Carbon Stock Sequestration in the Mangrove Forest of Barangay Camudmud MPA, Island Garden City of Samal, Davao Del Norte

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Abstract: The study mainly determined the potential of Barangay Camudmud mangrove forest to sequester carbon dioxide. Five sampling plots were established using the transect line in the study area parallel to the shore. Every sampling plot measured 20 m x 20 m, spaced at 20-m intervals, and covered 2,000 m^2. Two true mangrove species were found, namely: *Rhizophora stylosa* (bakhaw bato) and *Sonneratia alba* (pagatpat). *R. stylosa* was more abundant on the site and had a higher value of relative density, frequency, dominance, and importance value index compared to *S. alba*. Moreover, species diversity in the study area, including the saplings, was low (0.094). Furthermore, based on allometric equations computation for aboveground biomass and belowground organic carbon, *R. stylosa* sequestered *5.621 Mg ha* and *12.528 Mg ha* for *S. alba*. Generally, Barangay Camudmud Marine Protected Area (MPA) mangrove forest had the potential to sequester carbon with a total of *18.149 Mg ha*. Although *R. stylosa* dominated the study area, it sequestered less atmospheric carbon than *S. alba*. On the other hand, *S. alba* sequestered more carbon and was less dominant in the area. As a result, the value of *r* in the Pearson Correlation Coeffi- cient was computed as *-0.1717* and was interpreted as a *negative correlation* that exhibited an inversely proportional relationship between Importance Value Index (IVI) and total carbon sequestration values.

Keywords: carbon sequestration; mangrove forest; Marine Protected Area; biodiversity; aboveground biomass; belowground organic carbon; allometric equations

I. Introduction

Climate change is one of the most critical challenges facing the modern world that has a significant impact on ecosystems due to the warming of the planet [1] because of the increase of greenhouse gases [2]. There are risks of long-term change in the climate system, such as melting ice caps and glaciers, rising sea levels, and increasing temperature [3]. Therefore, there is a need for mandatory carbon sequestration [4][5]. Mangrove forests in coastal areas largely play crucial roles in climate change mitigation by sequestering carbon in the atmosphere [6].

The Philippines was once recognized internationally for its mangrove-rich ecosystem providing ecosystem services and climate change mitigation [7][8][9][10]. Thus, the potential of mangrove forests to sequester carbon dioxide (CO_2) must be recognized to promote conservation efforts in the ecosystem [11]. Studies on carbon storage and sequestration conducted in the Philippines focused on terrestrial vegetation; therefore, only limited data are available in the scientific literature on carbon sequestration and storage rates of blue carbon ecosystems. Recent studies, especially in Mindanao, utilized on the living aboveground biomass based on species-specific allometric equations to estimate the carbon stock accumulation [9][12][10] making belowground soil carbon pools the least studied reservoir [13].

Island Garden City of Samal (IGACOS) is the country's largest resort city [14] and one of the tourist spots because of its numerous powdery white sand beaches. Tourism is one of the livelihoods of the natives in IGACOS. However, the movement of people from nearby cities to ICAGOS creates human pressure. Additionally, the conversion of ICAGOS to commercialization can lead to land degradation, and as a result, more trees will be used for infrastructure. Therefore, there is a need to assess, monitor, and inventory carbon stocks, specifically in ICAGOS. Barangay Camudmud, IGACOS, Davao Del Norte, was selected as the study site because it is declared a Marine Protected Area and the least studied. The nearby areas of this MPA were also converted to commercial spaces. In addition, there had been no information about species composition, stand characteristics, aboveground biomass, belowground soil carbon, and carbon stock sequestration published in the study area.

The information gathered in this study would serve as the baseline information on the site's mangrove ecology and future studies that address mangrove forests' dynamics. Further, this study is aligned with the goal of both public and private sectors in local, national, and international settings to address the potential of mangrove forests in climate change mitigation through carbon

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sequestration. As such, this is harmonized on the research agenda of the Department of Science and Technology–Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development (DOST–PCAARRD) and the Department of Environment and Natural Resources (DENR) Research Agenda on the possibility of the CO_2 sequestration in the Philippine geological setting. This study is also harmonized with Climate Change Act (RA 9729) and the Disaster Risk Reduction Management Act (RA 10121) in the Local Government Unit. Lastly, this study could be the basis for a relevant, responsive, and sustainable approach to protecting and managing Barangay Camudmud MPA and all coastal vegetation ecosystems.

II. Materials And Methods

The study area was conducted in Marine Protected Area (MPA), Barangay Camudmud, Island Garden City of Samal (IGACOS), Davao Del Norte, and the entry protocol was followed. An endorsement letter was submitted to the City Mayor's Office and then to the City Fisheries and Aquatic Resources Management Councils (CFARMO) for the study's approval then to the Local Government Unit (LGU). The Barangay Kagawad, Hon. Teodoro Llanes was responsible for the assistance in the study area.

Barangay Camudmud MPA is in the western portion of IGACOS and comprises mangroves, coral reefs, seagrass beds, and sandy substrates. The area had an estimated elevation of 38.4 m above sea level with an average annual climate between 23°C to 30°C. Meanwhile, the average annual precipitation is 51.2 in and the average annual rainy days is 249.7 days [15][16]. Barangay Camudmud shares a common border with Barangay Tambo and Barangay San Isidro (Babak), Davao del Norte.

Under the City Ordinance No. 2010-160 series of 2010, Barangay Camudmud was declared an MPA for protecting, conserving, rehabilitation, and replenishing coastal and marine resources [16]. Based on the conversation of Barangay Kagawad Hon. Teodoro Llanes [17], the Barangay officials were planning to obtain sustainability in the area. Barangay Camudmud MPA had a total land area of 5 ha with 6,000 mangrove seedlings planted. However, the number of mangrove individuals diminished due to a lower survival rate after mangrove planting. Development for tourism in the coastal areas was also visible. Further, there was no inventory done at the barangay level.

The study was conducted in the month of May 2022. During the conduct of the study, the average temperature was 30°C, while the humidity was 81.5% [18]. High tides started around 6:12 AM to 6:39 AM, with a height of 2.06 m to 2.08 m. Meanwhile, low tides started around 12:41 PM to 1:11 PM, with a height of 0.08 m to 0.12 m [19].

The area's latitude and longitude were obtained using Garmin Global Positioning System (GPS) receiver. Plots were established using a transect line parallel to the shoreline to quantitatively describe species composition, stand structure, and biomass of mangroves. Five plots were established in the area. Each plot measured 20 m x 20 m using a transect line. Fig. 1 shows the sampling plots of Barangay Camudmud MPA, Island Garden City of Samal, Davao del Norte, created by Susulan [20] using Google Earth [21].

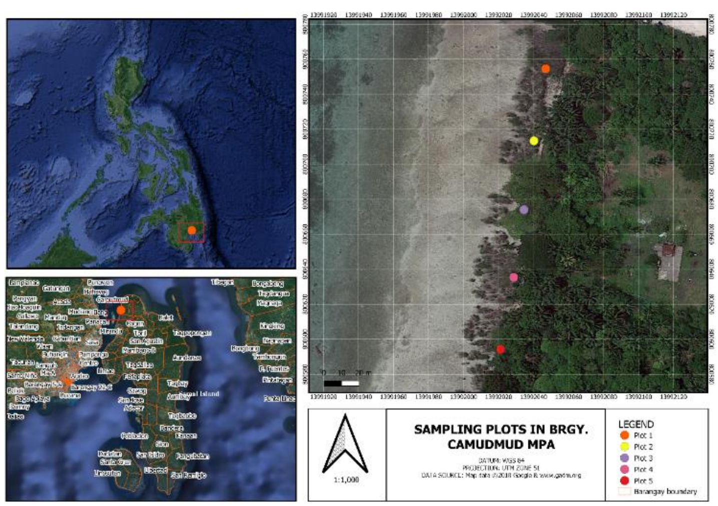

Fig. 1. Location of the study area in reference to national and local maps showing (a) Philippine map, (b) IGACOS map, and (c) Camudmud MPA mangrove forest

The gathering of samples was done during the lowest tide of May 2022. Inside the plot, all mangrove species were identified for species composition. All mangrove trees with at least 50% of their trunk within the plots were counted and recorded. Morphological characteristics were used for plant identification, such as the leaf, flowers, fruits, roots, and trunks of mangrove trees [22][23][24]. Initial identification was done in the study area during the conduct of the study. Verification for the identification of

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mangrove species was done by sending the data to Dr. Primavera, an expert on mangroves in the Philippines. Mangrove distributions were described using relative density, relative frequency, relative dominance in the basal area, and importance value.

To calculate the living aboveground biomass, factors such as height, wood density, and diameter at breast height (DBH) were used [25]. Altometer was used to determine the tree's height, 15 footsteps away from the mangrove tree. Saplings and seedlings found in the study area were not included for height and DBH measurement, only for diversity. Meanwhile, for wood density, a reliable online database for species-specific wood density of mangrove species was adopted from [26][27].

A diameter tape was used to measure the plant's diameter at breast height (DBH). The diameter of the tree usually measures 1.3 m from the ground [17][28]. However, measuring mangrove trees' DBH was not always easy due to anomalies in stem structure thus, methods used was adopted from [29]. Mangrove saplings and seedlings with DBH less than 4 cm only accounted for biodiversity assessment but not for carbon stock estimation [30].

To measure belowground soil carbon, soil or sediments were extracted using an improvised corer (PVC # 4) below the ground with a depth of 15 cm adapted from and 10 cm in diameter [28]. Sample sediments were extracted on a species-specific basis weighing 1 kg per mangrove species per plot using a spring scale. Samples were combined to obtain a composite sample in the study plot. Sediment samples in each plot were dependent on mangrove species. The more mangrove species, the more sediment is extracted. However, only two mangrove species in sampling plot 1 were found in the Barangay Camudmud MPA. The rest of the plots, from plot 2 to plot 5, only *R. stylosa* was recorded. Therefore, for sediment extraction, the composition of *R. stylosa* sediment and *S. alba* were extracted in plot 1 and only the composite of *R. stylosa* for plot 2 to plot 5.

Samples were stored, labeled, and sealed in plastic bags (Ziplock) for bulk density and organic carbon analysis [7][8][31]. The samples then transported to the Department of Agriculture (DA) Laboratory in Agdao within 24 hours after the extraction. To obtain bulk density, the sample was then transferred to a borer. Meanwhile, physico-chemical parameters such as temperature and salinity were obtained in the area manually. The thermometer was used to measure the mean of the three trials in every sampling plot to determine the atmospheric temperature in the morning (9:00 am to 11:00 am). In addition, a refractometer was used to measure the mean of the three trials made in every sampling plot. A few drops of seawater were placed in the prism to determine the salinity in the water area.

Data gathered in the area were analyzed to describe the mangrove stand, calculate the diversity index, quantify the amount of aboveground biomass, belowground soil carbon, and the estimated amount of carbon, and correlate the importance value of aboveground and belowground biomass. Table 1 describes the equations used in the study area to calculate the mangrove stand and the total carbon sequestration.

Table 1. Equations used for the parameters measured in the study

Areas to Measure	Parameters	Equations
Mangrove Stand Characteris-tic	Basal area per tree (m²)	$BA = \pi DBH\ (cm)^2/40000$
	Stand basal area (m² ha)	$SBA = \Sigma BA/a\ (ha)$
	Density (stems ha)	$D = N\ (10{,}000)/a\ (ha)$
	Relative density (%)	$RD_{en} = D_i/\Sigma D_i * 100$
	Relative frequency (%)	$RF = f/n * 100$
	Relative dominance (%)	$RD_{om} = \Sigma BA_i/\Sigma BA_{1+2+3\ldots} * 100$
	Importance Value Index (%)	$IVI = RD_{en} + RF + RD_{om}$
Diversity Analysis	Shannon-Weiner Diversity Index	$H = -\sum p_i \ln(p_i)$
	Aboveground Biomass (Kg DM/tree)	$AGB = 0.0776 \times (pD^2H)^{0.940}$
	AGB value (Mg ha^{-1})	$AGB = (\Sigma AU/1{,}000) * (10{,}000/a\ (ha))$
	Carbon Stock Estimation	$CSE = AGB * 0.521$
	CO_2 Sequestration Potential Estimation	$CSPE = CSE * 3.67$
	Belowground Soil Organic Carbon	BSOC = bulk density (g/cm^3) * soil depth interval (cm) * % C_{org}

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Carbon Sequestration	Total Carbon Stock Sequestration (Mg ha^{-1})	TCSS = CSPE + BSOC
Correlation Analysis	Pearson's Correlation Coefficient (r)	$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$

Pearson's Correlation Coefficient analysis determined the strength of the linear relationship between two variables, namely IVI and the total carbon sequestered in Barangay Camudmud MPA. To calculate the total carbon sequestration, the values of the aboveground biomass and belowground soil organic carbon obtained will be added.

III. Results And Discussion

There were 316 individuals found in five sampling plots in Barangay Camudmud MPA area, as indicated in Table 2. Dr. Primavera verified the species identified as *R. stylosa* and *S. alba*. Identification was made based on the morphological appearance of the mangrove's species, such as leaves, flowers, fruits, seeds, roots, trunk, propagules, and pneumatophores [22][23][24].

Identification of mangrove species in the study area was done based on morphological characteristics. A guidebook was used to initially identify mangrove species in the study area [22][23][24]. *R. stylosa* belongs to the Rhizophoraceae's mangrove family, also known as small, stilted mangrove. *R. stylosa* was classified in order Malpighiales, class Magnoliopsida, and phylum Tracheophyta under kingdom Plantae [32]. *R. stylosa* preferred area near the coastline. The maximum height *R. stylosa* measured 7.5 m using an altometer, 15 steps away from the tree, and a minimum of 4.5 m with a conical crown.

Fig. 2 shows the morphological characteristics of *R. stylosa* based on observation. Stilt roots of *R. stylosa* were visible on the trunks, and sometimes aerial roots emerged from lower branches. *R. stylosa* were generally small and multi-stemmed; trunks were gray to black and heavily fissured, reaching 15.1 cm for the DBH (Fig. 2c). Meanwhile, the leaves were green, elliptic, and had a pointed tip (Fig. 2a & Fig. 2b). Moreover, flowers were composed of off-white or cream-colored in a cross-shaped pattern with four yellowish to whitish petals (Fig. 2b). Flower heads were found in the axil between the petiole and the node, and broadest near the base. In addition, propagules were long, cylindrical, and emerged near the branch, and were present almost in every *R. stylosa* tree while the fruit is brown, pear-shaped, and attached to parent tree (Fig. 2a).

Fig. 2. Morphological characteristics of *R. stylosa* found in the study area showing (a) hypocotyl (propagules), (b) leaves and flowers, (c) trunk, bark, and roots, and (d) reference photo of *R. stylosa* [23]

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Morphological characteristics of *R. stylosa* were described by [33][34][35]. Leaves of *Rhizophora* species were characterized by opposite, simple, light green with a distinctive mucronate tip at the apex. Meanwhile, leaves on the upper surface were both shiny, while cork warts were scattered undersurface of the leaf. Moreover, flowers were located within or below the leaf axils. When matured, fruits of *R. stylosa* were pear-shaped with a smooth brown surface, and the calyx lobes elongate when hypocotyl is ready to emerge. Distinctive coloration in the attached propagule to the extended fruit was visible. Moreover, hypocotyls or propagules were cylindrical, elongate, smooth green with irregular small brown lenticels. The bark of *R. stylosa* was heavily fissured from gray to dark gray, occasionally red-brown and smooth. *R. stylosa* was known to be shorter, multi-stemmed, and more spreading in areas of higher salinity with distinct aboveground prop roots sturdy even when relatively thin.

Meanwhile, the same method was done in identifying *S. alba* in the study area. Based on the observation during data gathering, the maximum height *S. alba* was measured 13 m and a minimum of 10 m. *S. alba* is bigger than *R. stylosa* in the study area. Fig. 3 shows the morphological characteristics of *S. alba* based on observation. The roots of *S. alba* have a thick pneumatophore. Pneumatophores are where conical roots emerge vertically from the ground. Trunks of *S. alba* reached up to 34.6 cm for the DBH, gray and fissured (Fig. 3c). Moreover, the leaves were green, opposite, elliptic to ovate, and had rounded or broad tips (Fig. 3b). Flowers were not seen during the conduct of the study. Additionally, fruit berries were brown, indicating old, dried fruit (Fig. 3a).

Fig. 3. Morphological characteristics of *S. alba* found in the study area showing (a) fruits, (b) leaves, (c) trunk, bark, and pneumatophore, and (d) reference photo of *S. alba* [23]

S. alba locally known as pagatpat belongs to the mangrove family of Sonneratiaceae, order of Myrtales, class of Magnoliopsida, and phylum Tracheophyta under the kingdom Plantae [36]. They are usually found at medium-high tides (seaward) and are one of the pioneering species of mangroves [34]. Morphological characteristics of *S. alba* were described by [37][35]. Leaves of the observed *S. alba* were light green with a smooth texture on the upper surface, round with no angles, and the leaf tip and base were blunt. Moreover, the roots of the *S. alba* stand upright and have a conical shape known as pneumatophores. The bark was light gray, and the surface texture of the trunk was cracked. In addition, the rooting adaptation of *S. alba* is known as pneumatophores, where the primary roots are located. Furthermore, *S. alba* had a rapid development, from developing buds and flowers that became the fruit ready to be a new seedling.

Table 2 shows the mangrove species identified in the study area. A few individuals of *S. alba* were recorded in the study area. However, *S. alba* had a higher average in DBH, height, and basal areas than *R. stylosa*. The DBH of *R. stylosa* measured from 4 cm to 15.1 cm, while 20.2 cm to 34.6 m for *S. alba*. Furthermore, the mean DBH of *R. stylosa* is computed 5.60 cm, whereas 24.2 cm for *S. alba*. DBH was important to determine in the study area because it can estimate tree attributes like growth, wood volume, and basal area. Results indicated that *S. alba* had a bigger volume compared to *R. stylosa*. Moreover, wood density is valued at

0.510 g/cm^3 for *R. stylosa* and 0.840 g/cm^3 for *S. alba*. Meanwhile, the conservation status of *R. stylosa* and *S. alba*, were listed under the 'Least Concern' status despite their decreasing global population trend [38].

Table 2. Mangrove species identified in the study area

Species	Conservation status (IUCN)	Total # of indivi-duals	DBH range (cm)	Average DBH (cm)	Average height (m)	Average basal areas (m^2)	Wood density (g/cm^3)
R. stylosa	LC	310	4.0 – 15.1	5.60	5.2	0.133	0.510
S. alba	LC	6	20.1 - 34.6	24.2	10.5	0.44	0.840

Table 3 indicates the stand characteristics of the mangrove species in the Barangay Camudmud MPA. Equations for computations are reflected in Table 1. *R. stylosa* had the higher individuals counted in the sampling station. In terms of relative density and relative frequency, *R. stylosa* had a value of 98.09%, indicating an excellent reproductive ability compared to *S. alba*. The frequency value provided information about the distribution and adaptability of each type of mangrove in the research location. *R. stylosa* had the higher frequency indicating that this species had the higher adaptability and the wider distribution in the study area [39].

Table 3. Stand characteristics in the study area

Species	Total basal areas	Mean basal area (m^2)	Mean stand basal area ($m^2\ ha^{-1}$)	Mean density (stems ha^{-1})	Relative density (%)	Relative frequency (%)	Relative dominance (%)	Importan ce value (%)
R. stylosa	4.678	0.133	2.8075	$7.75x10^8$	98.09	98.09	63.93	260.17
S. alba	2.64	0.44	11	$1.5x10^6$	1.90	1.90	36.08	39.88

In dominance, out of two species found in the study area, *R. stylosa* had a value of 63.93%, for trees and saplings level. Meanwhile, *S. alba* had a value of 36.08% at the tree-level, with only six individuals recorded in the study area. Generally, the dominant species utilized the environment more efficiently than other species in the same place. However, in this study, the dominance value of *S. alba* is half of *R. stylosa*, considering the number of individuals. The larger the stem size, the more the species dominate the area. Therefore, if the number of *S. alba* individuals is the same as *R. stylosa*, the higher the dominance value for *S. alba* species.

These results concurred with the studies conducted in different Rhizophoraceae-dominated mangrove areas in the Philippines. *R. stylosa* is one with the highest mangrove species, along with *A. marina* in Banacon, Bohol [31]. Meanwhile, in Barangay Imelda, Dinagat Island, the family Rhizophoraceae obtained the highest composition of five species [30]. Furthermore, the family of Rhizophoraceae also dominated in areas such as in Maasim, Sarangani Province [9], Verde Passage, San Juan, Batangas [7], Barangay Cagdianao, Claver, Surigao Del Norte [40], and selected municipalities of Zamboanga Del Sur, Mindanao Island [35].

Along with the diversity index, Importance Value Index (IVI) determined the structure of the mangrove vegetation community. In the study, the importance value was used to show the importance of a mangrove species as it affects the community and ecosystem [41]. Based on the result for trees and saplings level, the mangrove species *R. stylosa* had the higher percentage value, 260.17%, compared to *S. alba*. Thus, *R. stylosa* is better in adaptability, competitive power, and reproductive capacity compared to *S. alba*. Species with the lower IVI value disappear from the ecosystem under stress due to their very small numbers, low reproduction, and narrow distribution [42].

Notwithstanding, a study conducted in Banaybanay, Davao Oriental [43], it was found that *S. alba* had the highest importance value (59.8%), relative density (13.5%), and dominance (37.5%). They concluded that the higher the IVI values, the largest contribution to mangrove biomass in the area. Additionally, according to the study conducted by [9], *S. alba* had the highest IVI (49.08%) out of five species identified. Meanwhile, other study of *S. alba* ranked second (71.83%) following *A. marina* (153.33%) [10]. However, a study conducted in Panabo, Davao Del Norte found out that in terms of basal area, *S. alba* had the largest basal area due to the large DBH of the accounted individuals [50].

Table 4 shows the physico-chemical parameters measured in the study area such as temperature, salinity, pH, bulk density (g/cm^3), organic carbon (%), and mechanical analysis. Those associated with *S. alba* were almost the same as *R. stylosa*. The

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measurement of temperatures in five sampling plots was consistent. The mean temperature in the study area was measured 28°C. *R. stylosa* can tolerate a wide range of temperatures [33]. The annual temperature of *R. stylosa* was recorded at 20°C to 30°C but could handle a maximum temperature of 30°C and as low as 10°C. Meanwhile, *S. alba* can tolerate 22.13°C to 32.95°C atmospheric temperature [44].

Salinity values were almost the same for *R. stylosa* in five sampling plots (28.6 ppt). Consequently, the value of salinity might be affected for two reasons during the conduct of the study: (a) the area was near a commercialized resort, which could contribute to the lower salinity value of the seawater, and (b) the study was conducted during the lowest tide therefore, samples were taken in the sampling plot where the seawater was scarce. *R. stylosa* grows best in saline soils, preferably between 34 to 36 ppt but could survive well in freshwater from 8 to 26 ppt [15], while *S. alba* had a broader range of tolerances salinity ranging from 0.299 to 38.5 ppt [46]. Due to higher limits in salinity tolerance, *S. alba* could be in the first category of salinity-tolerant species (>25 ppt). *S. alba* can tolerate a wider range of tolerances to varying water quality parameters that could help them survive in diverse environmental conditions.

Meanwhile, the textural classification of soils in the mangrove forest is more on sandy loam and less on sandy. The ideal environments for the growth of *S. alba* are loamy sand and sandy loam [44]. Moreover, *R. stylosa* grows best in light, medium, and heavy texture soils such as sands, sandy loams, sandy clay loams, sandy clays, clay loams, and clays. *R. stylosa* developed the greatest stature and columnar growth in fine clay and black mud sediments with relatively high organic carbon loads [33].

The pH value analyzed in the Department of Agriculture Laboratory Agdao, Davao City, varies among the five-sampling plot (species-specific). The pH value was measured 8.02. *R. stylosa* prefers pH between 6 to 8.5 [33]. On the other hand, *S. alba* can also tolerate a wide range of seawater pH ranging from 4.66 to 8.7 [35]. Meanwhile, bulk density and organic carbon content were also analyzed to determine the soil organic carbon of mangrove species found in the study area. *S. alba* can sequester 0.5% to 77% of organic carbon [45]. In the study area, the average soil organic carbon content is 1.45% for *R. stylosa* and 1.64% for *S. alba*.

Table 4. Physico-chemical analysis in the study area

Species	Parameters	Sampling Plots					Mean of all Parameters
		Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	
R. stylosa	Temperature (°C)	28	28	28	28	28	28
	pH	7.83	8.02	7.99	8.07	8.21	8.02
	Salinity (ppt)	28	28	29	29	29	28.6
	Bulk Density (g/cc)	1.28	1.25	1.25	1.09	1.21	1.22
	Organic Carbon (%)	1.79	1.50	1.74	0.71	1.50	1.45
	Mechanical Analysis	Sandy	Sandy	Loamy sand	Loamy sand	Loamy sand	Sandy, Loamy sand
S. alba	Temperature	28	-	-	-	-	28
	pH	8.02	-	-	-	-	8.02
	Salinity (ppt)	28	-	-	-	-	28
	Bulk Density (g/cc)	1.23	-	-	-	-	1.23
	Organic Carbon (%)	1.64	-	-	-	-	1.64
	Mechanical Analysis	Loamy sand	-	-	-	-	Loamy sand

Soil sediments were extracted to determine bulk density and soil organic carbon in Bahile, Puerto Princesa City, Palawan, and used an allometric equation to assess carbon sequestration in Palawan [8]. The development and use of allometric equations is

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the standard methodology for the estimation of trees, plots, and regional aboveground biomass [46]. Thus, allometric equations are important for quantifying biomass and carbon storage in terrestrial ecosystems and the aquatic ecosystem.

Shannon-Weiner Diversity Index was used to determine species diversity including species richness and evenness [47] in the sampling area using SPSS software. *Species richness* measures the number of mangrove species found within a particular area, while *species evenness* measures the relative abundance represented in each mangrove species. Species diversity in Barangay Camudmud was very low (0.094). In Shannon-Weiner Diversity Index, values such as 1.99 and below are considered very low, and 3.5 above considered very high in diversity. In the study, species richness is two and species evenness is 0.136. The limit of the Shannon-Weiner Diversity Index in the study area is the value of H max (0.693). The larger the population size the higher the value of H max.

Barangay Camudmud is not diverse and low in species evenness due to the following reasons: (a) only two species are represented in the study area, (b) a low number of individuals of *S. alba*, (c) lack of knowledge of the barangay officials on what type of mangroves should be planted in different mangrove zonation, and (d) environmental factors that might affect the growth of mangroves in the study area such as water and air temperature, salinity, pH, dissolved oxygen, turbidity, total suspended solids, and water nutrients as studied by [48].

The area was near a commercialized resort, which could contribute to the changes in environmental factors that could affect the survival rate of mangroves. In addition, tourism could contribute to environmental pollution, land degradation, natural habitat loss, and pressure on marine species in the area. Atmospheric temperature in the study area can be influenced by evaporation and cooled freshwater influx, while salinity can be affected by a high degree of evaporation, neritic water dominance from the sea, and continuous inflow of water from the estuary of the nearby freshwater area. In contrast, the distribution of nutrients can be influenced by the season’s tidal condition and water flow [48].

Barangay Camudmud mangrove area was very low in diversity (H’= 0.094). The computed value is comparable to the result of other mangrove studies in diversity assessment. Diversity analyses were computed as 0.715 in Sarangani Province [9], 0.914 in Tacloban City [49], 1.0273 in Panabo [10], 1.4185 in Batangas [7], 1.856 in Dinagat Island [30], 1.99 in Zamboanga Del Sur [35], and 2.067 in Carmen, 1.968 in Tagum, and 1.906 in Panabo [50]. Low diversity value in the mangrove areas is primarily due to the lack of species variation in the mangrove stands [8]. However, the study in Banaybanay, Davao Oriental [43], showed a high Shannon-Weiner Index of Diversity (H’ = 3.145). Higher values of richness and evenness contribute to a higher diversity index but are low in dominance.

Table 5 shows the parameters of carbon sequestration in the study area. For aboveground biomass, wood density values were derived from Global Wood Density Database used by [26][27] and allometric equations adopted from [25]. However, the value in Aboveground biomass (ABG) is still in *Kg DM/tree*; therefore, it was converted to units for carbon sequestration potential. Equations on how to convert the biomass of the tree into the total biomass from *Kg DM/tree* to *Mg ha* were provided from [51]. The CO_2 sequestration potential (AGB) for *R. stylosa* is *0.26339 Mg ha* meanwhile, *S. alba* accounts for *11.31802 Mg ha*. *S. alba* had a higher concentration of ABG despite the low number of individuals recorded in the study area because of its higher DBH, height, and wood density value compared to *R. stylosa*.

Table 5. Carbon stock sequestration in the study area

Species	Above ground biomass (Kg DM/tree)	Above ground biomass (Mg ha)	Carbon stock estimation (Mg ha)	CO_2 seques-tration potential (Mg ha)	Below ground soil organic carbon (Mg ha)	Total carbon seques-tration (Mg ha)
R. stylosa	5.51	0.13775	0.071768	0.263388	5.358	5.621387
S. alba	236.77	5.91925	3.083929	11.31802	1.210	12.52802

Consequently, for the soil organic carbon content, *R. stylosa* had a higher value, accounting for *5.358 Mg ha* while *1.210 Mg ha* for *S. alba*; hence, *R. stylosa* is located near the shoreline, and more debris and detritus can contribute to the amount of organic carbon content. Moreover, based on mangrove zonation, *S. alba* is found in seaward; thus, lesser detritus is present in its sediment, which explains why the value of soil organic content was low compared to *R. stylosa*.

Carbon capacity storage of *R. stylosa* increases with age and can dramatically increase 11 years onward [52]. In measuring soil organic carbon, soil depth, bulk density, and organic carbon concentration are important to be quantified, and an allometric equation was used (Table 1). Many carbon assessment is limited to 30 cm since soil carbon is in the top horizon and organic rich horizon are found between 0.10 m to >3 m [6][53]. This study's method of measuring organic carbon supports many studies conducted in carbon sequestration.

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The total carbon sequestered in the study area is the total amount of aboveground biomass and belowground soil organic carbon. The total carbon sequestered of *R. stylosa* is *5.621 Mg ha*, meanwhile *12.528 Mg ha* for *S. alba*. Although, *R. stylosa* dominated the study area with higher values in relative density, relative frequency, and relative dominance, making it higher in IVI compared to *S. alba*; however, it sequestered less atmospheric carbon. Meanwhile, *S. alba* had lower relative density, frequency, and dominance values, making it lower in IVI compared to *R. stylosa*; however, it sequestered more atmospheric carbon. The result of this study supported the studies of [9] and [12]. With these values presented (Table 5), *R. stylosa* and *S. alba* in Barangay Camudmud MPA could sequester carbon in the atmosphere. *S. alba* sequestered a higher amount in aboveground biomass due to its higher value in DBH, basal areas, and height than *R. stylosa*.

The computed value of carbon sequestration in the study area was low compared to studies conducted by other researchers due to the number of species found in the area. A total of *2, 010, 474 tons* of carbon was sequestered in Bohol [31], *522.792 Mg C* ha^{-1} in Sarangani Province [9], *356.1 t C* ha^{-1} in Palawan [8], *224,83 tons-C* in Barangay Lasang [12], *136.44 Mg* $CO_2\ ha^{-1}$ in Panabo [10], and *115.45 t* ha^{-1} in Batangas [7]. With these amounts of carbon sequestered in the atmosphere in different places, conservation and protection efforts should be continued in the Philippine archipelago.

The coefficient correlation analysis was used to measure the relationship between two variables. In this study, the variables measured were the total carbon sequestration and Importance Value Index (IVI) per plot and species. For total carbon sequestration, aboveground biomass and belowground soil organic carbon were used, while relative density, relative frequency, and dominance were used in determining the importance value index.

Pearson Correlation Coefficient measures the linear association between two variables, IVI and total carbon sequestration. Correlation ranges from the values of -1 to 1. The Pearson correlation results indicated a non-significant and minimal negative relationship between IVI and the total carbon sequestered. The value of *r* was computed at -*0.172* (weak negative correlation). Moreover, the *p-value* was computed *0.745* $(P(x \leq -0.3486) = 0.3725)$. The larger the p-value, the more it supports H_0 that there is no correlation between two variables. The value of covariance was also incorporated in Pearson Correlation Coefficient computation ranges from negative infinity to positive infinity. Positive covariance exhibits a direct relationship (same direction); meanwhile, in negative covariance exhibits an inverse relationship (opposite direction) [54].

Fig. 4 shows the correlation analysis of the two variables given. The value of *r* is -*0.1717* indicating a weak relationship between the two variables correlated in the study. The covariance was interpreted as negative covariance value (-*8.0998*). Thus, with an increase in IVI obtained in the study area, the value of carbon sequestration decreases. Unlike the value calculated in this study, other studies conducted yielded a positive correlation with two variables, IVI and total carbon sequestration [55][56].

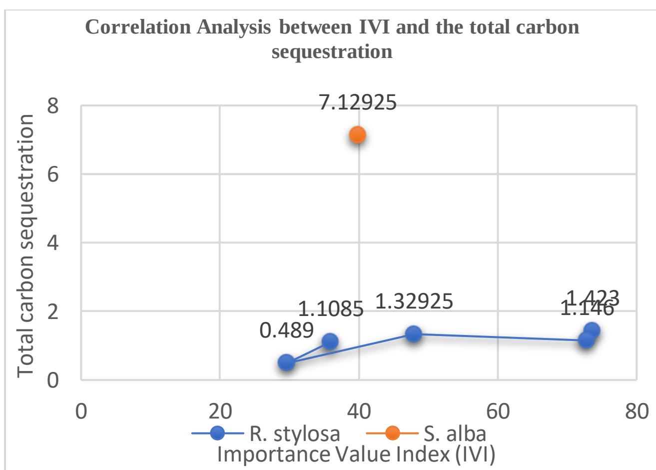

Fig. 4. Correlation analysis between IVI and the total carbon sequestration showing (a) blue - *R. stylosa* values and (b) red - *S. alba* value

Although *R. stylosa* dominated the study area with higher values in relative density, relative frequency, and relative dominance, making it higher in the IVI than *S. alba*, it sequestered less atmospheric carbon with a total carbon sequestered *5.621 Mg ha.* On the other side, *S. alba* had lower values in relative density, relative frequency, and relative dominance, making it lower in IVI compared to *R. stylosa*; however, it sequestered more atmospheric carbon with a total carbon sequestered *12.528 Mg ha.* With these values, the value of *r* is -*0.1717*. The result of the study supported the study conducted in Sarangani Province [9]. If the individuals represented by *S. alba* were higher than those represented by *R. stylosa*, the result of correlation analysis would be different from the yielded result in this study.

The negative correlation between the two variables supported the study of [57] in Western Bhutan Himalaya with a p-value >0.05. The study assessed the importance value index to determine the importance of each tree species concerning carbon stocks. It was also concluded that tree species' biomass and carbon sequestration capability variability depend on tree density and size, productivity rates, human disturbances, and proper forest management. Human disturbances can affect the productivity rates of a certain forest; thus, proper forest management for protection and conservation would help increase tree density and volume in Barangay Camudmud MPA. Anthropological activities such as land conversion for commercialization, environmental pollution due to tourism in the nearby resort, and any other developmental activities near the study area can contribute to less biomass accumulation and reduce carbon sequestration of the mangrove species.

IV. Conclusion

Two species were found, namely, *Rhizophora stylosa* (bakhaw bato) and *Sonneratia alba* (pagatpat). A total of 316 individuals were recorded in the sampling plots. *R. stylosa* dominated the area, with 310 out of 316 individuals recorded in five sampling plots, while only six individuals were recorded for *S. alba.* Meanwhile, *R. stylosa* had a higher value in relative density, relative frequency, relative dominance, and Importance Value Index (IVI) compared to *S. alba* considering the number of individuals represented in the study area. Consequently, *S. alba* had the largest basal area, height, and DBH for the mangrove community structure. Species diversity was low (0.094); therefore, Barangay Camudmud, a Marine Protected Area (MPA), was not an assurance for the variety of mangrove species in the area.

It was found that Barangay Camudmud MPA can sequester carbon with a total of *18.149 Mg ha*. *S. alba* had a higher value of carbon sequestered compared to *R. stylosa* despite the number of individuals represented in the study area. The total carbon sequestration of *R. stylosa* was calculated at *5.621 Mg ha,* while *12.528 Mg ha* for *S. alba*. Although *R. stylosa* dominated the study area, it sequestered less atmospheric carbon than *S. alba.* Thus, the *r* value in the Pearson Correlation Coefficient was computed as *-0.1717* and was interpreted as a negative correlation exhibiting an inversely proportional relationship between two variables studied in the area. Based on the result of the study, it agreed to many studies conducted in different areas in the Philippine archipelago about the higher sequestration potential of *S. alba* compared to *R. stylosa.*

V. Recommendations

The study area is low in terms of species diversity (0.094) and carbon sequestered (*18.149 Mg ha*); thus, it is recommended to increase the range of mangrove species in the study area through consistent tree planting in a proper mangrove zonation and suited to the study area for mangroves survival. Furthermore, it is recommended to continue and intensify the protection and conservation of the Marine Protected Area. In addition, it is also recommended to have a follow-up study for long-term monitoring to re-assess the mangroves' carbon sequestration potential in the study area and to re-check and verify the values as computed using Pearson Correlation Coefficient. Although *R. stylosa* dominated the study area with higher values in relative density, relative frequency, and relative dominance, making it higher in IVI compared to *S. alba*, it sequestered less atmospheric carbon and vice versa exhibiting a negative relationship in correlation analysis.

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