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Blue Carbon Stock Assessment of The Mangrove Swamp Forest Reserve in Baganga, Davao Oriental, Philippines

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Abstract

Mangrove ecosystems are vital carbon sinks, yet they are threatened by anthropogenic pressures and natural disturbances, causing significant carbon stock losses. Given the limited data for Baganga, Davao Oriental, this study quantified the aboveground biomass (AGB) and blue carbon stock in the Lucod mangrove swamp forest reserve. We identified mangrove species, measured AGB and carbon content via allometric equations, and compared storage among species. The results indicated that the mangrove forest AGB was within typical ranges for tropical wet regions and the Asia-Pacific region, but its overall carbon content did not reach highly productive ecosystem levels. Nonparametric analysis revealed significant heterogeneity in both the overall mangrove AGB across sites and the AGB among species. Among the six identified species, *Lumnitzera littorea* was the dominant carbon contributor (65%), whereas *Rhizophora apiculata* contributed the least (2%). These findings underscore the need for site- and species-specific approaches in mangrove management and future research to understand AGB variations.

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Introduction

Mangroves stand among the world's most productive ecosystems [1]. These trees or shrubs thrive in intertidal zones of coastal wetlands along tropical and subtropical coastlines across more than 118 countries [2]. There are 77 mangrove species worldwide, 46 of which are found in the Philippines. Despite constituting less than 1% of the coastal ecosystem component, this vegetation plays an indispensable role [3]. Mangroves provide vital ecosystem services, including carbon sequestration [4]. Atmospheric carbon dioxide levels have risen since the industrial revolution, causing global warming, sea level rise, and altered precipitation patterns [5]. Mangroves are carbon-rich forests that serve as crucial greenhouse gas sinks with long-term carbon storage capacity [6–7]. However, deforestation, coastal development, pollution, and land conversion threaten mangrove populations, leading to significant carbon stock losses [8].

Baganga, Davao Oriental's largest municipality, hosts vital coastal mangroves that serve as natural barriers against Pacific waves. In 2012, Typhoon Bopha devastated these mangroves, leaving areas such as Barangay Lucod vulnerable, degrading livelihoods, and promoting unsustainable practices [9]. Since 2013, rehabilitation efforts have restored 120 ha of mangroves, but threats such as shellfish collection, establishment of artificial ponds, and illegal cutting of mangroves persist in the present, reducing carbon storage and increasing greenhouse gas emissions [10]. This underscores an urgent need to quantify the carbon stock within the reserve to fill critical data gaps in its carbon sequestration potential.

Thus, this study assessed the blue carbon stock of the mangrove swamp forest reserve in Barangay Lucod, Baganga, Davao Oriental. Specifically, different species of mangroves present in the study area were identified, the aboveground biomass and the blue carbon stock of the mangrove ecosystem were determined, and the blue carbon stock of different mangrove species across sites was compared.

The findings of this study may contribute to the Philippine National REDD+ strategy and the Philippine Biodiversity Strategy and Action Plan. Specifically, this study aligns with the Agriculture, Aquatic, and Natural Resources (AANR) Research and Development Agenda of the country, as outlined in Section 3 of the Harmonized National Research and Development Agenda (HNRDA) for 2022–2028. All these goals adhere to the United Nations' Sustainable Development Goal (SDG) No. 13, which aims to take urgent action in mitigating climate change [7, 11].

Materials and methods

1) Location of the study area

The study was conducted in the coastal mangrove forest of Baganga, Davao Oriental. It is bordered by Cateel to the north, Caraga to the south, and Davao de Oro to the west and faces the Pacific Ocean to the east. Positioned between 7.5743° north latitude and 126.5592° east longitude, it boasted a total land area of 94,550 ha, a coastline stretching 46.44 km, and a mangrove forest covering approximately 1,500 ha. Barangay Lucod is distinct for its mangrove coverage spanning 120 ha, recognized as protected areas by the DENR, under the legal and local supervision of the Protected Area Management Board – Committee on Regulations and Law Enforcement and the Lucod Mangroves Rural Women's Association (LUMARWA), respectively.

The mangrove swamp forest reserve of Barangay Lucod has consisted of natural mangroves and mangroves reforested by local communities along with the DENR and the BFAR since 2013. A map of the Lucod mangrove forest is shown in Figure 1 [10, 12–17].

2) Establishment of sample plots

The study was conducted during the lowest tides of the first two weeks of June 2024. Five plots were established within the study area, designated as Sites A to E. These sites were characterized by dense mangrove vegetation, predominantly composed of species from the Rhizophoraceae family. Each site was surrounded by small, interconnected tidal pools with substrates ranging from muddy to sandy, interspersed with rocks, and reaching depths of up to 50 cm. Human-produced waste, primarily single-use plastics, and artificial ponds were observed throughout the study area. Additionally, remnants of sawed mangroves and pieces of timber were found at some sites, providing clear evidence of mangrove cutting.

Each plot, measuring 10×10 m², was established along the main transect with a 200 m interval from each other, primarily to observe the variation in mangrove species at each site. The LUMARWA office served as the starting point for the transect. Site A was established 100 m from the office, while the succeeding sites followed the 200 m interval along the main transect line. Establishing the primary transect line from the forest boundary toward the sea was discouraged because of limited accessibility and its distance from residential areas. According to the LUMARWA spokesperson, certain forest sections are rarely accessed because of deep muddy substrates, and survey efforts should be concentrated near residential zones for safety reasons. Reforestation of the Lucod mangroves was conducted without adherence to zonation principles, leading to relatively homogenous site characteristics throughout the area, in addition to a few localized variations. Figure 2 shows a map of the study area, which shows the locations and intervals of the five sample plots and the relative size of each [16].

Figure 1 Map of the study area [14–16].

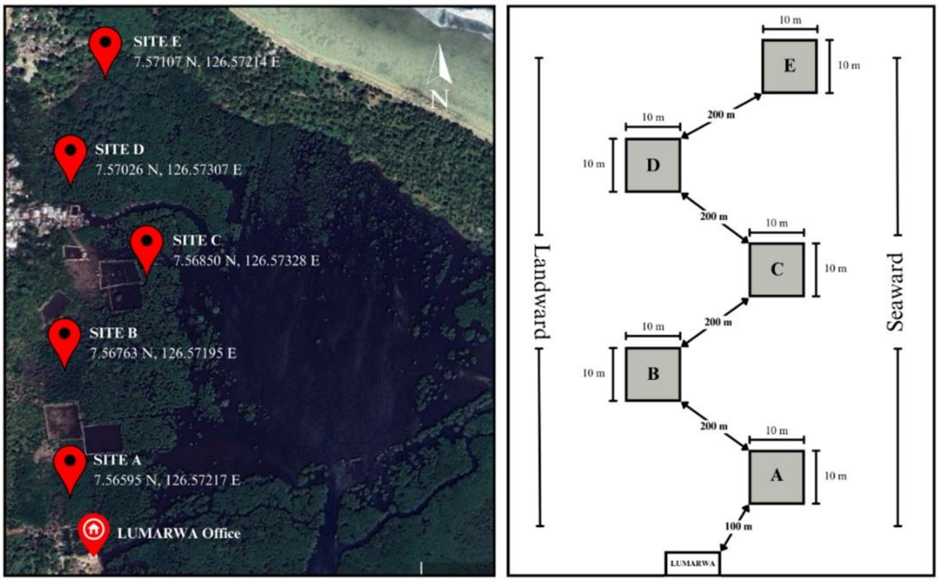

Figure 2 Map of the study sites.

3) Identification, diameter at breast height (DBH) measurement and categorization

Handbook of mangroves in the Philippines – Panay [24] was used to identify species, which were later examined further via collected photographs subjected to taxonomic keys, peer-reviewed literature, and expert verification.

The circumference of individual mangroves was measured in cm via a tape measure. The measurements of tree girth were taken at breast height, which was 1.3 m above the ground. For the seedlings, the point of measurement was 30 cm from the ground [18]. This procedure is unavoidably complex because of irregularities in stem structure. For trees whose height exceeded 1.3 m above ground level, the stem circumference was measured directly above the buttress. For trees that had multiple stems, the precise measurement point was directly beneath the point where the stems branched apart. For species whose stilt roots usually exceed 1.3 m, such as *Rhizophora* spp., girth was measured above the highest stilt root [19–20]. A mangrove was considered part of the survey if at least 50% of its main stem was rooted inside the perimeter of the plot [21].

The mangroves present were classified into three categories, namely, seedlings, saplings, and mature trees, on the basis of their height and DBH. Seedlings were defined as plants with a height of less than 1 m. Saplings included plants taller than 1 m but with a diameter of less than 4 cm. Mangroves taller than 1 m with a DBH greater than 4 cm were classified as mature trees. All individuals classified as mature trees were subjected to AGB and blue carbon stock measurements, excluding those that fell under categories of seedlings and saplings, as these, which constitute understory vegetation, are considered generally negligible in mangroves and their measurement of ecosystem carbon pools [21].

4) Data analysis

4.1) DBH

The recorded circumference of individual trees was converted into DBH via the following formula: $C = \pi d$, where d is the diameter and C represents the circumference in cm.

4.2) Aboveground biomass (BMAG) computation

To estimate the AGB, the allometric equation developed by Komiyama et al. (2005) was incorporated, which was found to be suitable because of the use of accurate predictive parameters, such as tree DBH and specific wood density [20]. The equation was as follows: $BMAG = 0.251\rho D^{2.46}$, where ρ represents the specific wood density (dry weight per unit volume in g cm^{-3}) and D represents the DBH in cm. Moreover, specific wood density measurements were obtained from the Food and Agriculture Organization (FAO) and Global Wood Density Database [22].

4.3) Carbon stock measurement

To determine the amount of carbon atoms stored in each tree, the AGB of each mangrove was multiplied by 0.521, which is particularly applicable to hardwood trees, indicating that approximately half of the biomass consisted of carbon [23–25]. The formula used was $C = AGB\ (0.521)$, where C is the carbon stored in kg, while AGB represents the aboveground biomass. The carbon storage values for all species within each plot were combined to calculate the total carbon stock per sample plot. The carbon stocks for all plots were subsequently summed and averaged to determine the mean stand carbon pool, which was then converted to megagrams per hectare (Mg ha^{-1}) [26–27]. Microsoft Excel was employed as the statistical tool for computing and analyzing the data.

4.4) Statistical analysis

Prior to comparing the groups, the assumption of normality for AGB data within each site and mangrove species was tested via the Shapiro–Wilk test. Given that the assumption of normality is violated, the non-parametric Kruskal–Wallis H test was employed to compare the median AGB values across the five sites and among mangrove species with a significance level of α = 0.05. A post hoc test using Dunn's test was performed to identify which specific pairs exhibited significant differences in their median AGB. To control the familywise error rate resulting from multiple pairwise comparisons, the Bonferroni correction was applied to the p values.

Results and discussion

1) Floristic composition

A total of six true mangrove species from five genera were identified across five study sites in the mangrove swamp forest reserve of Barangay Lucod (Table 1). These species represented 17.14% of the 35 true mangrove species recorded in the Philippines [17]. These species belong to four families, namely, Combretaceae, Lythraceae, Rhizophoraceae, and Meliaceae. The Rhizophoraceae family dominated the study area. The species with the greatest abundance in the mangrove forest on the basis of its density was *Rhizophora mucronata*.

Across the sampling area, 173 individuals were recorded and studied. Among these, 36 were seedlings, 60 were saplings, and 77 were mature. The average DBH of the different mangrove species in the study area ranged from a low of 7.29 cm (*R. mucronata*) to a high of 80.5 cm (*Sonneratia alba*). The latter's average DBH was quite expected, as it was among the known large mangrove trees. *S. alba* was followed by *Xylocarpus granatum* and *Lumnitzera littorea*, with 32.2 cm and 22.10 cm mean DBHs, respectively. These are then followed by *Ceriops tagal*, with an average DBH value of 17 cm. Finally, *Rhizophora apiculata* presented a mean DBH value of 8.73 cm, which was close to that of *R. mucronata*, which was 7.29 cm. The classification of mangroves was assessed via these parametric variables along with height approximation. Individuals classified as mature trees were subjected to AGB and blue carbon stock measurements [20].

2) Mangrove aboveground biomass

The computed AGB across all the study sites ranged from 27 Mg ha^{-1} to 215 Mg ha^{-1} (Figure 3). Site A presented the highest AGB value of 215 Mg ha^{-1}, primarily due to the presence of *L. littorea* and *S. alba* (Table 1), two common mangrove species known for their large trunk diameters. As illustrated in Figure 4, *L. littorea* contributed the most biomass among all the species, while *S. alba* ranked third. Sites B and D yielded similar AGB values, at 125 Mg ha^{-1} and 118 Mg ha^{-1}, respec-tively. Although *L. littorea* was present at Site B (Table 3), its low frequency was overshadowed by the dominance of *R. mucronata* and *R. apiculata*, both of which had the smallest trunk diameters and AGB values, alongside *C. tagal*, as depicted in Figure 4.

A similar pattern was observed at Site D, where the relatively low abundance of *X. granatum*, despite being the second highest biomass contributor among the species in the study area, was eclipsed by the dominance of *C. tagal* and *R. mucronata* (Table 3). Finally, Sites C and E presented the lowest AGB values of 27 Mg ha^{-1} and 31 Mg ha^{-1}, respectively, as both sites were characterized primarily by Bakauan (*Rhizophora*) stands.

The average AGB of the Lucod mangrove swamp forest reserve was 103 Mg ha^{-1} (Table 2), which was lower than the value of 189.26 Mg ha^{-1} recorded in the Thalassery estuarine wetland, southwest coast of India, via the same allometric equation [28]. This disparity likely stems from sampling differences. This study covered 0.17 ha with 17 plots, capturing greater species richness and abundance, whereas the present study sampled 0.05 ha with only five plots.

A similar study in Kerala, India, reported a lower mean AGB of 80.22 Mg ha^{-1} than the 103 Mg ha^{-1} reported in this study despite the former sampling 3 ha with 30 plots [29]. This study revealed a maximum DBH of 25.74 cm *in R. mucronata*, while this study, which covered only 0.05 ha, revealed that *R. mucronata* had the lowest mean DBH and that *S. alba* had the highest DBH at 80.5 cm (Table 1). Notably, a tree's DBH is directly correlated with its biomass and thus its carbon content [29].

Table 1 Mangrove distribution across sites

Family	Species	Average DBH (cm)	Abundance	Density (ha^{-1})	Site present
Combretaceae	*Lumnitzera littorea* (Jack) Voigt	22.10	22	440	A, B, E
Lythraceae	*Sonneratia alba* (L.) Smith	80.5	2	40	A, C
Rhizophoraceae	*Rhizophora mucronata* Lamk.	7.29	118	2,360	B, C, D, E
Rhizophoraceae	*Rhizophora apiculata* Blume	8.73	17	340	B, E
Rhizophoraceae	*Ceriops tagal* (Perr.) C.B. Rob.	17	9	180	D
Meliaceae	*Xylocarpus granatum* J. Koenig	32.2	5	100	D
Total		15.43	173		

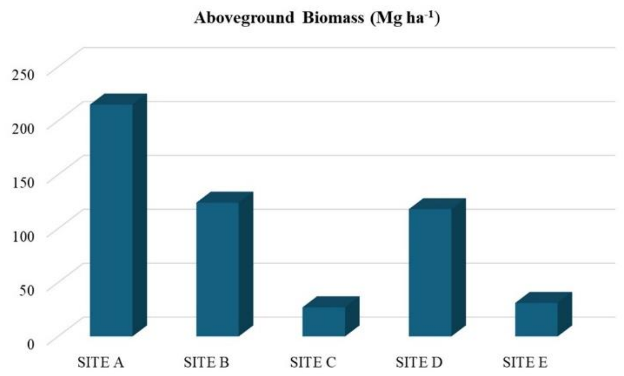

Figure 3 Mean aboveground biomass at the five sampling sites.

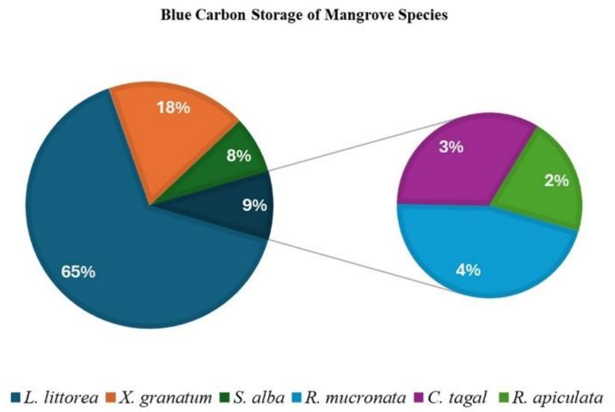

Figure 4 Percent aboveground living biomass per species of mangrove.

Moreover, the average AGB in this study (103 Mg ha^{-1}) was approximately 25% greater than the 77.45 Mg ha^{-1} recorded at Panabo Mangrove Park, Davao del Norte [30]. This study assessed only four species, including *R. apiculata* (0.28 Mg ha^{-1}), *R. mucronata* (2.89 Mg ha^{-1}), and *S. alba* (27.98 Mg ha^{-1}), whereas this study recorded higher values for these species: 11 Mg ha^{-1}, 22 Mg ha^{-1}, and 38 Mg ha^{-1}, respectively (Figure 4). This suggested that older mangroves in Lucod. Differences in species composition may also be attributed to variations in plot establishment and study area. Panabo Mangrove Park spans 73 ha [31], whereas Lucod mangroves cover approximately 120 ha.

Although other mangrove vegetation types presented excellent AGB values, the findings of the present study in Lucod remained noteworthy, as the data were relatively high compared with the AGB values from other assessments conducted across the country. These included the *Avicennia*-dominated small plots in Catmon and the *Rhizophora*-dominated large plot in Poctol, San Juan, Batangas [32]; the *Rhizophora* stand in Verde Passage, Batangas [33]; and a 22-year-old mangrove forest in Aklan [34]. Nonetheless, the IPCC (2013) provided a default range for mangrove aboveground biomass in tropical wet regions, from 8.7 to 384 Mg ha^{-1} [34], with the AGB estimated in the present study falling within this range. Additionally, the estimated mean AGB found in this study was within the mangrove biomass range reported by Komiyama et al. (2008) from 41 Mg ha^{-1} to 460 Mg ha^{-1} for Asia and the Pacific [35].

2) Total blue carbon stock

The average vegetation carbon stock of the mangrove swamp forest reserve in Lucod was determined to be 53 Mg ha^{-1} (Table 2). This value was slightly lower than the 67.30 Mg ha^{-1} AGB carbon obtained in the carbon stock estimation of the mangrove ecosystem of the Sulaman Lake Forest Reserve, Sabah, Malaysia [36]. This discrepancy may be attributed to the different experimental designs of these studies compared with those of the present study. In this study, nine transect lines, each 125 m in length, were randomly established across the study sites, with five circular plots, each with a 7 m radius, set up along each transect [36]. In contrast, the present study employed a single primary transect line with a total length of 1,050 m, which, when compared, is approximately the same length as the combined transects of the former. Furthermore, while both studies utilized different allometry methods, both similarly relied on the DBH as the sole parameter for calculating the AGB. Despite these methodological similarities, the assessment in Malaysia employed a significantly greater number of plots, covering a total area of approximately 0.7 ha, which is far greater than that covered by the present study, which covered only 0.05 ha. This advantage of the former likely allowed for the capture of greater mangrove density.

Table 2 AGB and carbon content of the study areas

Site	AGB (Mg ha^{-1})	Carbon stock (Mg ha^{-1})
A	215	112
B	125	65
C	27	14
D	118	61
E	31	15
Total	103	53

The carbon content recorded in this study was lower than that in the planted mangrove stand but slightly higher than that in the natural stand of Zumarraga, Samar, with AGB carbon values of 286.23 Mg ha^{-1}and 51.25 Mg ha^{-1}, respectively [42]. Using 10×10 m^2 plots, the study covered a larger area with 15 plots along five transects perpendicular to the shore, employing the same allometry for carbon computation. The AGB carbon values from this study, encompassing both planted and natural mangroves, fell between the two stands but were closer to the natural stand because of similar species richness (six species here versus five in Samar's natural stand). The planted stands, which included ten species, presented relatively high carbon stocks, highlighting the correlation between species diversity and carbon storage.

The carbon stock recorded in this study was comparable to that of mangroves in Bataan, Palawan, Aklan, and Samar, which also included restoration projects [34]. The carbon stock values in Puerto Princesa, Palawan (56 Mg ha^{-1}) and Balanga, Bataan (45.94 Mg ha^{-1}) were closest to those reported in this study, likely because of the dominance of *Rhizophora* species. The mean DBH of *Rhizophora* mangroves at these sites (6.74 cm in Bataan, 8.74 cm in Palawan) was similar to the 8.01 cm observed for *R. apiculata* and *R. mucronata* in this study. Differences in the carbon stock may stem from the mangrove area: Palawan (200 ha) and Bataan (8 ha) rather than Lucod (120 ha). In contrast, the carbon stock values in Kalibo, Aklan (24.39 Mg ha^{-1}) and Pinabacdao, Samar (132.84 Mg ha^{-1}) differed significantly. Aklan had the lowest tree density (957 trees ha^{-1}), which was far below the 3,460 trees ha^{-1} in this study. Although Samar had relatively high tree density, it lacked species diversity, with only *R. apiculata* present, unlike the greater richness observed in this study, highlighting the influence of diversity on carbon stocks [34].

In another study on carbon storage assessment and forest inventory conducted in the Pagbilao Mangrove Forest (PMF) in Quezon Province, the AGB carbon was recorded at 35.54 Mg ha^{-1} [26], which was lower than the findings of the present study. In the same study, 22 species were identified, including all six species recorded in the present study. Despite the rich species diversity and abundance, its reported diameter class distribution indicated that only 2.6% of the mangroves in their study area fell into the large-diameter class (31 cm DBH and above) [26]. This percentage was exactly half the percentage of large-diameter mangroves observed in the current study. Additionally, the PMF study reported an average DBH of 11.19 cm for all trees across the study sites, which was slightly lower than the mean DBH of 15.43 cm reported in this study (Table 1). Importantly, both studies employed the same formula, which excluded tree height as a predictive variable for biomass computation, implying that individual DBH directly influenced the total biomass values.

Despite the current study showing an average, comparable carbon storage capacity relative to some carbon stock assessments conducted within the country, this value was undeniably lower than that of a typical productive mangrove ecosystem in Asia and the Pacific region. Howard et al. (2014) reported that the carbon stock of a productive mangrove ecosystem was estimated to range from 55–1376 Mg ha^{-1}, with an average of 386 Mg ha^{-1} [27], a range in which the value recorded in this study did not decrease. This value was not as high as those in neighboring Asian countries such as Malaysia [39–40], Vietnam [41], India [42–44], Indonesia [45–48], and *Heritiera fomes* dominated vegetation in Sundarbans, Bangladesh [56].

4) Species-specific carbon storage

The six mangrove species recorded in this study were relatively less diverse than other mangrove ecosystems across the Davao Gulf in the Philippines, such as Banaybanay, Davao Oriental (33 species) [50], Hagonoy, Davao del Sur (12 species) [51], Sta. Cruz, Davao del Sur (17 species) [52], Tagum city (11 species), Carmen (12 species), and Davao del Norte [53]. Despite this, it is important to note that even if an ecosystem has very low species diversity, its ability to store carbon cannot be undermined [30].

Moreover, all the mangrove species identified in the current study, with the exception of *L. littorea*, were among the 22 species recorded in the Pagbilao mangrove forest [26]. In this study, *S. alba* presented the greatest DBH, which is consistent with the findings of the present study. Among the species common to both studies, *X. granatum* was the species with the next largest DBH according to PMF, followed by *Rhizophora* species and *C. tagal* [26]; a ranking that almost correspondingly aligned with DBH results in the present study (Table 1). However, the DBH appeared to depend on species density with respect to the species-specific carbon content. Among the six mangrove species identified, the highest recorded AGB and carbon stock values were recorded for *L. littorea*, with mean values of 335 Mg ha^{-1} and 174 Mg ha^{-1}, respectively, across all the sites. X. granatum had 95 Mg ha^{-1} AGB and 49 Mg ha^{-1} carbon stock (Table 3). The former ranked third in terms of the DBH value, followed by *R. mucronata* in terms of species density and mature mangrove abundance. *S. alba*, while having the largest recorded average DBH (Table 1), was the least abundant of the six identified species (Table 1). In contrast, despite the abundance of *R. mucronata*, it presented the lowest mean DBH among the six species. Therefore, the biomass and carbon contribution of both species were greater than the average density of *L. littorea* and *X. granatum*, which both presented average DBH values in reference to those of the other mangrove species.

In a study in Panabo Mangrove Park, four species were identified, with all but *Avicennia* marina recorded in the present study [30]. Their results revealed that *S. alba* presented a significantly greater carbon stock value than *Rhizophora* species did, with *R. mucronata* presenting a greater value than *R. apiculata* did. The same ranking of mangrove species by carbon stock value, excluding species not shared between the two studies, was observed in the present assessment from greatest to least. This pattern was likely due to the greater bulk developmental capacity of S. alba than of *Rhizophora* species and *R. mucronata* than of *R. apiculata* recorded in both studies, as DBH was directly linked to the AGB of each species and, consequently, to their carbon content. However, this contrasted with the findings of an assessment of species-wide contributions to the carbon stock in a mangrove ecosystem in Kerala, India [29]. In this study, *S. alba* presented the lowest carbon content, slightly behind *R. apiculata*, while *R. mucronata* presented the second-highest carbon content among the six species examined. Despite this discrepancy, the results still revealed that *R. mucronata* commonly presented a relatively high carbon content and was much denser than *R. apiculata* was [29]. The same phenomenon was also observed in the Kuta Raja subdistrict, Aceh Province, Indonesia [51]. This corroborated the results of this study, with *R. apiculata* being the least contributing species in terms of carbon storage. A study in Kerala, India, also revealed that the average DBH value recorded for *S. alba* was lower than that recorded for *R. mucronata* at 19.68±5.63 cm and 25.74±1.03 cm, respectively [29]. This finding suggested that DBH had a considerable impact on carbon storage [36]. This finding also suggested that *S. alba* trees in Kerala, India, were not yet fully developed, which implied that the carbon stock value was also related to tree age.

Table 3 Aboveground biomass and carbon content (Mg ha^{-1}) of the Lucod mangrove species

Species	AGB	Carbon stock
L. littorea	335	174
X. granatum	95	49
S. alba	38	20
R. mucronata	22	11
C. tagal	16	8
R. apiculata	11	5
Total	103	53

On the other hand, ten mangrove species constitute the mangrove vegetation on Belitung Island, Indonesia [55]. These included all six mangroves identified in the present study. Like those observed in the present study, Rhizophora species were found to dominate the vegetation [55]. This was primarily because the genus *Rhizophora* is a group of mangroves that tolerate various environmental conditions, such as tides, salinity, substrate, and nutrient availability, enabling them to survive in various zones. The same study revealed that *R. apiculata* had the greatest carbon content, followed by *S. alba*, *C. tagal*, *L. littorea*, *R. mucronata*, and *X. granatum*, excluding the species that were not present in the present study. The order of these species by carbon stock value also aligned with their individual abundance. Although this pattern does not resemble the findings of the present study, the apparent influence of density in the results of the assessment in Indonesia suggested that species density directly affected the carbon stock contribution when it aligned homogeneously with DBH [66].

Nonetheless, while L. littorea and X. granatum were the two species contributing the most to carbon storage, *C. tagal* was recorded as the least, ranking between the two Rhizophora species. *C. tagal* presented the lowest mean height and DBH in the PMF in southern Luzon [26]. This species is considered a small tree reaching 2 to 6 m tall and 5 to 10 cm DBH [17], which are parametric measures that are less likely to maximize its biomass and carbon storage capacity than other mangrove species are. Additionally, it was recorded as the least dense mangrove species (slightly ahead of *L. littorea*) among all species identified in this study, as shown in a community structural analysis in Banay-Banay, Davao Oriental [50]. These findings suggested that *C. tagal* was a limited contributor to carbon storage when assessed on the basis of bulk capacity alone, an observation that may extend to other species in its family, Rhizophoraceae, including *R. mucronata* and *R. apiculata*. Despite being the most diverse family in the study area, Rhizophoraceae contributed the least to the area's total carbon stock.

5) AGB comparisons among sites and mangrove species

Initially, normality assumptions were assessed for each site, revealing that the data for most sites significantly deviated from a normal distribution. Consequently, a nonparametric test was employed. The analysis yielded highly significant results, indicating substantial heterogeneity in mangrove AGB. The Kruskal–Wallis H test was applied to compare the median AGB across all five sites. The p value obtained ($p=0.00013$) is substantially lower than the predetermined significance level ($\alpha=0.05$). Therefore, there was a significant difference in the median AGB among the five sites. Given the significant results, Dunn's post hoc test with Bonferroni correction was performed to identify specific pairwise differences. There were significant differences in the median AGB between Sites C, D and E and between Site B and Sites C, D and E. However, no significant differences were found between Sites A and B or between Sites C, D and E. These findings suggest that factors driving mangrove growth and biomass accumulation differ substantially between the "high biomass" cluster (Sites A and B) and the "lower biomass" cluster (Sites C, D, and E). These differences could be attributed to variations in environmental parameters such as tidal inundation, nutrient influx and soil quality [57–59]. Furthermore, tree species, tree age, interspecific competition and human disturbances affect mangrove AGB [60–62].

Further analysis was performed to underscore the significant interspecific heterogeneity in AGB. Given that the calculated p value (0.000015) is substantially less than the chosen significance level ($\alpha=0.05$), this indicates a highly significant difference in median AGB among the mangrove species. Post hoc analysis revealed that *L. littorea* presented a significantly greater median AGB than *R. mucronata*, *R. apiculate*, and *C. tagal*. Similarly, *S. alba* presented a greater median than did *R. apiculata* and *C. tagal*, and most notably, *X. granatum* presented a significantly greater median than did *C. tagal*. On the other hand, several other pairs did not show significant differences at the adjusted α=0.05 level. Despite the smaller sample size of *X. granatum*, it emerged as having a significantly higher median than *C. tagal*, suggesting a strong inherent biomass accumulation potential for this species. Moreover, the absence of significant differences in some species implies that some mangrove species might share similar biomass accumulation characteristics or respond similarly to their environment.

Conclusions

The collection sites at the Lucod Mangrove Swamp Forest Reserve are composed of six mangrove species, with *Rhizophora mucronata* dominating. However, the greater carbon contribution of *Lumnitzera littorea* underscores the necessity of considering species-specific carbon storage. The forest AGB and vegetation carbon stocks play critical roles in carbon sequestration and coastal protection against sea-level rise and extreme weather. Given the lack of zonal reforestation and uniform site conditions, annual monitoring of vegetation dynamics and carbon trends is recommended. Our nonparametric analysis revealed significant AGB heterogeneity across both sites and species, emphasizing the crucial need for site- and species-specific management approaches. Future assessments should expand beyond AGB and accessible areas to incorporate soil and belowground biomass for a more comprehensive evaluation of total ecosystem carbon stocks and productivity.

References

[1] Harshad, S., Vanmali, R., Jadhav, N. Diversity of mangrove ecosystem from Vaitarna Estuary (Palghar), Maharashtra, India. Ecology, Environment and Conservation, 2022, 28, 143–146.

[2] Sharma, S. Mangrove ecosystem ecology and function. InTech, 2018.

[3] Rosario, G.R., dela Pena, R.V., de Guzman, R., Abalos, R.S., Tamayo, K.E. Species composition and diversity of mangroves in the Riverbanks of Barangay Basing, Binmaley, Pangasinan. Journal of Natural and Allied Sciences, 2021, 5, 51–59.

[4] Vanmali, H.S., Jadhav, R.N. Diversity of mangrove ecosystem from Vaitarna Estuary (Palghar), Maharashtra, India. Ecology, Environment and Conservation, 2021, 147–150.

[5] Le Quere, C., Andres, R.J., Boden, T., Conway, T., Houghton, R.A., House, J.I., …, Zeng, N. The global carbon budget 1959-2011. Earth System Science Data Discussions, 2012, 5, 1107–1157.

[6] Chatting, M., Al-Maslamani, I., Walton, M., Skov, M. W., Kennedy, H., Hüsrevoğlu, Y. S., Vay, L. L. Future mangrove carbon storage under climate change and deforestation. Frontiers in Marine Science, 2022, 9.

[7] Herr, D., Landis, E. Coastal blue carbon ecosystems: Opportunities for nationally determined contributions. Policy Brief. Gland, Switzerland: IUCN and Washington, DC, USA: TNC, 2016. [Online] Available from: https://portals.iucn.org/library/sites/library/files/documents/Rep-2016-026-En.pdf

[8] Food and Agriculture Organization (FAO). The world's mangroves in 1980–2005, FAO Forestry Paper 153, 2007, Forest Resources Division, FAO, 77.

[9] Department of Environment and Natural Resources XI (DENR XI). Baganga's mangrove forest restored: An NGP Success Story. DENR Davao. 2021. [Online] Available from: https://r11.denr.gov.ph/index.php/news-events/press-releases/1422 -baganga-s-mangrove-forest-restored-an-ngp-success-story.

[10] Bersaldo, M.J.I., Lacuna, M.G., Macusi, E.D., Avenido, P.M. Length-weight relationship of mangrove clam (*Pegophysema philippiana*) in different sites within the Baganga, Davao Oriental Province, Philippines. Marine and Fishery Sciences, 2023, 36 (2), 189–195.

[11] Department of Agrarian Reform (DAR). DENR administrative order NO. 15-90. Department of Agrarian Reform. 1990. [Online] Available from: https://www.lis.d ar.gov.ph/ documents/9231.

[12] Department of Environment and Natural Resources (DENR). Forest Cover of Davao Region. Forest Management Bureau. 2010. [Online] Available from: https://forestry.denr.gov.ph/index.php /forest-cover-region11.

[13] Jamandra, K.O. Exploring BAGANGA: The best place to be in Davao Oriental! K.O. The Explorer, 2022. [Online] Available from: https://kotheexplorer.net/2022/03/29/exploring-baganga-the-best-place-to-be-in-davao-oriental/.

[14] Google Earth. Mindanao. 2024. [Online] Available from: https://earth.google.com/web/@7.66 0485, 124.55548169,83337.10495606a,854702.4051 0777d,35y,-1.0934848h,1.01495372t,0.0003r/data=OgMKATA.

[15] Google Earth. Baganga, Davao Oriental. 2024. [Online] Available from: https://earth.google.com/web/@7.80296565,126.45637941,-60167.82079216a,114167.07821762d,35y,0.7672073 8 h,22.73978293t,0.0039 r/data=OgMKATA.

[16] Google Earth. Lucod Mangroves. 2024. [Online] Available from: https://earth.google.com/web/ @7.78676539,126.57867861,-58758.85547001a,65663.62086922d,35y,0.78311852h,22.65377988t,0.0026r/data=OgMKATA.

[17] Primavera, J.H., Sadaba, R.B., Lebata, M.J.L., Altamirano, J.P. Handbook of Mangroves in the Philippines - Panay. Southeast Asian Fisheries Development Center Aquaculture Department, 2004.

[18] Assefa, G., Mengistu, T., Getu, Z., Zewdie, S. Training manual on: Forest carbon pools and carbon stock assessment in the context of SFM and REDD+. Hawassa University, 2013.

[19] Clough, B.F., Scott, K. Allometric relationship for estimating above ground biomass in six mangrove species. Forest Ecology and Management, 1989, 27, 117–127.

[20] Komiyama, A., Poungparn, S., Kato, S. Common allometric equations for estimating the tree weight of mangrove. Journal of Tropical Ecology, 2005, 21, 471–477.

[21] Kauffman, J.B., Donato, D.C. Protocols for the measurement, monitoring and reporting of structure, biomass, and carbon stocks in mangrove forests. CIFOR, 2012.

[22] Zanne, A.E., Lopez-Gonzalez, G., Coomes, D.A., Ilic, J., Jansen, S., Lewis, S.L., …, Chave, J. Global wood density database. 2009. [Online] Available from: http://hdl.handle.net/10255/dryad.235.

[23] Barrett, T. Storage and flux of carbon in live trees, snags, and logs in Chugach and Tongass National Forests. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 2014. [Online] Available from: https://doi.org/10.2737/PNW-GTR-889.

[24] Hetland, J., Yowargana, P., Leduc, S., Kraxner, F. Carbon-negative emissions: Systemic impacts of biomass conversion: A case study on CO_2 capture and storage options. International Journal of Greenhouse Gas Control, 2016, 49, 330–342.

[25] Salas, C.A., Alegre, J.C., Iglesias, S. Estimation of above-ground live biomass and carbon stocks in different plant formations and in the soil of dry forests of the Ecuadorian coast. Research Gate, 2017. [Online] Available from: https://www.researchgate.net/publication/32030 9738.

[26] Malabrigo, P.L., Galang, M.A., Urriza, R.C., Umali, A.G.A., Replan, E.L., Dida J.J.V., …., Boncodin, J.C. Mangrove forest inventory and estimation of carbon storage and sedimentation in Pagbilao. Wealth Accounting and the Valuation of Ecosystem services, 2017.

[27] Howard, J., Hoyt, S., Isensee, K., Pidgeon, E., Telszewsk, M. Coastal blue carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and seagrass meadows. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature, 2014, 9 (1), 15–144.

[28] Vinod, K., Asokan, P.K., Zacharia, P.U., Ansar, C.P., Vijayan, G., Anasukoya, A., ..., Nikhiljith, M. Assessment of biomass and carbon stocks in mangroves of Thalassery Estuarine Wetland of Kerala, Southwest Coast of India. Journal of Coastal Research, 2019, 86, 209–217.

[29] Harishma, K.M., Sandeep, S., Sreekumar, V.B. Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. Ecological Processes, 2020, 9, 31.

[30] Alimbon, J.A., Manseguiao, M.R. Species composition, stand characteristics, aboveground biomass, and carbon stock of mangroves in Panabo Mangrove Park, Philippines. Biodiversitas Journal of Biological Diversity, 2021, 22 (6).

[31] City Government of Panabo City. Panabo mangrove park ecotourism project inaugurated, 2019. [Online] Available from: www.panabocity. gov.ph

[32] Gevaña, D.T., Pulhin, F.B., Pampolina, N.M. Carbon stock assessment of a mangrove ecosystem in San Juan, Batangas. J. Environ. Sci. Manag., 2008, 11, 15-25.

[33] Gevaña, D.T., Pampolina, N.M. Plant diversity and carbon storage of a *Rhizophora* stand in Verde Passage, San Juan, Batangas, Philippines. Journal of Environmental Science and Management, 2009, 12, 1–10.

[34] Castillo, J.A.A., Breva, L.A. Carbon stock assessment of four mangrove reforestations/plantation stands in the Philippines. Proceedings of the 1st ASEAN Congress on Mangrove Research and Development, 2012, 3–7.

[35] Intergovernmental Panel on Climate Change (IPCC). Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories. IPCC, Switzerland: Wetlands, 2013.

[36] Komiyama, A., Ong, J.E., Poungparn, S. Allometry, biomass, and productivity of mangrove forests: A review. Aquatic Botany, 2008, 89 (2), 128–137.

[37] Suhaili, N.S., Fei, J.L.J., Sha’ari, F.W., Idris, M.I., Hatta, S.H., Kodoh, J., Besar, N.A. Carbon stock estimation of Sulaman Lake Forest Reserve in Sabah, Malaysia. Biodiversitas, 2020, 21, 5657–5664.

[38] Calipayan, M.M., Bello, M.P., Aloquin, R.D., Aculan, M.C., Brillantes, S.G.A. Diversity, stand structure, biomass and carbon storage potential of natural and planted Mangrove Forests in Samar, Philippines. Journal of Biodiversity and Environmental Sciences, 2024, 24 (1), 92–104.

[39] Hossain, M. Carbon pools and fluxes in *Bruguiera parviflora* dominated naturally growing mangrove forest of Peninsular Malaysia. Wetlands Ecology and Management, 2014, 22, 15–23.

[40] Ismail, M.H., Zaki, P.H., Hamed, A.A. Wood density and carbon estimates of mangrove species in Kuala Sepetang, Perak, Malaysia. The Malaysian Forester, 2015, 78, 115–124.

[41] Nam, V.N., Sasmito, S.D., Murdiyarso, D., Purbopuspito, J., MacKenzie, R.A. Carbon stocks in

artificially and naturally regenerated mangrove ecosystems in the Mekong Delta. Wetlands Ecology and Management, 2016, 24, 231–244.

[42] Kathiresan, K., Anburaj, R., Gomathi, V., Saravanakumar, K. Carbon sequestration potential of *Rhizophora mucronata* and *Avicennia marina* as influenced by age, season, growth and sediment characteristics in southeast coast of India. Journal of Coastal Conservation, 2013, 17, 397–408.

[43] Hebbalalu, S.S., Bhat, D.M., Nijavalli, R.H., Raman, S. Diversity, structure and dynamics of a mangrove forest: A case study. Notulae Scientia Biologicae, 2014, 6(3), 300–307.

[44] Sahu, S.C., Kumar, M., Ravindranath, N.H. Carbon stocks in natural and planted mangrove forests of Mahandi Mangrove Wetland, East Coast of India. Current Science, 2016, 110, 2334–2341.

[45] Murdiyarso, D., Purbopuspito, J., Kauffman, J.B., Warren, M.W., Sasmito, S.D., Donato, D.C., …, Kurnianto, S. The potential of Indonesian mangrove forests for global climate change mitigation. Nature Climate Change, 2015, 5, 1089–1092.

[46] Alongi, D.M., Murdiyarso, D., Fourqurean, J.W., Kauffman, J.B., Hutahaean, A., Crooks, S., …, Wagey, T. Indonesia's blue carbon: A globally significant and vulnerable sink for seagrass and mangrove carbon. Wetlands Ecology and Management, 2016, 24, 3–13.

[47] Asadi, M.A., Yona, D., Saputro, S.E. Species diversity, biomass and carbon stock assessments of mangrove forest in Labuhan, Indonesia. IOP Conference Series: Earth and Environmental Science, 2018, 151, 012009.

[48] Widyastuti, A., Yani, E., Nasultion, E.K., Rochmatino. Diversity of mangrove vegetation and carbon sink estimation of Segara Anakan mangrove Forest, Cilacap, Central Java, Indonesia. Biodiversitas, 2018, 19, 246-252.

[49] Rahman, M.M., Khan, M.N.I., Hoque, A.F., Ahmed, I. Carbon stock in the Sundarbans mangrove forest: spatial variations in vegetation types and salinity zones. Wetlands Ecology and Management, 2015, 23, 269-283.

[50] Pototan, B.L., Capin, N.C., Delima, A.G.D., Novero, A.U. Assessment of mangrove species diversity in Banaybanay, Davao Oriental, Philipines. Biodiversitas, 2021, 22, 144–153.

[51] Jumawan, J., Flores, F.L., Aragon, R.T., Villamor, J.M.C., Sagot, J.C., Taguse, H.C., …, A.M.V. Diversity assessment and spatial structure of mangrove community in a rehabilitated landscape in Hagonoy, Davao del Sur, Philippines. AES Bioflux, 2015, 7, 475–482.

[52] Cardillo, J., Novero, A.U. Assessment of mangrove diversity in Santa Cruz, Davao del Sur, Philippines. Journal of Biodiversity and Environmental Science, 2018, 14, 53–62.

[53] Pototan, B.L., Capin, N.C., Tinoy, M.R.M., Novero, A.U. Diversity of mangrove species in three municipalities of Davao del Norte, Philippines. AACL Bioflux, 2017, 10, 1569–1579.

[54] Dewiyanti, I., Khairina, K., El-Rahimi, S.A. Carbon stock estimation of mangrove ecosystem in the Kuta Raja Subdistrict, Banda Aceh, Aceh Province. BIO Web of Conferences, 2024, 87.

[55] Henri, Farhaby, A.M., Supratman, O., Adi, W., Febrianto, S. Assessment of species diversity, biomass and carbon stock of mangrove forests on Belitung Island, Indonesia. Biodiversitas, 2024, 25, 21–29.

[56] Rachmawati, D., Setyobudiandi, I., Hilmi, E. Potensi estimasi karbon tersimpan pada vegetasi mangrove di wilayah pesisir muara gembong kabupaten Bekasi [Indonesian]. Omni-Akuatika, 2014, 10(2).

[57] Alhassan, A.B., Aljahdali, M.O. Nutrient and physicochemical properties as potential causes of stress in mangroves of the central Red Sea. PloS One, 2021, 16(12), e0261620.

[58] Wang, K., Jiang, M., Li, Y., Kong, S., Gao, Y., Huang, Y., …, Wan, S. Spatial differentiation of mangrove aboveground biomass and identification of its main environmental erivers in Qinglan Harbor Mangrove Nature Reserve. Sustainability, 2024, 16(19), 8408.

[59] Prihantono, J., Nakamura, T., Nadaoka, K., Wirasatriya, A., Adi, N. S. Rainfall Variability and tidal inundation influences on mangrove greenness in Karimunjawa National Park, Indonesia. Sustainability, 2022, 14(14), 8948.

[60] Azman, M.S., Sharma, S., Shaharudin, M.A.M., Hamzah, M.L., Adibah, S.N., Zakaria, R.M., MacKenzie, R.A. Stand structure, biomass and dynamics of naturally regenerated and restored mangroves in Malaysia. Forest Ecology and Management, 2021, 482, 118852.

[61] Martinez del Castillo, E., Zang, C.S., Buras, A., Hacket-Pain, A., Esper, J., Serrano-Notivoli, R., …, Resco de Dios, V. Climate-change-driven growth decline of European beech forests. Communications Biology, 2022, 5, 163.

[62] Chowdhury, A., Naz, A., Maiti, S.K. Community-based, cost-effective multispecies mangrove restoration innovation to maximize soil blue carbon pool and humic acid and fulvic acid concentrations at Indian Sundarbans. Environmental Science and Pollution Research, 2024, 1–14.