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Carbon Storage Potential and Microenvironment Preference of Mangrove Species in the Coastal Barangays of Tangub City, Misamis Occidental, Philippines

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ABSTRACT

This study aims to evaluate the aboveground and belowground carbon storage capacity and microenvironment preferences of mangrove species in the selected coastal barangays of Tangub City, Misamis Occidental. The study utilized non-destructive sampling for estimating the mangrove carbon, while, soil samples for organic carbon (SOC) were collected manually. Four mangrove species were recorded namely; *Avicennia alba*, *Dolichandrone spathacea*, *Rhizophora apiculata*, and *Sonneratia alba*. Results revealed that in Barangay Mantic, *A. alba* displayed the highest mean accumulated carbon value of 1.75 ± 0.30 Mg C ha^{-1}. Overall, the three coastal barangays of Tangub City recorded an average total carbon of 360.72 Mg C ha^{-1}, with soil having the highest carbon content (222.15 Mg C ha^{-1}), followed by aboveground C (trunk) (107.29 Mg C ha^{-1}) and belowground C (root) (31.28 Mg C ha^{-1}). In terms of environmental factors, *R. apiculata* is associated with high relative humidity while, *S. alba* tolerated high water salinity, *D. spathacea* prefer area with higher air temperature, and *A. alba* is link with high water and soil temperature and pH levels. In general, mangrove ecosystem in the coastal areas of Tangub City stores significant amount of carbon in its various pools. Hence, it is imperative to implement conservation measures focusing on mangrove protection, zonation and sustainability in order to enhance carbon accumulation of these mangrove species.

Key words: *Mangrove, Carbon stock, Zonation, Microenvironment*

Introduction

The concept of carbon sequestration is currently receiving a lot of attention in relation to global warming and climate change (Kowalska *et al.,* 2020). Carbon storage in the world's terrestrial vegetation living biomass is estimated to be between 450 and 700 Pg (Ussiri and Lal, 2017) while carbon stocks in the ocean has been calculated amounting to ~ 40,853 Pg. This is approximately 10 times greater than carbon stocks on land (~ 3,900 Pg) (Ciais *et al.,* 2014). In fact, it sinks 3-5 times more carbon than terrestrial forest

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(Donato *et al.*, 2011) in both above and below ground carbon pools, which vary from 140 – 1023 Mg C ha^{-1} (Suello *et al.,* 2021). And, according to Dittmar *et al.* (2006), soil organic carbon in mangroves store about 218 ± 72 Tg C per year, accounting 49% - 98% of the total carbon storage.

Mangrove distribution are determined by factors such as the salinity, substrate (Tupan and Lailossa, 2019) water, air and soil (Raganas and Magcale-Macandog, 2020). Salinity is viewed as a limiting factor with a critical function in the formation and productivity of mangroves (Kodikara *et al.,* 2017). On the other hand, the rising temperature caused by climate change also induces stress to mangrove seedlings (Lovelock *et al.,* 2009). Despite the ecological and economic services provided by mangrove forests, they decline at an alarming rate. Between 1996 and 2010, 12% of mangrove forests cover worldwide had loss due to anthropogenic degradation with greatest proportion observed in Southeast Asia (Thomas *et al.,* 2017*).* And approximately 60% of mangrove forest losses were observed between 2000 and 2016 particularly on conversion of mangrove cover to agriculture and aquaculture (Goldberg *et al*., 2020).

According to the Intergovernmental Panel on Climate Change (IPCC), strategies such as afforestation, reforestation, and preventing forest conversion are crucial components of the global abatement portfolio (Austin *et al.,* 2020) a cost-effective method for climate mitigation (Zeng *et al.,* 2020). As it changes the biophysical attributes (Locatelli *et al.,* 2015), improve air, soil and water quality (Fuss *et al*,. 2018), reduce the vulnerability of ecosystems and humans to current and future climate change (Doswald *et al.,* 2014), and notably sequester large-scale carbon (Mitchard, 2018). This approach aligns with the goal of Kyoto Protocol and United Nations Framework Convention on Climate Change (UNFCCC) through $REDD^{+}$ (Reducing Emissions from Deforestation and forest Degradation) to achieve emission reduction by increasing biological carbon sinks and carbon credits trading benefitting local livelihoods and biodiversity (Goetz *et al.,* 2015).

Panguil Bay has a large mangrove cover comprising the cities of Tangub and Ozamiz in Misamis Occidental, and number of towns in the provinces of Zamboanga del Sur and Lanao del Norte. For 59 years, the mangrove population decreased by over 50% due to fishponds, built-up areas, agriculture, and sea expansion, which resulted to alarming conditions in the Panguil Bay and nearby coast (Nabua *et al.,* 2020). Moreover, the construction of the Panguil Bay Bridge in Tangub City is expected to drive further development and population growth, posing a significant risk of conversion of the mangrove ecosystem for alternative livelihoods, settlements, and other coastal development as the city expands.

To date, no study has specifically delved on the carbon stock and microenvironment factors affecting the growth and abundance of mangrove forests in coastal barangays of Tangub City. Thus, this paper assesses the above and belowground carbon storage potential of mangrove species and the environmental parameters significantly influencing their proliferation in the selected coastal areas of Tangub City. The findings highlights the relevance of carbon abatement potential of mangrove ecosystem which can further be used in carbon credits trading once the Philippines participates with the international initiative to reduce atmospheric GHG emissions. Similarly, results serve as an insightful basis for policymakers to implement sustainable forest management practices beneficial to enhance carbon accumulation of the mangrove area.

Materials and Methods

Locale of the study

The study was conducted in the coastal Barangays of Tangub City, Misamis Occidental (Figure 1). It is bounded in the south by the calm waters of Panguil Bay, the cities and municipalities along Panguil Bay, have numerous hectares of mangrove regions, a portion of which have been designated as protected areas by the Department of Environment and Natural Resources (DENR) (Nabua *et al.,* 2020). The selected three coastal Barangays are San Apolinario, Mantic, and Lorenzo Tan, Tangub City, Misamis Occidental. Barangay San Apolinario has the largest mangrove cover among the sampling areas with 20.95 mangrove per hectare (mangrove/has). Local community claimed that mangrove species along and within the transect line were planted and situated meters away from residential zones. While, species in Barangay Mantic (17.87 mangrove/has.) were claimed naturally growing, situated close to a small river and fishpond, and is only a few steps away from residential dwellings. And in Barangay Lorenzo Tan (11.13 mangrove/has.), residential structures are closely situated near and within the mangrove area.

Biomass Sampling

This study's plot establishment is based on the Kauffman and Donato (2012) study, which evaluates the mangrove carbon stock. Six circular plots measuring 7 m in radius were established covering a total land area of 0.09 ha per sampling station. Measuring tape, bamboo sticks, and straw were used for marking the plots. All species discovered in each circularplotwere identified using the Field Guide to the Philippine Mangroves (Primavera *et al*., 2004, Primavera and Sadaba, 2012). The biomass was obtained in a non-destructive manner using data from tree trunk circumference. The study was conducted inthe months of September – November 2023.

Above and Belowground Biomass and Carbon Estimation

For above and belowground biomass (AGB and BGB), the allometric equation for Southeast Asian mangroves by Komiyama *et al.,* 2005 is used.

Eqn. 1.

$$AGB = 0.251\ \rho\ D^{2.46}$$

$$BGB = 0.199\ \rho^{0.899}\ D^{2.22}$$

Where D is diameterat breast height and ρ stands for wooddensity. The wood density used in the study was obtained from the World Agroforestry Center (Tobias *et al*., 2017). Meanwhile, the formulas below were used in converting biomass to carbon(Kauffman and Donato, 2012).

Eqn. 2

$$Cagb = 0.50xWtop$$

$$Cbgb = 0.39xWR$$

Where C is carbon content, Wtop is biomass above ground level (kg) and WR is biomass below ground level (kg).

Soil Collection and Preparation

Soil samples for soil organic carbon (SOC) and Bulk Density (BD) were collected in each plot near the center using an improvised core sampler with the length of 100 cm and diameter of 9.7 cm. Mangrove soils were sampled at two depths (0-50 cm and 50-100 cm) (Alsumaiti and Shahid, 2018). The samples for bulk density were oven dried at 105 °C for 24 hours and weighed individually. The air dried samples for SOC were ground using mortar and pestle ensuring that roots, sticks, and shells found were also removed. Then these were sieved through a 2-mm mesh screen, homogenized, stored in labeled containers, and were sent to the College of Agriculture, Soil and Plant Analysis Laboratory – Central Mindanao University – Main Campus,

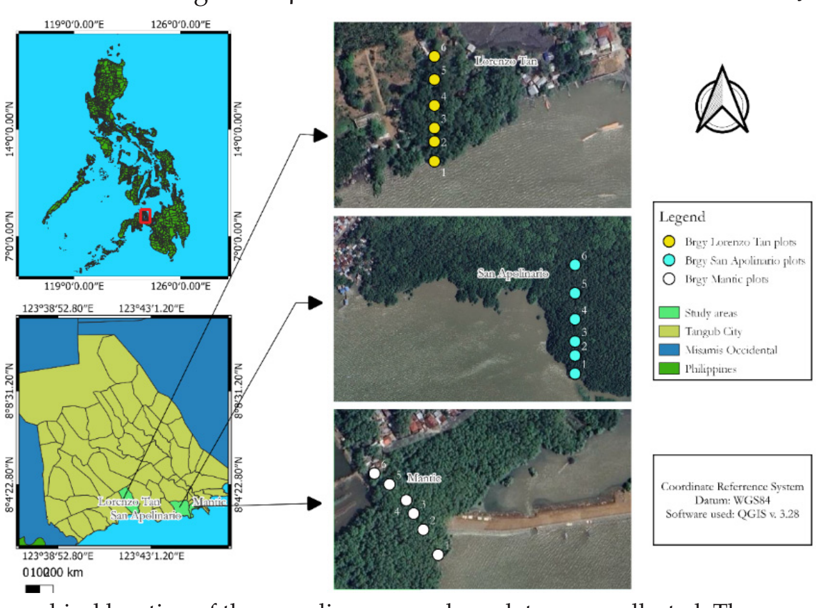

Fig. 1. Geographical location of the sampling areas where data were collected. The upper inset map is the map of the Philippines with Province of Misamis Occidental in red rectangle and the lower inset map is the map of Tangub City highlighting the study areas (Source: QGIS v. 3.28).

Bukidnon City for Soil Organic Carbon (SOC) Analysis. The soil carbon stocks in each layer was determined (Okolo *et al.*, 2023) as,

Eqn. 3.

$$SOC\ (Mg\ C\ ha^{-1}) = C \times T \times BD \times A$$

where C is organic carbon concentration (%), T is soil depth (m), BD is bulk density (kgm^{-3}) and A is area (ha).

Environmental factors

The environmental parameters such as salinity, relative humidity, water and soil pH, and air, water, and soil temperature were obtained from each plot per sampling site. Correspondingly, instruments used were refractometer, sling psychrometer, pH meter and laboratory thermometer.

Data Analysis

Canonical Correspondence Analysis (CCA) was used to determine the association between mangrove species abundance and microenvironment factors. This was performed using the PAST (Paleontological Statistics) Software version 4.03.

Results and Discussion

Mangrove species composition

A total of four mangrove tree species were recorded in the sampling areas namely, *Avicennia alba*, *Dolichandrone spathacea*, *Rhizophora apiculata*, and *Sonneratia alba* belonging to the families *Acanthaceae*, *Bignoniaceae*, *Rhizophoraceae*, and *Sonneratiaceae*, respectively (Table 1). *A. alba, R. apiculata*, and *S. alba* are common across all areas (Fig. 2) however, in Lorenzo Tan an additional species was identified, *D. spathacea*. Notably, appropriate zonation pattern is crucial for achieving higher survival rate of mangrove species. In San Apolinario, *A.alba* and *R.apiculata* were distributed at low-intertidal zone or fringing zone while *S.alba* were found at the fringing to intermediate zone. Meanwhile in Mantic, *R. apiculata* were observed at intermediate zone and *A. alba* and *S. alba* at fringing to intermediate zone. On the other hand, *A. alba*, *R. apiculata* and *S. alba* species were found at fringing –intermediate zone in Lorenzo Tan, whereas *D. spathacea* locally called as "tiwi" were observed between 75-90m from the mangrove ecotone, where saline water is stagnant. It can be gleaned that mangrove species in San Apolinario do not conform to the Philippine mangrove zonation pattern and few mangrove species in Mantic and Lorenzo Tan were also distributed outside from its usual zonation area. According to Kodikara mangroves generally grow optimally be-

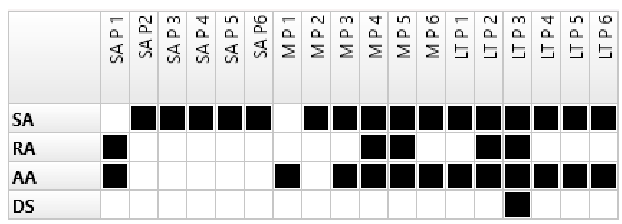

Fig. 2. Seriation analysis showing the mangrove tree species composition in the sampling areas.
Note: SA – Sonneratia alba, RA – Rhizophora apiculata, AA – Avicennia alba, DS – Dolichandrone spathacea

Table 1. Mangrove species Ecological status, Conservation status, and Distribution range in the sampling areas.

Family Name	Scientific Name	Local Name	Ecological Status	Conservation Status	Distribution DIS Range
Acanthaceae	*Avicennia alba*	Bungalon, Apiapi, Miapi	Non-endemic	Least Concern	Pacific; South East Asia; South and South West Asia (SSWA)
Bignoniaceae	*Dolichan dronespathacea*	Tiwi, Tui	Non-endemic	Least Concern	Pacific, South East Asia, South and South West Asia (SSWA)
Rhizophoraceae	*Rhizophora apiculata*	Bakhawlalaki	Non-endemic	Least Concern	East and North East Asia (ENEA); Pacific; South East Asia; South and South West Asia (SSWA)
Sonneratiaceae	*Sonneratia alba*	Pagatpat	Non-endemic	Least Concern	East and North East Asia (ENEA); Pacific; South East Asia; South and South West Asia (SSWA); East Africa; Southeastern Africa

Reference:Ecological Status and Distribution Range: Pelser *et al.*, 2011
**Conservation Status: IUCN, 2023

tween the 5–20 ppt, while the majority can survive under a salinity level of 35 ppt. In the sampling areas, the salinity ranges from 14 – 21 ppt, conducive for mangrove growth. Hence, comparable salinity values in the zones mangroves were found, characterized by frequent tidal inundation. Moreover, the mangrove species recorded were identified as not in danger of going extinct in the wild (IUCN, 2023). Nonetheless, conservation measures are still necessary, particularly when its population trend worldwide is decreasing.

Mangrove species carbon stock

Figure 3 illustrates the average carbon content of mangrove species where *A. alba* in Mantic emerged as the top-ranked species, exhibiting a mean value of 1.75 ± 0.30 Mg C ha^{-1}. This is attributed to the diameter at breast height (DBH) of the mangrove stands ranging from 1.59 – 40.76 cm and the wood density value of 0.506. Generally, larger trees with greater circumference store more biomass due to their larger volume and thus greater capacity for biomass accumulation (Harishma *et al.*, 2020). Likewise, mangrove species with higher wood density contribute more to the overall amount of biomass (Baker *et al.*, 2004). *S. alba* in San Apolinario followed closely with mean value of 0.98 ± 0.02 Mg C ha^{-1} and *R. apiculata* with 0.09 ± 0.04 Mg C ha^{-1}. *R. apiculata also* exhibited comparable carbon accumulation across sampling areas with values below 0.10 Mg C ha^{-1}. Results were ascribed to DBH among mangrove stands ranging from 1.27 – 4.78 cm determined as saplings. Lastly, *D. spathacea*, exclusively located in Lorenzo Tan, demonstrated the least

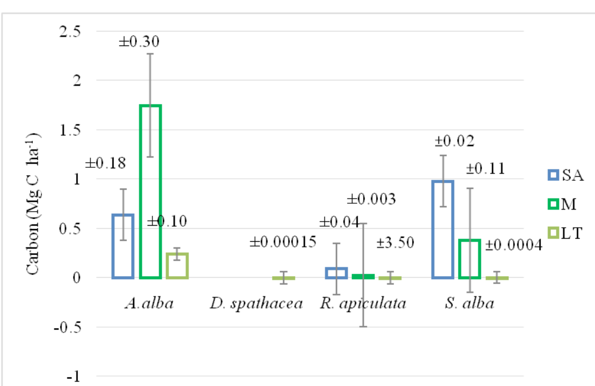

Fig. 3. Mean carbon of mangrove species in the sampling areas.
Note: SA – San Apolinario; M – Mantic; LT – Lorenzo Tan

mean carbon accumulation of .00025 ± 0.00015 Mg C ha^{-1}. Overall, the abundance of mangrove stands and the DBH observed within various mangrove species areas are significant factors influencing the average carbon content per individual in the sampling areas.

Soil Organic Carbon

Table 2 shows the overall soil organic carbon (SOC) revealing Mantic with highest value of 258.33 Mg C ha^{-1}. Significant contributors to SOC accumulation include the physicochemical parameters, vegetation, natural or human disturbances, and age of stands. In this study, the average soil pH was highest in Mantic followed by San Apolinario and Lorenzo Tan with values 7.25, 6.93 and 6.88, respectively. The soil temperature was also highest at Mantic with 26.5º C while the recorded soil pHs in all sampling areas were neutral. It was further observed that the mangrove canopy in Mantic allows more sunlight penetration influencing soil temperature and soil pH. Hence, the area recorded the highest SOC attributed to its high temperature and neutral pH. This is corroborated by Davidson and Janssens (2006) stating that warmer conditions enhance microbial activity, hastening decomposition and nutrient release thereby increasing SOC accumulation. Similarly, low to neutral pH promotes SOC accumulation (Malik *et al.*, 2018). Soil pH increases at a soil temperature ranging from 25°C – 39°C as a result of organic acid denaturation (Menzies *et al.*, 2003). Furthermore, vegetation type significantly influences biomass accumulation and decomposition rates, thereby affecting the input and output of SOC. Mantic was observed with more dense vegetation primarily composed of pneumatophores and seedlings. As reported by Alongi *et al.* (2014), vegetated areas promote higher SOC because mangroves have yielded a large amount of litter and fine roots, which enter the soil and slowly decompose under hypoxic conditions. Furthermore, Mantic and Lorenzo Tan display SOC variations at certain plots suggesting potential human disturbances. Specifically, there is a direct correlation where SOC increases with soil depth, except for plot 4 in Mantic and plot 2 at Lorenzo Tan where SOC decreases (Table 2). In these areas, human-induced activities were observed like cutting of mangroves use for certain fishing activities and improper waste disposal. On the contrary, the findings suggest an inverse correlation between SOC and soil depth in San Apolinario. This could be attributed to the younger stands present, where young mangroves have a few roots that can only hold less sediment than mature mangroves.

Total carbon stock

Table 3 presents the average carbon stock of the three mangrove ecosystems accounting to 360.72 Mg C ha^{-1} The assessment is divided into above-ground (107.29 Mg C ha^{-1}), below- ground C (31.28 Mg C ha^{-1}) and 222.15 Mg C ha^{-1} in soil C. The significant amount of the ecosystem pool is observed in SOC at up to 100 cm depth. The total carbon stock was particularly highest in Mantic with 404.57 Mg C ha^{-1} where the area is situated near and along creek banks. Soil got the highest carbon storage with 63.85% while only 27.93% is mounted up in aboveground; these results are in parallel to the studies of Murdiyarso *et al.* (2015) and Chen *et al*. (2017). Comparably, Lorenzo Tan recorded the highest carbon in soil with 58.94%, 32.11% was attributed to aboveground and 8.95% to belowground with 358.25 Mg C ha^{-1}. San Apolinario recorded the lowest total carbon with 319.33 Mg C ha^{-1} primarily due to the presence of younger mangrove stands that directly affect its biomass and soil C accumulation, as smaller trees have correspondingly smaller roots. According to Krauss *et al.* (2023) the biological root structure of mangrove species are effective at trapping organic sediments and study of Taillarda *et al*. (2018) revealed that ageing forests have higher carbon reserves in the soil, above and belowground biomass, and forest ecosystem.

Microenvironment preference

Figure 4 illustrates the association between mangrove species and physicochemical components. At the top left corner, *R. apiculata* are species found at ecotypes with high relative humidity of 92% recorded in San Apolinario. The area has been observed with denser canopy cover than Lorenzo Tan and Mantic. The study of Raganas and Magcale-Macandog (2020) proves that *R. mucronata* which also belongs to the family of *Rhizophoraceae*, are the species identified within ecotypes exhibiting high relative humidity. Meanwhile, *S. alba* as depicted in bottom left corner, are found adapted to high water salinity ecotype with 19.67 as recorded in San Apolinario. Across sampling areas, *S. alba* exhibited the highest occurrence making it the most prevalent among the recorded stands. In the Philippines, *S. alba* is one of the mangrove species considered with high salinity (Primavera *et al.,* 2011). Moreover, the specialized respiratory aerial roots of *Sonneratia* are more adapted to highly saline habitat (Srikanth *et al.,* 2015). On the other hand, *D. spathacea* displays high air and soil temperature preference as recorded in

Table 2. Soil Organic Carbon (SOC) in the selected coastal barangays of Tangub City

	San Apolinario		Mantic		Lorenzo Tan	
Plot	0 – 50 cm	50 - 100 cm	0 – 50 cm	50 - 100 cm	0 – 50 cm	50 - 100 cm
1	107.01	98.79	52.83	75.46	89.18	124.83
2	109.47	78.20	46.93	67.77	122.92	57.62
3	109.07	90.90	58.86	79.23	70.09	86.29
4	92.6	89.17	187.26	124.83	98.09	101.86
5	96.03	61.75	112.00	243.53	104.61	209.23
6	127.72	121.01	190.13	311.16	45.96	156.28
Average Soil Carbon	106.98	89.97	108.00	150.33	88.48	122.69
Total Carbon (MgC ha^{-1})	196.95 ± 12.41		258.33 ± 64.13		211.16 ± 22.13	

Table 3. Total carbon storage of mangrove ecosystem in the selected coastal barangays of Tangub City.
City.

Area	AbovegroundC (Mg C ha^{-1})	BelowgroundC (Mg C ha^{-1})	SoilC (MgC ha^{-1})	Total carbon (Mg C ha^{-1})
San Apolinario	93.83(29.38%)	28.55(8.94%)	196.95(61.68%)	319.33
Mantic	113.01(27.93%)	33.23(8.21%)	258.33(63.85%)	404.57
Lorenzo Tan	115.04(32.11%)	32.05(8.95%)	211.16(58.94%)	358.25
Average carbon by pool (MgC ha^{-1})	107.29 (29.74%)	31.28(8.67%)	222.15(61.58%)	360.72

Lorenzo Tan with 26.07 °C and 25.98 °C, respectively. Results were possibly attributed to sparse canopy sallowing more sunlight penetration in the area consequently delevating soil, air and water temperature. Moreover, *A. alba* species found at the bottom right corner have high tolerance to water and soil temperature and pH. Mantic notably has the widest open canopy cover among the sampled areas, hence, high water and soil temperature. Similarly, human and domestic animal wastes were more evident in the area influencing pH levels. And fish feeding in nearby ponds are presumed to contain chemicals possibly affecting pH levels.

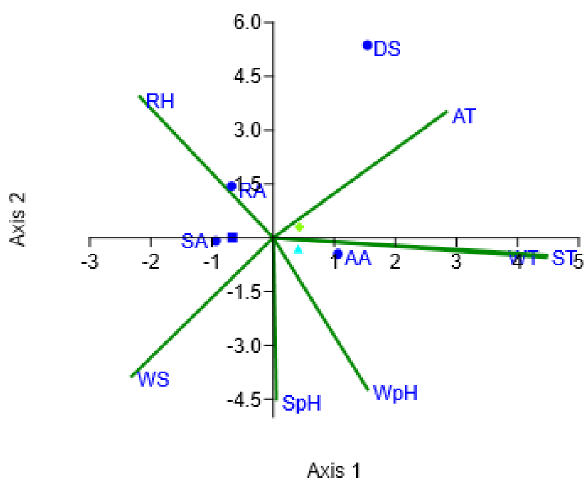

Fig. 4. Microenvironment preferences of mangrove species in the selected coastal barangays of Tangub City.

Note: RA -Rhizophora apiculata, SA - Sonneratia alba, AA - Avicenna alba, DS - Dolichnadrone spathacea. Variables: RH - Relative humidity, WS - Water salinity, SpH -Soil pH, WpH, Water pH, WT -Water temperature, ST - Soil temperature, AT – Air temperature. Legends for the sampling areas; San Apolinario, Lorenzo Tan and Mantic

Conclusion

In this study, four mangrove species were identified in the sampling areas namely: *Avicennia alba*, *Dolichandrone spathacea*, *Rhizophora apiculata*, and *Sonneratia alba*. Species *A. alba* exhibits the highest carbon mean value due to the notable diameter at breast height (DBH) range. The selected coastal areas accumulated an average carbon of 360.72 Mg C ha^{-1} with soil C recorded as the highest pool garnering an average of 222.15 Mg C ha^{-1}. Furthermore, mangrove species exhibits unique adaptations to various environmental factors, as *A. alba* preferred areas with high water and soil temperature and pH levels, *D. spathacea* was observed in areas with high air temperature, *R. apiculata* were found to thrive in ecotypes with high relative humidity, while *S. alba* showed tolerance to areas with high water salinity. With the mangrove species carbon sequestration potential, it is essential for policymakers and experts to conduct a capacity building workshops on the appropriate mangrove zonation pattern, carbon market principles and opportunities for community involvement. Likewise, it is recommended that local authority should implement comprehensive conservation measures and establish a mangrove protected area locally tailored to protect and sustain mangrove ecosystem.

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Conflict of Interest- None

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