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Above and below ground carbon stock assessment of natural and planted mangrove forest in Davao Occidental, Philippines

C. F. Mangaga*, **W. T. Tatil, H. A. R. Quiaoit, P. D. Suson**

Environmental Science Graduate Program, Department of Environmental Science, School of Interdisciplinary Study, Mindanao State University-Iligan Institute of Technology, Iligan City, Philippines

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ABSTRACT

Mangrove forests are important blue carbon ecosystems due to their ability to store carbon in aboveground biomass, belowground biomass, and soil. This study compared the carbon stock of natural and planted mangrove forests in Malita and Jose Abad Santos, Davao Occidental, Philippines. Carbon stocks were quantified using non-destructive quadrat and stratified random sampling across landward, mid, and seaward zones. Aboveground and belowground biomass was estimated using allometric equations, while soil organic carbon was determined through laboratory analysis and bulk density measurements. Total carbon stock in natural mangrove forests ranged from 372.28 to 8,167.92 Mg C ha^{-1}, whereas planted mangrove forests ranged from 245.92 to 2,506.52 Mg C ha^{-1}. The maximum carbon stock in natural forests was recorded in the landward zone of Transect 2 (8,167.92 Mg C ha^{-1}), while the highest value in planted forests occurred in the midzone of Transect 1 (2,506.52 Mg C ha^{-1}). Non-parametric analysis showed a significant effect of forest type on carbon stock ($H= 16.81$, $p < .001$), whereas ecological zone ($H= 0.18$, $p= .914$) and the forest type × zone interaction ($H= 0.03$, $p= .987$) were not significant. Correlation analyses indicated no significant relationships between total carbon stock and tree density or average basal area in either natural ($r= .01–.48$, $p > .05$) or planted forests ($r= .32–.38$, $p > .05$). These results demonstrate clear differences in carbon stock between natural and planted mangrove forest types.

***Corresponding Author:** C.F. Mangaga ✉ christelyn.mangaga@g.msuiit.edu.ph

INTRODUCTION

Mangrove forests play a crucial role in climate change mitigation by sequestering and retaining carbon in above and below-ground biomass of trees, dead tree and deadwood biomass, litter biomass, and soil (Gashu *et al.*, 2022). One of the most dreaded issues of the New Millennium is global warming, and carbon emissions are thought to be the main cause of it. The CO_2 emissions inventory and carbon stock assessments provide a baseline dataset for creating CO_2 reduction policies. According to studies, mangrove forests are some of the planet's most carbon-rich ecosystems (Bindu *et al.*, 2020). Calculating carbon (C) balances at different geographic scales and creating successful climate change mitigation plans depend on precise estimates of above-ground biomass (AGB) and below-ground biomass (BGB) (Victor Awé *et al.*, 2021).

Biomass has a significant role in the carbon storage and sinking capacity of mangroves (Rozainah *et al.*, 2018). With significant implications for global climate change, the rapid and accurate estimation of mangrove biomass has emerged as a key area of study for mangrove ecosystems in recent years (Tian *et al.*, 2021). Meanwhile, one of the ways to assess the ecological and economic benefits of mangrove ecosystems and the potential for environmental services is by estimating carbon stocks in mangrove ecosystems (Hadiyanto *et al.*, 2021). In a study by Jerath *et al.* (2016), high habitat quality means that the mangroves can function and be used properly such as the place for spawning and breeding of biota that inhabit their ecosystem. This shows that good habitat quality will also have high economic value.

Maintaining and managing mangroves well over the long term will yield the benefits of the mangrove ecosystem and contribute more to the growth of the regional economy. An ecosystem's carbon stock mainly includes vegetation biomass and soil carbon stock. In mangroves, carbon is stored primarily in sediments rather than tree biomass (Meng *et al.*, 2021). However, research on estimating mangrove carbon stocks as part of efforts to mitigate deforestation's effects and manage for conservation is still rare, especially in Davao Occidental (Soeprobowati *et al.*, 2024). To address this gap, this study was conducted and specifically aims: To quantify carbon stock in above and below-ground biomass of the planted and natural mangrove forest and the soil organic carbon; and to determine the relationship between the species diversity and carbon stock of the mangrove forest in Davao Occidental.

MATERIALS AND METHODS

Study area

The study was conducted in the municipalities of Malita and Jose Abad Santos, Davao Occidental, specifically in the coastal barangays of Tubalan and Baryo Bukid (Fig. 1). These sites were purposely selected due to the presence of both natural and planted mangrove forests, allowing for comparative analysis of species composition and diversity (Bersaldo, 2023). The geographic coordinates of the study sites are approximately 6°24'10"N, 125°36'25"E for Sitio Agdao, Barangay Tubalan, Malita, and 5°55'47"N, 125°41'13"E for Sitio Catumbala, Baryo Bukid, Jose Abad Santos.

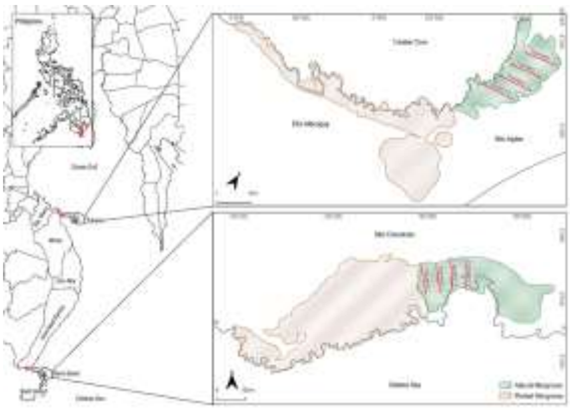

Fig. 1. Location of the natural and planted mangrove forest in Sitio Agdao Brgy. Tubalan Malita and Sitio Catumbala, Baryo Bukid Jose Abad Santos, Davao Occidental Philippines

Malita and Jose Abad Santos experience a Type IV climate according to the Modified Coronas Classification, characterized by an almost even distribution of rainfall throughout the year. The mean annual rainfall ranges from 1,800 to 2,500 mm, and the average temperature varies between 25°C and 32°C (PAGASA, 2024). With a total mangrove area of approximately 28.8 hectares, these barangays feature muddy to sandy substrates that support a variety of mangrove species and reflect typical zonation patterns (landward, mid, and seaward). In addition, Tubalan and Baryo Bukid have ongoing community-level conservation and reforestation programs, which strengthen the relevance of studying ecological dynamics in these locations (Pacyao, 2025).

Data collection

A total of 12 sampling plots of 400 m² were established through non-destructive quadrat and random sampling techniques to determine the composition and species types present in mangrove ecosystems (Aye *et al.*, 2022). Since individuals within a population are rarely distributed evenly, random sampling is essential to obtain a representative and unbiased view of the entire population (Goloran *et al.*, 2020).

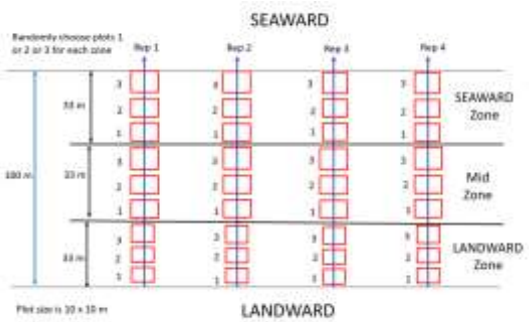

Fig. 2. The design of field survey using the random and quadrat sampling methods to measure observed variables in the natural and planted mangroves in Malita and Baryo Bukid Jose Abad Santos, Davao Occidental, Philippines

In each study site, 100-m transect lines were established across the mangrove area, spaced at 50-m intervals and oriented to capture variation across the three ecological zones: landward, midzone, and seaward (Fig. 2). Each transect line was stratified into these zones, and within each zone, 10 m × 10 m sampling plots were delineated. A total of twelve (12) sampling plots measuring 400 m² each were established using a non-destructive quadrat method combined with a stratified random sampling technique to assess mangrove carbon stock. Within each plot, the following carbon pools were sampled:

SOC

Soil organic carbon (SOC) samples were collected using a soil auger at depths of 0–100 cm along each 100-m transect line. Each transect line was divided into three ecological zones: landward, midzone, and seaward. Each zone covered approximately 33 m of the transect, within which 10 m × 10 m plots were established. A total of nine plots were delineated along each transect, and each plot was subdivided into 25 grids. One plot per zone was randomly selected through draw lots for soil sampling (Li *et al.*, 2016).

Collected soil samples were placed in labeled plastic zip-lock bags indicating their corresponding plot and zone. The samples were air-dried in a shaded, well-ventilated area, suspended on improvised racks to prevent exposure to direct sunlight and moisture, until constant weight was achieved. The dried samples were then submitted to Davao Analytical Laboratories, Inc. for the determination of organic carbon content.

Bulk density

Soil samples for bulk density determination were collected using a cylindrical core sampler with a diameter of 5.5 cm and a sampling depth of 5.5 cm (0–5.5 cm). The soil cores were carefully extracted to minimize compaction and disturbance of the soil structure and were immediately placed in labeled containers indicating the corresponding plot and zone for transport to the laboratory. In the laboratory, the soil samples were oven-dried at 105 °C for 24–48 hours until a constant weight was achieved. After drying, the oven-dry weight of each soil sample was recorded using an analytical balance. Bulk density was then calculated as the ratio of oven-dry soil mass to the volume of the soil core (Lang *et al.*, 2025).

Leaf litter

Leaf litter samples were collected by hand by gathering all undecomposed leaves from the forest floor within each sampling plot. The collected leaf litter was placed in labeled paper bags indicating the corresponding plot and zone and transported to the laboratory. In the laboratory, the samples were oven-dried at 65 °C for 48–72 hours until a constant weight was attained. The oven-dry mass of the leaf litter was then recorded using an analytical balance for biomass and carbon stock estimation.

Deadwood

Deadwood samples, including fallen branches and coarse woody debris, were collected from the entire sampling plot. All deadwood materials were placed in labeled containers indicating the corresponding plot and zone and transported to the laboratory. In the laboratory, the samples were oven-dried at 65–70 °C until a constant weight was attained. The oven-dry mass of the deadwood was then recorded using an analytical balance for biomass and carbon stock estimation.

Belowground litter

Belowground litter samples, including fine roots and decomposing organic matter, were collected by carefully excavating soil within designated subplots in each sampling plot. The collected materials were placed in labeled bags indicating the corresponding plot and zone and transported to the laboratory. In the laboratory, the samples were oven-dried at 65 °C until a constant weight was achieved. The oven-dry mass of the belowground litter was then recorded using an analytical balance for biomass and carbon stock estimation.

Data analysis

Soil organic carbon

Soil organic carbon (SOC) concentration (%) was determined through laboratory analysis conducted by Davao Analytical Laboratories, Inc. using the Walkley–Black method, a widely accepted procedure for soil organic carbon determination. SOC values were reported directly by the laboratory for each sampling plot and zone and were therefore not calculated within this study. The reported SOC concentrations ranged across transects and ecological zones, reflecting spatial variation in soil carbon content within the mangrove ecosystem.

Bulk density values measured in this study, together with the laboratory-determined SOC concentration and soil sampling depth, were used to estimate soil organic carbon stock (Mg C ha^{-1}) on an area basis. Soil organic carbon stock was calculated using the following equation:

$$SOC\ (Mg\ C\ ha^{-1})\ =\ BD\ (g\ cm^{-3})\ \times\ D\ (cm)\ \times\ SOC\ (\%)\ \times\ 100$$

where BD is bulk density, D is the soil sampling depth, and SOC (%) represents the organic carbon concentration obtained from laboratory analysis. Soil organic carbon stock values were calculated for each plot and subsequently summarized by forest type and ecological zone.

Bulk density was calculated as the ratio of oven-dry soil mass to the volume of the soil core using the formula:

$$BD\ (g\ cm^{-3}) = \frac{Oven-dry\ soil\ mass\ (g)}{Volume\ of\ soil\ core\ (cm^{3}}$$

Litter and deadwood carbon stock estimation

Biomass of leaf litter, deadwood, and belowground litter was calculated from oven-dry weights and expressed on a per-hectare basis using a uniform conversion approach. Biomass for each component was estimated as:

$$Biomass\ (Mg\ ha^{-1}) = \frac{Oven-dry\ weight\ (kg)}{Sampled\ area\ (m^{2})} x10$$

Carbon stock for each litter and deadwood component was then estimated by applying a carbon conversion factor of 0.47, following standard mangrove carbon accounting protocols:

$$Carbon\ stock\ (Mg\ C\ ha-1) = Biomass\ (Mg\ ha-1) \times 0.47$$

This approach was applied consistently to leaf litter, deadwood, and belowground litter samples to ensure comparability among carbon pools.

Aboveground and belowground biomass estimation and carbon stocks

According to the study of Aye *et al.* (2022) they used to estimate AGB and BGB as shown in equations:

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

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

Where:

AGB (kg) = aboveground biomass estimates in kg per tree

BGB (kg) = belowground biomass estimate in kg per tree

D = diameter at breast height (dbh) in cm

ρ = wood density in g cm^{-3}

The value of wood density (ρ) of each species was obtained from the World Agroforestry Wood Density Database. Then, total aboveground and belowground biomass production in the plots were obtained by summing the biomass of all the standing trees and the biomass of each sample plot had been converted to stand-level biomass (Mg ha^{-1}). Then, carbon stock of aboveground and belowground biomass showed in mega-grams per hectare (Mg C ha^{-1}).

Aboveground biomass (AGB) and belowground biomass (BGB) were converted to carbon stock using standard carbon conversion factors. A conversion factor of 0.47 was applied to aboveground biomass, while 0.39 was used for belowground biomass, following established protocols and guidelines for forest and mangrove carbon stock assessment (FAO, 2011; Feldpausch *et al.*, 2004; IPCC, 2006; Kauffman and Donato, 2012; Kauffman *et al.*, 2016).

Statistical analysis

Carbon stock values were summarized using descriptive statistics, including mean and standard deviation, for each forest type and ecological zone. Differences in carbon stock among forest types and zones were tested using appropriate statistical analyses. Relationships between forest structural attributes (tree density and basal area) and total carbon stock were assessed using correlation analysis. All statistical analyses were performed using appropriate statistical software, and the level of significance was set at $p < .05$.

RESULTS

Above ground and below ground carbon stock in natural mangrove forest

Carbon stock in the natural mangrove forest varied across transects and ecological zones (Table 1). Total carbon stock ranged from 372.28 Mg C ha^{-1} in the landward zone of Transect 4 to 8,167.92 Mg C ha^{-1} in the landward zone of Transect 2. Transect 2 consistently recorded the highest total carbon stock across all zones, with values of 8,167.92 Mg C ha^{-1} in the landward zone and 7,549.03 Mg C ha^{-1} in the seaward zone. In contrast, Transect 4 recorded the lowest total carbon stock values across zones, all remaining below 550 Mg C ha^{-1}.

Across transects, higher total carbon stock values were associated with higher aboveground biomass (AGB). Belowground biomass (BGB) also contributed to total carbon stock, with relatively higher BGB values observed in seaward zones across several transects. Zonal variation was evident, with landward and seaward zones generally exhibiting higher total carbon stock than midzones in Transects 1 and 2.

Table 1. Aboveground, belowground, and total carbon stock (Mg C ha^{-1}) of the natural mangrove forest across transects and ecological zones

Transect no.	Zone	ABG carbon stock (Mg C ha^{-1})	BGB carbon stock (Mg C ha^{-1})	Total carbon stock per hectare Mg C ha^{-1}
T1	LW	3051.515891	703.9828732	3860.452764
T1	MID	2149.795112	516.9271355	2738.242247
T1	SW	3852.905832	836.4838764	4751.455708
T2	LW	6408.999658	1670.335654	8167.923312
T2	MID	1951.898804	450.7009297	2464.163734
T2	SW	6192.539521	1300.440903	7549.026424
T3	LW	810.8513571	214.9711716	1094.642529
T3	MID	849.7375491	225.1563326	1168.051882
T3	SW	2520.762704	570.3091829	3156.405887
T4	LW	200.9535535	97.39967953	372.279233
T4	MID	259.6767471	77.40927498	415.2460221
T4	SW	360.5931584	104.8369385	547.7580969

Above ground and below ground carbon stock in planted mangrove forest

Carbon stock in the planted mangrove forest also varied across transects and ecological zones (Table 2). Total carbon stock ranged from 245.92 Mg C ha⁻¹ in the landward zone of Transect 4 to 2,506.52 Mg C ha⁻¹ in the midzone of Transect 1. Transect 1 recorded the highest total carbon stock values across zones, particularly in the midzone (2,506.52 Mg C ha⁻¹) and seaward zone (1,930.39 Mg C ha⁻¹). Transect 4 consistently recorded the lowest total carbon stock values across zones, all below 460 Mg C ha⁻¹.

Zonal variation was observed, with midzone and seaward zones often exhibiting higher total carbon stock than landward zones. Aboveground biomass accounted for the largest proportion of total carbon stock across all transects and zones, while belowground biomass contributed a smaller but measurable fraction.

Table 2. Aboveground, belowground, and total carbon stock (Mg C ha⁻¹) of the planted mangrove forest across transects and ecological zones

Transect no.	Zone	ABG carbon stock (Mg C ha⁻¹)	BGB carbon stock (Mg C ha⁻¹)	Total carbon stock per hectare Mg C ha⁻¹
T1	LW	1049.029613	269.2773995	1428.625012
T1	MID	1917.12902	459.3925945	2506.521614
T1	SW	1480.23746	358.9677742	1930.392235
T2	LW	704.0863818	195.4522279	953.8506097
T2	MID	731.200547	438.9574555	1228.767002
T2	SW	1259.372127	302.7776513	1645.423779
T3	LW	211.7772377	66.68430941	340.8835471
T3	MID	1332.113928	331.2450044	1726.031933
T3	SW	485.3002613	135.401763	677.4130244
T4	LW	138.5433631	45.58853525	245.9178984
T4	MID	275.614768	83.03767219	435.6024401
T4	SW	531.9614329	148.1358827	778.9353156

Table 3. Results of the non-parametric test comparing carbon stock between forest types and ecological zones

Test	Df	Sum Sq	H	*p*-value
Forest_Type	1	840.1666667	16.81064231	0.00004130103242
Zone	2	9	0.1800782949	0.9138954079
Forest_Type:Zone	2	1.333333333	0.02667826591	0.986749439
Residuals	18	299		

Across all transects and ecological zones, natural mangrove forests exhibited higher total carbon stock values than planted mangrove forests. The maximum total carbon stock recorded in natural mangroves (8,167.92 Mg C ha⁻¹) was more than three times higher than the maximum value recorded in planted mangroves (2,506.52 Mg C ha⁻¹).

Non-parametric analysis showed a significant effect of forest type on carbon stock ($H(1)= 16.81$, $p < .001$; Table 3). In contrast, ecological zone had no significant effect on carbon stock ($H(2)= 0.18$, $p= .914$). The interaction between forest type and ecological zone was also not significant ($H(2)= 0.03$, $p= .987$).

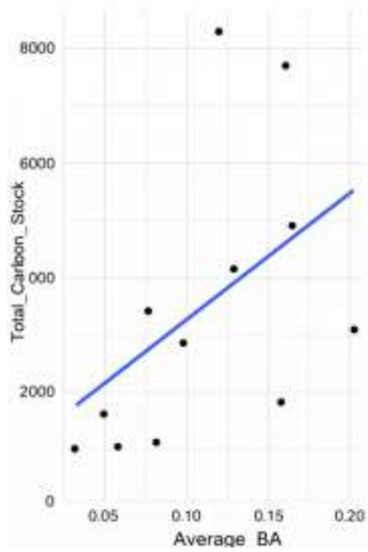

Fig. 3. Relationship between average basal area and total carbon stock in the natural mangrove forest

In the natural mangrove forest, the relationship between average basal area and total carbon stock was moderately positive but not statistically significant (*r*= .48, *p*= .11; Fig. 3). The relationship between tree density and total carbon stock was negligible and not significant (*r*= .01, *p*= .97; Fig. 4).

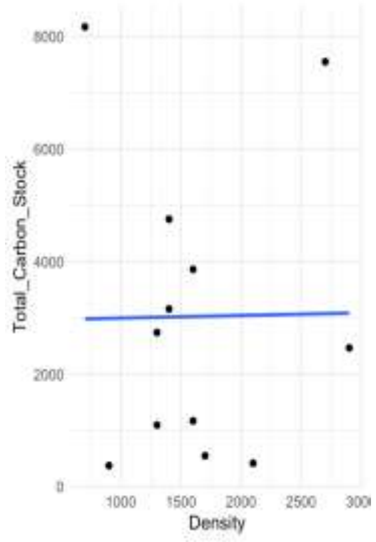

Fig. 4. Relationship between tree density and total carbon stock in the natural mangrove forest

In the planted mangrove forest, tree density showed a weak to moderate positive correlation with total carbon stock (*r*= .38, *p*= .23), while average basal area also showed a positive but non-significant correlation (*r*= .32, *p*= .31). None of the structural variables showed a statistically significant relationship with total carbon stock in either forest type (Table 4).

The relationship between average basal area and total carbon stock in the natural mangrove forest was moderately positive but not statistically significant (*r*= .48, *p*= .11). Although earlier scatterplots demonstrated a visible upward trend where plots with larger average basal area tended to have higher carbon stock, the lack of statistical significance suggests that this relationship was influenced by high variability among plots. This variability is consistent with previous interpretations indicating that factors such as species composition, stand age, and hydrological conditions contribute to carbon accumulation beyond basal area alone.

Table 4. Correlation between forest structure and total carbon stock in the natural mangrove forest

Comparison	*r*	*p*-value
Natural		
Density vs Total_Carbon_Stock	0.01131613483	0.9721564537
Average_BA vs Total_Carbon_Stock	0.4833153979	0.1114304519
Comparison	R	*p*-value
Planted		
Density vs Total_Carbon_Stock	0.3756713598	0.228809731
Average_BA vs Total_Carbon_Stock	0.3178092024	0.314095173

Correlation analysis showed that tree density was not significantly related to total carbon stock in either forest type. In the natural mangrove forest, density exhibited a negligible correlation with total carbon stock (*r* = .01, *p* = .97), indicating that stem abundance did not explain variation in carbon storage. Similarly, the relationship between average basal area and total carbon stock in the natural mangrove forest was moderately positive but not statistically significant (*r* = .48, *p* = .11), suggesting that high variability among plots influenced this association.

In the planted mangrove forest, tree density showed a weak to moderate positive correlation with total carbon stock (*r* = .38), but this relationship was not significant (*p* = .23). Average basal area in planted stands also exhibited a positive but non-significant relationship with total carbon stock (*r* = .32, *p* = .31). Overall, these results indicate that while forest structural attributes contribute to carbon storage, no single structural variable independently explained variation in total carbon stock, emphasizing the combined influence of forest type, stand maturity, species composition, and environmental conditions.

DISCUSSION

In the present study, there are striking differences in carbon stock of natural and planted mangrove forests in Davao Occidental, with natural mangrove stands storing progressively higher quantities of carbon throughout transect and ecological areas (Donato *et al.*, 2011; Alongi, 2018). In fact, the much higher carbon stocks of natural mangroves largely result from the long-term effects of forest development, plant diversity, and structural complexity (Primavera, 2008; Arifanti *et al.*, 2022). Many forests were under ecological succession that allowed different types of species, like those with various growth forms and rooting strategies, to grow together on a single, extended succession. This heterogeneity contributes to both biomass accumulation above ground and underground and therefore increases total ecosystem carbon storage (Komiyama *et al.*, 2005; Meng *et al.*, 2021). Planted mangrove forests, as opposed to native ones, typically had lower carbon stocks, attributed to their low age, simple architecture, and poor species abundance (Primavera, 2008; Alimbon and Manseguiao, 2021). In the Philippines, most (if not all) planted stands are dominated by a relatively limited number of species (the majority of them *Rhizophora* spp.) leading to sites in even age, less canopy stratification and smaller tree diameters (Primavera, 2019).

These constraints on structure limit biomass accumulation and, thus, carbon sequestration capability (Bindu *et al.*, 2020; Sharma, 2023). Similar trends have been demonstrated in other mangrove restoration studies, in which planted forests contain lower carbon than adjacent natural forests because of limited structural growth and shorter establishment time (Donato *et al.*, 2011; Arifanti *et al.*, 2022). While carbon stock variation was reported in ecological zones with respect to transects, ecological zones had no significant impact on carbon storage. It implies that type of forest has a greater impact on carbon stock than position along the landward–seaward gradient (Hamilton and Friess, 2018). Variation of the carbon stock values between zones can be attributed to species composition, hydrological conditions or sediment characteristics that overlap on a wider intertidal gradient in the study area (Lu *et al.*, 2014; Meng *et al.*, 2021).

These results suggest that zonation is not always an established proxy for carbon storage when forest structure level and forest maturity vary dramatically between sites (Alongi, 2018). Forest structural attributes, including tree density and basal area, are positively associated with total carbon stock both in natural and planted mangrove forest but were statistically insignificant (Komiyama *et al.*, 2005; Abdul-Hamid *et al.*, 2022). Despite the fact that larger basal area had a positive relationship with higher carbon storage, the high variability across plots significantly diminished the association between basal area density and carbon storage. In particular tree density was a low predictor of carbon stock, because plots with similar stem densities had different carbon-stored values (Jerath *et al.*, 2016; Lomoljo-Bantayan, 2023). This result underscores the role of tree size distribution, stand age and species-specific biomass allocation rather than stem abundance alone on carbon concentration (Rozainah *et al.*, 2018; Meng *et al.*, 2021). The large proportion of mangrove carbon sequestered belowground makes clear the need for incorporation of both aboveground and belowground carbon sources if the total system carbon stock is to be estimated accurately since the belowground pools might be missed and thus the overall carbon stocks of an ecosystem may be underestimated (Donato *et al.*, 2011; Pendleton *et al.*, 2012).

In large-scale context, our findings highlight the significance of maintaining of natural mangrove forests as priority blue carbon ecosystem (Alongi, 2018; Hamilton and Friess, 2018). Although these areas are essential for coastal protection and sustainably producing livelihoods, mangrove rehabilitation strategies should aim to improve habitat rather than focusing on planting target limits per area and on ecological suitability, species richness, and long-term structural growth (Primavera, 2008; Arifanti *et al.*, 2022). Restoration success will depend on site-specific species selection, greater community participation, and long-term monitoring to make sure that mangrove forests implanted *in situ* can gradually grow in sufficient structural complexity to support adequate and durable carbon sinks (Primavera, 2019; Sharma, 2023).

CONCLUSION

This study demonstrated that natural mangrove forests store substantially higher carbon stocks than planted mangrove forests, highlighting their critical role as effective and resilient carbon sinks. The significantly higher carbon stock observed in natural mangroves was strongly associated with greater species diversity, structural complexity, and stand maturity, as supported by the NMDS ordination and ANOSIM results showing clear compositional differences between forest types. Although positive trends were observed between forest structural attributes such as basal area and total carbon stock, correlation analyses indicated that tree density and basal area alone did not significantly explain variation in carbon storage, particularly due to high variability among plots. These findings suggest that carbon accumulation in mangrove ecosystems is governed by the combined effects of species composition, forest structure, stand age, and hydrological conditions, rather than by individual structural metrics in isolation. Zonal differences in carbon stock were not statistically significant, indicating that forest type exerts a stronger influence on carbon storage than position along the landward–seaward gradient. Overall, the results underscore the importance of conserving existing natural mangrove forests while improving restoration strategies to enhance structural development and long-term carbon sequestration in planted mangrove ecosystems.

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REFERENCES

Abdul-Hamid, Mohamad-Ismail, Mohamed J. 2022. Allometric equation for aboveground biomass estimation of mixed mature mangrove forest. Forests **13**(2), 325.
https://doi.org/10.3390/f13020325

Aguilera, Díaz-Gaona, García-Laureano. 2020. Agroecology for adaptation to climate change and resource depletion in the Mediterranean region: A review. Agricultural Systems **181**, 102809.
https://doi.org/10.1016/j.agsy.2020.102809

Alimbon J, Manseguiao A. 2021. Species composition, stand characteristics, aboveground biomass, and carbon stock of mangroves in Panabo Mangrove Park, Philippines. Biodiversitas **22**(6), 3130-3137. https://doi.org/10.13057/biodiv/d220615

Alongi DM. 2018. Carbon sequestration in mangrove forests. Carbon Management **9**(4), 377–392.
https://doi.org/10.1080/17583004.2018.1512737

Arifanti VB, Kauffman JB, Subarno, Ilman M, Tosiani A, Novita N. 2022. Contributions of mangrove conservation and restoration to climate change mitigation in Indonesia. Global Change Biology **28**(15), 4523–4538. https://doi.org/10.1111/gcb.16216

Bersaldo MJI. 2023. Biomass estimates using species-specific allometry in reforested mangrove areas of Malita, Davao Occidental, Philippines. SSRN Electronic Journal. Posted 21 March 2023. https://doi.org/10.2139/ssrn.4395390

Bindu G, Rajan P, Jishnu ES, Ajith Joseph K. 2020. Carbon stock assessment of mangroves using remote sensing and geographic information system. The Egyptian Journal of Remote Sensing and Space Science **23**(1), 1–9. https://doi.org/10.1016/j.ejrs.2018.04.006

Donato DC. 2011. Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience **4**(5), 293–297. https://doi.org/10.1038/ngeo1123

Hadiyanto H, Rahman Halim MA, Muhammad F, Soeprobowati T, Sularto S. 2021. Potential for environmental services based on the estimation of reserved carbon in the Mangunharjo mangrove ecosystem. Polish Journal of Environmental Studies **30**(4), 3545–3552. https://doi.org/10.15244/pjoes/126374

Hamilton SE, Friess DA. 2018. Global carbon stocks and potential emissions due to mangrove deforestation from 2000 to 2012. Nature Climate Change **8**(3), 240–244. https://doi.org/10.1038/s41558-018-0090-4

Idrus A. 2019. The diversity of fauna in mangrove community: success replanting of mangrove species in south coastal East Lombok, Indonesia. Journal of Physics: Conference Series **1402**(3), 033042. https://doi.org/10.1088/1742-6596/1402/3/033042

IPCC. 2006. Guidelines for national greenhouse gas inventories: agriculture, forestry, and other land use. https://doi.org/10.1007/springerreference_307012

Jerath M. 2016. The role of economic, policy, and ecological factors in estimating the value of carbon stocks in Everglades mangrove forests, South Florida, USA. Environmental Science and Policy **66**, 160–169. https://doi.org/10.1016/j.envsci.2016.09.005

Komiyama A. 2005. Common allometric equations for estimating the tree weight of mangroves. Journal of Tropical Ecology **21**(4), 471–477. https://doi.org/10.1017/S0266467405002476

Lang AK. 2025. Bulk density calculation methods systematically alter estimates of soil organic carbon stocks in United States forests. Biogeochemistry **168**(3). https://doi.org/10.1007/s10533-025-01235-6

Li C. 2016. Deep soil C, N, and P stocks and stoichiometry in response to land use patterns in the Loess Hilly region of China. PLoS ONE **11**(7), e0159075. https://doi.org/10.1371/journal.pone.0159075

Lomoljo-Bantayan NA. 2023. Carbon stock assessment of mangrove forests along Macajalar Bay, Misamis Oriental, Philippines. International Journal of Advanced and Applied Sciences **10**(10), 36–45. https://doi.org/10.21833/ijaas.2023.10.004

Lu W, Yang S, Chen L, Wang W, Du X, Wang C, Ma Y, Lin G, Lin G. 2014. Changes in carbon pool and stand structure of a native subtropical mangrove forest after inter-planting with exotic species *Sonneratia apetala*. PLoS ONE **9**(3), e91238. https://doi.org/10.1371/journal.pone.0091238

Meng Y. 2021. Relationships between above- and below-ground carbon stocks in mangrove forests facilitate better estimation of total mangrove blue carbon. Carbon Balance and Management **16**(1), 8. https://doi.org/10.1186/s13021-021-00172-9

Nelson DW, Sommers LE. 1996. Total carbon, organic carbon, and organic matter. In: Sparks DL *et al.* (Eds.), Methods of soil analysis: part 3-chemical methods, 961–1010. Soil Science Society of America. https://doi.org/10.2136/sssabookser5.3.c34

Odeny D. 2019. Impact of climate change on species distribution and carbon storage of agroforestry trees on isolated East African mountains. American Journal of Climate Change **8**(3), 364–386. https://doi.org/10.4236/ajcc.2019.83020

Pearson TRH. 2007. Measurement guidelines for the sequestration of forest carbon. https://doi.org/10.2737/NRS-GTR-18

Pendleton L. 2012. Estimating global "blue carbon" emissions from conversion and degradation of vegetated coastal ecosystems. PLoS ONE **7**(9), e43542. https://doi.org/10.1371/journal.pone.0043542

Primavera JH. 2008. A review of mangrove rehabilitation in the Philippines: successes, failures and future prospects. Wetlands Ecology and Management **16**(5), 345–358. https://doi.org/10.1007/s11273-008-9101-y

Primavera JH. 2019. The mangrove ecosystem. In: World Seas: An Environmental Evaluation, 1–34. Elsevier. https://doi.org/10.1016/B978-012-805052-1.00001-2

Rozainah MZ. 2018. Estimation of carbon pool in soil, above and below-ground vegetation at different types of mangrove forests in Peninsular Malaysia. Marine Pollution Bulletin **137**, 237–245. https://doi.org/10.1016/j.marpolbul.2018.10.023

Sharma S. 2023. Carbon stocks and fluxes in Asia-Pacific mangroves: current knowledge and gaps. Environmental Research Letters **18**(4), 044002. https://doi.org/10.1088/1748-9326/acbf6c