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Species diversity and composition, conservation status, and carbon stocks of the mangrove forests in Zamboanga City, Philippines

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[1]Department of Environmental Science, School of Interdisciplinary Studies, Mindanao State University-Iligan Institute of Technology. Andres Bonifacio Avenue, Iligan City 9200, Lanao del Norte, Philippines. Tel.: +63-063-221-4056, ♥email: patriciaangela.epan@g.msuiit.edu.ph
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Abstract. *Epan PAS, Torres AG, Mag-Aso JR, Tiu-Tatil WA. 2026. Species diversity and composition, conservation status, and carbon stocks of the mangrove forests in Zamboanga City, Philippines. Biodiversitas 27 (6): d270608. https://doi.org/10.13057/biodiv/d270608.* Mangrove ecosystems are essential protective barriers for coastal areas and provide important ecological services to society, such as shelter from storms and strong waves, habitat for a variety of fish species, and an extensive amount of carbon sequestration. However, specific data on the species composition and management strategies for this ecosystem are currently insufficient in Zamboanga City, Philippines. To address this gap, this study assessed the taxonomic diversity and composition, aboveground biomass and carbon stock, and conservation status of mangrove forests in three sites: Talabaan, Victoria, and Great Sta. Cruz Island (GSCI). The field sampling was conducted in June, July, December of 2025, and January of 2026. In each study site, three 150-m transects were established perpendicular to the shoreline. Within each transect, eight 10 m x 10 m quadrats were systematically positioned at 10-m intervals, resulting in a cumulative sample size of n = 72 quadrats across the study area. A total of 15 mangrove species from 7 families and 8 genera were identified across all sites, with *Rhizophora* genus dominating (*Rhizophora apiculata*, 346 individuals; *Rhizophora mucronata*, 223 individuals). Taxonomic surveys revealed that while the majority of the identified species are categorized as 'Least Concern' by the IUCN, the presence of *Avicennia marina* var. *rumphiana* (Vulnerable) and *Sonneratia ovata* (Near Threatened) indicates the conservation importance of the study sites. Victoria exhibited a relatively high diversity (H' = 1.86), while Talabaan showed the lowest (H' = 1.39). GSCI recorded the highest carbon stock at 41.61 t C ha^{-1} with a carbon equivalent of 152.71 t CO_2 ha^{-1}. Results show that while reforested sites like Talabaan and Victoria contribute to mangrove vegetation cover, protected natural stands like GSCI remain superior in both carbon sequestration and biodiversity. By quantifying the ecological disparities between reforested and natural stands, this study provides localized ecological data that may serve as a preliminary baseline for future conservation planning and carbon sequestration strategies in Zamboanga Peninsula.

Keywords: Aboveground biomass, allometry, coastal management, Rhizophoraceae, Zamboanga Peninsula

INTRODUCTION

The Philippines, an archipelago with a coastline stretching approximately 36,289 km (NAMRIA 2017; Alvarez and Otadoy 2023), provides favorable tropical environmental conditions for diverse mangrove growth. Consequently, the country supports nearly half of the world's known mangrove species (Garcia et al. 2014; Buitre et al. 2019). More broadly, Southeast Asia contains the most extensive mangrove ecosystems globally, accounting for 32.2% of global coverage (Gerona-Daga and Salmo 2022). Although the Philippines only contributes about 1.9% to 2% to this global total, its forests remain a primary focus for international research and urgent conservation because of their distinct ecological significance (Bunting et al. 2022).

Mangroves function as critical coastal buffers, maintaining water quality and acting as "bio-shields" that protect communities from storm surges and seasonal flooding (Goloran et al. 2020; Sunkur et al. 2023). They also provide essential socio-cultural resources, such as traditional medicines and building materials, for indigenous groups (Walters et al. 2005; Duryat et al. 2024). Mangroves are widely recognized as important natural climate solutions due to their capacity for carbon sequestration (Song et al. 2021; Friess et al. 2023). Although they cover only 0.2% of the Earth's surface, these "blue carbon" ecosystems store carbon at higher rates than many terrestrial forests (Nellemann et al. 2009; International Finance Corporation 2024). On average, a mangrove forest can sequester between 6 and 8 megatons of CO_2 equivalent per hectare annually, a capacity that is 2 to 4 times higher than that of mature tropical upland forests (Fatoyinbo et al. 2018). Thus, quantifying aboveground biomass (AGB) is a primary step in understanding carbon capture potential of mangrove forests compared to terrestrial upland forests (Donato et al. 2011).

Despite this profound ecological and socio-economic richness, mangrove ecosystems across the region face severe existential threats from rapid habitat degradation (Spalding et al. 2010; Spalding and Leal 2021; Bhowmik et al. 2022). This loss is primarily catalyzed by the conversion of intertidal habitats into brackish-water aquaculture ponds (Richards and Friess 2012; Garcia et al. 2014; Gandhi and Jones 2019). Locally, these ecosystems are further subjected to urban sprawl, industrialization, and salt bed conversion (Primavera 2000; Garcia et al. 2014).

In the southern part of the archipelago, these ecosystems are highly prominent along the southeastern coastlines of

Zamboanga City in Western Mindanao, a region where the surrounding province ranks 8th nationally in mangrove extent (Long and Giri 2011). These specific forests safeguard the city from tropical storms and flooding, while serving as a vital food and livelihood source for local coastal communities. However, the mangroves of Zamboanga City are under severe pressure from uncontrolled cutting, water pollution, resource overexploitation, and rapid aquaculture conversion. This continuous environmental pressure threatens to accelerate local destruction, directly jeopardizing dependent coastal populations (Alvarez and Otadoy 2023).

Despite their ecological importance, mangrove management in Zamboanga City remains limited by the lack of site-specific ecological data. While broad national-level surveys offer a generalized perspective, they lack the complexities of the local environment. The absence of detailed empirical records regarding taxonomic composition, aboveground biomass (AGB), and current conservation status prevents these ecosystems from being integrated into formal institutional management frameworks. Furthermore, this lack of local data restricts the city's capacity to participate in global biodiversity incentive programs or engage with international carbon markets.

To address this gap, this study assessed the taxonomic diversity, biomass, carbon stock, and conservation status of the mangrove forests in Zamboanga City. While acknowledging that mangrove sediments serve as vast carbon reservoirs, this research focuses specifically on the carbon sequestered within the living biomass. Establishing this baseline holds global and localized significance; it aligns directly with United Nations Sustainable Development Goals (SDGs) by advancing SDG 14 (Life Below Water) and SDG 15 (Life on Land) through biodiversity protection, while addressing SDG 13 (Climate Action) via carbon stock quantification. Ultimately, these results provide the missing empirical foundation required by policymakers to develop targeted coastal management and conservation strategies.

MATERIALS AND METHODS

Study sites

Zamboanga City is a coastal, highly urbanized city in the Zamboanga Peninsula region of the Philippines. The city has a land area of 1,483.38 km^2 and an estimated coastline length of 301 km (City Government of Zamboanga (CGZ) 2021). The study was carried out across its three distinct mangrove ecosystems: Victoria (7°02'35.1"N, 122°11'55.2"E) and Talabaan (6°56'42.7"N, 122°10'19.3"E), and the Great Sta. Cruz Island (GSCI) (6°51'59.8"N, 122°03'50.0"E) (Figure 1).

As described via QGIS software (v3.44) based on city boundary data (CGZ 2021), Victoria hosts the largest continuous forest at 364.62 ha. Field observation showed that these mangrove stands flourish on silty mudflats influenced by freshwater and low-wave energy. Due to its distance from human settlements, Victoria experiences relatively low environmental pressure. On the other hand, Talabaan covers 197.89 ha and is characterized by small-to-medium trees adapted to sandy and rocky substrates. This area maintains a vital connection with local indigenous communities. The current ecological profile of both sites has been significantly influenced by historical reforestation initiatives documented by the Department of Environment and Natural Resources-City Environment and Natural Resource Office R-IX (DENR-CENRO 2020).

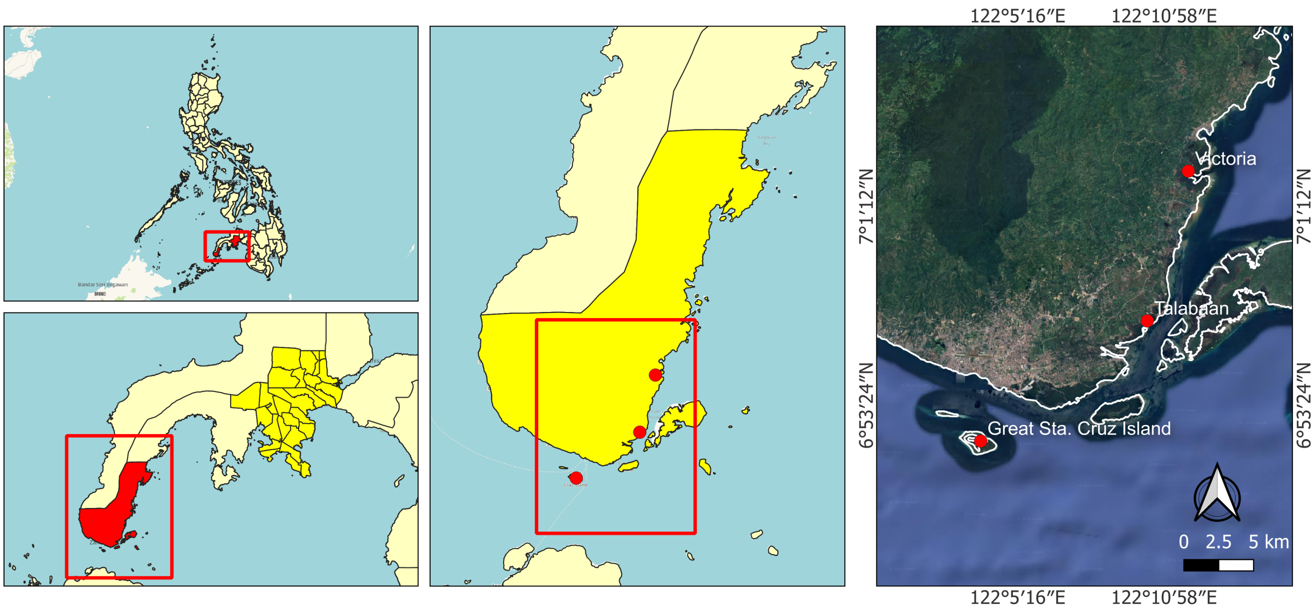

Figure 1. Geographic location of the mangrove sampling sites in Zamboanga City, Zamboanga del Sur, Philippines. The map illustrates the distribution of study areas: Victoria, Talabaan, and Great Sta. Cruz Island (GSCI)

Figure 2. Photos showing the identified mangrove forests in selected study sites. A. Victoria, B. Talabaan, C. Great Sta. Cruz Island (GSCI), Zamboanga City

In contrast, Great Sta. Cruz Island (GSCI) serves as a regional benchmark, as it preserves 169.20 ha of pristine mangrove forest. According to DENR-CENRO R-IX (2020), this area contains one of the region's most intact mangrove ecosystems, providing an important baseline for measuring the ecological health of neighboring stands. Established as a protected area via Proclamation No. 271 of 2000, it remains the city's only naturally occurring stands, which are uniquely characterized by their adaptation to loamy and rocky soil conditions. LGU representatives reported that this site is uniquely characterized by its intact biodiversity and is inextricably linked to the traditional resource-use patterns of the Sama-Banguingui tribe. It also serves as an ecotourism destination, supported by strictly regulated lagoon tours that balance environmental protection with public engagement. The representative forest structure and stand density of these sites are visually documented in Figure 2.

Entry protocol

Authorization for this study included local permits from the relevant Barangay Offices and a Gratuitous Permit (No. IX-PA-2025-07) issued by the DENR Region 9 Office according to Republic Act No. 9147. Fieldwork was conducted in conformity with national ethical guidelines for biodiversity studies in order to minimize the damage sustained in the area.

Field sampling

Data were collected from June to July and December 2025 to January 2026 using standard forest assessment methods with modifications following the manual for the modified Biodiversity Assessment and Monitoring System (BAMS) (BMB, GIZ 2017). To ensure an equal sampling across the three study sites, a uniform design was implemented: three 150-m transect lines were established perpendicular to the shore, and along each transect line, eight 10 m x 10 m quadrats were laid at 10-m intervals, resulting in a cumulative sample size of *n* = 72 quadrats across all sites. The sampling design standardized quadrat placement across tidal zones at all sites. This configuration established a total sampling area of 2,400 m² (0.24 ha) for each individual study site, yielding a cumulative total sampling size of 7,200 m² (0.72 ha) across the entire study. The sampling design standardized quadrat placement across tidal zones at all sites.

Only trees ≥5 cm Diameter at Breast Height (DBH) were measured, counted, and documented, while saplings and deadwood were omitted so that the focus was on the primary living carbon pools. Diameter was measured at breast height. In the case of multi-stemmed individuals, the DBH was measured and recorded separately, and the mean diameter was calculated (Kauffman and Donato 2012) to serve as a representative value for allometric models. Taxonomic identification was based on key morphological characteristics in situ using the diagnostic descriptions of Primavera (2009). Although this study used primarily non-destructive methods to reduce habitat disturbance, photographic records were viewed as disallowing long-term reproducibility compared to physical herbarium vouchers. Species identification was confirmed by a DENR mangrove focal point from the Biodiversity Management Unit. All photographic vouchers were archived digitally for easy access by the corresponding author as a means of allowing for verifying and comparing future studies. The IUCN Red List of Species, version 2010-2, was the reference for most species listed in this study (Duke et al. 2010a,b,c,d,e; Ellison et al. 2010a,b,c,d,e,f,g; Salmo et al. 2010) except for *Acanthus ilicifolius* L., using IUCN 2011-1 (Juffe Bignoli 2011).

Composition and diversity analysis

Species composition is the number of different species in the study area; it can be described in terms of relative density (RD), relative frequency (RF), and relative basal area (RBA). The importance value index (IVI) provides an overview of the influence or role of a type of mangrove species in the community (Aye et al. 2022).

The formula that calculates the RD, RBA, RF, and IVI is listed below:

$$RD = \left(\frac{\text{Density of a species}}{\text{Total density of all species}}\right) x\ 100$$

$$RBA = \left(\frac{\text{Basal area of a species}}{\text{Total basal area of all species}}\right) x\ 100$$

$$RF = \left(\frac{\text{Frequency of a species}}{\text{Total frequency of all species}}\right) x\ 100$$

$$IVI = RD + RBA + RF$$

The basal area was calculated based on the formula adapted from the study (Aye et al. 2022).

$$\mathrm{BA/tree(m^2)} = \left(\frac{\pi(\mathrm{DBH^2})x\ 0.0001}{4}\right)$$

Where, π: A constant (3.146); DBH: Diameter at breast height (cm), 0.01 is a constant used to convert the measured centimeter square into meter square.

Total stand basal area was calculated by:

$$TSBA(\mathrm{m^2/ha}) = \left(\frac{\text{Total basal area in the plot}}{0.01}\right)$$

Where, 0.01 is the plot size in hectares, and 100 is a constant used to extrapolate the measurement of the basal area from per plot (m^2/plot) to per hectare (m^2/ha) (Aye et al. 2022).

The Shannon-Wiener diversity index (*H'*), Simpson's Dominance index (*D*) and Evenness index (*e*), all of which provide a multi-dimensional view of the structure of mangrove communities, were used to measure species diversity in this study. *H'* is sensitive to species presence; *D* is weighted to include only the most abundant species; and e differentiates between dominance by a few species compared to an even distribution of individuals among all species. Taken together, these indices provide complementary information about the habitat and the degree of biodiversity in comparison to using just one index. The data were analysed using the PAST statistical software (Hammer et al. 2001) based on these equations:

For Shannon-Wiener diversity index (*H'*), this formula was used (Shannon 1948):

$$H' = -\sum PiInPi$$

Where: *H'*: The value of the Shannon-Wiener diversity index, *Pi*: The proportion of the *i*-th species individuals to total species individuals, ln: The natural logarithm of *Pi*.

For Simpson's dominance index (*D*), this formula was used (Simpson 1949):

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

Where, *D*: Value of Simpson's diversity index, *Pi*: Proportion of individuals in the *i*-th species, *S*: Number of species.

For the Evenness index (*e*), this formula was used (Heip 1974):

$$e = H'/In\ (S)$$

Where, *S*: Number of species in the study area.

Diversity and evenness indices were evaluated using standardized categorical scales developed by Fernando (1998), which has been an important standard in Philippine ecological literature and aids to compare the mangrove forests in Zamboanga City to other regional forest types. The use of this standardized scale means that the qualitative descriptors related to the indices will be based upon an accepted ecological benchmark and not on subjective or arbitrary limitations. The specific thresholds and corresponding qualitative interpretations of those thresholds for this study are presented in Table 1.

Biomass and carbon stock

To estimate the aboveground biomass (AGB) of sampled mangrove stands, three allometric growth models were generated based on the model templates reported by Komiyama et al. (2005) that were developed using an extensive data set throughout the Indo-west Pacific regions and therefore provide a broad applicability and reliability for estimates of AGB within the mangrove taxonomic groups of Thailand and other Southeast Asia countries. As DBH (stem diameter) and wood density (p) are the major contributing factors to the physiological and structural variances across species, both are viewed as primary predictors within the allometric growth model equation. All equations used in this study estimated AGB only, as a primary step for assessment, acknowledging that total blue carbon sequestration remains underestimated. To ensure accuracy in the absence of site-specific calibration, species-specific wood density values were sourced from the Global Wood Density Database (Zanne et al. 2009), listed in Table 2. This approach minimizes estimation bias by aligning the allometric calculations with the documented physical properties of the identified mangrove taxa. Furthermore, they account for variations in wood density across different species groups, which is critical for accurate biomass estimation in mixed-species forests.

A general/common model was applied to species not covered by specific equations, while specialized models were utilized for the dominant genera:

Common model:

$$AGB = 0.251 * p * DBH^{2.46}$$

For *Rhizophora* spp:

$$AGB = 0.105 * p * DBH^{2.68}$$

For *Sonneratia* spp:

$$AGB = 0.168 * p * DBH^{2.31}$$

The aboveground biomass (AGB) estimates in these models were calculated by taking tree diameter at breast height (DBH) and multiplying this value (DBH) by corresponding wood density (p) values for each species.

Carbon stock was estimated by multiplying AGB by 0.48, while CO_2 sequestration was calculated by multiplying carbon stock by 3.67, following established protocols (Kauffman and Donato 2012; Howard et al. 2014; Alavaisha and Mongora 2016).

Table 1. Diversity index and species evenness values and their interpretation (Fernando 1998)

Ecological index	Range value	Interpretation
Shannon-Wiener diversity (*H'*)	≥3.50	Very high
	3.00-3.49	High
	2.50-2.99	Moderate
	2.00-2.49	Low
	≤1.99	Very low
Simpsons dominance (*D*)	1.00	Absolute
	0.81-0.99	High
	0.61-0.80	Moderate high
	0.41-0.60	Moderate
	0.01-0.40	Low
Evenness (*e*)	>0.8-0.9	Balanced
	>0.5-0.8	Semi-balanced
	≤0.5	Unbalanced

Table 2. Mangrove species wood density values used in this study (Zanne et al. 2020)

Species	Wood density (g/cm^3)
Avicennia officinalis L.	0.72
Avicennia marina var. *rumphiana* (Hallier f.) Bakh.	0.60
Lumnitzera racemosa Willd.	0.87
Pemphis acidula J.R.Forst. & G.Forst.	0.51
Sonneratia alba Sm.	0.51
Sonneratia ovata Backer	0.37
Xylocarpus moluccensis (Lam.) M.Roem.	0.57
Xylocarpus granatum J.Koenig	0.71
Aegiceras corniculatum (L.) Blanco	0.51
Ceriops tagal (Perr.) C.B.Rob.	0.78
Rhizophora apiculata Blume	0.85
Rhizophora mucronata Poir.	0.82
Rhizophora stylosa Griff.	0.84
Scyphiphora hydrophylacea C.F.Gaertn.	0.68

Note: Biomass and carbon estimations were limited to true mangrove species. Shrub-like taxa, specifically *Acanthus ilicifolius*, were excluded to maintain allometric consistency, as the utilized wood density is specifically for tree-form mangroves

Data management and analysis

For statistical analysis and data management, descriptive statistics (i.e., counts, percentages, means, and ranges) were calculated using Microsoft Excel and the subsequent analyses of the data were completed using PAST (Paleontological Statistics). Prior to analysis, Shapiro-Wilk and Levene's tests were done to assess normality of data and evaluate the homogeneity of variance. All three of the data sets failed to meet the normality assumption after attempts at transforming the data; therefore, a non-parametric Kruskal-Wallis H test (One-Way ANOVA) was performed to evaluate whether there was a statistical difference in the tree DBH, biomass and total carbon storage across the three study sites. Dunn's post-hoc test with Bonferroni correction was used to determine where pairwise differences occurred between each of the study sites.

RESULTS AND DISCUSSION

Species composition

A total of 15 mangrove species were documented and identified across the study sites in Zamboanga City. Among these locations, Victoria recorded the highest number of species, followed by Great Sta. Cruz Island (GSCI), while Talabaan has the fewest species (Figure 3). These identified species: *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, *Sonneratia alba*, *Sonneratia ovata*, *Scyphiphora hydrophylacea*, *Lumnitzera racemosa*, *Avicennia marina* var. *rumphiana*, *Avicennia officinalis*, *Aegiceras corniculatum*, *Ceriops tagal*, *Xylocarpus granatum*, *Acanthus ilicifolius*, *Xylocarpus moluccensis*, and *Pemphis acidula*, are distributed across 7 distinct families (Table 3), which comprises about 30% of the total number of mangrove species recorded in the country (Garcia et al. 2014). However, *S. ovata, P. acidula,* and *A. ilicifolius* were rarely encountered; present only in Victoria and GSCI. Both *R. apiculata and R. mucronata* emerged as the most dominant species across sites. A comprehensive visual guide of these identified taxa, along with their respective local names, is provided in Figure 4. This study found similar taxonomic trends as described by Calumpong and Menez (1996) for the distribution of mangrove genera from Rhizophoraceae, Acanthaceae and Lythraceae in addition to other sites within Mindanao, such as; Ozamis (Villanueva et al. 2021); Surigao City (Hugo et al. 2025); Davao Del Sur (Baylon et al. 2025) and Dumanquillas Bay (Zamboanga Del Sur) (Emeterio et al. 2024), providing further evidence of the importance of these mangrove families.

The conservation status of each of these species based on their respective IUCN Red List categories (IUCN, 2010-2; IUCN, 2011-1) (IUCN 2026) reflects the presence of threatened taxa of conservation concern; it should be noted that while the majority of taxa identified were evaluated as Least Concern (LC), the lack of future concerns for long-term stability in ecosystems subject to significant and persistent pressure from anthropogenic activities make this classification less than relevant for many of the communities within these sites. Further, the regional conservation concerns by co-locating identified taxa described above with the Vulnerable (VU) and Near Threatened (NT) taxa, such as *A. marina* var. *rumphiana* (VU) exemplify the importance of the study sites in Zamboanga in terms of their regional conservation significance, as this species is distributed in only a few small areas, is locally rare, and has been documented as experiencing declines in population and habitat degradation globally (Duke et al. 2010b; Triest et al. 2021). *A. marina* var. *rumphiana* is frequently located on the upper portion of the intertidal zone where habitat degradation is prominent (Dapar et al. 2023). Regional trends indicate that mangrove habitats within the range of *A. marina* var. *rumphiana* declined by at least 30% between 1980 and 2005 (Chan et al. 2022). However, current population data and site-specific conservation measures remain limited. Locally, while the majority of the species are designated as Other Wildlife Species (OWS), *P. acidula* is notably listed as Endangered under the Philippines Department of Environment and Natural Resources (DENR)

Administrative Order No. 2026-20. The classification of *P. acidula* as Endangered (EN) under national regulatory frameworks highlights its high conservation priority and the vulnerability of its habitat. Ecologically, this hardy species acts as a critical frontline barrier along high-energy, coralline, and rocky shorelines, stabilizing coasts against erosion and providing specialized micro-habitats (Demapitan et al. 2024). Because it occupies narrow seaward zones, it is highly susceptible to coastal development, tourism pressures, and severe habitat degradation (Demapitan et al. 2024).

Evidence of anthropogenic disturbances was found during field sampling, as shown by unauthorized timber extraction, localized accumulations of solid waste, and residential encroachments in and around the study sites. Other field observations included the use of estuaries at Talabaan and Victoria as docking locations for small-scale fishing vessels, which are also a source of stress through repeated physical disturbances. Though these field observations were not made systematically, they do provide visible examples of human impact on the special habitats of the mangrove community recorded earlier in this study. Also noted here is that the anthropogenic stressors and all ecological inferences regarding habitat health drawn from this research are geographically limited and relate only to the specific study areas; they do not represent the totality of the Zamboanga Peninsula.

Abundance and distribution

A total of 942 true mangrove individuals were recorded across all sampling sites (Table 4). *R. apiculata* was the dominant species with 346 individuals, followed by *R. mucronata* with 223 and *R. stylosa* with 100 individuals. The next most abundant were *S. alba* and *S. hydrophylacea* (71 and 60 individuals, respectively) and then *A. marina* var. *rumphiana* with 27 total individuals. There was a moderate and low frequency of other species including *C. tagal* (25), *L. racemosa* (19), *X. granatum* (18) and *A. corniculatum* (14). The least abundant species included *A. officinalis* (12), *X. moluccensis* (10), *A. ilicifolius* (7), *S. ovata* (5), and *P. acidula* (5). Victoria was unique in being considered a hotspot of biodiversity containing 12 species, including the locally found species *S. ovata* and *A. corniculatum*. While Talabaan was low in terms of richness with 7 total mangrove species, it still contained a high density of *R. mucronata.* GSCI had assembled 11 different mangrove species in total, with the only known occurrence of *A. ilicifolius*, *X. moluccensis*, and *P. acidula.*

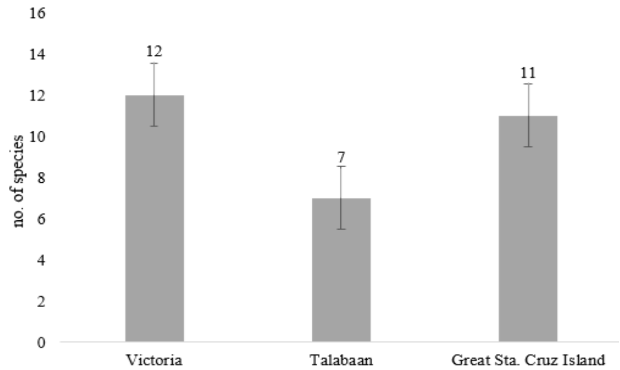

Figure 3. Mangrove species count recorded across sampled areas in Zamboanga City, Philippines

Table 3. Checklists of mangrove species, their local names, distribution, and conservation status across three sites in Zamboanga City, Philippines

Family	Species	Local name	Distribution per site			Conservation status	
			Victoria	Talabaan	GSCI	IUCN	DAO-2026-20
Acanthaceae	*Acanthus ilicifolius*	*Ragoyroy*			✓	LC[2]	OWS
	Avicennia officinalis	*Api-api*	✓	✓		LC[1]	OWS
	Avicennia marina var. *rumphiana*	*Bungalon*	✓	✓		VU[1]	OWS
Combretaceae	*Lumnitzera racemosa*	*Culasi*	✓	✓	✓	LC[1]	OWS
Lythraceae	*Pemphis acidula*	*Bantigi*			✓	LC[1]	EN
	Sonneratia alba	*Pagatpat*	✓	✓	✓	LC[1]	OWS
	Sonneratia ovata	*Pedada*	✓			NT[1]	OWS
Meliaceae	*Xylocarpus moluccensis*	*Piag-ao*			✓	LC[1]	OWS
	Xylocarpus granatum	*Tabigi*	✓		✓	LC[1]	OWS
Primulaceae	*Aegiceras corniculatum*	*Tinduk-tindukan*	✓			LC[1]	OWS
Rhizophoraceae	*Ceriops tagal*	*Tangal*	✓		✓	LC[1]	OWS
	Rhizophora apiculata	*Bakhaw lalaki*	✓	✓	✓	LC[1]	OWS
	Rhizophora mucronata	*Bakhaw babai*	✓	✓	✓	LC[1]	OWS
	Rhizophora stylosa	*Bakhaw bato*	✓	✓	✓	LC[1]	OWS
Rubiaceae	*Scyphiphora hydrophylacea*	*Nilad*	✓		✓	LC[1]	OWS

Note: Conservation Status: LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered; OWS: Other Wildlife Species
1: IUCN Red List of Threatened Species 2025-2; DAO 2026-20 (https://www.philippineplants.org/dao-2026-20.pdf)

Population density and spatial range had a clear significant association with the distribution of these species across the Zamboanga sites, with the characteristics of the mangroves evaluated corresponding to the recognized and documented ecological requirements of the mangrove species evaluated thus far. The preference of *R. stylosa* for seaward sandy/rocky substrates is confirmed by the results of this study and supported by available literature (Fernando and Pancho 1980; Patindol and Casas 2019; Stuart 2023a). *S. alba*'s occurrence within high-salinity areas supports this particular mangrove species' tolerance to newly formed sandy mudflats found in estuarine environments (Melana et al. 2000; Primavera et al. 2012). The reports of *R. apiculata*'s almost complete, widespread distribution within the study area also confirm its identification as a generalist species occupying areas of soft mud that are flooded by tidal waters (Patindol and Casas 2019; Bersaldo et al. 2023). Many of the observations of *S. hydrophylacea* and *R. mucronata* along tidal streams and riverbanks also support their adaptability to both brackish water and humus-rich soils (Patindol and Casas 2019; Stuart 2023b).

The observed abundance and distribution patterns would indicate that *R. apiculata*, *R. mucronata*, *R. stylosa*, *S. alba*, and *S. hydrophylacea* would have a great potential to restore mangrove forests in Zamboanga City. The planting of these mangrove species to re-establish mangrove forest ecosystems will be maximized with the use of previously established ecological zones. *S. alba* is the most appropriate species for planting in high-exposure seaward zones (Primavera et al. 2012), while *R. mucronata* and *R. stylosa* should be planted in riverbank and lower exposure areas, where there will be little to no wave action (Patindol and Casas 2019). *S. hydrophylacea* and *R. apiculata* would be highly adaptable to mangrove swamp areas across a variety of tidal zones (Patindol and Casas 2019).

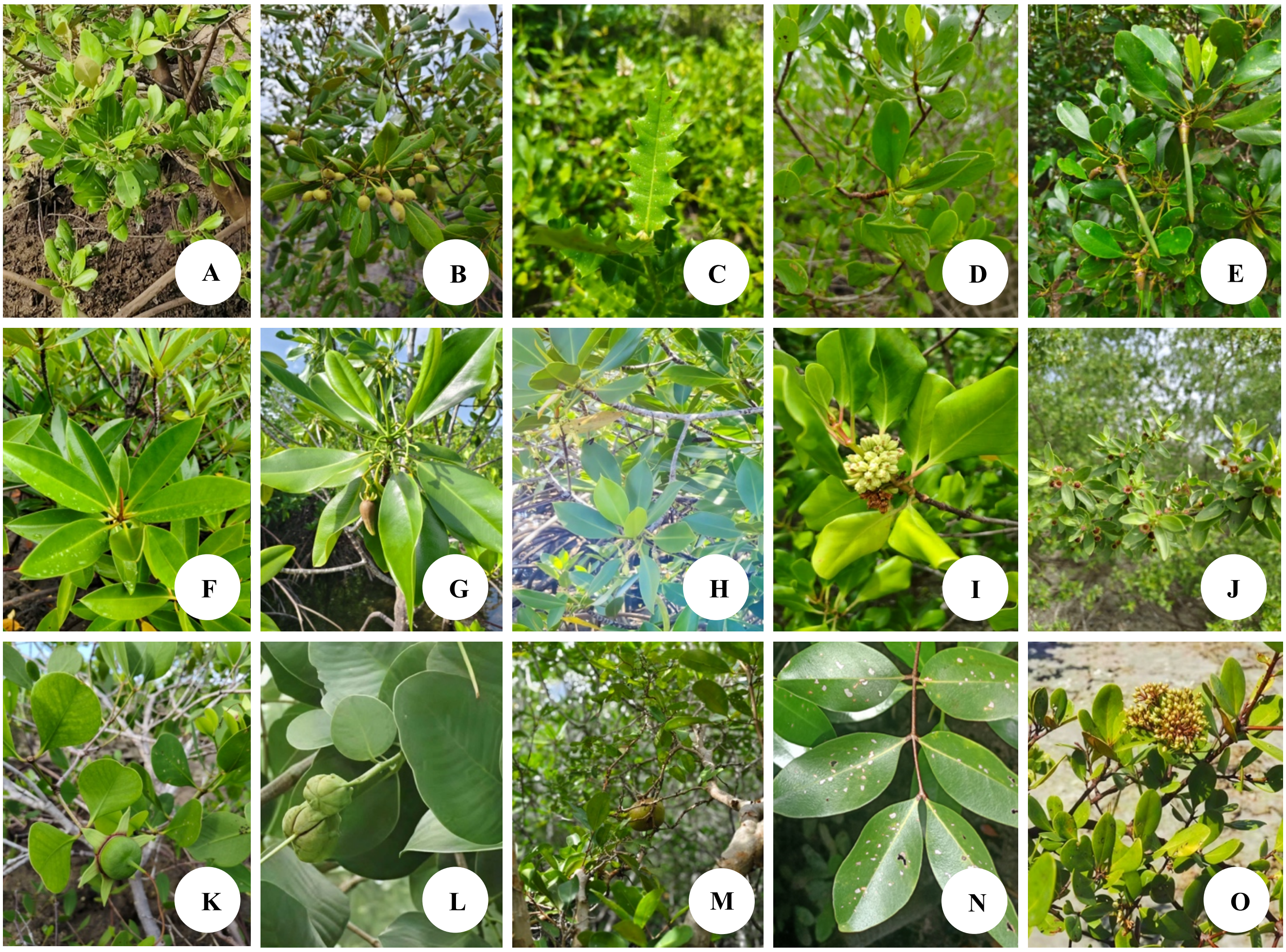

Figure 4. Mangrove species identified, and their local names, in three forests of Zamboanga City. A. *Avicennia officinalis*, B. *Avicennia marina* var. *rumphiana*, C. *Acanthus ilicifolius*, D. *Lumnitzera racemosa*, E. *Ceriops tagal*, F. *Rhizophora apiculata*, G. *Rhizophora mucronata*, H. *Rhizophora stylosa*, I. *Scyphiphora hydrophylacea*, J. *Pemphis acidula*, K. *Sonneratia alba*, L. *Sonneratia ovata*, M. *Xylocarpus granatum*, N. *Xylocarpus moluccensis*, O. *Aegiceras corniculatum*

Table 4. Distribution of abundance, frequency and Importance Value Index of species in the mangrove stands of Zamboanga City

Site	Species	Total no. of individuals	RD (%)	RF (%)	RBA (%)	IVI (%)
Victoria	*Aegiceras corniculatum*	14	4.62	7.41	4.67	16.66
	Avicennia officinalis	2	0.66	3.70	0.48	4.84
	Avicennia marina var. *rumphiana*	14	4.62	11.11	9.23	24.96
	Ceriops tagal	14	4.62	11.11	7.47	23.20
	Lumnitzera racemosa	10	3.30	3.70	1.02	8.02
	Rhizophora apiculata	124	40.92	11.11	30.47	82.50
	Rhizophora mucronata	33	10.89	11.11	5.00	27.00
	Rhizophora stylosa	2	0.66	3.70	0.54	4.91
	Sonneratia alba	29	9.57	11.11	21.77	42.46
	Scyphiphora hydrophylacea	54	17.82	11.11	17.27	46.20
	Sonneratia ovata	5	1.65	11.11	1.77	14.53
	Xylocarpus granatum					
	Aegiceras corniculatum	2	0.66	3.70	0.33	4.69
Talabaan	*Avicennia officinalis*	10	3.36	15.00	3.74	22.09
	Avicennia marina var. *rumphiana*	13	4.36	15.00	4.20	23.56
	Lumnitzera racemosa	5	1.68	10.00	1.19	12.87
	Rhizophora apiculata	32	10.74	15.00	52.75	78.48
	Rhizophora mucronata	168	56.38	15.00	9.41	80.79
	Rhizophora stylosa	41	13.76	15.00	11.70	40.46
	Sonneratia alba	29	9.73	15.00	16.99	41.72
Great Sta. Cruz Island	*Acanthus ilicifolius*	7	2.05	3.57	0.22	5.85
	Ceriops tagal	11	3.23	10.71	1.09	15.03
	Lumnitzera racemosa	4	1.17	7.14	0.26	8.58
	Pemphis acidula	5	1.47	7.14	0.33	8.94
	Rhizophora apiculata	190	55.72	10.71	71.37	137.80
	Rhizophora mucronata	22	6.45	10.71	3.47	20.64
	Rhizophora stylosa	57	16.72	10.71	11.21	38.64
	Sonneratia alba	13	3.81	10.71	3.98	18.51
	Scyphiphora hydrophylacea	6	1.76	7.14	1.17	10.07
	Xylocarpus granatum	16	4.69	10.71	4.46	19.86
	Xylocarpus moluccensis	10	2.93	10.71	2.48	16.12

Note: RD: Relative density, RF: Relative frequency, RBA: Relative basal area. The important value is calculated as IVI = RD+RF+RBA, and the IVI value (Aye et al. 2022)

Structural analysis and species diversity

The Importance Value Index (IVI), as shown in Table 4, is the metric used to quantify the ecological dominance of individual species within the community, calculated from the integrated contributions of relative density (RD), relative basal area (RBA), and relative frequency (RF) (Aye et al. 2022). The comparative results for the Shannon-Wiener Diversity index (*H'*), Simpson's Dominance index (*D*), and evenness (*e*) across the three study sites are summarized in Figure 5.

Table 4 shows that the most prevalent genus in this ecosystem is *Rhizophora*, resulting in a less complex forest structure at two out of three locations studied (Talabaan, Victoria, and Great Sta. Cruz Island). In Talabaan, *R. mucronata* is the most prevalent species, making up 56.38% of the total relative density (RD) and 80.79% of the total importance value index (IVI). In Victoria and GSCI, however, *R. apiculata* is the predominant species with RD's of 40.92% and 55.72%, respectively. The concentration of *Rhizophora* in both Victoria and Talabaan, along with a low Shannon-Wiener diversity index value (H' = 1.39) for Talabaan, suggests little ecological diversity in these locations. This pattern illustrates the prevalence of only a small number of abundant species. The data indicates that the current forest composition found in both Victoria and Talabaan is likely due to human interventions and/or reforestation initiatives that emphasize planting of *Rhizophora* propagules compared to other species based on their greater likelihood of survival (Dapar et al. 2023). Of the three sites, Talabaan is characterized by the lowest species diversity.

The GSCI is an inadequate representation of a more complex mangrove community. It has a diversity index categorized as "low" (H' = 1.56), but it has a high ecological value because of the type of species found within the community. There are 11 species of mangroves that are found at GSCI, and three of these species (*A. ilicifolius*, *X. moluccensis*, *P. acidula*) were recorded only at GSCI and are seldom included in standardized reforestation programs. The existence of these species shows that the habitat conditions are still representative of what they would have been under their natural state. The presence of *P. acidula* and *X. moluccensis* together supports the idea that the mangrove system has a naturally zonated structure and is made up of species with different environmental tolerances. In comparison, the Victoria mangrove community contains 12 species and has a higher diversity index (H' = 1.86); therefore, it can be assumed that the Victoria mangrove community contains some portions that were affected by natural processes and other portions that were affected by human-related ecological disturbance.

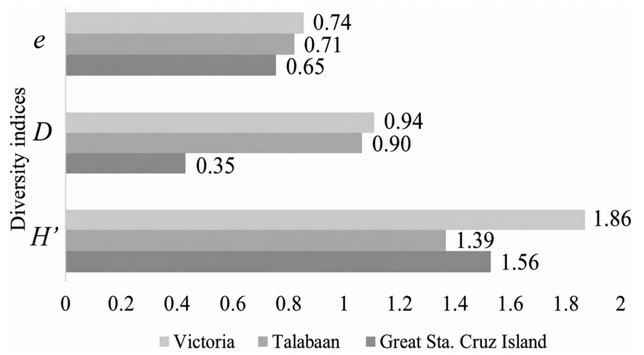

Figure 5. Mangrove species' diversity indices in terms of richness and evenness (*H'*), dominance (*D*), and evenness of distribution (*e*) across the study area

Biomass and carbon stock

The allometric method was utilized to estimate biomass of the forest community due to its reputation as a low-cost, non-destructive way to collect biological data relative to other methods (Kridiborworn et al. 2012). The allometric equations from Komiyama et al. (2005) were used because of their high applicability to tropical mangrove taxa. The site-specific DBH measurements indicated significant differences in the stand maturity of each of the study areas in Zamboanga City. As shown in Table 5, the largest DBH measured in Victoria was for *S. alba* at 36.30 cm, followed by *A. marina* var. *rumphiana* at 28.66 cm, and finally *R. apiculata* at 28.34 cm. The measurements show that whereas Victoria has more mature trees than the other two areas of study, *C. tagal* has an average DBH of 12.73 cm. Talabaan has the lowest relative maturity due to the very narrow range of DBH in the area. The largest recorded DBH for *S. alba* (the second most abundant species in Talabaan) was only 13.69 cm, while the dominant species, *R. apiculata*, had an average DBH of only 7.64 cm. When comparing all of the sites, it is obvious that Victoria and GSCI (which contained *R. apiculata* >27.70 cm) were both examples of mature forests, while Talabaan was potentially located in the early stages of succession or under environmental stress, limiting DBH.

AGB (aboveground biomass) and carbon stocks for the three sites measured show how tree DBH influences carbon sequestration capabilities within the sites. As shown in Table 6, GSCI had the highest ecological value with an AGB of 88.54 t ha^{-1} and carbon stock of 41.61 t C ha^{-1}, which is attributed to the population of mature *R. apiculata* trees within the site. Victoria also functions as a significant carbon sink with an AGB of 79.89 t ha^{-1} and carbon stock of 37.55 t C ha^{-1}. Talabaan represented the lowest carbon storage potential of the three sites, with an AGB of only 9.16 t ha^{-1} and a carbon stock of 4.31 t C ha^{-1}. The data also demonstrate a clear relationship between the range of DBH measurements across the three sites, the amount of AGB, and the amount of carbon stored. The carbon storage for both GSCI and Victoria can be converted to a high CO_2 equivalent value (maximum of 152.71 t CO_2 ha^{-1}) representing the locations' importance as a local carbon storage area. The lower DBH and biomass at Talabaan reflect the long-term carbon sequestration potential of this site. Provided adequate protection exists, younger stands will continue to sequester carbon until eventually reaching the high AGB levels seen at the more developed sites as the trees age and change to larger size classes.

While studies on the biomass and carbon sequestration of Philippine mangroves have expanded in recent years, data remain limited for the Zamboanga Peninsula, particularly in Zamboanga City. Based on previous studies (Komiyama et al. 2008), this study puts these local areas within the broad range of global extremes. Most were generally located toward the lower end of this continuum. It should be noted that biomass estimates for mature Stands in both GSCI (88.54 t ha^{-1}) and Victoria (79.89 t ha^{-1}) were lower than what has been recorded for Kota Marudu, Sabah, Malaysia, at 100.87 t ha^{-1} (Suhaili et al. 2024). While cumulative aboveground carbon stock values in Zamboanga are greater than the 77.45 t C ha^{-1} reported in Panabo Mangrove Park, Davao (Alimbon and Manseguiao 2021), these values are well below what has been reported for *Rhizophora*, 127.68 t C ha^{-1} in the Verde Island Passage and 188.09 t C ha^{-1}) in Poctol, Batangas (Gevaña et al. 2008).

These estimates are based upon aboveground pools only, which are consistent with similar studies that utilize the same methodology for comparison, and are significantly below the lower end of the range in Bohol, 173.9 to 948.0 t C ha^{-1} (Gevaña et al. 2017; Camacho et al. 2020) on this basis. A wide range of variance observed regarding biomass and carbon storage, as noted by Komiyama et al. (2008) suggest that biomass and carbon storage are influenced or driven by species composition and range, as well as ecological factors, highlighting the specific environmental constraints within the Zamboanga Peninsula.

The mangrove forest of Zamboanga City has great value both ecologically and economically, as shown in terms of species diversity, community development (stages in succession), and aboveground biomass data of site conditions. The capacity of the mangrove forest to sequester carbon is based primarily on the age and structural diversity of the mangrove forest. For example, the older mangrove forest stands located at both (GSCI) and Victoria locations have aboveground carbon storage potential; average aboveground biomass density data are approximately 88.54 tons per hectare at GSCI and 79.89 tons per hectare at Victoria. In addition to storing carbon, these forests also produce substantial quantities of CO_2 equivalents; for example, the two mature forests have peak CO_2 equivalents of 152.71 t CO_2 ha^{-1}, which demonstrates the importance of these areas in terms of producing local aboveground carbon reservoirs. Additionally, some flora species, such as *S. hydrophylacea* (nilad) illustrate the need to conserve brackish tidal habitats. On the other hand, although the Talabaan site has lower levels of carbon (4.31 t C ha^{-1}), its relative abundance-occupancy patterns reveal strong potential to develop. Thus, under proper protection, the Talabaan mangroves will become larger and eventually provide an essential carbon sink.

Table 5. Species' aboveground biomass and carbon (C) sequestered in the mangrove forest across all sites in Zamboanga City

Scientific name	Victoria			Talabaan			Great Sta. Cruz Island (GSCI)		
	DBH range (cm)	**AGB (t ha⁻¹)**	**(t C ha⁻¹)**	**DBH range (cm)**	**AGB (t ha⁻¹)**	**(t C ha⁻¹)**	**DBH range (cm)**	**AGB (t ha⁻¹)**	**(t C ha⁻¹)**
Aegiceras corniculatum	5.41-17.83	3.42	1.61	-	-	-	-	-	-
Avicennia officinalis	5.09-12.10	0.04	0.02	5.09-9.87	0.82	0.39	-	-	-
Avicennia marina var. *rumphiana*	6.05-28.66	7.30	3.43	5.09-8.28	0.73	0.34	-	-	-
Ceriops tagal	6.05-41.40	9.8	4.61	-	-	-	5.09-8.28	0.87	0.41
Lumnitzera racemosa	5.41-10.82	1.07	0.50	5.09-5.73	0.27	0.13	5.41-6.05	0.21	0.10
Pemphis acidula	-	-	-	-	-	-	5.09-5.41	0.16	0.08
Rhizophora apiculata	5.73-28.34	29.89	14.05	5.09-7.64	0.94	0.44	5.41-27.70	70.46	33.12
Rhizophora mucronata	5.41-14.33	1.56	0.73	5.09-11.14	5.19	2.44	5.73-10.50	2.06	0.97
Rhizophora stylosa	9.55-10.19	0.11	0.05	5.09-7.64	1.14	0.54	5.41-14.64	8.08	3.80
Sonneratia alba	5.41-36.30	11.78	5.54	6.36-13.69	0.07	0.03	5.41-16.24	1.27	0.60
Scyphiphora hydrophylacea	5.41-27.07	14.24	6.69	-	-	-	5.09-10.19	0.55	0.26
Sonneratia ovata	9.23-12.73	0.61	0.29	-	-	-	-	-	-
Xylocarpus granatum	7.32-7.96	0.07	0.03	-	-	-	6.05-14.02	3.08	1.45
Xylocarpus moluccensis	-	-	-	-	-	-	5.09-12.73	1.8	0.85

Note: DBH range shows the minimum and maximum DBH in cm; (t C ha⁻¹) denotes metric tons of carbon per hectare; (-) indicates that the species is not found at the site

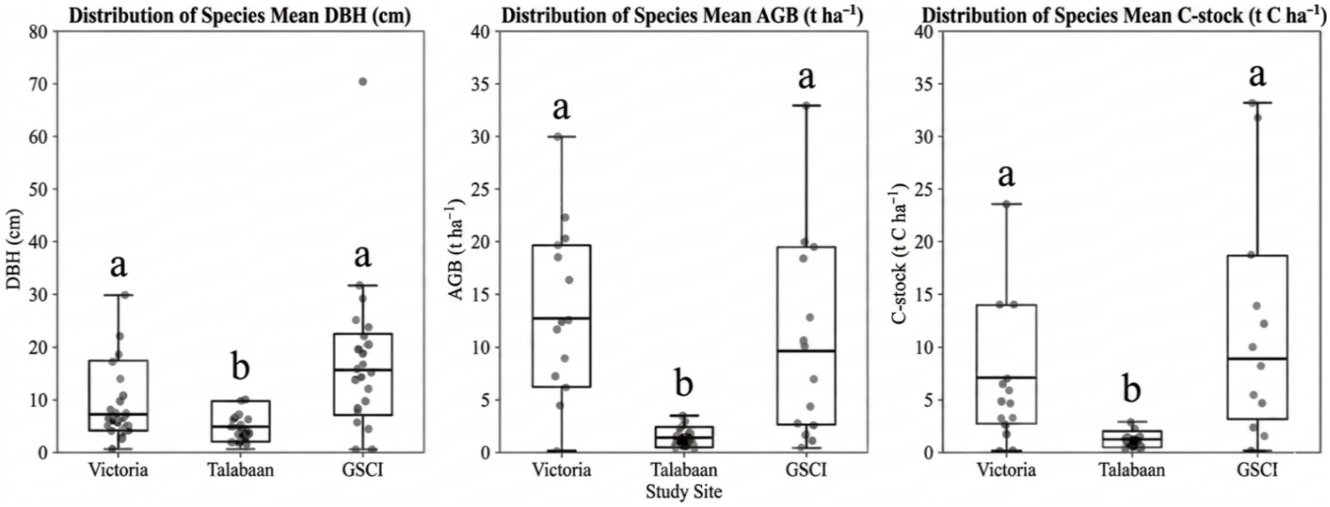

Figure 6. Comparative analysis of tree structural parameters and carbon density across three study sites: Victoria, Talabaan, and Great Sta. Cruz Island (GSCI). Different letters indicate significant differences among sites based on Dunn's post hoc test with Bonferroni correction ($p<0.05$).

Table 6. Aboveground biomass and carbon stock across all sites in Zamboanga City

Site	Aboveground living biomass (t ha^{-1})	Carbon stock (t C ha^{-1})	CO_2 equivalent (t CO_2 ha^{-1})
Victoria	79.89	37.55	137.80
Talabaan	9.16	4.31	15.82
Great Sta. Cruz Island (GSCI)	88.54	41.61	152.71

Comparative analysis of forest structure and carbon stocks

Forest structure across study sites was evaluated using a Kruskal-Wallis H test on the average of 14 mangrove species, excluding *A. ilicifolius*, to become the primary unit of evaluation. The results indicate a statistically significant level of heterogeneity for all measured parameters ($df = 2$) including: diameter at breast height (DBH (2) = 14.67, p = 0.001), aboveground biomass (AGB (2) = 15.92, p = 0.001), and carbon (C) stock (H (2) = 16.40, p = 0.0005) (Figure 6). The rejection of the null hypothesis confirms that biomass accumulation in these areas is not uniform; rather, it is highly site-dependent, suggesting that localized ecological drivers and varying degrees of environmental stress are actively shaping the carbon potential of Zamboanga's mangroves.

According to the results of Dunn's post-hoc test, the majority of the variation in statistics among the different trial sites was primarily due to the statistical differences between Talabaan and the other two sites, which consisted of significant differences when comparing Talabaan to both Victoria (Z = 2.85, p = 0.004) and GSCI (Z = 3.12, p = 0.002). This statistical isolation implies a functional lag in Talabaan's development, while Victoria and GSCI represent mature and stable carbon reservoirs. The lower biomass values indicate younger vegetation, likely due to site disturbance. From a management perspective, this means Victoria and GSCI should be prioritized as high-capacity reservoirs for climate mitigation, while Talabaan represents a strategic opportunity for active rehabilitation and enrichment planting to bridge the gap toward the mature forest benchmark. Ultimately, local environmental conditions such as tidal influence, regulating salinity, variations in soil fertility, and anthropogenic disturbance such as urbanization likely influenced forest structure and carbon storage (Alongi 2018; Buitre et al. 2019; Alimbon and Mansequiao 2021).

In conclusion, this study documented 15 mangrove species across Zamboanga City, representing a significant portion of the Philippines' total mangrove diversity. While structural variations were comparable between natural and reforested sites, distinct site dynamics emerged: Great Sta. Cruz Island (GSCI) harbored rare species like *P. acidula* and *X. moluccensis* and stored the highest ecosystem carbon at 41.61 t C ha^{-1}; Victoria exhibited the highest species richness (12 species) but a low diversity index (1.86) due to anthropogenic *Rhizophora* dominance; and Talabaan represented an early successional stage with a "very low" diversity value (1.39) and low total biomass (9.16 t C ha^{-1}). Given the presence of regional mangrove species classified as "Vulnerable," "Near Threatened," and "Endangered," alongside ongoing pressures from illegal logging, waste disposal, and coastal development, implementing improved coastal management strategies is imperative. To maximize long-term restoration success, Zamboanga City should adopt a zoned approach, primarily planting *S. alba* at outer edges and *Rhizophora* adjacent to freshwater systems while prioritizing the conservation of high-value carbon stocks in GSCI and Victoria (up to 152.71 t CO_2 ha^{-1}) and protecting younger stands in Talabaan as future carbon sinks. Integrating these findings into local frameworks is a critical first step toward preserving regional biodiversity and maintaining essential carbon sinks to mitigate climate change.

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