Carbon Sequestration Potentials of Mangroves in Northern Mindanao

Fae G. Ucat., Annielyn D. Tampus

Department of Marine Science, College of Science and Mathematics, Mindanao State University – Iligan Institute of Technology, Andres Bonifacio Avenue, Iligan City 9200, Philippines.

DOI: https://doi.org/10.51584/IJRIAS.2024.908028

Received: 26 July 2024; Accepted: 30 July 2024; Published: 06 September 2024

ABSTRACT

The estimated mean biomass across sites of Northern Mindanao was 947.47 Mg ha^{-1} with a carbon stock of 142.12 Mg ha^{-1}. Camiguin Island exhibited the highest aboveground and belowground biomass and carbon stock, attributed to the prevalence of large-diameter trees. In contrast, Cagayan de Oro and Laguindingan had higher numbers of smaller-diameter trees, resulting in lower biomass and carbon stock. The study highlighted the critical role of soil carbon, which constituted a significant portion of the total carbon stock. Overall, the combined mean carbon stock of biomass and sediments across all sites was 447.86 Mg ha^{-1}, translating to a carbon sequestration potential of 1,643.66 Mg CO2 ha^{-1}. The study emphasizes the species composition, mangrove stand age, and site protection in enhancing the carbon sequestration capabilities of mangrove forests.

Keywords: mangroves, Northern Mindanao, carbon stock, sediment, biomass

INTRODUCTION

Mangroves are unique ecosystems found in tropical and subtropical coastal regions. They are characterized by salt-tolerant trees and shrubs that thrive in the intertidal zone, where they are subjected to saltwater inundation and fluctuations in water levels [1]. Mangroves play a crucial role in maintaining coastal stability, reducing erosion, and providing habitat for a diverse range of species [2]. Additionally, mangroves also have a significant role in carbon sequestration and can help to reduce climate change. [3-4]. Scientific literature about carbon sequestration and storage in blue carbon ecosystems is limited in the Philippines because more studies are concentrated on terrestrial vegetation.

Additionally, most carbon sequestration studies are primarily focused on the potential above/below ground biomass of mangroves in different areas of the country such as in Palawan [5], Leyte [6], Verde Island Passage [7], Aklan [8-9], Quezon [10], Batangas [11], Davao [12]. In contrast, limited studies are conducted in Mindanao. Recent studies of mangroves particularly in the Mindanao region, have relied on species-specific allometric equations to estimate carbon stock accumulation [13-15]. Soil carbon accounts for a substantial proportion, ranging from 40% to 90%, of the total carbon stocks of the studied areas in Macajalar Bay, highlighting the vital role of mangrove soils as carbon reservoirs [16]. Primarily focusing on the mangroves, carbon sequestration potentials in belowground and aboveground biomass of these are merely explored carbon reservoirs in Northern Mindanao. There are several studies conducted on the composition and diversity of mangroves in some of Northern Mindanao. However, limited studies have been conducted on the biomass, carbon stock, and sequestration potentials of mangrove forests in the region. Thus, this study aims to determine the aboveground and belowground root biomass, and carbon stocks and estimate the carbon sequestration potentials using allometric equations in Northern Mindanao, Philippines. The results of this study will serve as a guide to recommend management and conservation strategies for a marine ecosystem like mangroves and explore the potential of mangroves in climate change mitigation.

MATERIALS AND METHOD

A. Description of the study sites

The area of the study is in Region X, Northern Mindanao, Philippines which spans a total land area of 2,049,602 hectares (5,064,680 acres). The seas surrounding Northern Mindanao are rich in marine biodiversity and serve as major fishing grounds of the region. Sampling of mangrove ecosystems is conducted across six (6) stations specifically in (1) Mahinog; (2) Guinsiliban; (3) Bulua; (4) Bayabas; (5) Bonbon; (6) Mauswagon, encompassing three (3) coastal areas namely the municipality of Laguindingan, City of Cagayan de Oro and the island province, Camiguin (Fig. 1). Significant presence of marine ecosystems such as mangroves in all areas have high potentials for conservation and regeneration which may contribute to the fisheries production and future resilience against climate change threats.

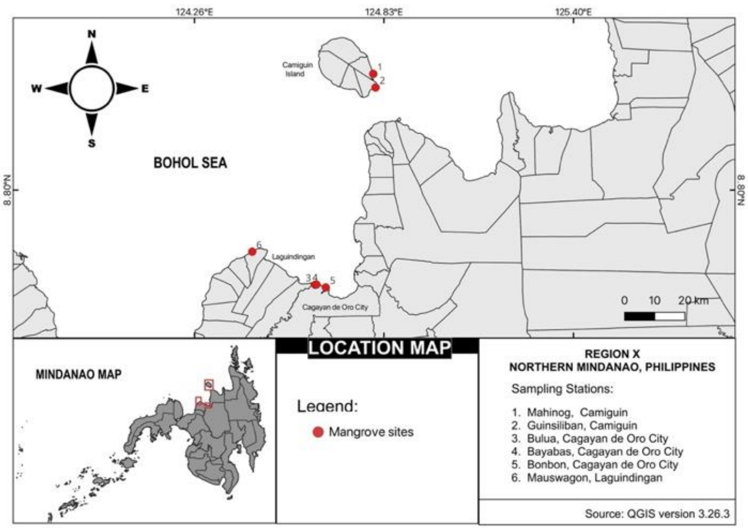

Fig. 1 Geographical locations of the six (6) sampling sites in the Region X, Northern Mindanao, Philippines

B. Measurement of Diameter at Breast Height, Basal Area, and Height

Utilizing a technique modified from the ASEAN-Survey Manual for Tropical Marine Resources, the mangrove profile was evaluated using the purposive transect-quadrat method [17]. Plots were established in six (6) sampling sites in Northern Mindanao. Three (3) 20 x 10 (200 m2) plots were established in each station at a 50-meter interval each plot. The girth (or diameter at a standard breast height of 1.3m) of mangroves was measured using a tape measure. The diameter at breast height or DBH was calculated using the formula: circumference divided by 3.1416(DBH)2/4 [17]. At a standard height of 1.3 m above ground, the girth at the breast height (GBH) of each tree will be measured. Tree height measurement in meters was determined by applying trigonometric techniques and by using a modified clinometer.

C. Estimation of Aboveground Biomass (AGB) and Belowground Root Biomass (RB) of mangroves

Following the allometric equations for Southeast Asian mangroves [18] having a coefficient of determination (R^2) of 0.98 and 0.95, respectively, the aboveground biomass, and root biomass (kg) were estimated using the following common allometric equations:

$$W_{agb} = 0.251p\ D^{2.46}$$

$$W_R = 0.199p^{0.899}\ D^{2.22}$$

Where:

W_{agb} = aboveground biomass(kg)

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

W_R = root biomass (kg)

p = wood density of species

D = DBH/Diameter of tree trunk

The average wood density for each species was based on studies conducted in Southeast Asia derived from the Global Wood Density Database [17], [19-21]. The total biomass (both aboveground and belowground) per plot was obtained by summing all the individual plot measurements and then averaged to calculate the mean stand biomass. This mean stand biomass was subsequently converted into tons per hectare (t ha^{-1}). The carbon pools of both the aboveground, leaf, and root components were determined by multiplying the biomass values by a carbon concentration of 0.45, which represents 45% [22]. This concentration is equivalent to the amount of carbon content typically found in tropical trees, including mangroves.

D. Sampling and Measurement of Sediment Carbon

Determination of Organic C in the sediment of mangrove sites was done by extraction of approximately one kilogram of sediment from the upper 20-cm layer in randomly chosen areas within the plots using a sediment corer (PVC #4) with 5cm diameter of known volume and was placed inside a Ziplock bag to be transported in the laboratory. Five (5) replicate soil samples were collected within each plot. The obtained sediment samples were weighed and oven-dried for 48 hours at 105 degrees Celsius to get their constant mass [23]. Bulk density expressed in g cm-3 will be calculated using the following formulas:

Sediment Bulk Density (g cm^{-3}) = Dry weight of sample (g)/ Volume of cylinder (cm^3),

where:

Sample Volume= Cross-sectional area of the corer x height of the sub-section

The dry mass of sediment and the equivalent C stock were determined using the following formula:

Sediment mass at specified depth (t ha-1) = Bulk density at specified depth (Mg m^{-3}) x 10,000 m^2 x depth (m)

Sediment Cat specified depth (t ha^{-1}) = Soil mass at specified depth (Mg) x % organic Cat specified depth/100

Where:

% organic C was obtained by submitting the soil samples to the Department of Agriculture Region 10-Soils Laboratory for analysis.

E. Calculation of the Total Carbon Storage and CO_2 Equivalent

The sum of the aboveground, root, and soil C-stocks was used in getting the total carbon storage estimate. In obtaining the CO_2 equivalent of the biomass and C- stocks, the ratio of molecular weight of CO_2 to carbon was utilized. In this study, to obtain the carbon dioxide equivalent, carbon stocks were multiplied by 3.67, which is the molecular ratio of CO_2 to C [24].

RESULTS AND DISCUSSION

A. Species Composition and Diversity

Table 1 shows the overall species composition of the three (3) sites surveyed in Northern Mindanao, Philippines. Thirteen (13) species belonging to four (4) orders, six (6) families, and eight (8) genera were found in three (3) coastal sites of Northern Mindanao, namely: Province of Camiguin, Cagayan de Oro City and the municipality of Laguindingan. The identified mangroves are *Aegiceras corniculatum* (Family Myrsinaceae), *Avicennia marina, Avicennia rumphiana* (Family Avicenniaceae), *Bruguiera gymnorhiza, Ceriops decandra, Ceriops* *tagal, Rhizophora apiculata, Rhizophora mucronata, Rhizophora stylosa* (Family Rhizophoraceae), *Exoecaria agallocha* (Family Euphorbiaceae), *Lumnitzera racemosa, Son-neratia caseolaris* and *Sonneratia alba* (Family Lythraceae).

Table I: Classification of Mangroves Identified in Northern Mindanao, Philippines.

Order	Family	Species	Local name
Primulales	Myrsinaceae	*Aegiceras corniculatum*	saging-saging
Lamiales	Avicenniaceae	*Avicennia marina*	apiapi, miapi
Lamiales	Avicenniaceae	*Avicennia rumphiana*	apiapi, miapi
Malpighiales	Rhizophoraceae	*Bruguiera gymnorhiza*	pototan
Malpighiales	Rhizophoraceae	*Ceriops decandra*	baras-baras
Malpighiales	Rhizophoraceae	*Ceriops tagal*	tungog
Malpighiales	Rhizophoraceae	*Rhizophora apiculata*	bakhaw lalaki
Malpighiales	Rhizophoraceae	*Rhizophora mucronata*	bakhaw babae
Malpighiales	Rhizophoraceae	*Rhizophora stylosa*	bakhaw bato
Malpighiales	Euphorbiaceae	*Exoecaria agallocha*	lipata
Myrtales	Combretaceae	*Lumnitzera racemosa*	tabao
Myrtales	Lythraceae	*Sonneratia alba*	pagatpat
Myrtales	Lythraceae	*Sonneratia caseolaris*	pagatpat

Among the over-all 302 individuals, the species of *Sonneratia alba* dominated the sites along with *Avicennnia rumphiana*. These species are usually linked with habitats experiencing continuous inundation in mid to high intertidal, particularly evident in most study sites situated along coastal areas [25-26]. Specifically, *Sonneratia alba* is typically thrived in rocky-sandy substrata and well adapted to a wide range of salinity, ranging from medium to more saline waters [25], [27-28]. With larger basal areas, often exceeding 1 meter in diameter, *Sonneratia alba* and *Avicennia rumphiana* stand out for their significant contribution to the overall importance values among identified mangrove species. These characteristics make them more resilient to natural disasters, leading to higher survival rates of the species [29].

Based on the importance value indices of mangrove species, the total h-value of 2.054 in Northern Mindanao falls within the low category [30]. However, it still exceeds those reported in Dumanquilas Bay (1.1) [31] Leyte Island (1.245) [32], Sarangani Province (0.75) [33], Panguil Bay [34] and the entire municipality of Kinoguitan (1.63) [35]. The high evenness index of 0.60 indicates that the species in the area are distributed in nearly equal proportions. Several studies have reported that mangrove forests exhibit relatively low diversity indices, attributed to their distinctive stand formation when compared to other tropical forest ecosystems [36]. Furthermore, for conservation status, all 11 species were recorded to be at Least Concern (LC), based on the International Union for Conservation of Nature (IUCN) red list [37] except for *Avicennia rumphiana* which has been recently assessed as Vulnerable (VU) and *Ceriops decandra* as Near Threatened (NT) [36]. Natural calamities such as tropical storms, waves, and high-water surges are common contributors to the decline of mangrove ecosystems, however, several studies have emphasized the significantly higher impact of anthropogenic factors such as fishpond conversions, deforestation, and urban development [38-43].

Comparing the local distribution of mangroves across the three (3) sites, Cagayan de Oro City has the highest number of species and species richness, followed by Camiguin Province, and Laguindingan has the lowest. Among this site- only four (4) species are commonly located in all sites namely *Avicennia rumphiana*,

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

Rhizophora apiculata, Rhizophora mucronata, and *Sonneratia alba*. Based on the diversity profile, Cagayan de Oro has the highest h-value of 1.908, followed by Laguindingan (1.824) and Camiguin (1.513). These can be projected on the number of species found in the City of Cagayan de Oro. Meanwhile, the dominance of the species *Sonneratia alba* attributed the highest dominance value in Camiguin among the three sites consequently, attributing to sparse distribution in the area. Other sites namely, Cagayan de Oro and Laguindingan showed high equitability and evenness values which can imply more uniformly distributed mangroves in both sites.

B. Aboveground, Belowground Biomass and Carbon Stock

Table 2 presents the mean biomass of both aboveground and below-ground biomass and their carbon stock of the (3) selected sites in Northern Mindanao. Based on the allometric equations [18], the overall estimated mean biomass and carbon stock across sites is 947.47 Mg ha^{-1} (C-stock of 142.12Mg ha^{-1}).

Table II: Aboveground Biomass (Agb) and Belowground Root Biomass (Rb) of Mangroves in the Three Selected Sites of Northern Mindanao, Philippines

Biomass and Carbon Stock	Sampling Sites			Total (Mg ha^{-1})
	Camiguin	Cagayan de Oro	Laguindingan	
Mean biomass	569.91	147.03	230.53	947.47
C-stock AGB	202.80	51.22	78.42	332.44
C-stock RB	53.66	14.95	25.32	93.92
Total C-stock	256.46	66.16	103.74	426.36

As seen in Fig. 2 the highest aboveground, belowground, and carbon stock of mangroves observed is 569.91 Mg ha^{-1} (C-stock of 256.46 Mg ha^{-1}), recorded in the Camiguin Island. Followed by the Municipality of Laguindingan with 230.53 Mg ha-1 (C-stock of 103.74 Mg ha^{-1}) and lastly, Cagayan de Oro City with 147.03 Mg ha^{-1} (C-stock of 66.16 Mg ha^{-1}).

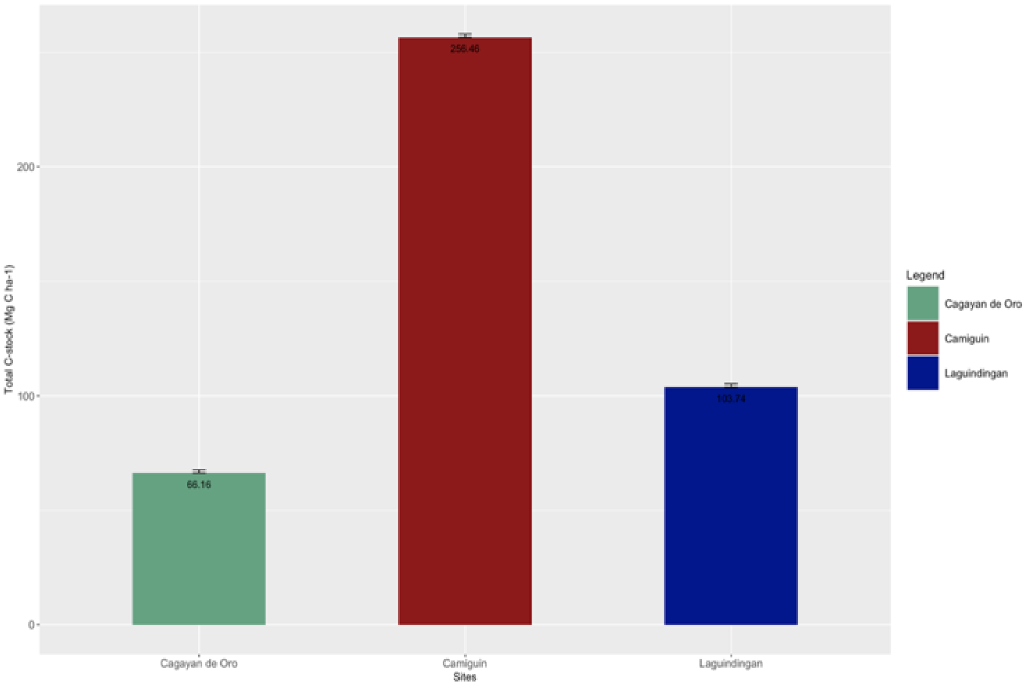

Fig. 2 The Distribution of Total Carbon Stocks AGB and RB of Mangroves in the Three Selected Sites of Northern Mindanao, Philippines

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

Classifying the mangrove trees by diameter Fig. 3 showed that Camiguin has the highest number of trees with diameters greater than 20 cm, while Cagayan de Oro and Laguindingan have fewer such trees and a higher number of trees with diameters less than 5 cm.

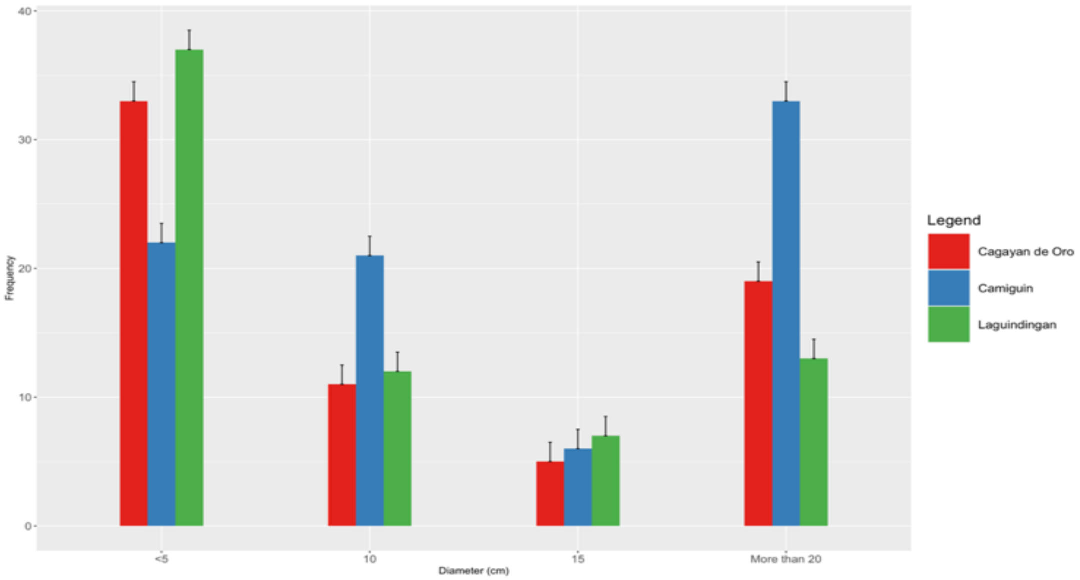

Fig. 3 The Frequency Distribution for the Mangroves DBH in the Three Selected Sites Of Northern Mindanao, Philippines

Diameter at breast height is directly related to tree biomass [18]. Hence, the abundance of mangrove trees with diameters over 20 cm in Camiguin, particularly the presence of large basal areas of Sonneratia sp. stands, leads to higher aboveground and belowground biomass, resulting in greater carbon stock in that mangrove site. The different quantities of estimated biomass and carbon stocks were influenced by the girth size of the mangrove trees within the plots and the wood density characteristic of each species [5]. In a mangrove forest, large trees with a substantial DBH contribute more significantly to the aboveground biomass than numerous young trees with small DBH measurements [44-46].

The mean above-ground biomass estimates observed across the study sites exceed those of various locations locally and across Asia, including studies conducted in China, Japan, India, and Malaysia, as well as local studies in Southern Luzon and Misamis Oriental [47-51]. Meanwhile, the overall ratio of above-ground biomass to root biomass in the study ranged from 1.41 to 4.21, with an average of 2.32. These results align with the findings of Komiyama et al., which reported a range of 1.1 to 4.4. Mangrove forests generally have lower ratios than terrestrial forests, attributed to the need for substantial root biomass to stabilize their bottom-heavy tree form in wet and soft mud [52-53].

Biomass and carbon stock in mangrove forests are also significantly influenced by the type of mangrove species present. Each species exhibits unique growth characteristics and biomass distribution, which in turn affect the overall carbon sequestration potential of the forest. Several studies show that different species contribute differently to biomass and carbon stocks, highlighting the need for species-specific models [54-55]. Similarly to the distribution and composition of species within mangrove sites, the allocation of above-ground and root biomass can vary among species and is influenced by factors including geographical location and ecology [48],[52].

C. Soil Carbon

The soil carbon content in the upper 20 cm of sediment at the mangrove sites in Northern Mindanao is summarized in Fig. 4. The mean soil carbon estimated across the three sites was 917.23 Mg ha^{-1}. Camiguin recorded the highest soil carbon content (491.78 Mg ha^{-1}), accounting for more than half of the total average across all sites, followed by Cagayan de Oro City (224.85 Mg ha^{-1}) and, least Laguindingan (200.60 Mg ha^{-1}).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

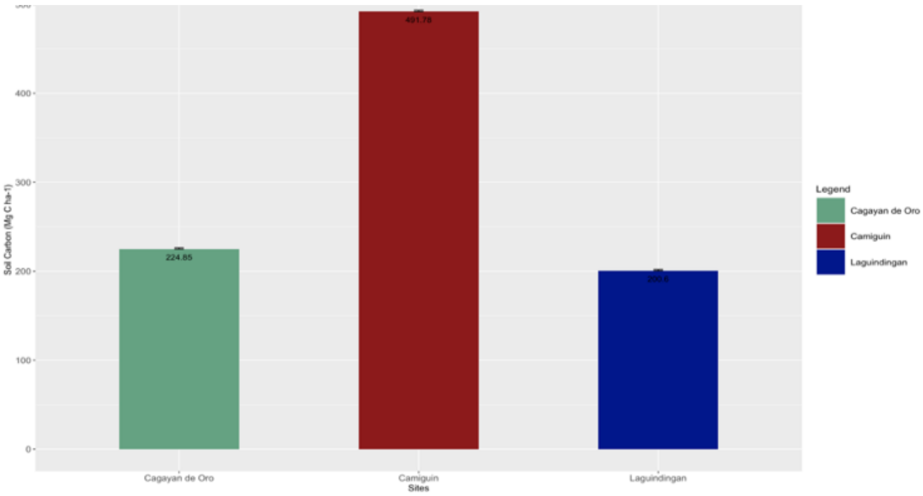

Fig. 4 The Distribution of Soil Carbon Stocks in Mangrove Areas of Three Selected Sites in Northern Mindanao, Philippines

Soil characteristics within the upper 20 cm reveal that Laguindingan and Cagayan de Oro, which have clay to muddy sediments, exhibit higher bulk density. In contrast, Camiguin, with lower bulk density, shows higher organic carbon content which contradicts the study findings [16], [56-57]. However, this could indicate the considerable variability in soil characteristics across sites suggesting that localized environmental factors may influence soil properties in different sites.

The variations in the soil carbon content across the (3) three sites may be attributed to the age of the mangrove stands and the environmental factors impacting soil carbon in the region [16], [58]. The higher diameter or GBH of mangrove stands observed in Camiguin compared to other sites can linked to its higher soil carbon content. Studies show that as mangroves age, their trunk girth increases, serving as a common indicator of biomass accumulation and tree maturity. For instance, research in Kerala, India, indicated that larger GBH is often associated with older mangrove stands, reflecting their growth over time [51].

D. Total Carbon- Stock (C-stock) and Carbon dioxide (CO_2) Sequestration Potentials

The combined mean C-stocks of biomass and sediments across all sites in Northern Mindanao is 447.86 Mg ha^{-1}, equivalent to a carbon dioxide sequestration potential of 1,643.66 CO_2 Mg ha^{-1}. Camiguin recorded the highest CO_2 sequestration potential among the sites (2746.02 Mg CO_2 ha-1), with 66% attributed to soil c-stock and the 34% remainder to biomass. Despite Cagayan de Oro displaying a higher carbon sequestration potential in terms of soil carbon, overall, Laguindingan still follows with a greater CO_2 sequestration potential of 1116.93 Mg CO_2 ha^{-1} and, lastly, Cagayan de Oro with the least CO2 sequestration potential (1068.03 Mg CO_2 ha^{-1}) (Table 2).

Table II: Total Carbon Stock Summary of the Study Sites in Northern Mindanao

Sites	AGB + BGB 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})
Camiguin	256.46	491.78	748.24	2746.02
Cagayan de Oro	66.16	224.85	291.02	1068.03
Laguindingan	103.74	200.60	304.34	1116.93

The study revealed that sediment carbon across the three sites is relatively 65-78% higher than the combined values of above and below-ground biomass. These findings are consistent with several studies that reported that soil carbon constitutes a significant portion of total carbon stock, approximately accounting for about 40-98% of the total carbon stock in mangrove forests [16], [21], [23], [59-60]. These studies emphasize the crucial significance of mangrove soil as carbon reservoirs (Fig.5).

ISSN No. 2454-6194 | DOI: 10.51584/IJRIAS |Volume IX Issue VIII August 2024

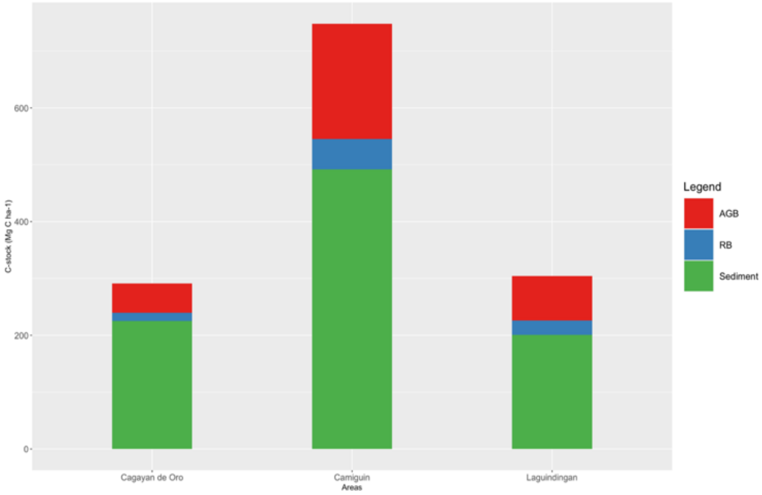

Fig. 5 AGB, RB and sediment C-stock values, and equivalent CO_2 of mangroves in of three selected sites in Northern Mindanao, Philippines. AGB = above ground biomass, RB = root biomass, C-Stock = carbon stock, CO_2 Eq = carbon dioxide equivalent.

The total CO_2 stock potential value derived from the study is higher than the carbon stocks recorded in several studies in Puerto Prinsesa, Palawan [5], Batangas [11], Bohol [61], and Macajalar Bay [16]. Differences in carbon sequestration potentials are attributed to the species present across sites. In Camiguin, large basal areas of Sonneratia sp. and Avicennia sp. influence biomass, while the age of mature trees impacts their soil carbon stock. In Cagayan de Oro and Laguindingan, the presence of dense, smaller GBH values of Rhizophora species may have been a factor in the values of sequestration potentials in both sites. The mangrove forest in Camiguin is well-protected since the site selected is within the mangrove sanctuary, compared to Cagayan de Oro and Laguindingan where both areas are highly vulnerable due to the presence of nearby residential areas and commercial resorts. Other factors that may contribute to the differences in values include sampling designs, allometric equations used, soil depth, organic matter discrepancies, site selections, and localized conditions of the mangrove sites [5],[60].

CONCLUSION

The mean biomass and carbon stock in across (3) three sites in Northern Mindanao is 947.47 Mg ha-1 (C-stock of 142.12Mg ha-1). Camiguin Island recorded the highest biomass and carbon stock, attributed to the presence of large-diameters trees like Sonneratia alba, while Cagayan de Oro and Laguindingan had higher numbers of smaller-diameter trees, resulting in comparatively lower biomass and carbon stocks. Soil carbon content, particularly in Camiguin, influenced the overall carbon sequestration potential, highlighting the critical role of soil carbon in mangrove ecosystems. The overall mean C-stocks of both biomass and sediments across all sites in Northern Mindanao is 447.86 Mg ha-1, equivalent to a carbon sequestration potential of 1,643.66 Mg ha-1. The study emphasizes the biomass and carbon stock contributions of mangrove forests in Northern Mindanao, particularly the role of species composition, girth diameter, and soil characteristics. The study implies that soil carbon constitutes a major portion of the total carbon stock in mangrove forests.

RECOMMENDATIONS

Effective conservation and management strategies like species and site-specific initiatives are crucial to enhancing the carbon sequestration potential of mangrove forests particularly in vulnerable areas like Cagayan de Oro and Laguindingan. Further research should focus on refining allometric models and consider depth intervals in soil carbon analysis to support sustainable mangrove forest management and carbon sequestration efforts.

ACKNOWLEDGEMENT

I am grateful to the Department of Science and Technology- Accelerated Science and Technology Human

Resource Development Program (DOST-ASTHRDP) for providing the financial support necessary to carry out this research. The authors declare no conflicts of interest related to the study.

REFERENCES

1. Duke, N. C., Schmitt, K., (2015). Mangroves: unusual forests at the seas edge. Tropical forestry handbook, 1.
2. UNEP-WCMC. (2018). Mangroves. Retrieved from https://www.unep-wcmc.org/habitats/mangroves
3. Chatting, M. (2022). Carbon stocks and productivity in mangroves under climate change: regional and global perspectives. Bangor University (United Kingdom).
4. Kelleway, J. J., Saintilan, N., Macreadie, P. I., Skilbeck, C. G., Zawadzki, A., & Ralph, P. J. (2016). Seventy years of continuous encroachment substantially increases 'blue carbon' capacity as mangroves replace intertidal salt marshes. Global change biology, 22(3), 1097-1109.
5. Abino A. C., Castillo J. A. A., Lee Y. J., (2014). Assessment of species diversity, biomass and carbon sequestration potential of a natural mangrove stand in Samar, the Philippines. Forest science and technology, 10(1), 2-8.
6. Decena, S. C., Avorque, C., Arribado, A., Macasait Jr, D. (2023). Aboveground and belowground carbon stocks in mangrove ecosystems along Carigara Bay in Leyte, Philippines.
7. Salmo III, S. G., Malapit, V., Garcia, M. C. A., & Pagkalinawan, H. M. (2019). Establishing rates of carbon sequestration in mangroves from an earthquake uplift event. Biology Letters, 15(3), 20180799.
8. Barrientos, K., & Apolonio, J. W. (2017). Species diversity and soil carbon sequestration potential of mangrove species at Katunggan It Ibajay (KII) Eco-Park in Aklan, Philippines. PRISM: The Official Research Publication of Negros Oriental State University, 2546-0390.
9. Raga-as, M.L. et al., (2022) 'Aboveground blue carbon stock assessment of Bakhawan Eco-Park Mangrove Plantation in New Buswang, Kalibo, Aklan, the Philippines'. Open Journal of Ecology. **12**(12). pp. 773–787.
10. Nesperos, V. J., Villanueva, C. M., Garcia, J., Gevaña, D. (2021). Assessment of blue carbon stock of mangrove vegetation in Infanta, Quezon, Philippines. Ecosystems and Development Journal, 11(1 and 2), 48-60.
11. Gevaña D., Pulhin F., Pampolina N., (2008). Carbon stock assessment of a mangrove ecosystem in San Juan, Batangas. J Environ Sci Manag 11 (1):15–25.
12. Agua, J. R., & Wong Jr, H. L., (2023). Carbon Stock Sequestration in the Mangrove Forest of Barangay Camudmud MPA, Island Garden City of Samal, Davao Del Norte. International Journal of Research and Innovation in Applied Science, 8(6), 143-155.
13. Bigsang R.T., Agonia N. B., Toreta C. G. D., Nacin C. J. C. B., Obemio C. D. G., Martin T. T.B., (2016). Community structure and carbon sequestration potential of mangroves in Maasim, Sarangani Province, Philippines. Advances in Environmental Sciences, 8(1), 6-13.
14. Jubilo, A.B. & Rizon, M.V., (2018). Carbon Sequestration Potential of Selected Mangrove Species in Lasang, Davao City. Retrieved from https://www.researchgate.net/ publication/339227439
15. Alimbon, J. A., & Manseguiao, M. R. S., (2021). Species composition, stand characteristics, aboveground biomass, and carbon stock of mangroves in Panabo Mangrove Park, Philippines. Biodiversitas: Journal of Biological Diversity, 22(6).
16. Lomoljo-Bantayan N. A., Tatil W.T., Dagoc F. L. S., Tampus A. D., Amparado R. J. F., (2023). Carbon stock assessment of mangrove forests along Macajalar Bay, Misamis Oriental, Philippines.
17. English, S., Wilkinson, C. and Baker, V., (1994) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townville, 34-49.
18. Komiyama, A., Poungparn, S., & Kato, S. (2005). Common allometric equations for estimating the tree weight of mangroves. Journal of tropical ecology, 21(4), 471-477.
19. Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J., (2009) Data from: towards a worldwide wood economics spectrum. Dryad Digital Repository. doi:10.5061/dryad.234
20. Saenger P, Hegerl E.J, Davie J.D.S (eds)., (1983) Global status of mangrove ecosystems by the Working Group on Mangrove Ecosystems of the IUCN Commission on Ecology in cooperation with the United Nations Environment Programme and the World Wildlife Fund. Environmentalist 3:1–88

21. Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M., (2011). Mangroves among the most carbon-rich forests in the tropics. Nature geoscience, 4(5), 293-297.
22. Lasco, R. D., & Pulhin, F. B., (2003). Philippine forest ecosystems and climate change: carbon stocks, rate of sequestration and the Kyoto Protocol. Annals of Tropical Research, 25(2), 37-52.
23. Kauffman J. B., Donato D. C., (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests (Vol. 86). Bogor, Indonesia: Cifor.
24. Kauffman, J. B., Heider, C., Norfolk, J., Payton, F., (2014). Carbon stocks of intact mangroves and carbon emissions arising from their conversion in the Dominican Republic. Ecological Applications, 24(3), 518-527.
25. Spencer, T., Möller, I., & Reef, R., (2016). Mangrove systems and environments. In Reference Module in Earth Systems and Environmental Sciences. Elsevier.
26. Alappatt, J. P., (2008). Structure and species diversity of mangrove ecosystem. In Biodiversity and Climate Change Adap-tation in Tropical Islands pp. 127-144. Academic Press. doi: 10.1016/B978-0-12-813064-3.00005-3
27. Feng, X., Xu, S., Li, J. et al., (2020). Molecular adaptation to salinity fluctuation in tropical intertidal environments of a mangrove tree Sonneratia alba. BMC Plant Biol 20, 178. https://doi.org/10.1186/s12870-020-02395-3
28. Yuliana, E., Hewindati, Y. T., Winata, A. D. I., Djatmiko, W. A., & Rahadiati, A. T. I., (2019). Diversity and characteristics of mangrove vegetation in pulau rimau protection forest, Banyuasin District, South Sumatra, Indonesia. Biodiversitas Journal of Biological Diversity, 20(4), 1215-1221.
29. Onrizal, O., & MANSOR, M., (2016). Status of coastal forests of the Northern Sumatra in 2004's tsunami catastrophe. Bi-odiversitas Journal of Biological Diversity, 17(1).
30. Fernando E.S., (1998). Forest formations and flora of the Philippines: Handout in FBS 21. College of Forestry and Natural Resources, University of the Philippines at Los Baños (Unpublished).
31. Bitantos B. L., Abucay M. D., Dacula J. A., Recafort R. D., (2017). Mangrove in the grove: diversity, species composition, and habitat in Pamintayan, Dumanquillas Bay, Philippines. AES Bioflux 9(3):183-192.
32. Carnice, P. A. B., (2021). Above ground Carbon Storage and Species Diversity of Mangrove Stand in Leyte Island, Philip-pines. ARADMAN: Multidisciplinary Research Journal, 1(1), 50-69.
33. Bigsang, R. T., Agonia, N. B., Toreta, C. G. D., Nacin, C. J. C. B., Obemio, C. D. G., & Martin, T. T. B., (2016). Community structure and carbon sequestration potential of mangroves in Maasim, Sarangani Province, Philippines. Advances in En-vironmental Sciences, 8(1), 6-13.
34. Osing, P. K. A. S., Jondonero, M. A. P., Suson, P. D., Guihawan, J. Q., & Amparado Jr, R. F., (2019). Species composition and diversity in a natural and reforested mangrove forests in Panguil Bay, Mindanao, Philippines. J. Biodivers. Environ. Sci, 15, 88-102.
35. Tampus, A. D., Bungcasan, A. S. G., Inte, S. B., Inotao, P. R. V., Longcob, D. J. H. E., Salise, P. C. K. G., ... & Sinco, A. L., (2023). Abundance and diversity of mangroves in Kinoguitan, Misamis Oriental, Philippines.
36. Gevaña, D. T., & Pampolina, N. M., (2009). Plant diversity and carbon storage of a Rhizopora stand in Verde Passage, San Juan, Batangas, Philippines. Journal of Environmental Science and Management, 12(2), 1-10.
37. Duke, N., Kathiresan, K., Salmo III, S.G., Fernando, E.S., Peras, J.R., Sukardjo, S. & Miyagi, T., (2010). Avicennia rumphiana. The IUCN Red List of Threatened Species 2010: e.T178809A7613129. https: //dx.doi.org/10.2305/IUCN.UK.20102.RLTS.T178809A7613129.en. Accessed on 24 April 2024.
38. Garcia, K. B., Malabrigo, P. L., & Gevaña, D. T., (2014). Philippines' mangrove ecosystem: status, threats and conservation. Mangrove ecosystems of Asia: Status, challenges and management strategies, 81-94.
39. Long, J., Napton, D., Giri, C., & Graesser, J., (2014). A mapping and monitoring assessment of the Philippines' mangrove forests from 1990 to 2010. Journal of Coastal Research, 30(2), 260-271
40. Giri, C.; Pengra, B.; Zhu, Z.L.; Singh, A., and Tieszen, L.L., (2007). Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. Estuarine Coastal and Shelf Science, 73(1–2), 91100.
41. Macintosh, D.J. and Ashton, E.C., (2005). Principles for a code of conduct for the management and sustainable use of man-grove ecosystems. World Bank. http://mit.biology.au.dk/cenTER/MCB_Files/2005_MCB_Code_March.pdf.

42. Fortes, M.D., (2004). Wetland conservation and management in the Philippines: where are we now? The case of seagrass and mangrove. Developments in Ecosystems, 1, 233–262.
43. Primavera, J. H. (Ed.). (2004). Primavera, J. H. (2004). Philippine mangroves: Status, threats and sustainable development. In M. Vannucci (Ed.), Mangrove Management and Conservation: Present and Future. Tokyo, Japan: United Nations Uni-versity Press., 117, 192-207).
44. Zhang, R., Jia, M., Wang, Z., Zhou, Y., Mao, D., Ren, C., ... & Liu, X., (2022). Tracking annual dynamics of mangrove forests in mangrove National Nature Reserves of China based on time series Sentinel-2 imagery during 2016–2020. International Journal of Applied Earth Observation and Geoinformation, 112, 102918.
45. Jones, A. R., Raja Segaran, R., Clarke, K. D., Waycott, M., Goh, W. S., & Gillanders, B. M., (2020). Estimating mangrove tree biomass and carbon content: a comparison of forest inventory techniques and drone imagery. Frontiers in Marine Science, 6, 784.
46. Ávila-Acosta, C. R., Domínguez-Domínguez, M., Vázquez-Navarrete, C. J., Acosta-Pech, R. G., & Martínez-Zurimendi, P., (2024). Aboveground Biomass and Carbon Storage in Mangrove Forests in Southeastern Mexico. Resources, 13(3), 41.
47. Aziz, I., & Khan, F., (2014). Distribution, ecology and ecophysiology of mangroves in Pakistan. Sabkha Ecosystems: Volume IV: Cash Crop Halophyte and Biodiversity Conservation, 55-66.
48. Chandra, S., (2013). Incidence and consequences of mangrove exploitation in the Sunderbans. JCE JCE, 4(1), 23.
49. Chen, Q., Zhao, Q., Li, J., Jian, S., & Ren, H., (2016). Mangrove succession enriches the sediment microbial community in South China. Scientific reports, 6(1), 27468.
50. Tobias A., Umali A. G. A., Malabrigo P., Galang M. A., (2017). Mangrove Forest Inventory and Estimation of Carbon Storage and Sedimentation in Pagbilao. Wealth Account. Valuat. Ecosyst. Serv, 1-95.
51. Harishma, K. M., Sandeep, S., & Sreekumar, V. B., (2020). Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. Ecological Processes, 9, 1-9.
52. Komiyama A., Ong J. E., Poungparn S., (2008). Allometry, biomass, and productivity of mangrove forests: A review. Aquatic botany, 89(2), 128-137.
53. Khan M.N.I., Suwa R., Hagihara A., (2009). Biomass and aboveground net primary production in a subtropical mangrove stand of Kandelia obovata (S., L.) Yong at Manko Wetland, Okinawa, Japan. Wetlands Ecol. Manage., 17: 585-599.
54. Njana, M. A., Bollandsås, O. M., Eid, T., Zahabu, E., & Malimbwi, R. E., (2016). Above-and belowground tree biomass models for three mangrove species in Tanzania: a nonlinear mixed effects modelling approach. Annals of Forest Science, 73, 353-36
55. Aye, W. N., Tong, X., Li, J., & Tun, A. W., (2023). Assessing the carbon storage potential of a young mangrove plantation in Myanmar. Forests, 14(4), 824.
56. Ansari S., Sadeghi H., (2022). Carbon storage assessment in soil and plant organs: The role of Prosopis spp. on mitigate soil degradation. Environmental Monitoring and Assessment, 194(1): 1-10. https://doi.org/10.1007/s10661-021-09612-y PMid:34862577
57. Amhakhian S.O, Otene I.J.J, Adava I.O, Muhammed B., Are E.C., Ozovehe N.O., (2021). Bulk density of soils from oil palm agroforestry systems in Kogi East, Nigeria. International Journal of Environment and Climate Change, 11(12): 396-402. https://doi.org/10.9734/ijecc/2021/v11i1230590
58. Lunstrum, A., & Chen, L., (2014). Soil carbon stocks and accumulation in young mangrove forests. Soil Biology and Biochemistry, 75, 223-232.
59. Murdiyarso D., Donato D., Kauffman J.B., Kurnianto S., Stidham M., Kanninen M., (2009). Carbon storage in mangrove and peatland ecosystems in Indonesia – a preliminary account from plots in Indonesia. Working Paper 48, Center for International Forestry Research.Bogor, Indonesia. pp. 35.
60. Sitoe A.A., Comissario Mandlate L.J., Guedes B.S., (2014). Biomass and carbon stocks of Sofala Bay mangrove forests. Forests, 5(8): 1967-1981. https://doi.org/10.3390/f5081967
61. Camacho L. D., Gevaña D. T., Carandang A. P., Camacho S. C., Combalicer E. A., Rebugio L. L., Youn Y. C., (2011). Tree biomass and carbon stock of a community-managed mangrove forest in Bohol, Philippines. Forest Science and Technology, 7(4), 161-167.