	Natural Stand	Planted Stand	Conservation Status
Aegiceras floridum	Primulaceae	-	✓	Near Threatened
Avicennia alba	Acanthaceae	✓	✓	Least Concern
Avicennia marina	Acanthaceae	✓	✓	Least Concern
Avicennia rumphiana	Acanthaceae	✓	-	Vulnerable
Avicennia officinalis	Acanthaceae	✓	✓	Least Concern
Ceriops decandra	Rhizophoraceae	-	✓	Near Threatened
Osbornia octodonta	Myrtaceae	-	✓	Least Concern
Rhizophora apiculata	Rhizophoraceae	-	✓	Least Concern
Rhizophora stylosa	Rhizophoraceae	✓	✓	Least Concern
Sonneratia alba	Lythraceae	-	✓	Least Concern
Sonneratia caseolaris	Lythraceae	-	✓	Least Concern

For conservation status, eight species fall under the Least Concern status. According to the IUCN, these species have a lower risk of extinction. Similarly, one species (*A. rumphiana*) is considered Vulnerable, and two species (*C. decandra* and *A. floridum)* were listed as Near Threatened. Moreover, four species (*A. alba*, *A. marina*, *A. officinalis*, and *R. stylosa*) were observed at both sampling sites. In comparison, six species (*A. floridum, C. decandra, O. octodonta, R. apiculata, S. alba,* and *S. caseolaris*) occurred only in the planted stand.

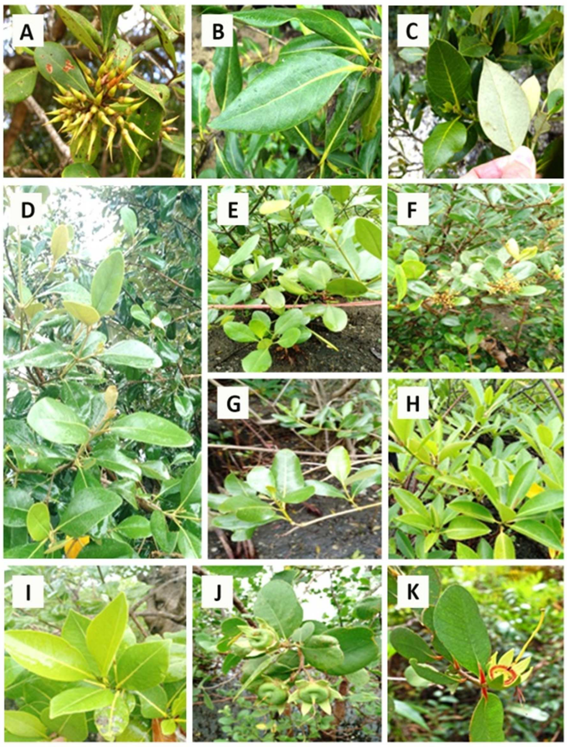

Fig. 2. True mangrove species identified in natural and planted stands of Zumarraga, Samar (A) *Aegiceras floridum*; (B) *Avicennia alba*; (C) *Avicennia marina*; (D) *Avicennia rumphiana*; (E) *Avicennia officinalis*; (F) *Osbornia octodonta*; (G) *Ceriops decandra*; (H) *Rhizophora apiculata*; (I) *Rhizophora stylosa*; (J) *Sonneratia alba*; (K) *Sonneratia caseolaris.*

Species Diversity Analysis

The Shannon-Wiener index estimates species diversity and distribution, while Pielou's evenness index measures the distribution of species and individuals within a plot. The species diversity in the planted stand was higher (H'= 1.90) compared to the natural stand (H'= 1.13) (Table 2). In Pielou's evenness index, the planted stand has more evenly distributed species (J'= 0.83) than the natural stand (J'= 0.70).

Mangrove Community Structure

Importance value (IVI) looked more closely at the variations of mangrove forests based on the significance of a species to the overall community structure (Rotaquio *et al.,* 2007). These came from the summation of the percentages of mangrove species' relative density (RDen), relative frequency (RF), and relative dominance (RDom). Based on the computed IVI, *A. marina* turns out to dominate the natural stand with a value of 168.55%, followed by *R. stylosa* (64.07%) and *A. alba* (33.13%) (Table 3). The lowest IVI in this area was *A. officinalis,* with only 5.71%. The dominance of *A. marina* in this area resulted in many homogeneous plots, thus making it the primary species for this sampling site.

Table 2. Mangroves diversity analysis in the different sampling sites.

Diversity Analysis	Natural Stand	Planted Stand
Shannon-Wiener Diversity Index (H')	1.13	1.90
Pielou's Evenness Index (J')	0.70	0.83
No. of Species	5	10

The IVI results in the planted stand showed that *A. marina* still has the highest IVI value (75.61%), followed by *S. alba* (63.83%), *R. apiculata* (52.89%) *R. stylosa* (33.88%), and *A. alba* (23.02%), while the lowest IVI was registered in *S. caseolaris* with 4.04% (Table 4). The data further revealed that *A. marina* had the highest values for relative density (26.62%) and relative dominance (27.37%), while *S. alba* recorded the highest relative frequency (24.32%) among other species.

Table 5 shows the characteristics of all mangrove species identified in natural and planted stands. *Avicennia marina* has the widest DBH with 50cm and accounts for the highest stand basal area with 11.72m^2 ha^{-1} in the natural stand.

The same species also registered the tallest at 25m. *Avicennia alba* came next with a DBH of 36cm. This species also obtained the second-highest stand basal area with 2.70m^2 ha^{-1}. The narrowest DBH measurement was recorded in *A. rumphiana* and *R. stylosa* at 10cm. The stand basal area of *A. officinalis* was relatively low, with only 0.18m^2 ha^{-1}.

Table 3. Relative density (RDen), relative frequency (RF), relative dominance (RDom), and importance value (IVI) in the natural stand.

Mangrove Species	No. of Individuals	RDen (%)	RF (%)	RDom (%)	IVI (%)	Rank
Avicennia marina	24	47.41	50.00	71.15	168.55	1
Rhizophora stylosa	5	39.12	19.23	5.72	64.07	2
Avicennia alba	4	5.18	11.54	16.41	33.13	3
Avicennia rumphiana	4	7.51	15.38	5.63	28.53	4
Avicennia officinalis	1	0.78	3.85	1.09	5.71	5

Table 4. Relative density (RDen), relative frequency (RF), relative dominance (RDom), and Importance Value (IVI) in the planted stand.

Mangrove Species	No. of Individuals	RDen (%)	RF (%)	RDom (%)	IVI (%)	Rank
Avicennia marina	22	26.62	21.61	27.37	75.61	1
Sonneratia alba	19	23.38	24.32	17.13	64.83	2
Rhizophora apiculata	23	15.58	8.11	29.20	52.89	9
Rhizophora stylosa	8	12.34	13.51	8.03	33.88	3
Avicennia alba	7	8.44	8.11	6.65	23.02	4
Aegiceras floridum	3	5.84	5.41	2.69	13.94	5
Osbornia octodonta	4	4.55	5.41	3.65	13.60	6
Avicennia officinalis	2	1.30	5.41	2.86	9.57	7
Ceriops decandra	2	1.30	5.41	1.72	8.43	8
Sonneratia caseolaris	1	0.65	2.70	0.69	4.04	10

Table 5. DBH range (cm), height range (m), and stand basal area (m^2 ha^{-1}) of natural and planted stands in Zumarraga, Samar.

Mangrove Species	DBH Range (cm)		Height Range (m)		Stand Basal Area (m^2 ha^{-1})	
	Natural	Planted	Natural	Planted	Natural	Planted
Aegiceras floridum	-	18-40	-	4-5	-	2.88
Avicennia alba	24-36	15-47	5-12	3-5	2.70	7.13
Avicennia marina	15-50	17-50	4-25	3-8	11.72	29.33
Avicennia officinalis	15	40-43	15	3-4	0.18	3.06
Avicennia rumphiana	10-21	-	10-21	-	0.92	-
Ceriops decandra	-	25	-	3	-	1.85
Osbornia octodonta	-	20-40	-	5-7	-	3.92
Rhizophora apiculata	-	22-60	-	4-8	-	31.29
Rhizophora stylosa	10-22	20-40	10-22	3-8	0.94	8.61
Sonneratia alba	-	15-47	-	3-9	-	11.84
Sonneratia caseolaris	-	20	-	4	-	0.74

Rhizophora apiculata registered the widest DBH range with 22-60cm, accounting for the highest stand basal area (31.29 m^2 ha^{-1}) in the planted stand. *Avicennia marina* ranked second with a DBH mostly between 17-50cm and a stand basal area of 29.33 m^2 ha^{-1}. *Sonneratia caseolaris* got the smallest DBH and stand basal area, with only 20cm and 0.74 m^2 ha^{-1}, respectively. The tree height at this sampling site varies between 3 m and 9 m, with an average of 6 m. *Sonneratia alba* was the tallest tree among the species, followed by *R. apiculata, A. marina,* and *R. stylosa*. Trees recorded with wider DBH values were generally observed to register the tallest height among trees. Most of the larger trees dominated the planted stand compared to the natural stand, based on the recorded DBH and tree height measurements.

Estimation of Biomass and Carbon Stock

Tree biomass measurement is necessary to estimate carbon stocks and determine its potential for sequestering carbon dioxide (Howard *et al.,* 2014). Stem diameter and wood density were included in the allometric equations since these factors are quantifiable (Komiyama *et al.,* 2005). As shown in Table 6, the AGB in the natural stand was 106.76 t ha^{-1}, while the BGB produced 53.15 t ha^{-1}. In terms of the equivalent total carbon stock, the value ranged from 5.53 to as high as 28.48 t C h^{-1}.

Among the different species, the highest AGB and BGB belong to *A. alba*, with 42.75 t ha⁻¹ and 20.41 t ha⁻¹, respectively. The same species also obtained the highest value in carbon stock, with 20.52 t C ha⁻¹ (AGB) and 7.96 t C ha⁻¹ (BGB). In this study, the greater percentage of the total biomass is attributed to AGB, accounting for 67%, while BGB accounts for the rest. The planted stand's total AGB was 596.30 t ha⁻¹, while its BGB was 269.77 t ha⁻¹ (Table 7). In detail, *R. apiculata* contributed the highest AGB with 128.35 t ha⁻¹ and BGB equivalent to 54.28 t ha⁻¹. The total AGB carbon varies among species from 6.07 t C ha⁻¹ to a high of 61.61 t C ha⁻¹. The BGB carbon stock also ranged from 2.67 to 21.17 t C ha⁻¹. Among the mangrove species, huge quantities of biomass and stored carbon were estimated in those trees with large girths and species with high wood density values.

Table 6. Summary of biomass and carbon stock by species in a natural stand in Zumarraga, Samar.

Mangrove Species	Biomass (t ha⁻¹)			Carbon (t C ha⁻¹)		
	AGB	BGB	Total	AGB	BGB	Total
Avicennia alba	42.75	20.41	63.16	20.52	7.96	28.48
Avicennia officinalis	7.88	4.47	12.35	3.78	1.74	5.53
Avicennia marina	31.22	15.08	46.29	14.98	5.88	20.86
Avicennia rumphiana	12.32	6.58	18.90	5.91	2.57	8.48
Rhizophora stylosa	12.60	6.61	19.21	6.05	2.58	8.63
TOTAL	106.76	53.15	159.91	51.25	20.73	71.97

Table 7. Summary of biomass and carbon stock by species in a planted stand in Zumarraga, Samar.

Mangrove Species	Biomass (t ha⁻¹)			Carbon (t C ha⁻¹)		
	AGB	BGB	Total	AGB	BGB	Total
Rhizopora apiculata	128.35	54.28	182.64	61.61	21.17	82.78
Avicennia marina	84.67	37.44	122.11	40.64	14.60	55.24
Avicennia alba	37.36	18.16	55.52	17.93	7.08	25.02
Avicennia officinalis	96.54	42.87	139.41	46.34	16.72	63.06
Rhizopora stylosa	63.15	28.77	91.92	30.31	11.22	41.53
Sonneratia alba	36.74	17.40	54.15	17.64	6.79	24.42
Osbornia octodonta	53.19	24.42	77.60	25.53	9.52	35.05
Sonneratia caseolaris	12.65	6.86	19.50	6.07	2.67	8.75
Aegicera floridum	43.98	20.38	64.36	21.11	7.95	29.06
Ceriops decandra	39.67	19.19	58.86	19.04	7.49	26.53
TOTAL	596.30	269.77	866.08	286.23	105.21	391.44

Discussion

Tree Composition and Diversity

Of the world's 70 true mangrove species, the Philippines alone has at least 39 tree species from 18 families (Primavera *et al.*, 2004). The country also ranks 15th among the most mangrove-rich countries, accounting for 1.9% of the global mangrove (Buitre *et al.,* 2019). This study recorded 11 true mangrove species in the natural and planted mangrove forests of Zumarraga, Samar, constituting 28.21% of the total mangrove species recorded in the Philippines. The result was low compared to the study of Lillo *et al.* (2022) at Camotes Island, Cebu, with 31 species; Palawan Island and Tacloban City, Leyte, both with 23 species (Dangan-Galon *et al.,* 2016; Patindol and Casas, 2019); and in Pagbilao, Quezon, with 22 species (Tobias *et al.,* 2017). However, this contrasts with the study of Abino *et al.* (2014a) in Pinabacdao, Samar, where only eight species were recorded. It seems that several specific species were only observed in particular mangrove stands. Species like *A. floridum, C. decandra, O. octodonta, S. caseolaris,* and *R. apiculata* were only found in the planted stand, while *A. rumphiana* was only identified in the natural stand.

This study also recorded *A. rumphiana*, which the IUCN Red List has categorized as Vulnerable since this species is rare in some areas, and the population generally declines (IUCN, 2022). The list also includes two Near Threatened species (*C. decandra* and *A. floridum*), while the rest are of Least Concern. *Ceriops decandra* and *A. floridum* are considered nearly threatened species since they are uncommon and have limited distribution. Although this classification is based on a global assessment and may not be true in all other regions and countries, it is useful in guiding conservation measures that need to be implemented locally. Overall, the findings of this study could serve as a basis for prioritizing future conservation projects in the municipality of Zumarraga, Samar, where mangrove species need protection.

The Shannon-Wiener diversity index (H') used in this report assumes that all species are represented and randomly sampled. According to the classification scale by Fernando (1998), as used by Gevaña and Pampolina (2009), a relative value of more than 3.5 is exceptionally very high, while a value of less than 1.99 is considered very low. Pielou's Evenness index (J') is another measure of diversity that focuses on how evenly the individuals in the community are distributed. A value closer to 1.0 indicates a comparatively even distribution.

The diversity index in this study for natural and planted stands was very low compared to Banaybanay, Davao Oriental, with a computed value of H'= 3.145 (Pototan *et al.,* 2021) and Camotes Island, Cebu, with H'= 3.011 (Lillo *et al.,* 2022). However, the result of this study is relatively higher than that of Patindol and Casas (2019), which only obtained a value of H'= 0.914 and Abino *et al.* (2014a) with H'= 1.63. Low diversity in the natural stand could be due to the few species present and the dominance of *A. marina*. Tomlinson (1986) states that *A. marina* is the Indo-Pacific region's most widely distributed and dominant species. This pioneering species usually colonizes young mangrove forests and forms dense, single-species communities (Chen *et al.,* 2016). To increase diversity in this natural mangrove forest, future restoration programs may consider planting more *A. marina* to develop and improve succession, eventually resulting in a diverse mangrove forest.

On the other hand, although the planted stand has ten species, the diversity is still very low according to the classification, probably because some species, like *S. caseolaris*, *C. decandra*, *A. officinalis,* and *A. floridum,* have very low counts, thus likely affecting the diversity value. In addition, anthropogenic activities at the sampling sites may have caused damage to the mangrove forest and likely impacted the diversity. Some of the observed anthropogenic activities include illegal cutting and the presence of garbage. Meanwhile, the evenness index was classified as relatively high for natural (J'= 0.70) and planted stands (J'= 0.83), indicating that the mangrove species were evenly distributed. In general, several authors (Fries and Webb, 2014; Martinez and Buot, 2018; Goloron *et al.,* 2020) emphasized that species diversity is influenced by various factors, including environmental conditions (salinity and soil characteristics), hydrological dynamics (tidal regime and water circulation), substrate characteristics, climate (temperature and precipitation), and anthropogenic impacts. However, these factors were not investigated; hence, this needs further study.

Mangrove Community Structural Features

The importance value (IVI) indicates the structural importance of each species in the community. It shows the degree to which a species dominates the forest stands and its contribution to productivity (Faridah-Hanum *et al.,* 2012). This study has shown that the most important species in the natural and planted stands are the same. Among the 11 species identified, *A. marina* is the most important since it obtained the highest values in relative density and relative dominance among different species. This implies that *A. marina* has the highest number of individuals per unit area and contributes most significantly to mangrove biomass. Meanwhile, *S. alba* has the highest relative frequency, which means this species appears the most in each sampling plot and could have the highest contribution to the energy cycle of the ecosystem.

Avicennia marina in the natural stand obtained an IVI value of 168.55%, while the planted stand was 75.61%, lower than the computed value reported in Davao Del Norte of only 19% (Pototan *et al.,* 2017). Alimbon and Manseguiao (2021) also reported that

A. marina was the most important species in Panabo Mangrove Park, Davao del Norte, with an IVI of 153.33%. According to Tomlinson (1986), *Avicennia* plants have a worldwide occurrence. They are densely distributed mangrove species found in rivers and seabeds in tropical and temperate regions. This dominance could be explained by the adaptability of this species to high salinity and anaerobic environments (Hariyanto *et al.,* 2019). Also, the environmental conditions are probably favorable for its growth; hence, the species thrives well in this area. Important factors controlling mangrove distribution include tidal inundation, salinity, degree of flooding, and soil characteristics (Das *et al.,* 2019; Raganas and Magcale-Macandog, 2020). Furthermore, many mangrove seedlings and saplings of the dominant species also contributed to the recruitment of mangroves in the natural stand in Zumarraga, Samar. A total of 159 seedlings and saplings of *A. marina* were recorded, and only a few for other mangrove species.

Avicennia marina (11.72 m^2 ha^{-1}) and *R. apiculata* (31.29 m^2 ha^{-1}) had the highest stem basal areas in natural and planted mangrove forests. This can be attributed to the wider DBH obtained by each tree. The widest DBH of *A. marina* and *R. apiculata* is 50cm and 60cm, respectively. These values are much larger than those of the same species studied by Alimbon and Manseguiao (2021) in Panabo Mangrove Park, which only reached 7.22cm and 5.90cm, respectively. Compared with other mangrove communities in the Philippines, the mean DBH measurement in this study is relatively lower than those in Verde Island Passage (Cuadimat and Rodriguez, 2017) but higher than those in Dinagat Island (Lillo and Fernando, 2017).

Biomass and Carbon Stock in Mangrove Forests

The allometric equations formulated by Komiyama *et al.* (2005) were utilized in this investigation, which used the tree's trunk diameter and wood density. These variables largely influence a tree's biomass and carbon storage potential (Kridiborworn *et al.,* 2012). The results in Tables 6 and 7 illustrate that the planted stand is higher than the natural stand in terms of biomass and carbon pool concentration. The difference may be attributed to the fact that planted mangroves have larger tree trunks. *Avicennia marina*, *R. apiculata,* and *S. alba* had the largest trunk sizes among other species. Trees' spacing is also regarded as instrumental in hastening tree biomass accumulation. Trees in the planted stand do not compete for space since there was enough distance between seedlings during planting; hence, growth for the stem and girth are not limited. Furthermore, the varying topography, hydrologic regime, erosion, and exposure to current may also hold significant factors for a tree's faster growth and survival (Samson and Rollon, 2008). Such assumptions, however, need further assessment to identify the environmental factors affecting biomass accumulation.

In detail, the total biomass (159.91 t ha^{-1}) obtained in this study for the natural stand is lower than in Bahile, Puerto Princesa City, Palawan (757.7 t ha^{-1}; Abino *et al.,* 2014b), Pinabacdao, Samar (401.07 t ha^{-1}; Abino *et al.,* 2014a), and Sarangani Province (1267.87 t ha^{-1}; Barsete *et al.,* 2016), which used the same allometric equations. However, this contrasts with the study in Panabo Mangrove Park (77.45 t ha^{-1}; Alimbon and Manseguiao, 2021) and Pagbilao, Quezon (61.34 t ha^{-1}; Tobias *et al.,* 2017), where the total biomass was lower compared to the present study.

While several literatures are available on the biomass of a natural mangrove forest, only a few studies have been conducted in a planted mangrove forest in the Philippines. The total biomass estimates acquired in this study (866.08 t ha^{-1}) are worth comparing to the reports undertaken in different parts of the country. The result in this study was lower than in Malita, Davao Occidental (1309.37 t ha^{-1}; Bersaldo, 2023), and in Banacon Island, Bohol (1942.9 t ha^{-1}; Camacho *et al.,* 2011). Meanwhile, the estimated carbon in the planted stand (391.44 t C ha^{-1}) was much higher than those obtained in the natural stand (71.97 t C ha^{-1}). The carbon pool estimated by Gevaña *et al.* (2017) (1120.5 t C ha^{-1}), Camacho *et al.* (2011) (874.3 t C ha^{-1}), and Bersaldo, (2023) (654.69 t C ha^{-1}) was much higher than in the planted stand in this study, but the estimated value is lower than in Aklan (82.12 t C ha^{-1}; Barrientos and Apolonio, 2018) and Palawan (5.2 t C ha^{-1}; Castillo and Breva, 2012).

According to Howard *et al.* (2014), the carbon stock ranges from 55 to 1376 Mg C ha^{-1}, the average being 386 Mg C ha^{-1}. With this, the estimated carbon stock in this study was within the acceptable range of values. In an assessment of the biomass of mangrove forests conducted over several years, Komiyama *et al.* (2008) found that the difference in biomass estimations depends on species and geographic location. In addition, variations in biomass and carbon stock values could be attributed to various environmental factors, including nutrients, salinity, temperature, precipitation, tidal inundation, and river flows (Alongi, 2012).

Conclusion

This study has demonstrated that natural and planted mangrove stands in Zumarraga, Samar, still have a good number of mangroves, as evidenced by the high importance value of dominant mangrove species of *A. marina* and *R. apiculata*. Although the diversity of mangroves is very low, these values suggest that mangrove diversity could increase further if a sustainable conservation effort is implemented and maintained. Unfortunately, the present study cannot further conclude the increase or decrease in the diversity of mangroves in these areas since no baseline data was collected. Even if the natural and planted stands have very low species diversity, the ability to store and sequester carbon cannot be undermined since the carbon stock values in this study were within the acceptable range of values. The total carbon stored in the natural stand is 71.97 t C ha$^{-1,}$ while in the planted stand is 391.44 t C ha^{-1}. However, anthropogenic activities like cutting down trees observed at the sampling sites may release this stored carbon into the atmosphere as carbon dioxide and compromise its potential to sequester a significant amount of carbon. Therefore, local communities should actively protect and manage both mangrove stands to maintain forest carbon sequestration capacity.

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