



Pattern of Species Diversity and Carbon Stocks along the Intertidal Zones of Protected Mangrove Forest in Southern Philippines

Joseph C. Paquit and Ellen C. Vergara¹

Department of Forest Biological Sciences, College of Forestry and Environmental Science
Central Mindanao University, Musuan, Bukidnon, 8714 Philippines

¹Graduate School, Department of Wood Science and Technology, College of Forestry and Environmental Science
Central Mindanao University, Musuan, Bukidnon, 8714 Philippines
E-mail: jcpaquit@cmu.edu.ph

Abstract: This study examined the composition, structure, and carbon storage of the Pangasihang Mangrove Forest Reserve in the Philippines. The reserve, spanning 64 hectares, was established in the 1990s and comprises natural and planted mangrove species dominated by *Sonneratia alba*, *Avicennia marina* var. *rumphiana*, and *Rhizophora apiculata*. Sampling was conducted along three transects covering the tidal gradient, with three sampling plots established along each transect. Trees with a diameter at breast height (DBH) ≥ 5 cm were inventoried, and vegetation analysis was performed to determine species importance value, species richness, and diversity indices. Biomass estimation for carbon stock utilized published allometric equations and specific wood density values were applied. Carbon stock estimates were converted to CO₂ equivalents. Based on the result, the richness and abundance of mangrove species in the different intertidal zones is higher in the landward zone than in the seaward and middle ward zones. Species richness indices were 1.58, 1.00, and 3.37, while the diversity index is generally low at 1.57, 1.53, and 2.25 for seaward, middle ward, and landward, respectively. The carbon stocks from mangrove tree biomass in different intertidal zones were higher in the seaward region with computed values of 777, 422, and 488 t ha⁻¹ and carbon stock densities of 350, 190, and 219 t C ha⁻¹ for seaward, middle ward, and landward, respectively. This study generated valuable insights on which zone has higher species diversity and carbon stock, which could be helpful in the planning and management of the study area.

Keywords: Mangrove forest, Species richness and diversity, Carbon, Intertidal zones

The Philippines boasts a rich diversity of mangrove species, with around 42 species from 18 families, making it one of the most diverse in the world (Samson and Rollon 2011). This starkly contrasts North and Central America, which have a mere ten species (Abantao et al 2015). Most mangrove areas are situated in the southern part of the archipelago, particularly in Mindanao, Samar, and Palawan to the west. In 1918, the Philippines had an estimated 500,000 hectares of mangrove forest, but by 1994-1995, this had dwindled to 100,000 hectares (Primavera 2000). However, according to the 2011 Philippine Forestry Statistics, citing 2003 data, the total mangrove area was reported at 247,362 hectares, showing an increase since 1995 (DENR-FMB 2011).

Mangroves play a crucial role in coastal ecosystems, providing essential nursery habitat for numerous species and acting as natural barriers against storm damage and coastal erosion. In addition to their well-known ecological and economic benefits, coastal ecosystems are increasingly valued for their ability to store and sequester carbon. Blue carbon refers to the carbon stored in coastal systems such as mangroves, seagrasses, and salt marshes, with the majority found in the tropics (Siikamaki et al 2013). According to Donato et al (2011), cited by Castillo et al (2018), mangroves are

among the most carbon-dense tropical forests, storing three to five times more carbon than terrestrial forests. Their ability to trap suspended matter and associated organic carbon during tidal inundation further enhances their contribution to long-term carbon sequestration (Mcleod et al 2011). Despite their significant ecological importance, mangrove forests face a severe threat from deforestation. In Southeast Asia and the Philippines, the rapid expansion of aquaculture development is the leading cause of mangrove forest loss (Cañizares and Seronay 2016). In the Philippines, brackish-water pond development alone accounts for approximately 50% of estimated mangrove deforestation. This loss of mangrove forests contributes to a substantial reduction in forest biomass and significantly adds to the alarming concentration of CO₂ in the atmosphere (Abino et al 2014).

Several studies from different parts of the world have highlighted the ecological significance of mangrove forests and their role in carbon sequestration. A survey conducted in the Labuhan mangrove forest in Indonesia by Asadi et al (2018) revealed a substantial carbon storage capacity of 74.70 t C ha⁻¹, with an equivalent CO₂ sequestration potential of 274.15 t ha⁻¹. The dominance of *R. apiculata* underscores its ecological importance in carbon sequestration. Similarly, a study in the Kanhlyashay natural mangrove forest in

Myanmar found that the mean biomass of the mangrove stand was 335.55 t ha^{-1} , with aboveground biomass (AGB) at 241.37 t ha^{-1} and below-ground biomass (BGB) at 94.17 t ha^{-1} while the mean carbon stock was $150.25 \text{ t C ha}^{-1}$. This underscores the significant carbon storage potential of the forest, emphasizing the importance of sustainable management to maintain and enhance carbon storage. Despite the low species diversity, *Avicennia officinalis* is dominant and displays high adaptive abilities, suggesting its suitability for afforestation efforts on mudflats due to its tolerance to increased salinity. Proper forest management is essential for preserving carbon sequestration capacity (Cañizares and Seronay 2016).

Despite the numerous studies conducted worldwide on mangrove identification and diversity, more information on species composition and diversity studies of mangroves from various parts of the Philippines is needed. Understanding the mangrove species is crucial for ecological assessment and matching sites with suitable species for reforestation and forest protection. This approach can enhance survival rates, unlike past efforts where success was limited due to incorrect site or species selection (Baleta and Casalamitao 2016). Therefore, assessing the remaining mangrove forest is essential for preserving and protecting the ecosystem in the Philippines (Cañizares and Seronay 2016). Despite their ecological significance, mangrove forests are threatened by deforestation driven by aquaculture development, resulting in substantial loss of forest biomass and exacerbating atmospheric CO_2 concentrations. This study is crucial for informed conservation and management efforts, providing valuable insights to guide strategies for preserving and protecting mangrove forests and upholding their ecological functions and benefits. Meanwhile, there is little precise knowledge about the amount of biomass and carbon sequestration and storage in this coastal vegetation (Abino et al 2014). Therefore, this study aims to assess species diversity and biomass and estimate the carbon sequestration potential of a natural mangrove stand in Pangasihang, Gingoog City, Misamis Oriental, Philippines.

MATERIAL AND METHODS

Study area: The Pangasihang Mangrove Forest Reserve, located at the geographic coordinates between $125^{\circ}10'$ longitude and $8^{\circ}51'$ latitude, falls within climatic type III. The area experiences distinct wet and dry seasons, with the dry period from November to April and higher rainfall from May to October, averaging 1,500 to 2,500 millimeters annually. The temperatures range from 25°C to 32°C throughout the year, with occasional tropical cyclones during the wet season bringing heavy rain and strong winds (DENR 2019). This 64-

hectare mangrove reforestation was initiated in the 1990s, combining natural and planted mangrove species, mainly *Sonneratia alba*, *Avicennia marina* var. *rumphiana*, and *Rhizophora apiculata*. The soil in the area is hydrosol, which is ideal for fishpond and mangrove development. Nipa and mangrove forests dominate this area, characterized by rocky, muddy, and sandy substrate. The site can be categorized into closed and open canopy mangrove forests. The closed canopy ones are dense and intact, located far from human developments, while the open canopy features more dispersed vegetation, creating varied microclimates and essential roles in coastal ecosystems.

Sampling procedure: In setting up sampling plots in the study, three transects were established to cover the natural tidal gradient: near the sea (seaward), in the middle/middle ward, and near the land/upstream (landward) (Kauffman and Donato 2012; Castillo et al 2018). The seaward transects began approximately 15m - 20m from the interface between the mangroves and the sea. Three 10m x 20m (200m²) sampling plots were established for each transect, spaced 50m apart. Geographic coordinates were recorded for each plot. In each plot, the species name of each tree was recorded, and the diameter at breast height (DBH) was measured 1.3 m from the ground or 30 cm above the highest prop root for stilt-rooted species. All mangroves within the plots with a DBH of $\geq 5\text{cm}$ were inventoried, while vegetation with less than 5cm was not included in the sampling. This measurement standard is used for assessing species diversity and carbon stock, ensuring consistency, precise above-ground biomass estimation, and minimal ecosystem disturbance (Abino et al 2014). This approach aligns with established protocols for accurate and comparable research findings, as Aye et al (2022) and Abino et al (2014) suggested. An inventory form was completed, including the species name (common, scientific, and family name) and the DBH of each tree. The species were identified by CENRO Gingoog City personnel and further verified through intensive reviews of relevant field guides.

Estimation of importance value: Vegetation analysis employing various ecological parameters was utilized to ascertain the density (D), relative density (RD), frequency (F), relative frequency (RF), dominance (D), relative dominance (RD), and the species importance value (SIV) within the area. The computed importance value aided in identifying the dominant species within the area (Table 1).

Species richness and diversity: Four distinct diversity indices-Margalef's, Shannon H's, Pielou's J, and Jaccard's-were calculated using a custom Microsoft Excel template designed for this specific purpose. The template efficiently computed the desired output values (Table 2).

Estimation of carbon stock in tree biomass: Survey was conducted to assess species richness and estimate biomass. Since specific allometric equations for the study site or Philippine mangroves were unavailable, we utilized published allometric equations to calculate each tree's aboveground and belowground biomass. For aboveground biomass (AGB) and belowground biomass (BGB) of mangroves, we used species/genus-specific equations; otherwise, we used the ordinary allometric equation developed by Komiyama et al (2005). The species-specific wood density values for some mangrove species and genera in the Philippines were used. Species without available wood density data relied on information from published literature, such as the compilation by Howard et al (2014). The biomass allometric equations and their corresponding wood density values (Table 3).

The quantitative carbon stock estimates in mangrove forests were derived from aboveground biomass (AGB) and belowground biomass (BGB). The biomass content was determined using a standard value of 45%, representing the average carbon content found in tree biomass and root biomass density of tree species in forests (Lasco and Pulhin 2000). To convert AGB and BGB data to their respective carbon (C) stock equivalents, the values were multiplied by 48% and 39%, as recommended by Kauffman and Donato (2012) as cited by Castillo et al (2018). The combined C stocks of AGB and BGB, referred to as tree C stock, were

calculated to assess the tree C stock per plot, then averaged per site and zone to obtain the mean tree C stock. These generated values were then transformed into CO₂-equivalents (CO₂) by multiplying the C stocks by 3.67, based on the methods of Pendleton et al (2012) and Castillo et al (2018). Additionally, the basal area of each tree was computed using the formula $0.7854 * (dbh)^2$, and the results were summed together per plot.

RESULTS AND DISCUSSION

Species composition, importance value, and ecological status: The study area was home to 420 individual trees and 20 mangrove species from ten genera and eight families (Table 4). Compared to the other two zones, the landward zone exhibited a higher diversity of families, genera, and species. Interestingly, despite the

Table 2. Different species diversity indices used in the study (Magurran 2004)

Index	Measures of diversity	Equation
Margalef's	Species richness	$Da = \left[\frac{S-1}{(\ln N)} \right]$
Shannon H'	Species diversity-evenness	$H' = \left[- \sum (Pi \times \ln Pi) \right]$
Pielou's J	Species diversity-evenness	$J' = \left[\frac{H'}{\ln(S)} \right]$
Jaccard	Community similarity/dissimilarity	$SJ = \left[\frac{a}{(a+b+c)} \right]$

Table 1. Vegetative analysis formula used in the study

Parameter	Formula	Description
Density $\left(\frac{trees}{ha} \right)$	$D = \frac{total\ no.\ of\ individuals\ of\ a\ species}{total\ area\ sampled\ in\ m^2 \times \frac{1\ ha}{10000m^2}}$	These were used to determine the number of individual trees per unit area.
Relative Density	$RD = \frac{density\ of\ a\ species}{total\ density\ of\ all\ species} \times 100$	These were used to compute the number of trees between two areas of equal size.
Frequency	$F = \frac{no.\ of\ quadrant\ in\ which\ species\ A\ occurs}{total\ no.\ of\ quadrant\ examined}$	These were used to determine the probability of finding the species in any quadrant.
Relative Frequency	$RF = \left(\frac{frequency\ value\ of\ species\ A}{total\ frequency\ value\ of\ all\ species} \right) \times 100$	These were used to compare the numerical frequency of one species to the total frequency of all species.
Dominance $\left(\frac{m^2}{ha} \right)$	$C = \frac{area\ covered\ by\ a\ species}{sum\ of\ all\ plot\ areas}$	These were used to determine the species that exert a major controlling influence on the community by virtue of size or number.
Relative Dominance	$RC = \frac{dominance\ value\ of\ species}{total\ dominance\ value\ of\ species} \times 100$	The data on the number of individuals per species and the total number of all species were used.
Species Importance Value (SIV)	$SIV = \left(\frac{RD + RF + RC}{3} \right)$	Were used to reveal what species are dominant in the area.

greater diversity, the landward zone had fewer trees and a smaller basal area. This suggests that human activities may have led to greater disturbance in the landward zone.

Rhizophora apiculata (Rhizophoraceae) was the most common tree species across the three zones, with 116 out of 420 (28%) individual trees sampled. The greatest SIV value (22.96), indicative of its high importance as a component

species in the study, was also observed in the study area. The top three most common tree species across the zonation are *R. apiculata*, *Sonneratia alba*, and *R. stylosa*, respectively. These three species are the only four, including *R. mucronata*, which appeared in each zone. Meanwhile, *Excoecaria agallocha*, *Heritiera littoralis*, *Hibiscus tiliaceus*, *Bruguiera cylindrica*, and *Xylocarpus moluccensis* were the

Table 3. Biomass allometric equations and wood density values used by Komiyama et al (2005)

Species	Above ground	Below ground	Source	Wood density (g cm ⁻³)
<i>Avicennia marina</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.71 ^a
<i>A.officinalis</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.71 ^a
<i>Bruguiera cylindrica</i>	Biomass (kg) = $0.186 \cdot \rho \cdot D^{2.31}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Clough and Scott (1989)	0.85 ^b
<i>B. gymnorrhiza</i>	Biomass (kg) = $0.186 \cdot \rho \cdot D^{2.31}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Clough and Scott (1989)	0.85 ^b
<i>B. parviflora</i>	Biomass (kg) = $0.168 \cdot \rho \cdot D^{2.42}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Clough and Scott (1989)	0.89 ^b
<i>B. sexangula</i>	Biomass (kg) = $0.168 \cdot \rho \cdot D^{2.42}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Clough and Scott (1989)	0.87 ^b
<i>Ceriops decandra</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.89 ^b
<i>C. tagal</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.89 ^b
<i>Excoecaria agallocha</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.71 ^a
<i>Heritiera littoralis</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.84 ^a
<i>Hibiscus tiliaceus</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.71 ^a
<i>Lumnitzera littorea</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.71 ^a
<i>L. racemosa</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.71 ^a
<i>Rhizophora apiculata</i>	Biomass (kg) = $0.235 \cdot \rho \cdot D^{2.42}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Ong et al (2004)	1.04 ^a
<i>R. mucronata</i>	Biomass (kg) = $0.235 \cdot \rho \cdot D^{2.42}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Ong et al (2004)	0.98 ^b
<i>R. stylosa</i>	Biomass (kg) = $0.235 \cdot \rho \cdot D^{2.42}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Ong et al (2004)	0.98 ^b
<i>Sonneratia alba</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.83 ^b
<i>S. caseolaris</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.83 ^b
<i>Xylocarpus moluccensis</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.66 ^b
<i>X. granatum</i>	Biomass (kg) = $0.251 \cdot \rho \cdot D^{2.46}$	Biomass (kg) = $0.199 \cdot \rho^{0.899} D^{2.22}$	Komiyama et al (2005)	0.66 ^b

Table 4. Dendrological characteristics of the site

Zone	No. of family	No. of genera	No. of species	No. of trees	Mean DBH (cm)	Basal area (m ² /ha)
Seaward	4	5	9	157	16.39	77.27
Middleward	3	4	6	148	11.19	67.44
Landward	8	10	17	115	13.86	30.75
Mean	5	6	11	140	13.81	58.49
Total	8	10	20	420	41.44	175.46

least frequent species with only one individual tree in the entire area. The mangrove forests at the study site are dominated by *Rhizophora spp.* This is comparable to the study by Castillo et al (2018) in Honda Bay, Palawan, and that of Cañizares and Seronay (2016) in Barangay Imelda, Dinagat Island, Philippines. *Avicennia marina* is also the top species found in the area, comparable to the study by Pototan et al (2017) of the three municipalities in Davao del Norte. In terms of conservation status, most of the species collected were classified as “least concern” except *Ceriops decandra*, which has been categorized as near-threatened, and *Bruguiera gymnorrhiza*, *Hibiscus tiliaceus*, *Bruguiera sexangula* as not assessed by IUCN (Table 5).

Species richness, diversity, and evenness: The landward zone exhibited the highest species richness index value (3.37) among the three zones (Fig. 1). Seventeen mangrove species were documented in the landward zone, surpassing the 1.58 and 1.0 recorded for the seaward and middle ward zones, respectively. The richness index is higher in the landward zone due to the more significant number of species. Despite having fewer individuals than the seaward zone, the landward zone also achieved the highest diversity index value. This highlights that, although the zones are relatively similar in abundance, the landward zone's more significant

variety of species results in higher diversity. Richness measures do not differentiate among species and account for all species equally, including the rare ones (Magurran 2004).

The diversity and prevalence of mangrove species in intertidal zones are believed to be shaped by factors like tides, salinity levels, and human impact. The distribution and zonation pattern of mangroves is primarily influenced by the geographical location, tidal flooding, and freshwater inflow (Sreelekshmi et al 2018). Coastal areas closer to the sea are subject to more frequent tidal inundation, leading to the prevalence of species that can endure saltwater submersion. The genus *Rhizophora*, in particular, demonstrates a relatively high tolerance to salt (Hogarth 2015), which accounts for its widespread presence in these areas. On the other hand, areas further inland may experience less frequent saltwater inundation, allowing for a greater diversity of species, particularly those with lower salt tolerance, such as those belonging to the genus *Bruguiera* and *Sonneratia* (Hogarth 2015). Kodikara et al (2017) also revealed that *R. mucronata* exhibited the highest survival rate among tested mangrove species under varying salinity levels. This finding supports the widespread occurrence of this species across the three zones studied.

Biomass and carbon stock: The biomass density of the

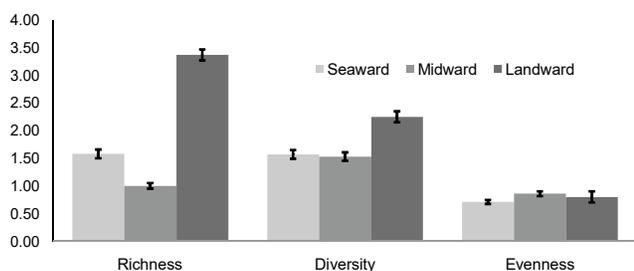
Table 5. SIV and ecological status of species

Species	Seaward	Middleward	Landward	SIV	Ecological status
<i>Rhizophora apiculata</i>	/	/	/	22.96	LC
<i>Sonneratia alba</i>	/	/	/	21.62	LC
<i>Avicennia marina</i>	/	/	/	12.49	NT
<i>Rhizophora stylosa</i>	/			11.65	LC
<i>Avicennia officinalis</i>		/	/	7.29	LC
<i>Rhizophora mucronata</i>	/	/	/	7.09	LC
<i>Lumnitzera littorea</i>	/		/	4.15	LC
<i>Ceriops decandra</i>		/	/	2.11	LC
<i>Bruguiera parviflora</i>	/			1.69	LC
<i>Bruguiera gymnorrhiza</i>	/			1.51	NA
<i>Lumnitzera racemosa</i>	/		/	1.44	LC
<i>Ceriops tagal</i>			/	1.13	LC
<i>Xylocarpus granatum</i>			/	1.06	LC
<i>Sonneratia caseolaris</i>			/	0.64	LC
<i>Bruguiera sexangula</i>			/	0.61	NA
<i>Hibiscus tiliaceus</i>			/	0.52	NA
<i>Excoecaria agallocha</i>			/	0.52	LC
<i>Xylocarpus moluccensis</i>			/	0.52	LC
<i>Bruguiera cylindrica</i>			/	0.51	LC
<i>Heritiera littoralis</i>			/	0.51	LC

Legend: / - Presence in zone NT- Near-threatened, LC – Least concern, NA- Not assessed

Table 6. Biomass and C stock of different zones

Zone	Tree biomass density	ABG C stock density	BGB C stock density	Tree C stock density
Seaward	777	673	104	350
Middleward	422	359	63	190
Landward	488	418	70	219
Mean	488	483	79	253

**Fig. 2.** Variation in species richness, diversity, and evenness indices among zones

computed tree for seaward, middle ward, and landward areas were 777 t ha⁻¹, 422 t ha⁻¹, and 488 t ha⁻¹, respectively. In addition, the carbon stock density for seaward, middle ward, and landward areas were 350 t C ha⁻¹, 190 t C ha⁻¹, and 219 t C ha⁻¹ (Table 6).

The findings indicate that the natural mangrove forest in Pangasihian, Gingoog City, and the mangrove forest in Botoc, Pinabacdao, Samar, are comparable and have the potential to store as much as 350 tons of carbon per hectare, despite having lower species diversity. This estimated value is similar to the average carbon storage of Philippine mangroves, as Lasco and Pulhin (2004) reported. The Seaward zone showed higher carbon stock despite its lower diversity. This demonstrates that carbon storage varies significantly within different areas of the forest. Consequently, there are cases where forests with high species diversity may not be rich in carbon, and vice versa. This suggests there may be trade-offs between carbon and biodiversity conservation (Lawton et al 1998, Heino et al 2009).

Mangrove forests face a critical threat from climate change, particularly sea-level rise. Therefore, it is crucial to develop sustainable funding and effective incentive systems that support mangrove conservation and coastal communities' well-being. Promising options for achieving this balance include Payments for Ecosystem Services (PES) and the Blue Carbon Fund, similar to REDD (Reducing Emissions from Deforestation and Forest Degradation) but focusing on carbon sequestration in coastal areas. Additionally, it is essential to conduct further research to develop a biomass equation applicable to different Philippine mangrove species and wide diameter at breast height (DBH)

classes. Having site- and species-specific allometric equations will improve the accuracy of current biomass estimates for mangroves, which is crucial for initiatives like carbon trading. This aligns with the study conducted by Abino et al (2014) and is consistent with the average carbon storage of Philippine mangroves as determined by Lasco and Pulhin (2004).

CONCLUSION

The study revealed that the richness and abundance of mangrove species in the various intertidal zones are higher in the landward zone compared to the other two zones. Carbon stocks from mangrove tree biomass in different intertidal zones were highest in the seaward region, and carbon stock densities for seaward, middle ward, and landward zones. This indicates that these zones may exhibit differences in ecosystem productivity, carbon storage, and sequestration capacity. This underscores the importance of understanding and preserving mangrove habitats across their intertidal gradient for effective coastal management and carbon storage strategies.

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