Article

Quantifying carbon stock of a community-managed overwashed mangrove forest in Batangas, Philippines

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Abstract
Mangrove ecosystem plays a crucial role in promoting biodiversity and mitigating climate change impacts. Calatagan, Batangas as a corridor of the Verde Island Passage, Philippines – the center of the center of marine shore fish biodiversity in the world, has a huge potential for carbon storage because of its rich biodiversity. The biodiversity of mangroves and carbon sequestration estimation are important aspects in conservation planning to reduce the impact of climate change. This research assessed the carbon storage of a community-managed mangrove forest in terms of vegetation and soil carbon. The transect plot technique was employed to assess the forest structure and carbon stock. Vegetative carbon was estimated in terms of the aboveground and belowground biomass of the mangroves using allometric models. Physico-chemical analyses of the sediment were conducted to calculate the soil organic carbon density. Based on the findings, Calatagan Mangrove Forest Conservation Park has 12 species. In terms of edaphic patterns, soil organic carbon showed inverse relationship with soil bulk density. Among the species, *Avicennia marina* and *Sonneratia alba* had high amounts of vegetative carbon stock. Furthermore, it was found that higher carbon stock is accumulated in the soil than vegetative carbon. From these results, the blue carbon approach to community-based conservation and management of mangrove forests is endorsed. This implies that more locally managed marine protected areas (MPA) should be established to promote and strengthen the blue carbon approach as a nature-based solution to climate change. It also suggests that carbon sequestration must be an integral component of the community-based mangrove conservation and restoration plans towards climate change mitigation and adaptation.

Keywords biomass; carbon stock; climate change; mangrove forest; mitigation.

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1 Introduction

Mangroves are critical to mitigating the impacts of climate change as nature-based solutions (NBS) through carbon storage (Song et al., 2023) and improving the well-being of humans. These ecosystems capture carbon dioxide from the atmosphere, storing it in plants and sediments, where it is known as "blue carbon". Blue carbon ecosystems (BCEs), including mangrove forests, tidal marshes, and seagrass meadows, are gaining international recognition as a NBS to climate change (Macreadie et al., 2021). Increasingly, the value of carbon in coastal ecosystems is being integrated into conservation and restoration programs.

Despite their numerous ecological and environmental services, they are severely threatened around the world (Fries, 2023). Climate change and global warming are becoming major threats to these coastal ecosystems (McLeod and Salm, 2006; Alongi, 2008) making them more vulnerable to climate change and other related stressors such as sea level rise, increasing CO_2, temperature, and rainfall. Studies also show a considerable impact of climate change on mangrove ecosystems (Ellison, 2015; Ward et al., 2016). Gevaña and Pampolina (2009) presented in their study that mangrove ecosystem plays an important role in promoting biodiversity and mitigating climate change impact.

Mangroves are considered one of the most carbon-rich tropical ecosystems. They are keystone coastal ecosystems providing numerous environmental services and critical ecological functions, affecting both upland and marine resources. These values include protection from storms and tsunamis (Giesen et al., 2007; Mitsch and Gosselink, 2007; Alongi, 2008), regulation of water quality, breeding, and rearing habitats for many species of fish and shellfish, habitats for many rare and endangered species (Duke et al., 2007; FAO, 2007).

Mangrove carbon pools are among the highest of any forest type and are among the major carbon sinks of the tropics (Cahoon et al., 2003; Bouillon et al., 2008; Nellemann et al., 2009; Kauffman and Donato, 2012). For example, ecosystem carbon pools of mangroves in the Indo-Pacific region are more than twice those of most upland tropical and temperate forests (Page et al. 2011, Hooijer et al., 2010).

Nowadays, mangroves are today's global issue because more than 100 countries have mangrove resources (Spalding et al., 2010).Of the approximately 100 countries that have mangrove vegetation, around 20 have undertaken rehabilitation initiatives (Field, 1998) and establishing nurseries and replanting in degraded areas (Erftemeijer and Hamerlyck, 2005). The continuous decline of mangrove forests is also true in the Philippines (Gevaña and Pampolina, 2009). Historical data reveal that over the 450,000 ha. of mangroves existing in the 1920s, were tremendously trimmed down to 120,000 ha. that remain today (Roldan et al. 2010). This suggests a huge loss in biodiversity and biomass (DENR, 2005).

In recent years, carbon sequestration has played a significant role in climate change adaptation. Carbon sequestration is the capturing of carbon and diverting it to secured storage. Trees act as a sink for CO_2 by fixing carbon during photosynthesis and storing excess carbon as biomass (Bipal et al., 2009). Compared to other land forests, mangrove ecosystem accumulates sequestered carbon in the sediment (Seema et al., 2012).
Because of their exceptionally large carbon stocks and importance as a coastal buffer, their protection and restoration have been proposed as an effective mitigation strategy for climate change. The inclusion of mangroves in mitigation strategies requires the quantification of C stocks (both aboveground and belowground) and changes to accurately calculate emissions and sequestration (Fatoyinbo et al., 2018). The information on mangroves' carbon is essential because when the changes occur much of the carbon stocks in the ecosystem are released into the atmosphere (Rabiatul et al., 2012). Mangrove ecosystems are important to the community and conserving them is very important.

One of the major challenges in ecology today is to determine the actual values of carbon in mangrove vegetation. Standing biomass studies provide important information on the amount of carbon. Estimation of the aboveground biomass of mangroves is an important issue because of its relevance to nutrient turnover and the potential to store carbon (Abib and Appado, 2012; Tamooh et al., 2008). Perhaps the least investigated, yet critically important, ecosystem service of mangroves is that of carbon storage. Mangrove carbon pools are among the highest of any forest type (Kauffman and Donato, 2012). Integrating activities and initiatives on blue carbon in the conservation and management of mangroves will assist and build adaptive capacity of the coastal community to mitigate the impacts of climate change.

Research on carbon stocks in mangroves has primarily focused on fringing forest types, with considerably less attention given to overwashed mangrove systems, particularly in the Philippines. Fringing mangroves, which are typically found along coastlines, have been well-documented for their carbon sequestration capabilities due to their relatively stable geomorphic setting and extensive root systems (Alongi, 2012; Friess et al., 2012). In contrast, overwashed mangroves, which occur in areas periodically inundated or reshaped by storms, such as barrier islands and floodplains, present unique challenges in terms of carbon storage due to their dynamic and often disturbed environments. Despite the importance of these systems in coastal protection and carbon cycling, limited studies have assessed their carbon stock potential compared to more stable mangrove types (Macreadie et al., 2017).

Because of these values and threats to mangroves, surveys to describe the forest composition, structure, and ecosystem carbon pools are needed to monitor status and trends (Kauffman et al., 2014) in overwashed type of mangrove geomorphic setting. In the context of the Philippines, which is home to diverse mangrove ecosystems, there is a notable research gap concerning the carbon stocks of overwashed mangroves. While the country's fringing mangroves have received some attention in terms of carbon inventory (Guerrero et al., 2016), very few studies have focused on overwashed geomorphic settings. In addition, a lot of research studies focus on the taxonomy and ecology of mangroves but very few of these focus on the aspect of carbon sequestration in overwashed types of mangroves. These systems, often located in high-risk coastal areas affected by frequent storms, are understudied in the context of their potential for carbon sequestration, despite their ecological and socio-economic significance (Vega et al., 2020). Understanding the carbon dynamics in overwashed mangroves is crucial for more accurate global carbon budget estimations and for enhancing conservation strategies in the Philippines' increasingly vulnerable coastal zones.

The objectives of the study are:

1. To describe the species composition, forest structure, and soil physico-chemical characteristics (soil organic carbon and bulk density) of the mangrove ecosystem.
2. To estimate the aboveground and belowground biomass of the mangrovesusing allometric models.
3. To determine the total carbon stock and the potential carbon dioxide (CO_2) emission equivalent basedon the aboveground and belowground biomasses and soil organic carbon.

2 Methods

2.1 Study area

The Calatagan Mangrove Forest Conservation Park otherwise known as the “Ang Pulo” is a 7.5 ha mangrove park located within a Marine Protected Area declared by the Municipality of Calatagan in 2009 (Cudiamat and Querijero, 2023). It is home to different species of mangroves, birds, and invertebrates. The nature park is managed by a local people’s organization, the PALITAKAN. It is characterized by an overwashed mangrove forest located between $120^0$37’01” East and $13^0$37’56.07” North.

2.2 Survey of forest structure

Twenty (20) plots (Fig. 1) were established in the sampling site through transect plot technique or quadrat sampling (English et al., 1997) to assess the mangrove structural parameters for the carbon stock assessment (Kauffman and Donato, 2012). Survey of the forest structure of mangroves included the following parameters: species composition, height, girth at breast height (GBH). In terms of stand structure, each mangrove tree was tagged, counted, and identified using the field guide of Primavera et al. (2004). GBH of each tree was recorded by measuring the trees’ circumference 1.37 m above the ground. Only mangrove trees with greater than 1.5 cm diameter at breast height (DBH) were included in the biomass assessment (Gevaña and Pampolina, 2009; Duncan et al., 2016).

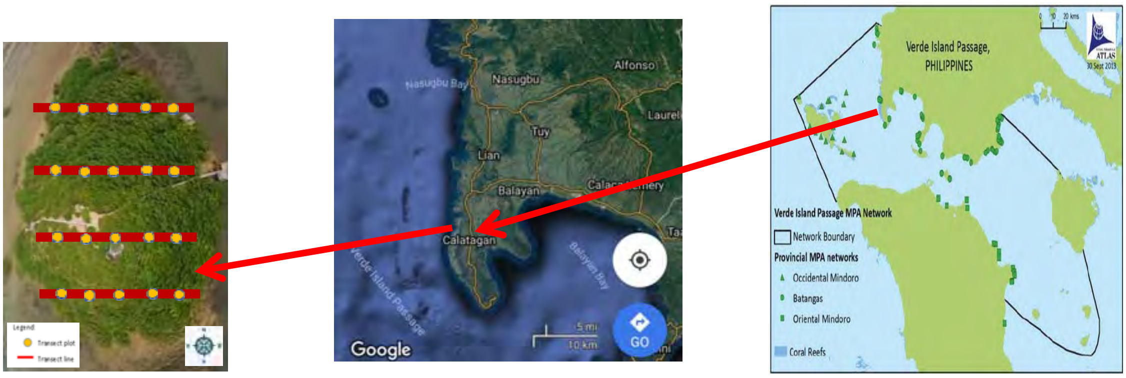

Fig. 1 Map of the study site.

2.3 Soil collection and physico-chemical analysis of the sediments

Forty (40) soil samples were collected to determine the soil physico-chemical factors using a stainless and metallic soil auger in the sampling site during low tide with an interval depth of 1-15 cm and 16-30 cm. A global positioning system (GPS) meter was used to determine the location of each plot. Collection was done in each of the transect plots using a 5-cm diameter core sampler. Soil samples were air-dried for soil organic carbon and soil bulk density and were sent to the Soils Laboratory, Analytical Services Institute, Division of Soil Science, College of Agriculture and Food Science (CAFS) at the University of the Philippines Los Baños, Laguna, Philippines. Soil bulk density was determined by using the core method by dividing the oven-dried soil (g) by the total volume of the soil (cm^3). Using the same soil sample, soil organic carbon was determined based on the Walkley and Black chromic acid wet oxidation method. Oxidizable organic carbon in the soil is oxidized by 0.167 M potassium dichromate ($K_2Cr_2O_7$) solution in concentrated sulfuric acid. The heat of the reaction raises the temperature sufficient to induce substantial oxidation.

To determine the soil organic carbon and bulk density of the two layers of sediments taken from each plot of the different zones of mangrove forest, the following equations were used:

$$Bulk\ density\ (g\ cm^{-3}) = \frac{oven - dried\ mass\ (g)}{Sample\ volume\ (g\ cm^{-3})}$$

Soil carbon (Mg ha^{-1}) was calculated for each soil horizon as shown below (Kauffman and Donato, 2012):

Soil Carbon (Mg ha^{-1}*) = bulk density (g* cm^{-3}*) x depth (cm) x organic carbon (%)*

2.4 Carbon stock assessment

The standard protocols of Howard et al. (2014) for the assessment of coastal blue carbon in the mangrove forest were utilized in this study. The protocols provide quantification methods for determining vegetation biomass and its carbon equivalent, sediment carbon analysis, and computation of potential carbon dioxide emission. Vegetation biomasses in the 20 transect plots were obtained using the allometric equations developed by Komiyama et al. (2005). Both general allometric models for the aboveground and belowground biomass were used to calculate the carbon stock. Sediment samples (n=40) from 1-15 cm and 16-30 cm horizons were collected using a stainless metallic soil auger (diameter = 2.86 cm) in each of the plots.

2.5 Data analysis

2.5.1 Mangrove diameter at breast height (DBH)

Using the measurement of the girth at breast height (GBH) measured at 1.37 m above the ground or starting at the top of the buttress or prop root (*Bruguiera*, *Rhizophora*),the diameter at breast height (DBH) of the mangroves was calculated using the given formula: $DBH = GBH * \pi$ $(\pi = 3.1416)$

2.5.2 Estimation of aboveground and belowground biomass using allometric equations

Allometry is a powerful tool for estimating the biomass of mangroves. This study employed the allometric equations of Komiyama et al. (2005).

a. *Aboveground Biomass* $(W_{AGB}) = 0.251pD^{2.46}$

where: W_{AGB}= aboveground biomass (kg)

p = wood density (g cm^{-3})

D = diameter at breast height (cm)

b. *Belowground Biomass* $(W_{BGB}) = 0.199p^{0.899}D^{2.22}$

where: W_{BGB}= belowground biomass (kg)

p = wood density (g cm^{-3})

D = diameter at breast height (cm)

For multi-stemmed trees, aboveground biomass was estimated using the method of Fu and Wu (2011). W_{AGB} (kg) was calculated as:

$W_{AGB} = CD^2 \, x \, H$

where CD is the maximum canopy diameter (m) and H is tree height (m). This method applies to species with variable growth forms such as *Avicennia marina* (Fu and Wu, 2011; Duncan et al., 2016).Wood density (p) of each species of mangrove (Table 1) was based on Howard et al. (2014), Kauffman and Donato (2012), and Zanne et al. (2009).

Table 1 Wood density of mangroves.

Mangrove Species	Wood Density (g cm^{-3})
Aegiceras corniculatum	0.51
Avicennia marina	0.62
Bruguiera cylindrica	0.71
Ceriops tagal	0.85
Ceriops zippeliana	0.87
Excoecaria agallocha	0.41
Lumnitzera racemosa	0.60
Rhizophora apiculata	0.87
Rhizophora mucronata	0.83
Rhizophora stylosa	0.84
Sonneratia alba	0.47
Xylocarpus granatum	0.61

2.6 Total carbon stock assessment

The aboveground carbon (AGC) and belowground carbon (BGB) were computed to obtain the total vegetation carbon stock estimates by multiplying each type of biomass by the carbon concentration values of 0.464 (Donato et al., 2011) and 0.39 (Kauffman and Donato, 2012; Howard et al., 2014) respectively. The average amount of vegetative carbon in a plot and the associated standard deviation were calculated to determine the variability. To obtain the total amount of carbon in the ecosystem, the vegetative component carbon pool or the biomass carbon (Mg C ha^{-1}) and the soil carbon stock (Mg C ha^{-1}) were added.

Estimate of biomass carbon in the mangrove ecosystem (Mg C) = Average vegetative carbon (Mg C ha^{-1}) x area of the ecosystem studied (ha)

Soil organic carbon (Mg C) = Average soil organic carbon (Mg C ha^{-1}) x area of the ecosystem studied (ha)

Generally, the carbon stock was calculated using the given equation:

Total Blue Carbon Stock (Mg C) = biomass carbon (Mg C) + soil carbon (Mg C)

2.6.1 Estimation of carbon dioxide emission

The total potential CO_2 emissions per hectare (Mg CO_2) were calculated using the conversion factor for the CO_2 that can be produced from the carbon present in the mangrove ecosystem and the carbon in the mangrove ecosystem being investigated (Howard et al., 2014).

Potential CO_2 emissions (Mg CO_2) = total carbon stock x carbon conversion factor (3.67)

The conversion factor is based on the ratio of the molecular weights of CO_2 (44) and carbon (12). Statistical analyses were run through Paleontological Statistics (PAST) software version 4.12.

3 Results

3.1 Community structure of the mangrove forest

Calatagan Mangrove Forest Conservation Park is characterized by an overwashed type of mangrove forest. In terms of species composition, a total of 12 species of mangroves (Fig. 2) under seven (7) families were identified systematically in this type of mixed mangrove forest (Table 2). Of these 12 species, *Sonneratia alba* and *Avicennia marina* were dominant due to their high density and greater DBH in the area. On the other hand, *Lumnitzera racemosa*, *Bruguiera cylindrica*, and *Xylocarpus granatum* had the lowest number of individuals within the forest stand. At the family level, Family Rhizophoraceae (1st), Family Lythraceae (2nd), and Family Acanthaceae (3rd) were dense in the plots when it comes to the number of individuals while Family Combretaceae and Family Meliaceae had the least number.

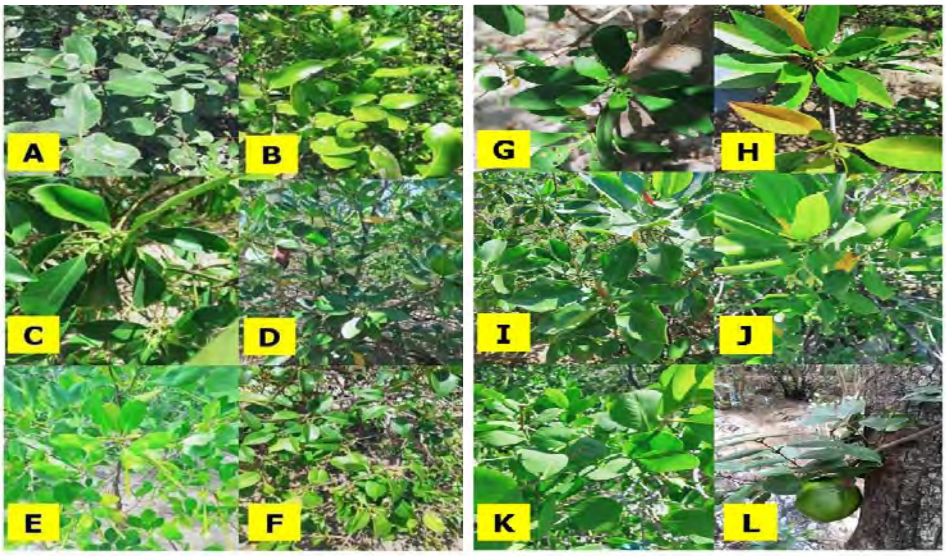

Fig. 2 Mangrove species recorded in the site. *A.corniculatum* (A), *A.marina* (B), *B.cylindrica* (C), *C.tagal* (D), *C.zippeliana* (E), and *E.agallocha* (F), *L.racemosa* (G), *R.apiculata* (H), *R.mucronata*(I), *R.stylosa*(J), *S.alba* (K), and *X.granatum* (L). (Photos by M. Cudiamat).

Table 2 Species composition and forestst and structure of mangroves.

Family	Species	n	DBH (cm)	Height (cm)
Acanthaceae	*Avicennia marina*	42	2.35±1.24	3.02±0.85
Combretaceae	*Lumnitzera racemosa*	1	1.90+0.00	2.75+0.00
Euphorbiaceae	*Excoecaria agallocha*	3	2.77±0.64	3.77±0.64
Lythraceae	*Sonneratia alba*	59	2.42+1.52	4.18+0.97
Meliaceae	*Xylocarpus granatum*	1	2.10+0.00	3.20+0.00
Myrsinaceae	*Aegiceras corniculatum*	3	2.05+0.07	3.00+0.71
Rhizophoraceae	*Bruguiera cylindrica*	1	1.80+0.00	3.20+0.00
	Ceriops tagal	4	2.37+0.23	3.27+0.06
	Ceriops zippeliana	2	2.00+1.41	3.15+0.92
	Rhizophora apiculata	11	3.11+1.25	4.00+1.48
	Rhizophora mucronata	13	1.80+1.44	2.52+1.27
	Rhizophora stylosa	33	1.40±1.75	3.89±1.18

3.2 Soil organic carbon and bulk density

The results of the soil physico-chemical analysis in terms of organic carbon and soil bulk density. Soil bulk density is higher compared to the reported bulk density of (Salmo III et al., 2019) probably due to sandy substrate present in the mangrove forest. The findings showed that there is a significant inverse relationship between soil bulk density and organic carbon in the 1-15 and 16-30 cm layers of the soil (Fig. 3).

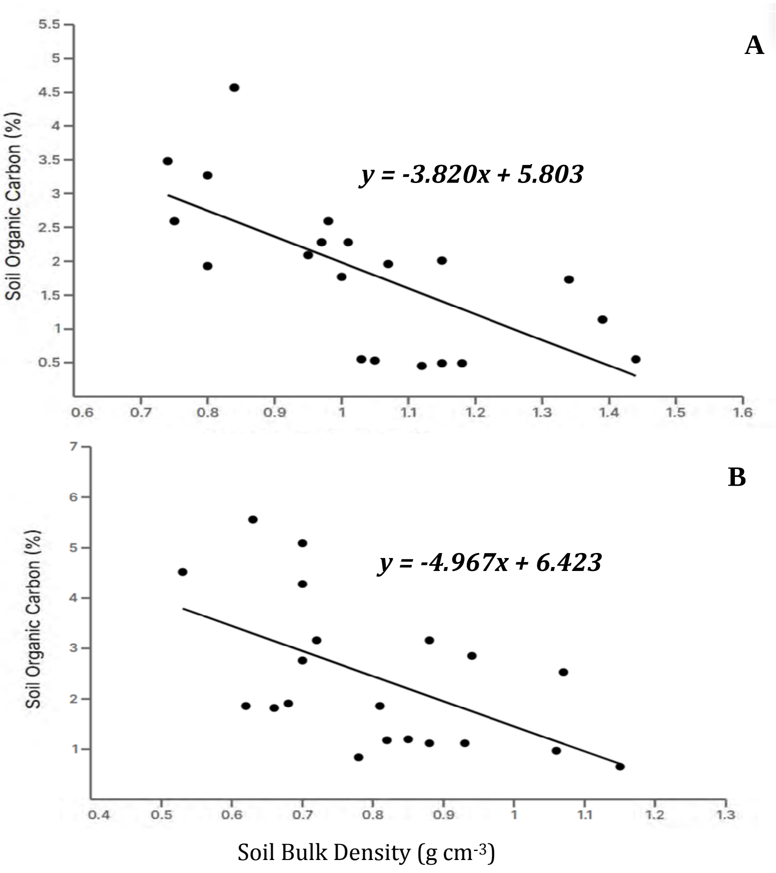

Fig. 3 Linear regression model showing an inverse relationship between organic carbon and soil bulk density at 1-15 cm with r^2=0.452 and p=0.001 (A) 16-30 cm at 0-15 cm with r^2 =0.308 and p=0.011(B).

3.3 Biomass and vegetative carbon stock of mangroves

The vegetative carbon stocks showed that Family Lythraceae had the highest vegetative carbon pool of 56.393 Mg ha^{-1}. Family Acanthaceae and Family Rhizophoraceae had also a high vegetative carbon pool of 37.671 Mg ha^{-1} and 13.84 Mg ha^{-1}, respectively. However, Family Euphorbiaceae (0.794 Mg ha^{-1}), Family Myrsinaceae (0.095 Mg ha^{-1}), and Family Meliaceae (0.028 Mg ha^{-1}) had a low vegetative carbon pool. Likewise, Family Combretaceae had the lowest vegetative carbon pool (0.027 Mg ha^{-1}) among the 7 identified families of mangroves.

Data revealed that *S. alba* (a multi-stemmed species) had the highest combined biomass (126.968 Mg ha^{-1}) from its aboveground and belowground biomass. It was followed by *A. marina*, also a branching mangrove species with a total biomass of 84.767 Mg ha^{-1}. These two species also had the highest vegetative carbon pool in the forest (*A. marina* = 37.671 Mg ha^{-1} and *S. alba* = 56.393 Mg ha^{-1}). On the other hand, *L. racemosa* had the lowest total biomass (0.061 Mg ha^{-1}) and vegetative carbon (0.027 Mg ha^{-1}) followed by *X. granatum* with a total biomass and vegetative carbon of 0.063 Mg ha^{-1} and 0.028 Mg ha^{-1} respectively. This further means that the higher the biomass, the higher the vegetative carbon of mangrove species (Table 4).

Table 4 Aboveground and belowground biomass and vegetative carbon stocks of mangroves.

Family	Species	Total Biomass (Mg ha^{-1})	Aboveground Carbon (Mg ha^{-1})	Belowground Carbon (Mg ha^{-1})	Vegetative Carbon Pool Mg C ha^{-1})
Acanthaceae	*A.marina*	84.767	28.916	8.755	37.671
Combretaceae	*L.racemosa*	0.061	0.018	0.009	0.027
Euphorbiaceae	*E.agallocha*	1.800	0.579	0.215	0.794
Lythraceae	*S.alba*	126.968	43.110	13.283	56.393
Meliaceae	*X.granatum*	0.063	0.019	0.009	0.028
Myrsinaceae	*A.corniculatum*	0.216	0.064	0.030	0.095
Rhizophoraceae	*B.cylindrica*	0.378	0.119	0.047	0.166
	C.tagal	0.618	0.190	0.082	0.271
	C.zippeliana	0.177	0.053	0.025	0.077
	R.apiculata	7.893	2.560	0.927	3.487
	R.mucronata	3.554	1.121	0.443	1.565
	R.stylosa	18.755	6.015	2.258	8.274

3.4 Total blue carbon stock of mangroves

Data on vegetative carbon, soil carbon density, and total carbon stock revealed that there was 108.63 Mg ha^{-1} of vegetative carbon, and 537.13 ha^{-1} soil carbon in the sampling site (Table 5). Combining these 2 carbon pools resulted in a total blue carbon stock of 645.76 Mg ha^{-1}. In terms of carbon pool partition (Fig. 4), the findings conform to the worldwide partition of mangrove ecosystem carbon stocks which dominates the soil carbon stock followed by aboveground carbon stock and belowground carbon pool having the least carbon pool (Donato et al., 2011). The carbon emission equivalent based on the total blue carbon stock of 645.76 Mg ha^{-1} is 9 479.76 Mg CO2 following the estimation protocol of Howard et al. (2014).

Table 5 Total blue carbon stock of mangroves.

Zone	Aboveground Carbon (Mg ha^{-1})	Belowground Carbon (Mg ha^{-1})	Total Vegetative Carbon (Mg ha^{-1})	Soil Carbon Density (Mg ha^{-1})	Total Carbon Stock (Mg ha^{-1})
I	42.01	15.77	57.78	432.02	489.80
II	20.87	7.79	28.66	519.48	548.14
III	219.44	63.94	283.38	608.61	891.99
IV	47.92	16.79	64.71	588.39	653.10
Mean	82.56	26.07	108.63	537.13	645.76

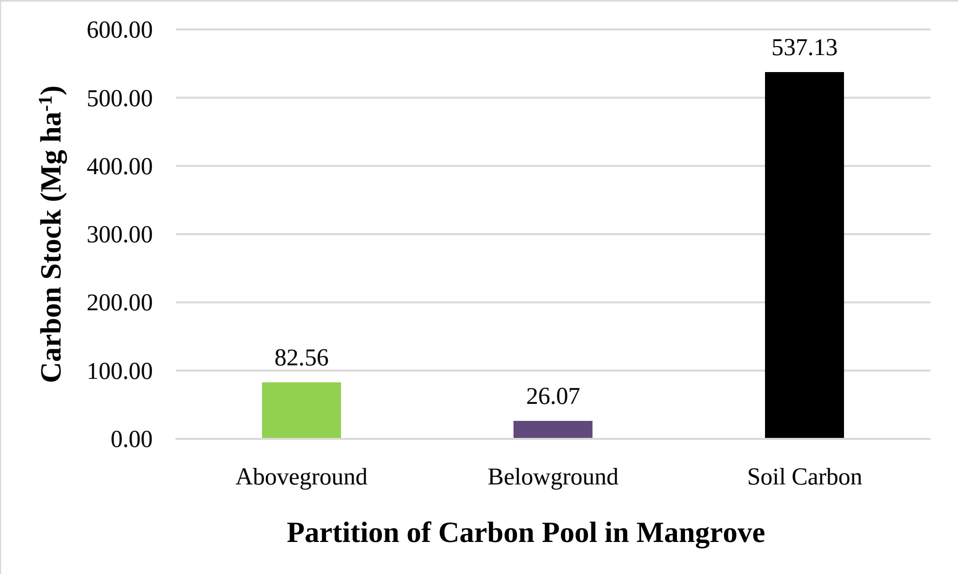

Fig. 4 Aboveground, belowground and soil carbon stock (Mg ha^{-1}).

4 Discussion

The forest structure of the mangroves with 12 species belonging to 7 families showed a very young stand structure (Cudiamat and Rodriguez, 2017) based on its overall mean DBH, height, canopy length, and canopy width. This is also an update to existing vegetation analysis conducted by Cudiamat and Rodriguez (2017). *A. marina* had the highest DBH, while *S. alba* dominated in terms of height. Chemical analyses of the sediment showed high soil bulk density compared to the reported bulk density of (Salmo III et al., 2019) due to presence of sandy substrate within the mangrove forest. The findings showed that there is a significant inverse relationship between soil bulk density and organic carbon in the 1-15 and 16-30 cm layers of the soil (Fig. 3). The vegetative carbon pool also shows variation across mangrove zonation. Zone III had the highest amount of vegetative carbon with 283.38 Mg ha^{-1} followed by Zone IV with a vegetative carbon of 64.71 Mg ha^{-1}. This is attributed to the presence of mangroves with higher aboveground and belowground biomass. In contrast, Zones I and II had the least amount of vegetative carbon with 57.78 Mg ha^{-1} and 28.66 Mg ha^{-1} of biomass carbon respectively.

From the findings of the vegetative carbon and community structure of mangroves, it was shown further that the higher the biomass, the higher the vegetative carbon of mangrove species (Seema et al., 2012; Paglinawan, 2016). In addition, species with high abundance also contribute to higher amounts of carbon from their biomass.

In general, there was a total of 108.63 Mg ha^{-1} vegetative carbon in the mangrove forest. This is higher compared to the estimates of Gevaña and Pampolina (2009) in San Juan, Batangas with few species across the Rhizophora mangrove stand in the area. However, this amount of carbon stock is lower compared with the reported amount of carbon in the study of Salmo et al. (2019). In terms of carbon pool partition, the findings conform to the worldwide partition of mangrove ecosystem carbon stocks which dominates the soil carbon stock followed by aboveground carbon stock and belowground carbon pool having the least carbon pool (Donato et al., 2011). The carbon emission equivalent to this carbon stock is 9 479.76 Mg CO_2. This amount is lower compared to the amount of carbon stock of the mangroves in Mindoro (Salmo et al., 2019) although the current study is in an overwashed forest type.

5 Conclusions

Calatagan Mangrove Forest Conservation Park has 12 mangrove species with varied characteristics of vegetation-related forest structure. The community-managed forest shows a high carbon stock in the soil compared to vegetative carbon. Soil bulk density and organic matter could contribute to high soil carbon stock in the mangrove forests. *A. marina* and *S. alba* showed higher amounts of vegetative carbon among the species of mangroves. This could be attributed to their larger GBH, branching characteristics, and high density in the area. The calculated carbon stock in the sampling site will serve as a baseline record for Calatagan mangroves. This leads to potential climate change mitigation programs in the area in the future.

From these results, a blue carbon approach as a nature-based solution to climate change mitigation and adaptation to strengthen community-based conservation and management of mangrove forests is endorsed. Using this carbon-centric approach to conservation, empowerment of local people in the conservation of mangroves and establishment of marine protected areas can be integrated into building sustainability planning (Cudiamat and Valdez, 2022). In addition, the conservation and propagation of mangrove species that accumulate or sequester greater amounts of biomass and carbon equivalent may also be prioritized. Carbon stock assessment should also be included in the planning of marine ecosystems, especially in monitoring and assessment of mangrove growth. This implies that it must be an integral component of the community-based mangrove conservation and restoration.

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