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Carbon stock assessment of mangrove forests along Macajalar Bay, Misamis Oriental, Philippines

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ABSTRACT

Mangrove ecosystems are widely recognized for their crucial role in mitigating climate change through carbon storage and sequestration services. These ecosystems possess significant carbon reservoirs, particularly in their soils. Nevertheless, the unremitting development of coastal areas and alterations in land use constitute impending threats to these ecosystems, endangering the continuity of their invaluable services. Recognizing the crucial role of mangrove ecosystems in mitigating climate change, this study meticulously evaluates the cumulative carbon stocks encompassing the aboveground and soil components within three mangrove-protected areas in the Macajalar Bay region of Misamis Oriental. The research findings show that soil carbon makes up a significant portion, ranging from 40% to 90%, of the total carbon stocks in the three study areas. This emphasizes the crucial function of mangrove soils as carbon repositories. Furthermore, the study establishes a direct connection between the age of mangrove stands and the occurrence of large-girth trees, both of which add to the rise in carbon stocks. Despite their substantial carbon storage capacity, mangrove forests in the Macajalar Bay region are still facing encroachments due to urbanization pressures. This assessment of carbon stocks in these coastal ecosystems plays a critical role in developing localized strategies that align with the United Nations Framework Convention on Climate Change's (UNFCCC) REDD+ initiatives, thus preventing further degradation of these vital carbon sinks.

1. Introduction

Mangroves are essential coastal ecosystems that offer various ecosystem services and benefits for preserving environmental health and human well-being. They provide protection from storm surges and sea level rise, offer habitats for numerous endangered and commercially significant marine species, regulate coastal water quality, support nutrient cycling, trap sediment, and provide food security to various coastal communities (Alongi, 2009; Carlson et al., 2021; Cullen-Unsworth and Unsworth, 2013; Duke et al., 2007; FAO, 2007). Among the critically important, but least investigated functional services of mangroves is that of carbon storage. Because of its ability to sequester and store significant amounts of carbon - known as blue carbon - in the atmosphere and oceans, mangrove carbon pools are among the highest of any forest type in carbon storage, making them significant carbon sinks (Chatting et al. 2022; Fourqurean et al., 2012; Lavery et al., 2013; Pendleton et al., 2012). Mangroves are crucial in mitigating climate change and reducing emissions from deforestation and degradation (REDD+) programs. Therefore, they are regarded as significant components (Adame et al., 2021; Sahu et al., 2016).

In spite of their strategic significance, mangrove ecosystems find themselves among the highly exploited and rapidly vanishing natural habitats

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worldwide (Abino et al., 2014; Ellison et al., 2020; Goldberg et al., 2020). In 2007, the Food and Agriculture Organization (FAO, 2007) reported that global mangrove coverage had declined from 18.8 million ha in 1980 to 15.2 million ha by the end of 2005, which can be attributed to unsustainable anthropogenic activities and encroachment in coastal areas due to population growth (Rudianto et al., 2020; Swangjang and Panishkan, 2021). The same scenario is happening in the Philippines where the total mangrove area recorded in the country is 450,000 ha. However, these mangrove forests are constantly subjected to immense pressures of human-induced degradations like illegal logging and conversion to fish and shrimp ponds, leaving only 117,700 hectares in 1995. This loss adds to the remarkable reduction in forest biomass and can therefore contribute to the increasing carbon dioxide levels in the atmosphere.

In recognition of the pivotal role of mangroves in carbon storage, sequestration, climate change mitigation, and their potential as sources of carbon emissions when subjected to degradation, this present investigation was initiated to undertake an evaluation of biomass and carbon stocks in three designated mangrove protected areas situated along the Macajalar Bay in Misamis Oriental, Philippines. The specific objectives of this study encompass the following:

1. To ascertain the species composition, community structure, and diversity index of mangrove forests in the three coastal municipalities along Macajalar Bay in Misamis Oriental, Philippines.
2. To compute the living aboveground biomass employing allometric equations and determine the aboveground carbon stock within the three selected mangrove sites.
3. To estimate the belowground carbon sequestered in the sediments of the three mangrove sites along Macajalar Bay.
4. To conduct an assessment of the overall carbon stock, encompassing both aboveground and sediment carbon, within the three mangrove areas situated along Macajalar Bay.

The present study serves as foundational data for the assessment of species diversity, tree biomass, and carbon stock in the three designated coastal zones situated within Macajalar Bay. The quantification of carbon stocks and sequestration rates in mangroves is an essential prerequisite for the future implementation of climate change mitigation strategies and REDD+ initiatives (Sahu et al., 2016; Zeng et al., 2020). As a result, this research affords opportunities for the integration of coastal blue carbon considerations into policies and management practices. Furthermore, it has the potential to stimulate additional conservation efforts, including ecosystem restoration and protection, in other Local Government Units (LGUs) bordering Macajalar Bay. Such endeavors aim to safeguard and enhance the numerous benefits these ecosystems offer to human populations, including climate adaptation and resilience in coastal communities. This is of particular significance given that Northern Mindanao stands as one of the three primary growth centers in the Southern Philippines, with its industrialized coastal cities and municipalities facing Macajalar Bay.

The rapid economic expansion in these areas has given rise to increased land speculation, illegal logging, sea piracy, destructive fishing and mining practices, shipping and industrial pollution, siltation, and soil erosion. These multifaceted challenges now pose significant threats to the coastal resources and ecosystems along Macajalar Bay.

2. Study sites

Macajalar Bay represents the catchment basin for two significant river basins in central Northern Mindanao: the Cagayan de Oro and Tagoloan River basins. These two river basins traverse the provinces of Bukidnon and Misamis Oriental, as well as the chartered city of Cagayan de Oro in Region 10. The bay is flanked by a multitude of light, medium, and large-scale industries and serves as the principal gateway to Northern Mindanao, offering exceptional industrial infrastructure. Since the 1970s, Macajalar Bay has functioned as a prominent industrial hub in Northern Mindanao, as mandated by Executive Order No. 85 of 1993 (Cagayan-Iligan Corridor Special Development Project) and Presidential Decree No. 538 of 1974.

This study focused on three specific marine protected areas located along Macajalar Bay, as illustrated in Fig. 1. These areas are: 1) Tubajon Marine Protected Area in Barangay Tubajon, Laguindingan; 2) Alubijid Marine Protected Area in Barangay Baybay, Alubijid; and 3) Barangay Taytay in El Salvador City.

The designation of these protected areas is established through the enactment of Barangay and Municipal Ordinances, namely Brgy. Ordinance No. 94, Municipal Ordinance No. 45-2006, and the City Fishery Code of 2012 for the respective three study areas. These protected areas are situated in the coastal barangays bordering Macajalar Bay, which is positioned to the north of the province of Misamis Oriental, located in the Southern Philippines.

The first study site encompasses a 22-hectare mangrove area found in Barangay Tubajon, Laguindingan, which was established in 1990 and is predominantly characterized by mangrove species belonging to the Rhizophoraceae family. This area has been officially designated as a protected area under Municipal Ordinance No. 94. Notably, a portion of this area has been made accessible to tourists, functioning as an aquamarine park since November 2013. The management of this site is overseen by the Barangay Council of Tubajon, offering recreational activities such as swimming, boating, and gleaning, while strictly prohibiting the cutting or removal of any part of mangrove plants and other endangered invertebrates.

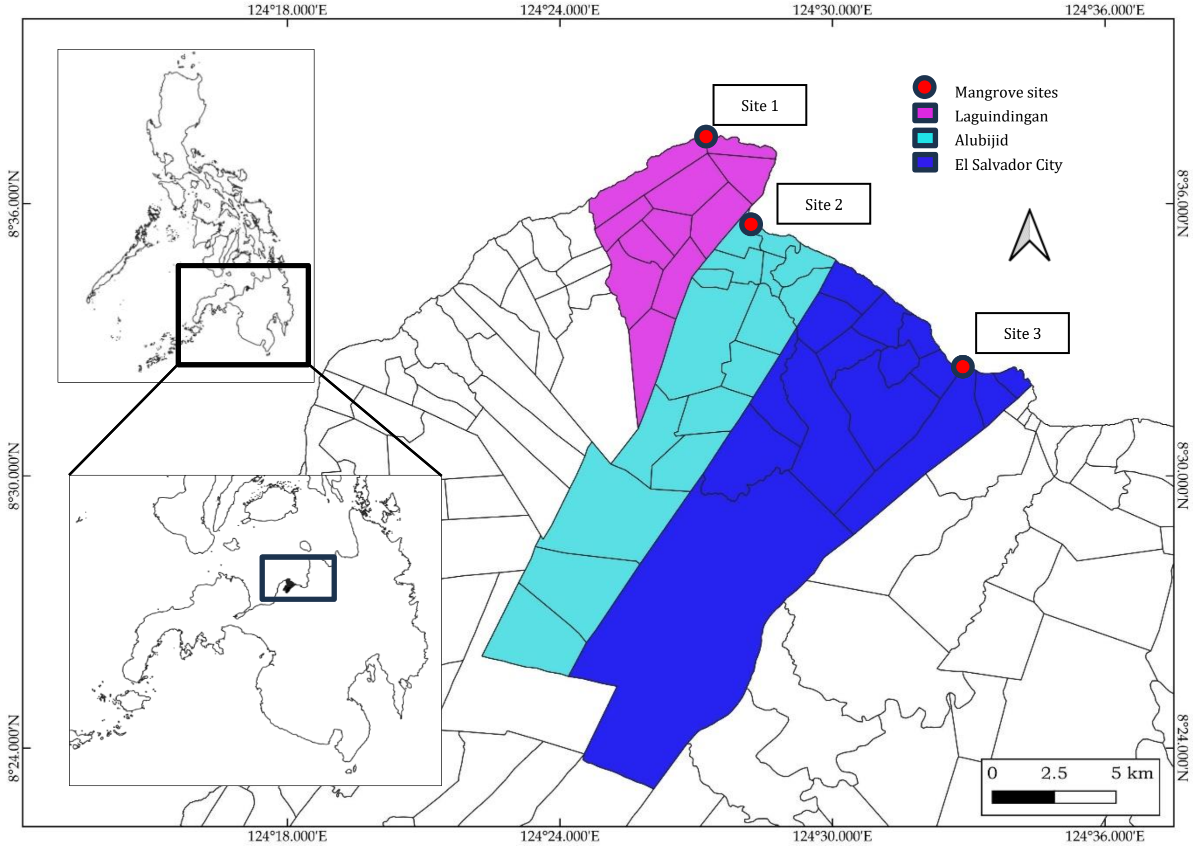

Fig. 1: Geographic map of the sampling area showing the relative location of the three sampling sites

The second mangrove site encompasses a 27-year-old, naturally occurring mangrove stand located in Barangay Baybay, Alubijid, which was declared a protected area in 2006 under Municipal Ordinance No. 45-2006. Covering a total land area of 25 hectares, this site has unfortunately been subjected to severe threats of deforestation and land-clearing activities to support aquaculture development.

The third mangrove site is a 17-year-old planted mangrove area, established in the year 2000 in Barangay Taytay, El Salvador City, with a total land area of 25 hectares. This mangrove site is adjacent to a coastal community, and the proximity of the community to the forest has resulted in household solid waste becoming entangled in the prop roots of mangrove trees, preventing these wastes from entering the ocean. Nevertheless, it has been reported by key informants that sea turtles have been observed foraging beyond the mangrove areas, and the trapped solid waste in the prop roots could potentially pose a hazard to these sea turtles.

3. Methodology

The study area's assessment of species composition and structure employed a nondestructive random line quadrat sampling technique. Within each of the sampling sites, three 150-meter line transects were established perpendicular to the shoreline, maintaining a 50-meter spacing between them. Furthermore, within each of the 150-meter line transects, five 100-square-meter quadrats were created, spaced at intervals of 20 meters, for the purpose of determining species diversity and tree biomass.

Within each plot, all trees with a minimum girth measurement of 4 centimeters were meticulously identified. The measurement of trunk circumference (in centimeters) and total height (in meters) was conducted using a tape measure and a clinometer, respectively. The identification of mangrove trees was conducted on-site with reference to the field guide to Philippine mangroves authored by Primavera and Esteban (2008). These identifications were further refined to the taxonomic level of individual species.

The analysis of the mangrove community structure encompassed the calculation of dominance, density, and frequency, each expressed as relative values for every mangrove species. To gauge the species diversity of the mangrove community, the Shannon-Wiener Diversity Index (Shannon and Weaver, 1963) was employed. This index provides a quantitative characterization of the mangrove habitat in terms of species distribution and evenness. The calculations were facilitated with the utilization of the Paleontological Statistics (PAST) Software, developed by Hammer et al. (2001). Wood densities of the harvested plant part were determined by obtaining its dry weight and volume. A general allometric equation modified from Kauffman et al. (2011) was used for determining tree biomass. In order to enhance the precision of biomass estimation, the study conducted assessments of the Diameter at Breast Height (DBH), tree height, and wood density, recognizing the variances in structure and wood density among different mangrove species. Subsequently, branch samples, with dimensions of 6 centimeters in diameter and 15 centimeters in length, were extracted from the dominant mangrove species within the study site. These samples were then transported to the laboratory for analysis of their carbon content. The data derived from this analysis served as a crucial carbon conversion factor for the determination of the carbon content in each individual tree.

In addition to tree assessments, soil samples were procured from undisturbed sections within each of the designated sampling plots, using a soil corer with dimensions of 50 centimeters in height and 6 centimeters in diameter. The determination of total soil carbon involved segmenting the soil horizon into depth intervals of 0-15 centimeters, 15-30 centimeters, and 30-50 centimeters. Separate soil samples were collected for both soil bulk density determination and analysis of soil organic carbon content (C_{org}), across each of these specified soil depth intervals. The soil samples intended for C_{org} analysis were dispatched to the laboratory, where analysis was performed using an elemental analyzer (Howard et al., 2014).

4. Results and discussions

4.1. Mangrove community structure and species composition

Four true mangrove species comprise the three study sites. The species composition of Site 1 was the most monospecific of the three sites being dominated by mangroves of the family Rhizophoraceae- particularly of the species *R. apiculata* and *R. mucronata*. This is not particularly unusual since it is mostly common for mangroves to form monospecific stands, especially considering that Site 1 is a planted mangrove stand. These two species dominating Site 1 are also found to be abundant in Site 2 and Site 3. These mangroves are likely to be opportunistic due to their relatively wide tolerance for salinity and soil conditions (Ball et al., 1997; Duke, 2006) and thereby out-competing other mangrove species. *Avicennia marina* was found in Site 2 and Site 3. In Site 3, *Sonneratia alba* was found in the low- to mid-intertidal zone, along with *Avicennia marina*, forming a tree line along the seaward margin, while mangroves of the Family Rhizophoraceae line the high intertidal wetland zone about 0-6 meters above sea level (Duke, 2006). Table 1 shows the species diversity and community structure of mangrove forests in the three study sites.

The analysis reveals that the DBH of the mangrove trees within the three sampled sites exhibits a range spanning from 1.3 centimeters to 110 centimeters, while tree height varies between 1.0 meter and 22 meters. Specifically, Site 1 exhibits an average DBH of 6.9 centimeters and an average height of 5.8 meters, with the tallest tree being of the Rhizophora *mucronata* species, reaching a height of 10.20 meters. Site 3 mirrors Site 1 in both mean DBH (6.9 centimeters) and average height (5.8 meters). In this case, the *Sonneratia alba* species attains the greatest height in the stand, reaching 13.07 meters. Conversely, Site 2 displays a mean DBH of 9.1 centimeters and an average height of 7.2 meters. Within this site, the *Rhizophora apiculata* species boasts the maximum height, standing at 22 meters and possessing the largest girth of 110 centimeters. In contrast, the Rhizophora *mucronata* sapling is the shortest tree in the stand, measuring merely 1.0 meter in height.

Table 1: Species diversity and community structure of mangrove forests in the three sampling sites

Site	H	DBH (cm)			Height (m)		
		Mean	Min	Max	Mean	Min	Max
1	0.64	6.9	1.9	26.7	5.8	1.4	10
2	1.1	9.1	2.1	110	7.2	1.0	22
3	1.2	6.9	1.3	28.7	5.8	1.5	13

H: Species diversity index

Upon computation, the species diversity index, as determined by the Shannon-Weiner Index, equates to 0.64 for Site 1, 1.1 for Site 2, and 1.2 for Site 3. However, it is noteworthy that all of the calculated diversity indices for each site fall within the category of "very low," as assessed according to the scale employed by Gevaña and Pampolina (2009).

The low diversity index value for the three mangrove sites reflects the dominance of a few species of the Rhizophoraceae family over other species in terms of density, dominance, and frequency, implying that this species must be relatively well-developed in these areas. Similar low diversity values were observed by Gevaña and Pampolina (2009) in a natural mangrove stand in San Juan, Batangas where Rhizophora mangrove species tend to dominate. Gevaña et al. (2009) and ENFOR (2004) found the same observations in the mangrove stands of Padre Burgos and Pagbilao, Quezon, respectively. The low species diversity can also be attributed to the introduced mangrove species in these mangrove plantations, which are mainly dominated by two to three mangrove species. These findings are supported by several studies that concluded that mangrove forests have lean biodiversity compared to other tropical forest ecosystems (Joshi and Ghose, 2014; Kusmana and Azizah, 2022; Siregar et al., 2022).

Fig. 2 illustrates the distribution of mangrove trees among various diameter classes. It is evident that a substantial proportion of the mangrove tree species within these sites have yet to attain their maximum growth potential, a characteristic discerned through their height and DBH values. Notably, approximately 88% of the mangrove trees exhibit a DBH measurement of less than 10 centimeters. Conversely, the distribution of mangrove trees based on diameter classes within Site 2 reveals a distinctive pattern. This particular stand encompasses newly established saplings alongside the mature naturally grown trees in the mangrove ecosystem. Approximately 71% of the trees in Site 2 exhibit a DBH measurement of less than 10 centimeters, indicative of the presence of recent growth within the stand.

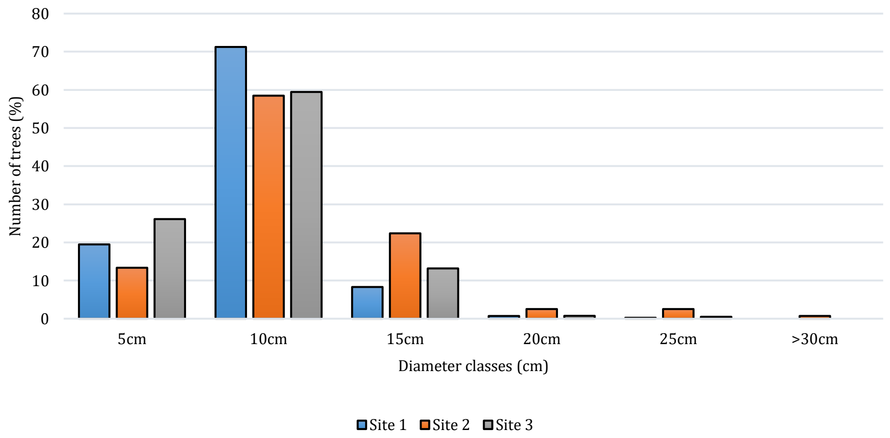

Fig. 2: Distribution of mangrove forest trees by 5cm diameter classes

4.2. Aboveground biomass and carbon stock

Table 2 presents the aboveground biomass and carbon stock of the three mangrove sites. Based on allometric equations, the estimated mean aboveground biomass and carbon stock across sites is 419.2 Mg ha^{-1} (C-stock of 220.3 Mg C ha^{-1}).

The highest aboveground biomass and carbon stock were recorded in the natural forest stand of Site 2 with a mean biomass of 256.9 ± 152.2 Mg ha^{-1} (C-stock of 135.2 ± 80 Mg C ha^{-1}). The lowest aboveground biomass and carbon stock was recorded in the planted forest stand of Site 1 with a mean biomass of 80.23 ± 17.5 Mg ha^{-1} (C-stock of 41.76 ± 9.09 Mg C ha^{-1}), while Site 3 planted mangrove forest stand has closely the same values of average biomass (82.1 ± 19.3 Mg ha^{-1}) and carbon stock (43.3 ± 10.2 Mg C ha^{-1}) as Site 1.

Allocating the mangrove trees into different diameter classes (Fig. 3) revealed that the planted mangrove stands in Site 1 and Site 3 have low aboveground biomass and carbon stock because of the low occurrence of trees with diameters > 20 cm.

Based on allometric equations, DBH is directly correlated to tree biomass (Komiyama et al., 2008). Hence, the presence of mangrove trees > 20cm in the natural mangrove stand in Site 2 resulted in high aboveground carbon stock in the mangrove forest.

Table 2: Aboveground biomass and carbon stock in the three selected mangrove sites

Site	Biomass density (Mg ha^{-1})		Carbon stock (Mg C ha^{-1})	
	Mean	SE	Mean	SE
1	80.23	17.46	41.76	9.09
2	256.9	152.2	135.2	80.0
3	82.1	19.3	43.3	10.2
Total	419.2		220.3	

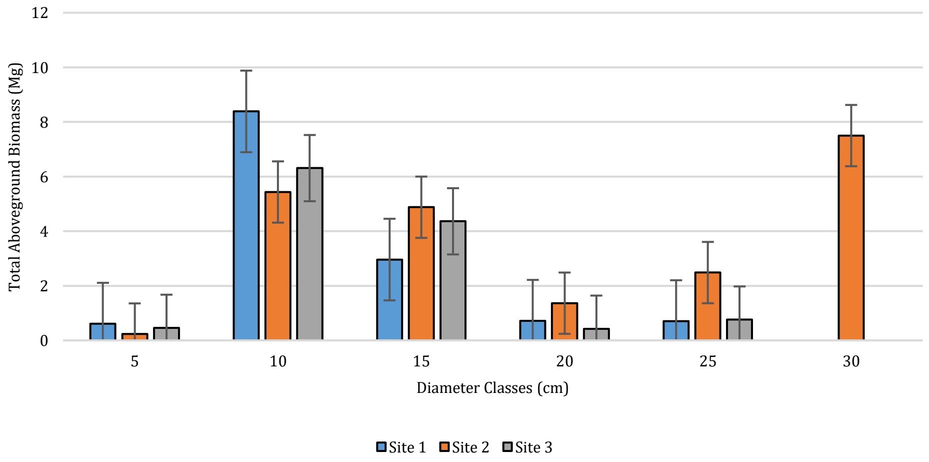

Fig. 3: The distribution of aboveground carbon of living trees by 5cm diameter classes in the three study areas

The presence of large trees in the area greatly affects the total biomass density estimation. For instance, the natural mangrove stand in Site 2 has a total biomass of 256.9 Mg ha^{-1} 63% of this biomass was estimated from trees with DBH greater than 25cm, which comprise only 3% of the mangrove trees. Few large trees in a mangrove forest, as characterized by large DBH, are more important contributors to the aboveground biomass than many young trees with small DBH measurements.

The estimated mean aboveground biomass found in this study is within the mangrove biomass range reported by Komiyama et al. (2008) from 41 to 460 Mg ha^{-1} for Asia and the Pacific. The mean carbon stock found in this study is above the average of the reported carbon stock of mangrove species (163 ± 35 Mg C/ha) in the Indo-Pacific region.

4.3. Soil carbon

The average soil carbon estimated across the three study sites is 360.89 Mg C ha^{-1}. The highest mean soil carbon was recorded in the natural mangrove forests in Site 2, with a mean soil carbon of 147.81 Mg C ha^{-1}, followed by the mean soil carbon of 117.32 Mg C ha^{-1} in mangrove Site 3, while the natural mangrove forests in Site 1 has the least recorded soil carbon of 95.76 Mg C ha^{-1}. Table 3 presents the soil carbon measurements in the different depth intervals across the three study sites.

Table 3: Soil carbon stock with depth

	Mean soil carbon (Mg/ha)		
Depth	Site 1	Site 2	Site 3
0-15 cm	32.72	48.63	43.65
15-30 cm	35.35	53.73	37.14
30-50 cm	27.68	45.45	36.54
Total	95.76	147.81	117.32

The differences in the estimated soil carbon between the three sites can be attributed to the age of the stand and the environmental factors affecting soil carbon in the stand (Lunstrum and Chen, 2014). The highest soil carbon stock across the study sites was observed in the natural mangrove stand in Site 2. This is attributed to the age of the stand - which is 27 years old – the oldest stand among the three sites.

In a chronosequence study conducted by Lunstrum and Chen (2014) in young mangrove forests in a national nature reserve in Guangdong, China, soil carbon accumulation was observed to increase with the age of the forest stand. In this study, Site 1 and Site 2 mangrove forests are of the same age (27 years old) yet observed soil carbon in Laguindingan was the lowest among the three sites. This suggests that localized environmental differences within the study sites affect age-related patterns in soil carbon (Chen et al., 2018; Ha et al., 2018; Marchand, 2017). For instance, the characteristic sandy soil in Site 1 contributes to its high bulk density and low organic carbon content, while the silty loam soil characteristic of Site 2 contributes to its low bulk density and high organic carbon content (Ansari and Sadeghi, 2022; Amhakhian et al., 2021). It has been reported that the differences in soil carbon stocks in different regions could be explained by the differences in carbon content across depth layers in each region (Cooray et al., 2021; Sitoe et al., 2014). Comparisons of soil carbon stocks are notoriously difficult due to natural variation as well as differences in sampling approaches (Kauffman et al., 2011; Holmes et al., 2011). Table 4 provides the total carbon stock across the three mangrove study sites.

The highest carbon stock was recorded in the natural mangrove forests of Alubijid, 283.01 Mg C ha^{-1} or approximately 1,038.65 Mg CO_2 ha^{-1}, followed by the planted mangrove stand in El Salvador with a total carbon of 160.62 Mg C ha^{-1} or 589.48 Mg CO_2 ha^{-1}, while the planted mangrove stand in Laguindingan holds approximately 137.52 Mg C ha^{-1} or 504.7 Mg CO_2 ha^{-1}. Around 52% - 73% of the total carbon stock in the three sites – Sites 1, 2, and 3, respectively, are stored in the sediments. These results are supported by the findings of several studies, for instance, Donato et al. (2011) where soil carbon accounted for about 40-98%, about 85% in Sitoe et al. (2014), and Murdiyarso et al. (2009) found 72% - 98% of the total carbon stock in a mangrove forest. These values show the importance of mangrove soil as carbon pools, and its degradation could be a potential source of CO_2.

Table 4: Total carbon stock summary of the three study sites

Site	Above-ground carbon (Mg C ha^{-1})	Sediment carbon (Mg C ha^{-1})	Total carbon stock (Mg C ha^{-1})	CO_2 equivalent (Mg CO_2 ha^{-1})
1	41.76	95.76	137.52	504.7
2	135.2	147.81	283.01	1,038.65
3	43.3	117.32	160.62	589.48
Total	220.26	360.89	581.15	2,132.83

The total carbon stock obtained from the sites is relatively higher (Fig. 4) than the carbon stocks recorded in the study of Abino et al. (2014) in a natural mangrove forest in Palawan, the mangrove forests in San Juan, Batangas (Gevaña et al., 2008), Segara Anakan, Central Java, Zambezi, River delta in Mozambique (Stringer et al., 2015) and in Sofala Bay (Sitoe et al., 2014). These differences may be associated with differences in tree species composition and forest structure, the density of trees, sampling methodologies, allometric equations used, forest conservation status, soil depth, carbon concentration, site selection, and soil water content in each region (Abino, et al., 2014; Sitoe et al., 2014).

For instance, the higher carbon stock in the mangrove stand of Indonesia (Alongi et al., 2016) is attributed to the deeper soils and large stature trees present in the stand which is clearly different from the forest structure of the present study. Relatively lower carbon stocks recorded in Sofala Bay, Central Mozambique (Sitoe et al., 2014) are also due to the deforestation activities in the area. Because of the natural variations, spatiotemporal variability, and differences in sampling methodologies employed in each of these studies, comparisons in total carbon stocks can be difficult. A comparison of total carbon stocks in different terrestrial ecosystems in the Philippines is shown in Fig. 5. Fig. 5 shows that carbon stored in wetland ecosystems is higher than the carbon stored in other terrestrial forest ecosystems in the Philippines. This is consistent with the findings of Donato et al. (2011) in their study on the comparison of mangrove carbon storage with that of major global forest domains. In his study, he concluded that mangroves are among the most carbon-dense forests in the tropics and exceptionally high compared to the mean carbon storage of the world's major forest domains (sample-wide mean 1,023 ± 88 Mg C ha^{-1}).

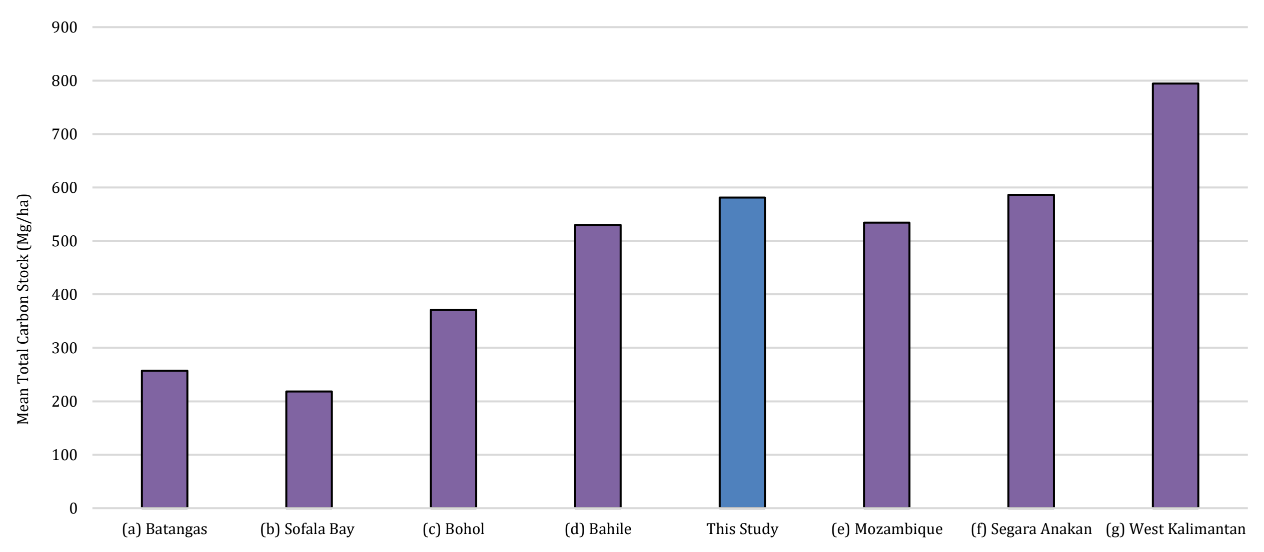

Fig. 4: Comparison of mean total carbon stock across different mangrove forests (Letters in parenthesis indicate literature sources: (a) Gevaña et al. (2008), (b) Sitoe et al. (2014), (c) Camacho et al. (2011), (d) Abino et al. (2014), (e) Bosire et al. (2012), (f) Murdiyarso et al. (2009), and (g) Alongi et al. (2015))

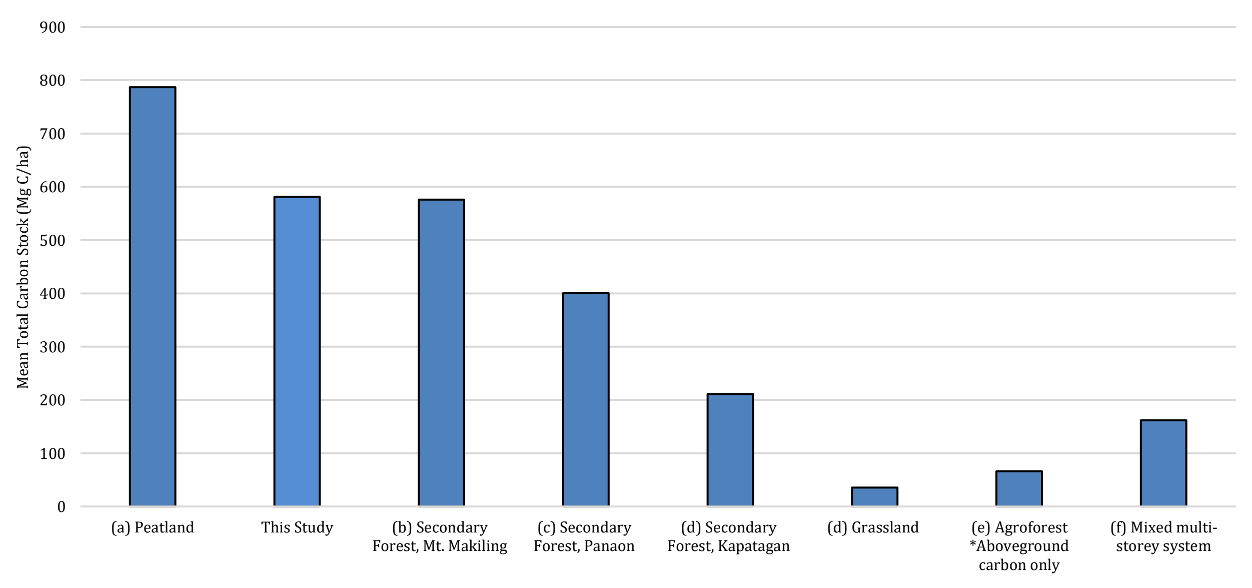

Fig. 5: Comparison of mean total carbon stocks across different terrestrial ecosystems in the Philippines including the present study (Letters in parenthesis indicate literature sources: (a) Orella et al. (2022), (b) Lasco et al. (2004), (c) Ebasan et al. (2016), (d) Zaragoza et al. (2016), (e) Brakas et al. (2011), and (f) Labata et al. (2012))

Most of these carbon stocks are stored in the sediment. The difference in soil carbon accumulation in terrestrial versus coastal systems is that potential carbon storage in upland soils is limited by the high availability of oxygen, allowing for aerobic microbial carbon oxidation and release back into the atmosphere (Schlesinger and Lichter, 2001). In blue carbon systems, however, the soil is saturated with water keeping it in an anaerobic state (low to no oxygen), and it continually accretes vertically at high rates resulting in continuous build-up of carbon over time (Chmura et al., 2003).

5. Conclusion

A substantial proportion of the overall carbon stock within the mangrove sites of Laguindingan, Alubijid, and El Salvador is sequestered within the sediment layers, underscoring the pivotal role played by mangrove soil in serving as reservoirs for carbon. The comprehensive evaluation of the total carbon stock encompassing both biomass and sediment components in these three sites underscores the significant function fulfilled by these mangrove ecosystems situated in Macajalar Bay. It is crucial to recognize that these ecosystems have the potential to become sources of carbon dioxide emissions upon degradation, particularly when subjected to conversion into aquaculture farms or ponds.

In light of this, it is imperative for the LGUs to undertake proactive measures aimed at safeguarding, conserving, and preserving their respective mangrove sites. Such initiatives are vital, given that these ecosystems contribute to enhancing the resilience of coastal areas in the face of the adverse impacts of climate change. Furthermore, it is advisable to conduct an economic analysis to assess the trade-offs associated with the preservation of mangrove stands versus their conversion into aquaculture farms and saltpans. This analysis will help in identifying the sustainability, costs, and benefits linked to each decision made, providing a valuable framework for informed environmental and economic management practices.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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