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Forest structure, aboveground biomass and carbon potential of Sangalang mangrove forest in Biliran Island, Philippines

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Key words: Forest structure, Aboveground biomass, Carbon potential, Climate change, Coastal ecosystems

Abstract

Mangrove forests are renowned for their ecological importance and capacity to sequester carbon, making them vital in climate change mitigation and providing valuable ecosystem services. This study was conducted in the Sangalang locality of Biliran Island, Philippines. Using a random sampling approach, we established nine permanent plots along three transect lines. Descriptive statistics and simple ANOVA were employed to assess forest structure variations, estimate biomass, and carbon sequestration potential. The biomass in the study area ranged from 1460 to 9496kg/ha (equivalent to 23 – 208 tAGB/ha) across all plots, with a coefficient of variation of 1.9. Total carbon stock varied from 11 to 100 tC/ha, and the maximum carbon sequestration potential was estimated at 368 tC/ha. Despite the relatively low species richness, with only five recorded species, the mangrove locality demonstrated significant potential for carbon sequestration and storage. These findings provide valuable baseline data that can inform the implementation of stricter conservation efforts aimed at preserving and safeguarding this critical ecosystem. The study further highlights the importance of these mangrove forests in carbon sequestration and emphasizes the need for their protection to maintain their ecosystem services.

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Introduction

Mangrove forests, renowned for their unique ecological importance and significant carbon sequestration capacity, play a crucial role in mitigating climate change and providing valuable ecosystem services (Estoque *et al.*, 2018; Alongi, 2012). Among the diverse array of mangrove habitats, the Sangalang mangrove forest, situated in Biliran Island, Philippines, stands as a promising site for studying forest structure, aboveground biomass, and carbon potential. This scientific article aims to investigate the structural characteristics, quantify aboveground biomass, and estimate carbon storage potential within this important coastal ecosystem.

The Sangalang mangrove forest offers an exceptional research opportunity due to its biodiversity potential, extensive mangrove cover, and its location within the biologically diverse region of the Island. Philippine mangrove forests are recognized as vital coastal ecosystems, serving as nurseries for numerous fish species, protecting coastlines from erosion, and providing sustenance for local communities. However, these invaluable habitats face increasing threats due to human activities, such as urbanization, aquaculture, and deforestation, underscoring the need to assess their current condition and potential for carbon sequestration (Friess *et al.*, 2019; Alongi, 2002).

Understanding the forest structure is fundamental for evaluating the ecological functionality and carbon sink potential of mangrove ecosystems (Lee *et al.*, 2014; Suratman, 2008)). The architectural complexity of mangroves, characterized by intricate root systems, prop roots, and dense canopy cover, contributes to the unique structure of these forests. Various structural attributes, including tree height, stem diameter, basal area, and canopy cover, are essential indicators that help quantify the overall health and biomass distribution within a mangrove forest (Rouzbeh Kargar *et al.*, 2020; Clough, 1992).

The estimation of aboveground biomass is of paramount importance in assessing the carbon storage capacity of mangrove forests (Alimbon, 2021). Aboveground biomass acts as a major reservoir of carbon, capturing and storing atmospheric carbon dioxide, thereby mitigating climate change impacts. Accurate quantification of aboveground biomass not only contributes in understanding the carbon cycle in mangrove ecosystems but also assists in designing effective conservation strategies and implementing climate change mitigation initiatives (Howard *et al.*, 2017; Kauffman, 2012).

Thus, this study aims to comprehensively address the following questions; (a) is there a variation of forest structure across the study area? (b) estimate the aboveground biomass on a plot level?, and (c) quantify the carbon sequestration potential of the Sangalang mangrove forest in Biliran Island, Philippines. This research endeavors to provide useful insights into the ecological dynamics and carbon sequestration capacity of this crucial coastal ecosystem. Lastly, the findings of this study can guide conservation efforts, support sustainable management practices, and contribute to regional initiatives aimed at preserving mangrove forests and mitigating climate change impacts.

Material and methods

Study Area

Biliran Province, located in Region VIII, is an island characterized by volcanic activity and is comprised of eight municipalities (refer to Fig. 1). Due to its vulnerability to various natural disasters, including storm surges, floods, and earthquakes, Biliran Island provides an excellent setting for establishing permanent monitoring plots to study the productivity of mangrove forests in the face of recurring natural disturbances, which are particularly prevalent in Philippine island locations. The research was specifically conducted in the mangrove forests of the Sangalang locality, situated in Biliran Island, Philippines (refer to Fig. 1). The selection of this particular study site was based on several factors, including the availability and accessibility of the mangrove forest. Moreover, the frequent occurrence of natural disturbances in this area offered a unique opportunity to observe and monitor the productivity of mangrove forests under such conditions.

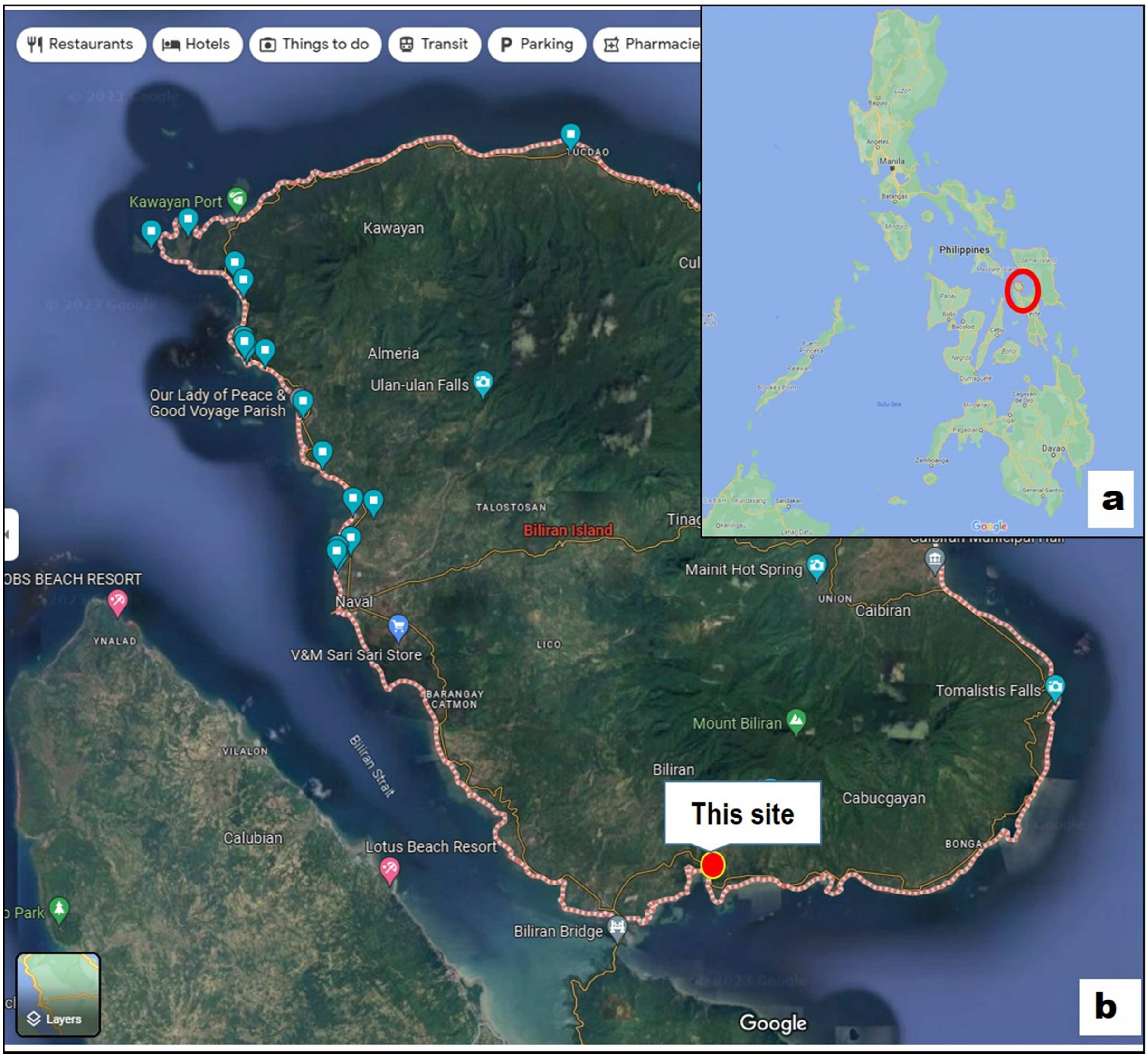

Fig. 1. (a) Fig. 1 provides an overview map of the Philippines, specifically highlighting the geographical location of Biliran Island. (b) Fig. 2 presents a more detailed map of Biliran Island, zooming in to showcase the specific study site within the Sangalang locality (Source: Google Maps (Satellite)).

Sampling and Data Collection

In this study, a random sampling method was employed to establish a total of nine permanent sampling plots within the mangrove areas. Each plot was located along a transect line that extended from the shoreline, spanning a distance of 100 to 200 meters. These transect lines were evenly distributed, with a 30-meter interval, resulting in three lines in total.

A 10-meter diameter tape was used to measure dbh of each tree. All mangrove tree species encountered during the study were identified and classified based on the taxonomic information provided in the field guide manual "Philippines Mangroves" by Primavera *et al.* (2016; Primavera, 1995). The identification and classification process in this study relied on the guidance provided in the field guide manual authored by Primavera *et al.* (2016).

Data Analysis

Descriptive statistics were employed in this study to analyze both the diameter at breast height (dbh) and basal area, including measures such as mean, minimum, maximum, standard deviation (sd), and coefficient of variation (cv). These statistics were used to identify variations among plots and across different tree species. Further, an allometric equation developed by Komiyama *et al.* (2015) was utilized to analyze aboveground biomass using wood density and dbh parameters. The equation used was AGB = 0.251 * p * D^2.46, where AGB represents aboveground biomass, p is wood density, and D is the diameter at breast height. Species-specific wood density were adapted from Komiyama *et al.* (2005), multiplied by a factor 0.48 to estimate aboveground biomass (Alavaisha and Mangora. 2016; Howard *et al.*, 2014; Kauffman and Donato, 2012). Lastly, carbon sequestration potential was estimated by multiplying the carbon stock of a factor 3.67 (Howard *et al.* (2014).

For data visualization and table extraction, we utilized the ggplot2, tidyverse, and dplyr libraries (Wickham, 2016). To verify the significant differences in carbon stock among the five recorded species, a simple Analysis of Variance (ANOVA) was conducted using the R Core Team software. All visualization and statistical analyses were performed using the R Core Team (2021) software package.

Results and discussion

Forest structure

In our study, a total of five mangrove species were recorded, namely *Avicennia alba, Avicennia rumphiana, Rhizophora apiculata, Rhizophora mucronata,* and *Sonneratia alba* (Table 1). Among these species, the Avicennia family exhibited the largest tree size compared to the other species. However, when considering the total basal area, *Rhizophora apiculata* dominated (with a coefficient of variation of 0.71), followed by *Rhizophora mucronata* (with a coefficient of variation of 1.22). Interestingly, only one individual from the *Sonneratia alba* species was recorded, with a diameter at breast height (dbh) of 14.6cm.

Table 1. Species-level structure of Sangalang mangrove forest in Biliran Island.

SN	nbtrees	nbspec	meandbh	mindbh	maxdbh	sd_dbh	cv_dbh	meanba	minba	maxba	sd_ba	cv_ba	Sumba
Avicennia alba	3	1	23.87	22.70	25.70	1.61	0.07	4.49	4.05	5.19	0.61	0.14	13.46
Avicennia rumphiana	7	1	16.27	1.30	30.90	11.23	0.69	2.93	0.01	7.50	2.88	0.98	20.50
Rhizophora apiculata	20	1	8.62	2.00	16.60	3.50	0.41	0.68	0.03	2.16	0.48	0.71	44.05
Rhizophora mocrunata	25	1	5.73	0.80	16.90	3.50	0.61	0.35	0.01	2.24	0.43	1.22	32.84
Sonneratia alba	1	1	14.60	14.60	14.60	-	-	1.67	1.67	1.67	-	-	1.67

Plot-level information revealed a range of dbh values, with mean dbh ranging from 5.01cm to 11.16cm. The maximum dbh observed varied from 12.40cm to 30.90cm. The coefficients of variation among the plots' dbh values were relatively high, as expected when comparing smaller and larger tree sizes (Table 2). The total basal area in plot 2 transect 1 was found to be 28.11 m2 per hectare, whereas the lowest recorded total basal area was 3.58 m2 per hectare. These results indicate relatively low species diversity, although we did not calculate any diversity indices. However, our results are consistent with a study conducted by Alimbon and Manseguaio (2021), which also reported the presence of Avicennia, Rhizophora, and Sonneratia species. It is worth noting that Rhizophora and Avicennia species are common in the Philippines, aligning with our expectations (Ogawa *et al.*, 2022; Alimbon and Manseguaio, 2021).

Furthermore, our results demonstrate a wide range of diameter variations across different tree sizes, as indicated by the standard deviations ranging from 2 to 5 (Table 2). These significant variations could be attributed to the impact of typhoon Urduja, which severely affected coastal ecosystems in the Philippines (ADRC, 2023), resulting in substantial ecological disturbances.

Table 2. Plot-level structure of singalong mangrove forest in Biliran Island.

plot_id	nbtrees	nbspec	meandbh	mindbh	maxdbh	sd_dbh	cv_dbh	meanba	minba	maxba	sd_ba	cv_ba	Sumba
Plot_1_1	19	2	7.42	1.30	14.50	4.21	0.57	0.56	0.01	1.65	0.53	0.94	10.72
plot_1_2	22	3	11.16	2.20	30.90	6.31	0.57	1.28	0.04	7.50	1.61	1.26	28.11
plot_1_3	8	1	7.31	4.20	10.00	2.01	0.28	0.45	0.14	0.79	0.23	0.52	3.58
plot_2_1	16	2	7.98	2.00	15.80	3.63	0.45	0.60	0.03	1.96	0.50	0.84	9.54
plot_2_2	19	3	7.62	2.70	26.70	5.73	0.75	0.70	0.06	5.60	1.25	1.79	13.29
plot_2_3	16	1	5.01	2.00	12.30	2.76	0.55	0.25	0.03	1.19	0.33	1.29	4.05
plot_3_1	25	4	7.45	0.80	25.70	6.86	0.92	0.79	0.01	5.19	1.36	1.72	19.76
plot_3_2	19	4	8.64	2.50	23.20	4.88	0.57	0.76	0.05	4.23	0.94	1.24	14.50
plot_3_3	25	1	5.82	1.90	12.40	3.51	0.60	0.36	0.03	1.21	0.37	1.04	8.96

Carbon stock and carbon sequestration potential

The allometric method used in this study for estimating the biomass of the forest community is widely adopted due to its non-destructive nature and relative simplicity compared to other methods (Kridiborworn *et al.*, 2012). Specifically, the allometric equations developed by Komiyama *et al.* (2005) were employed, which rely on easily measurable forest variables. These two forest parameters strongly influenced each species' biomass and carbon stocks (Venturillo, 2016).

The aboveground biomass in our study ranged from 1460 to 9496kg/ha (equivalent to 23 – 208 tAGB/ha) across all plots, with a coefficient of variation of 1.9. Total carbon stock ranged from 11 to 100 tC/ha, while the maximum carbon sequestration potential was estimated to be 368 tC/ha (Table 3a). At the species level, *R. apiculata* and *R. mucronata* exhibited the highest aboveground biomass (323 and 205 tC/ha, respectively, see Table 3b). *R. apiculata* also displayed the highest carbon stock (155 tC/ha), while *R. apiculata* and *R. mucronata* had the highest carbon sequestration potential (569 and 362 tC/ha, respectively). The simple Analysis of Variance (ANOVA) results indicated a significant difference between each species, except for *R. apiculata* and *R. mucronata* (see Fig. 3).

Table 3a. Plot-level carbon stock and carbon sequestration potential in the study site.

plot_id	Mean AGBkgha	Cv AGBkgha	Mean tAGB tha	cv AGB tha	Sum AGB tha	Meancarbonstock tCha	cv_carbonstock tCha	Sumcarbonstock tCha	cv_carbonpo tCha	Sumcarbonpot Cha
Plot_1_1	4149.76	1.08	1.99	1.08	78.85	1.99	1.08	37.85	1.08	138.89
plot_1_2	9496.53	1.34	4.56	1.34	208.92	4.56	1.34	100.28	1.34	368.04
plot_1_3	2627.80	0.62	1.26	0.62	21.02	1.26	0.62	10.09	0.62	37.03
plot_2_1	4312.35	1.02	2.07	1.02	69.00	2.07	1.02	33.12	1.02	121.55
plot_2_2	4846.68	1.93	2.33	1.93	92.09	2.33	1.93	44.20	1.93	162.22
plot_2_3	1460.16	1.63	0.70	1.63	23.36	0.70	1.63	11.21	1.63	41.16
plot_3_1	5301.37	1.81	2.54	1.81	132.53	2.54	1.81	63.62	1.81	233.47
plot_3_2	5084.04	1.28	2.44	1.28	96.60	2.44	1.28	46.37	1.28	170.16
plot_3_3	2204.50	1.18	1.06	1.18	55.11	1.06	1.18	26.45	1.18	97.09

Table 3b. Species-level carbon stock and carbon potential in the study site.

SN	nbtrees	nbspec	meantC_ha	cv_tC_ha	sumtC_ha	meancarbonstock_tCha	cv_carbonstock_tCha	sumcarbonstock_tCha	cv_carbonpot_tCha	sumcarbonpot_tCha
Avicennia alba	3	1	15.02	0.17	93.90	15.02	0.17	45.07	0.17	165.42
Avicennia rumphiana	7	1	10.00	1.08	145.81	10.00	1.08	69.99	1.08	256.85
Rhizophora apiculata	20	1	2.39	0.84	323.54	2.39	0.84	155.30	0.84	569.95
Rhizophora mocrunata	25	1	1.06	1.49	205.51	1.06	1.49	98.64	1.49	362.02
Sonneratia alba	1	1	4.19	NA	8.72	4.19	-	4.19	-	-

Furthermore, we plotted the relationship between diameter at breast height (dbh) and carbon sequestration potential (Fig. 2), revealing a substantial increase in carbon sequestration potential from 5cm onwards, while the increase was stagnant in the range of 1-5cm dbh. This observation clearly illustrates that carbon stock and sequestration potential are strongly correlated with dbh (using a reference point). Our findings align with the study conducted by Abino *et al.* (2014) in terms of carbon stock at the plot level, where a similar plot size was employed. However, our carbon sequestration potential values are lower compared to all their plots conducted in Samar Island, Philippines (although the minimum value was 41.43 tC/ha). Although Abino *et al.* (2014) considered both below and aboveground biomass, with aboveground biomass contributing more than 75 percent of the total biomass, we can still infer that the Sangalang mangrove forest possesses substantial carbon sequestration potential, as our values are comparable to those derived for Philippine mangroves by Lasco and Pulhin (2014). Similarly, despite the low species richness (only five species recorded), these mangroves have the potential to sequester and store vast amounts of carbon.

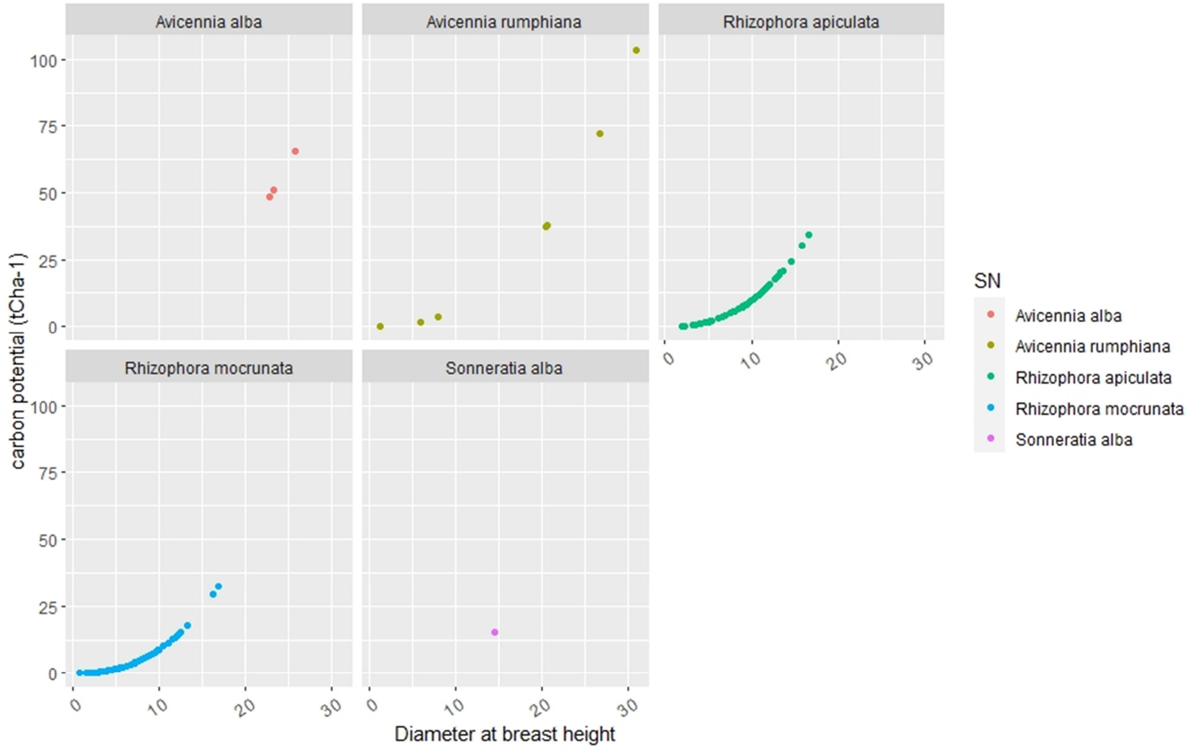

Fig. 2. Depicts the relationship between carbon potential and diameter at breast height (dbh) for each species.

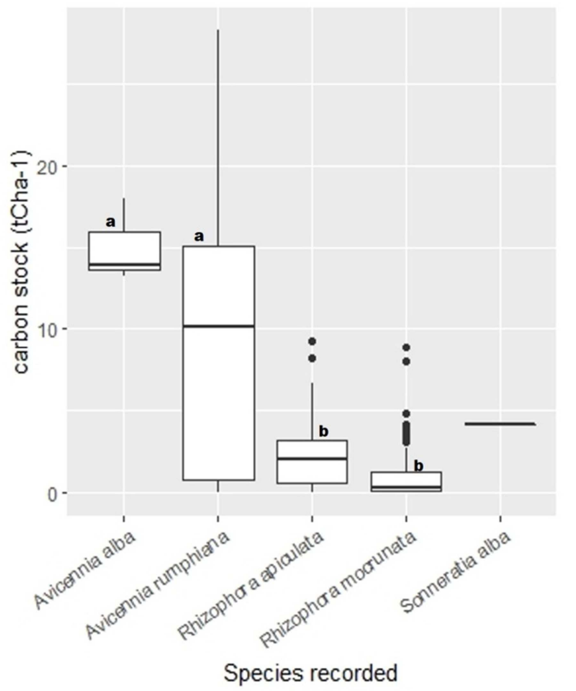

Fig. 3. Illustrates the carbon stock of different species in the study area. Differing letters indicate a significant difference between each species at $p < 0.05$ based on simple ANOVA (ab*, a^s).

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