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Assessing Diversity, Carbon Stock Quantification and Economic Valuation of Mangrove Forest along the Coastal Areas of Davao Oriental, Philippines

Cresencio C. Cabuga Jr. ^{1,2,*}, Rylle G. Añuber ^{1,3}, Mark John T. Pepito ^{1,4}, Arizza Joy Tan-Evardone ^{1,5}, Blenah O. Perez ^{1,5}, Orlan G. Celestial ^{1,6}, Sheryl C. Patiño ^{1,7}, Lea B. Jimenez ⁸ and Emily S. Antonio ⁸

¹ PhD Biology Program, Faculty of International and Advanced Studies, Davao Oriental State University, City of Mati 8200, Philippines

² Department of General Education, Caraga State University, Cabadbaran City 8605, Philippines

³ College of Forestry and Environmental Studies, Mindanao State University–Maguindanao, Datu Odin Sinsuat 9601, Philippines

⁴ Coleoptera Research Center, University of Mindanao, Davao City 8021, Philippines

⁵ College of Science, University of Eastern Philippines, University Town, Catarman 6400, Philippines

⁶ Department of Biology, Tagum Doctors College Inc., Tagum City 8100, Philippines

⁷ College of Teacher Education, Northeastern Mindanao State University–Tagbina Campus, Tagbina, Surigao del Sur 8308, Philippines

⁸ Faculty of International and Advanced Studies, Davao Oriental State University, City of Mati 8200, Philippines

* Correspondence: cccabuga@csucc.edu.ph

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Abstract: This study assessed the diversity, aboveground carbon stock, and economic value of mangrove forests along the coastal areas of Davao Oriental, Philippines. Field-based mangrove inventories were conducted using three 100-m transects comprising 20 plots and a total sampled area of 2000 m². The sampling was intended to characterize the mangrove community at the assessed field sites and is not treated as statistically representative of all mangrove forests in the province. Remote sensing using the Mangrove Vegetation Index (MVI) and Landsat 8 imagery was used to delineate mangrove extent. The mangrove community comprised seven species and had a Shannon–Wiener diversity index (H') of 1.65 and Pielou's evenness index (J') of 0.85, indicating moderate diversity and relatively high evenness. *Sonneratia alba* was the most abundant and structurally dominant species and contributed 12,908.43 kg (88.86%) of the estimated 14,524.63 kg aboveground carbon stock in the sampled plots. The current GIS output indicates a total mapped mangrove extent of 3065.82 ha; however, municipal-level values require verification against the original GIS zonal-statistics output before publication. The field-based carbon estimate was not extrapolated to the remotely sensed provincial extent. Using an assumed conservative carbon-market scenario of US\$5 tCO₂e⁻¹ and a social-cost scenario of US\$51 tCO₂e⁻¹, the sampled carbon stock was valued at US\$266.45 and US\$2717.79, respectively. The findings highlight the ecological and socioeconomic importance of mangroves for biodiversity conservation, carbon storage, fisheries, coastal protection, and local livelihood support.

Keywords: Blue carbon; livelihood; marine ecosystem; Mindanao



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1. Introduction

The Philippines supports a high diversity of mangrove species and mangrove forests provide habitat for invertebrates, fish, and other coastal organisms. Mangroves also contribute to nutrient cycling, sediment retention, erosion mitigation, shoreline protection, nursery habitat, fisheries, and carbon sequestration. Despite these functions, mangrove ecosystems remain exposed to land-use change and other anthropogenic pressures, including aquaculture development and deforestation. Recent Philippine studies continue to document variation in mangrove composition and disturbance among coastal sites, demonstrating the importance of site-specific assessment and monitoring (Pototan et al., 2021; Emeterio et al., 2024; Lillo et al., 2024). Such pressures may reduce habitat complexity and ecosystem functions even where mangrove cover remains present.

Mangrove condition is also relevant to ecosystem resilience. A community with several co-occurring species and relatively even abundance may retain a broader set of functional responses to environmental variability, although diversity metrics alone cannot establish resilience or long-term ecological stability. Conversely, continued deforestation, conversion to aquaculture, shoreline modification, and other disturbances can simplify stand structure and reduce the capacity of mangroves to recover from storms, sea-level rise, and other climatic pressures. Accordingly, assessment of species composition should be considered together with forest extent, structural dominance, carbon storage, and the socioeconomic functions that mangroves provide to coastal communities.

Moreover, mangrove forests in the Philippines once spanned approximately 400,000 to 500,000 hectares in the 1920s, but by 1994, this coverage had decreased significantly to about 120,000 hectares (Chapman, 1983; Brown and Fischer, 1920; Primavera, 2005). The decline could be linked to excessive exploitation by coastal residents and conversion for agriculture, salt flats, industry, and habitation (Primavera, 2000). This loss led to a notable reduction in mangrove ecosystem services, such as fish production and carbon storage. A study indicates that the similar reduction in mangrove regions in the Philippines and output from coastal municipal fisheries stands in contrast to the rise in brackish water pond areas and the contribution of aquaculture to overall fish production (Primavera, 1997).

Mangrove ecosystems offer a diverse range of ecohydrographic functions, including nutrient recycling, erosion mitigation, sediment retention, wildlife habitat provision, nurseries for fish and invertebrates, and resources for fisheries and forestry (Robertson et al., 1992; Hogarth, 2015; Kathiresan and Bingham, 2001; Saenger, 2002; Harborne et al., 2006). It protects the coast from wave attenuation; this has been a known function of mangroves (Mazda et al., 1997, 2006; Massel et al., 1999). While it is known that this ecosystem is known to protect from typhoons and, thus, reduce the impact (Williams et al., 2014; Das and Vincent, 2009; Salmo et al., 2017). Nevertheless, mangroves facilitate carbon sequestration and climate regulation. These unique forests, called “friends of the climate”, store over 1000 tons of carbon per hectare, more than most terrestrial forests (Donato et al., 2011).

Nonetheless, despite their ecological and socioeconomic significance, mangrove forests in the Philippines face severe threats, primarily due to widespread deforestation. One of the major pressures of mangrove loss in Southeast Asia, including the country, is the rapid expansion of aquaculture, particularly brackish-water pond development (Dodd and Ong 2008). Approximately 50% of mangrove deforestation in the Philippines has been directly attributed to converting mangrove areas into aquaculture ponds (Primavera, 1995). Although conservation initiatives and localized reforestation efforts have been implemented, mangrove degradation remains a pressing concern and is expected to persist (Samson and Rollon 2008). Therefore, this study aimed to (i) assess mangrove diversity in the assessed coastal areas of Davao Oriental, (ii) estimate mangrove forest cover using the Mangrove Vegetation Index (MVI), (iii) estimate aboveground carbon stock from the field inventory, and (iv) estimate the economic value of the sampled carbon stock using market-value and social-cost scenarios.

2. Materials and Methods

2.1. Location of the Study Area and Line Transect Plot Sampling

This study was conducted in Davao Oriental, Philippines (Figure 1). Three 100-m-long transects were laid out perpendicular to the mangrove forest, yielding 20 plots and a total sampled area of 2000 m². Mangrove individuals within the plots were identified and counted using the field guide for Philippine mangroves (Primavera et al., 2004). The 20 plots were used to characterize the mangrove community and provide field-based measurements for the sampled sites. Because the field inventory covered only 2000 m² and was concentrated in three transects, the design is considered site-level rather than a province-wide

probability sample. Consequently, the resulting diversity and carbon estimates are interpreted for the sampled mangrove stands and are not assumed to represent the entire mangrove area of Davao Oriental. Broader province-level inference would require additional stratified sampling across municipalities, habitat types, disturbance gradients, and mangrove zones.

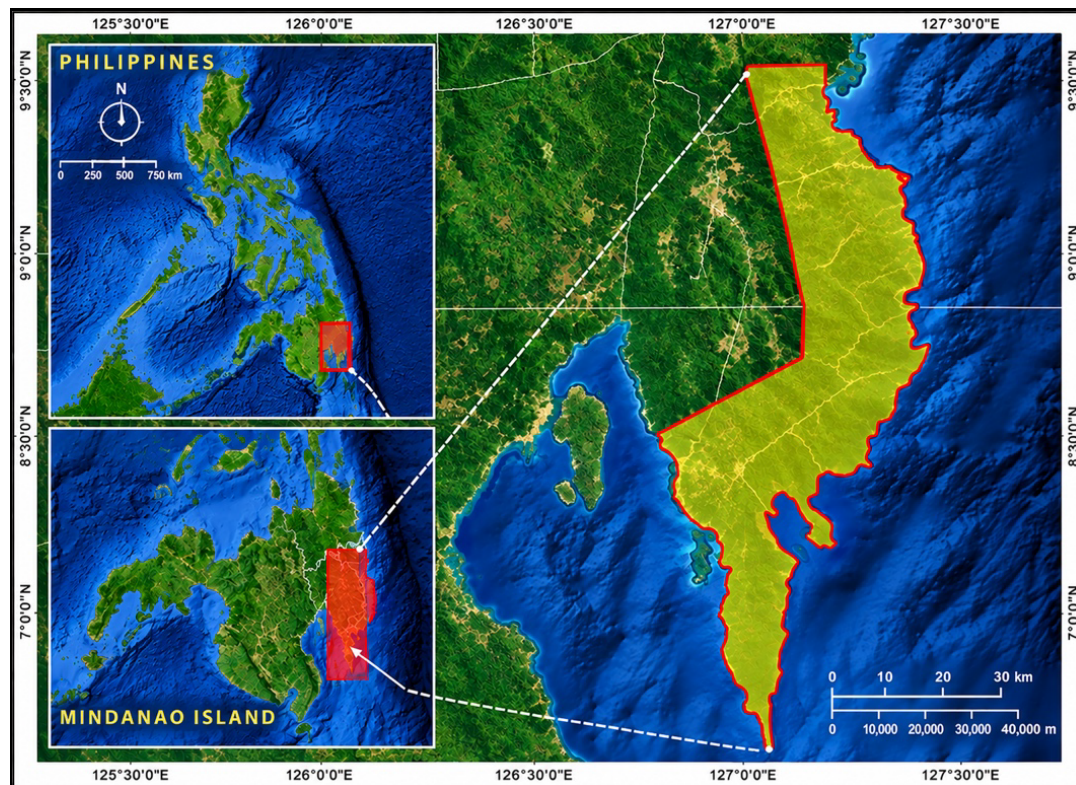


Figure 1. Location Map of the Study Area, Davao Oriental, Philippines.

2.2. Diversity Analysis

Species richness (S) was calculated as the number of species recorded. The Shannon–Wiener diversity index was calculated as $H' = -\sum p_i \ln(p_i)$, where p_i is the proportion of individuals belonging to species i and $\ln$ denotes the natural logarithm. Pielou's evenness was calculated as $J' = H'/\ln(S)$, where S is species richness. The use of the same natural-logarithm base in both equations constrains J' to the theoretical range of 0–1.

2.3. Mangrove Remote Sensing Technique

The Mangrove Vegetation Index (MVI) proposed by Baloloy et al. (2020) was applied to Landsat imagery to delineate mangrove vegetation. The index combines the near-infrared (NIR), green, and short-wave infrared (SWIR) bands and was calculated as $MVI = (NIR - Green)/(SWIR - Green)$. Threshold-based classification in QGIS was used to distinguish mangrove from non-mangrove pixels, with base maps and Google Earth imagery used as ancillary visual references.

2.4. Data Collection and Processing

Level-2 products provide atmospherically corrected surface reflectance (SR) data, thereby reducing the need for additional atmospheric correction prior to spectral analysis. The relevant surface-reflectance bands were subsequently used to derive the spectral information required for mangrove identification and classification. Standard quality-assurance information accompanying the Landsat products was considered to identify and exclude cloud-, cloud-shadow-, and other contaminated pixels where applicable (USGS, 2018).

Following data acquisition, the 2024 Landsat 8 imagery was prepared for spatial analysis by selecting the bands relevant to mangrove discrimination and applying the corresponding quality-assurance information. The processed imagery was then used to identify mangrove vegetation based on its spectral response and to generate the spatial representation of mangrove areas within the study site. The use of recent imagery, combined with the Level-2 surface-reflectance products, provided a consistent and standardized dataset for

assessing the current spatial extent of mangrove vegetation. Where field inventory data were available, these observations served as important reference information for interpreting and validating the remotely sensed results, thereby strengthening the reliability of the mapped mangrove distribution (Figure 2).

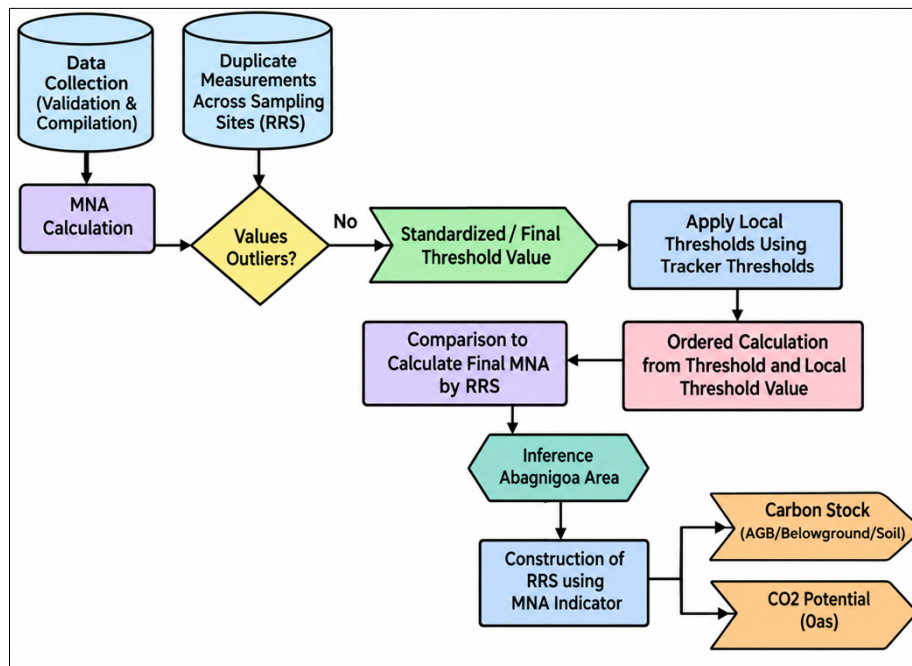


Figure 2. Conceptual framework of the study in developing a local threshold value and for the estimation of carbon stock and carbon sequestration potential.

2.5. Mangrove Vegetation Delineation

Mangrove habitats were classified using the MVI. In QGIS, the selected threshold was applied to identify mangrove and non-mangrove pixels. Post-processing was used to remove obvious misclassifications and establish mangrove boundaries. The resulting map was used to estimate mangrove extent, while the field inventory was retained as the basis for species-level ecological and carbon calculations.

2.6. Local Mangrove Threshold Value

A local mangrove threshold value was determined using zonal statistics applied to areas identified as mangrove. Mean, majority, and weighted threshold statistics were considered to reduce spectral confusion with non-mangrove areas. Because a formal independent ground-truth accuracy assessment was not available in the supplied study records, the threshold should be considered an operational classification threshold rather than a fully accuracy-validated provincial threshold.

2.7. Above-ground Carbon and Equivalent Stock

Aboveground carbon stock was estimated from the field inventory rather than by multiplying the remotely sensed provincial mangrove extent by a literature biomass value. For each species, the recorded number of individuals and corresponding aboveground biomass (AGB) values were compiled to estimate species-level biomass. Species-level total biomass was calculated from the recorded individuals and their corresponding AGB values, after which aboveground carbon was estimated using a carbon fraction of 0.47. The resulting carbon stock was converted to CO₂ equivalent using 3.667. The assessment includes aboveground biomass only and excludes belowground biomass and soil carbon. Importantly, the field-based carbon estimate represents the sampled plots and was not directly extrapolated to the full remotely sensed mangrove extent. A widely used published equation for mangrove biomass is the general allometric model developed by Komiyama et al. (2005). It estimates aboveground biomass using tree diameter and wood density.

The equation is:

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

where:

AGB = aboveground biomass of an individual tree (kg)

ρ = wood density (g cm^{-3})

D = tree diameter at breast height (DBH, cm)

2.8. Economic Value of Carbon

Economic valuation was performed on the estimated carbon stock from the sampled mangrove trees. First, carbon stock in tonnes of carbon (tC) was converted to tonnes of CO₂ equivalent (tCO_{2e}) using 3.667. Two valuation scenarios were then applied: (1) an assumed conservative carbon-market value of US\$5 per tCO_{2e} and (2) a social-cost-of-carbon value of US\$51 per tCO_{2e}, adopted in the submitted manuscript as a non-market damage-cost scenario. The market-value scenario was calculated as $V_{\text{market}} = \text{tCO}_{2e} \times \text{US\$5}$, while the social-cost scenario was calculated as $V_{\text{SCC}} = \text{tCO}_{2e} \times \text{US\$51}$. The US\$5 value is treated here as an explicit valuation assumption rather than as a claim about a current transaction price. The US\$51 value likewise represents a reference social-cost scenario and should not be interpreted as a local market price.

3. Results and Discussion

3.1. Mangrove Diversity

As presented in (Table 1), the mangrove forest along the coastal areas of Davao Oriental recorded a Shannon diversity index (H') of 1.65, with seven species identified. The Pielou's evenness index (J') of 0.85 indicates a relatively uniform distribution of individuals among the recorded species, suggesting that the community was not strongly dominated by a single species. The combination of moderate species diversity and relatively high evenness reflects a comparatively balanced mangrove assemblage and suggests that the forest retains important elements of ecological structure. The recorded species richness is within the range reported for Philippine mangrove communities, although species composition and richness may vary considerably depending on habitat condition, environmental gradients, and disturbance history (Primavera et al., 2004).

Table 1. Shannon Diversity Indices of Mangroves in the coastal areas of Davao Oriental, Philippines.

Diversity Metrics	Value
Shannon Index H'	1.65
Richness (S)	7.00
Pielous Evenness (J')	0.85

The relatively high evenness value further indicates that the recorded species contributed relatively comparably to the overall community structure. However, diversity indices alone should not be interpreted as definitive evidence of forest maturity or ecological stability, as these characteristics are also influenced by environmental conditions, disturbance regimes, stand age, and species-specific ecological tolerances. Nevertheless, the observed diversity and evenness suggest that the mangrove forest may retain functional capacity to provide important ecosystem services, including carbon sequestration, shoreline protection, and nursery habitat for estuarine and coastal fauna (Alongi, 2002; Field, 1999). Despite these ecological contributions, Philippine mangrove forests have experienced substantial historical decline associated with anthropogenic pressures and land-use changes (Brown & Fischer, 1920; Primavera, 2000). In addition, increasing climate-related pressures, particularly sea-level rise and associated changes in coastal conditions, may further affect mangrove distribution, productivity, and long-term persistence (Giri et al., 2011). These pressures underscore the importance of sustained conservation, rehabilitation, and science-based management of mangrove ecosystems in Davao Oriental.

Moreover, the observed species richness in the present study can be contextualized within the broader mangrove diversity reported in the Davao Region. Previous studies have documented considerable mangrove species richness in the region, with *Sonneratia alba* among the frequently recorded species (Pototan et al., 2021; Cardillo & Novero, 2018). The prominence of *S. alba* may be associated with its ecological adaptability and reproductive characteristics, including its capacity for frequent flowering and fruiting, which may facilitate its establishment and regeneration in suitable coastal habitats (Giffin et al., 2021). These regional patterns provide a useful basis for examining the relative ecological importance of individual species within the mangrove stand. Accordingly, the Importance Value (IV), which integrates

Relative Density (RD), Relative Frequency (RF), and Relative Dominance (RDo), was used to assess the contribution of each species to the overall structure of the mangrove community (Curtis & McIntosh, 1951). As presented in Table 2, the seven recorded mangrove species exhibited varying IVs, revealing differences in their abundance, spatial distribution, and dominance within the study area. These variations provide further insight into the species composition and structural organization of the mangrove forest beyond the overall diversity patterns presented in Table 1.

Table 2. Ecological Importance of Mangrove Species in the Coastal Areas of Davao Oriental, Philippines.

Scientific Name	Count	Relative Density	Relative Frequency	Relative Dominance	Importance Value
<i>Sonneratia alba</i>	21	32.31	32.31	83.67	49.43
<i>Rhizophora mucronata</i>	16	24.62	24.62	4.59	17.94
<i>Aegiceras floridum</i>	15	23.08	23.08	8.25	18.14
<i>Rhizophora apiculata</i>	4	6.15	6.15	1.42	4.58
<i>Ceriops tagal</i>	3	4.62	4.62	0.66	3.30
<i>Avicennia marina</i>	3	4.62	4.62	0.62	3.29
<i>Sonneratia ovata</i>	3	4.62	4.62	0.77	3.33

However, anthropogenic pressure remains an important consideration. Mangrove conversion, aquaculture expansion, shoreline modification, and other land-use pressures can alter species composition and stand structure. Recent observations from Philippine mangrove systems demonstrate that composition and disturbance vary among coastal locations (Emeterio et al., 2024; Lillo et al., 2024), while community-based management in Davao Oriental also faces practical conservation challenges (Pototan et al., 2021). The present diversity results should therefore be viewed as a baseline for the sampled stands rather than as evidence that all mangroves in Davao Oriental are ecologically stable.

3.2. Ecological Importance of Mangrove Species

Consistent with the diversity patterns presented in Table 1, the Importance Value (IV) analysis in (Table 2) revealed distinct differences in the structural contribution of the seven mangrove species. *S. alba* exhibited the highest IV (49.43), primarily driven by its exceptionally high Relative Dominance (83.67%), indicating that it contributed substantially to the total basal area of the mangrove stand. Although its relative abundance was comparable with that of *R. mucronata* and *A. floridum*, the larger diameter and height of *S. alba* individuals accounted for its pronounced structural dominance. This pattern is consistent with the ecological characteristics of *S. alba*, a pioneer species commonly occurring along exposed seaward margins of mangrove forests (Primavera et al., 2004; Thampanya et al., 2006). Its tolerance to high salinity, tidal inundation, and fluctuating coastal conditions, together with adaptations such as pneumatophores that facilitate gas exchange under waterlogged conditions, may enhance its establishment and persistence in exposed habitats (Ball & Pidsley, 1995; Polidoro et al., 2010; Raganas et al., 2020; Saro et al., 2025). Its widespread occurrence across several Philippine coastal areas further demonstrates its ecological adaptability and broad distribution (Natividad et al., 2014; Benecario et al., 2016; Barcelete et al., 2016; Bitantos et al., 2017; Lillo et al., 2022).

In contrast, *A. floridum* and *R. mucronata* recorded moderate IVs of 18.14 and 17.94, respectively. Their relatively high Relative Density and Relative Frequency values (approximately 23–25%) indicate that they were comparatively common and widely distributed within the sampling plots; however, their low Relative Dominance values (<10%) suggest a smaller contribution to overall basal area than *S. alba*. This pattern may reflect differences in growth form, size structure, and habitat preference, particularly for *R. mucronata*, which commonly occupies mid-intertidal areas and may occur at relatively high densities through active regeneration without attaining comparable structural size (Duke et al., 1998). Similar distributions of *R. mucronata* and *A. floridum* have been reported in Dumanquillas Bay, Zamboanga del Sur (Emeterio et al., 2024). Overall, the observed IV patterns correspond with the characteristic spatial organization of mangrove communities, in which *Sonneratia* and *Avicennia* are often associated with seaward zones, while *Rhizophora* commonly occurs behind these front-line species (Primavera et al., 2016; Tomlinson, 2016; Calumpo & Meñez, 1996). The pronounced structural contribution of *S. alba* and the moderate importance of *A. floridum* and *R. mucronata* therefore highlight the role of species-specific adaptations and spatial zonation in shaping the structure and ecological organization of the mangrove forest in Davao Oriental (Figure 3).

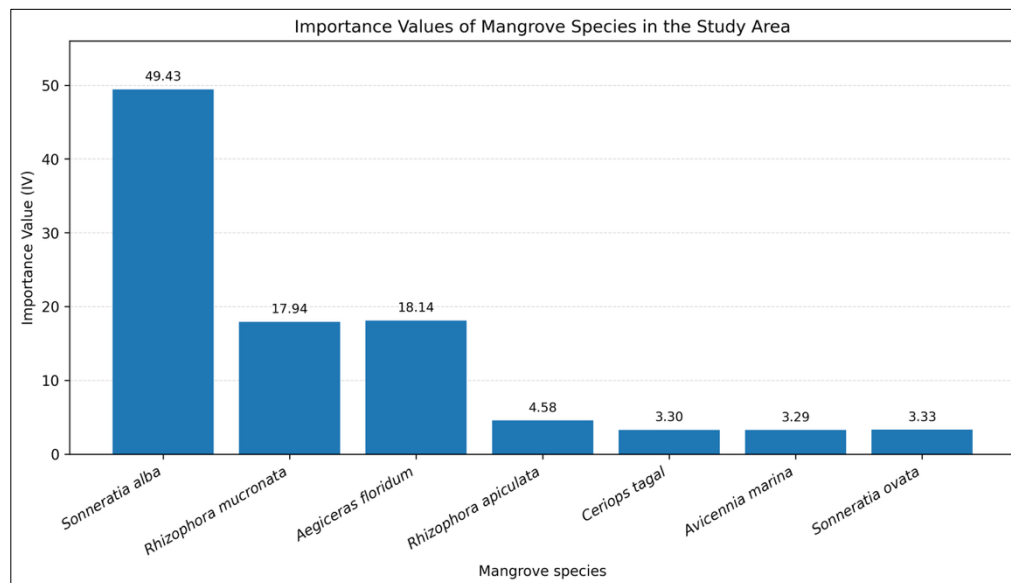


Figure 3. Importance value of mangrove species in the study area.

Similarly, *R. apiculata*, *C. tagal*, *A. marina*, and *S. ovata* recorded relatively low Importance Values (IVs) of less than 5.0, indicating their comparatively limited contributions to the structural composition of the mangrove stand. Their low Relative Density (RD), Relative Frequency (RF), and Relative Dominance (RDo) suggest that these species occurred less frequently and contributed less to the overall stand basal area. Such patterns may reflect differences in habitat preference, environmental tolerance, competitive interactions, or the availability of suitable microsites within the study area rather than necessarily indicating recent colonization or lower competitive ability (Tomlinson, 2016; Alongi, 2002). The observed species composition is also consistent with the characteristic spatial zonation of mangrove communities, wherein *Avicennia* and *Sonneratia* are commonly associated with more seaward and frequently inundated areas, while other mangrove species tend to occupy landward zones and areas along tidal creeks and streams. Species-specific responses to salinity, elevation, tidal inundation, and substrate conditions further contribute to this spatial differentiation. In general, lower-elevation sites with relatively lower salinity can provide favorable conditions for mangrove establishment and growth; however, species differ considerably in their tolerance to saline environments (Barik et al., 2018; Cuenca et al., 2015). *Ceriops* and *Avicennia*, for example, are capable of tolerating relatively high salinity, whereas *Nypa* and *Heritiera* are more commonly associated with less saline environments. These ecological differences in salinity tolerance and habitat preference likely contribute to the variation in species occurrence, abundance, and structural importance observed within the mangrove forest.

3.3. Mangrove Area Estimation

Table 3 presents the spatial distribution of mangrove vegetation across the municipalities of Davao Oriental, expressed in hectares (ha), and percentage of the total mapped mangrove area. The results indicate considerable spatial variation in mangrove coverage, potentially reflecting differences in coastal geomorphology, hydrological conditions, substrate characteristics, and the availability of suitable intertidal habitats. Banaybanay recorded the largest mangrove coverage at 1672.72 ha (16,727,228 m²), followed by Lupon (554.32 ha), San Isidro 1 (290.00 ha), Mati City (171.16 ha), Pantukan (157.93 ha), Governor Generoso (157.43 ha), and San Isidro 2 entry covering (62.26 ha). This heterogeneous distribution highlights the varying extent and ecological capacity of mangrove habitats across the province.

The extensive mangrove cover in Banaybanay underscores its importance as a major mangrove landscape and potential provider of ecosystem services, including shoreline stabilization, sediment retention, nutrient cycling, carbon storage, and habitat provision. Mangrove root systems provide shelter, feeding grounds, and nursery habitats for fishes, crustaceans, mollusks, and other aquatic organisms (Farley et al., 2010). Likewise, the mangrove areas of Lupon and San Isidro may contribute to biodiversity conservation and ecological connectivity, while smaller stands in Mati City, Pantukan, and Governor Generoso may function as localized habitat patches and ecological stepping stones. However, mangrove ecosystems remain vulnerable to pressures associated with settlement expansion, resource extraction,

aquaculture, agriculture, and coastal development, which can alter forest structure and reduce ecosystem functions (Pototan et al., 2021). Thus, conservation significance should be assessed not only by area but also by species composition, stand condition, regeneration, connectivity, and disturbance intensity.

Table 3. Mangrove Area Per Municipalities in Davao Oriental, Philippines.

Municipalities	Area (Ha)	Percentage
Banaybanay	1672.72	54.56%
Lupon	554.32	18.08%
San Isidro 1	290.00	9.46%
Mati City	171.16	5.58%
Pantukan	157.93	5.15%
Governor Generoso	157.43	5.14%
San Isidro 2	62.26	2.03%
Total	3065.82	100%

Mangroves also provide important socioeconomic benefits by supporting fisheries, coastal protection, resource provision, tourism, and environmental education. Their nursery and feeding functions sustain fishes, shrimps, crabs, mollusks, and other aquatic resources important to coastal livelihoods (Giesen et al., 2007; Primavera, 2005). In the Philippines, mangrove ecosystems further contribute to fisheries production, coastal protection, and sustainable community-based resource management (Brander et al., 2012; Miranda et al., 2013; Primavera, 2000). Moreover the distribution pattern in Table 3 emphasizes the need for integrated and site-specific mangrove management across Davao Oriental, combining habitat protection, restoration, sustainable resource use, community participation, and periodic monitoring of mangrove extent and condition to maintain ecosystem services and strengthen long-term coastal resilience.

3.4. Socioeconomic Importance and Implications for Local Communities

Mangroves provide ecosystem services that directly and indirectly support coastal communities. They function as nursery and feeding habitats for fish, crustaceans, mollusks, and other organisms that contribute to fisheries and food security. Mangrove areas can also support nature-based tourism, environmental education, and community conservation activities. For local households whose livelihoods depend on fishing and other coastal resources, maintaining mangrove habitat can help sustain the ecological processes underlying fisheries production. At the same time, conversion for aquaculture or other land uses may generate short-term economic benefits while reducing longer-term ecosystem services. The management implication is therefore not simply to maximize mangrove area, but to maintain structurally diverse forests, prevent avoidable conversion, and involve local communities in protection, restoration, monitoring, and sustainable use. The present study does not quantify household income or livelihood dependence directly; these socioeconomic implications are interpreted from the documented ecosystem functions and should be tested with community-level socioeconomic data in future research.

3.5. Above-Ground Carbon Stock

The field inventory estimated a total aboveground carbon stock of 14,524.63 kg in the sampled mangrove stand (Table 4). *S. alba* contributed the largest share, with 12,908.43 kg (88.86%), followed by *A. floridum* (815.67 kg; 5.61%), *R. mucronata* (460.65 kg; 3.17%), and *R. apiculata* (153.45 kg; 1.06%). The lowest carbon stocks were recorded for *S. ovata* (68.43 kg), *C. tagal* (62.02 kg), and *A. marina* (55.98 kg). The pronounced contribution of *S. alba* is consistent with its structural dominance in the sampled stand and may be associated with its relatively high abundance (21 individuals) and substantial aboveground biomass (1307.85 kg). Differences in carbon storage among species likely reflect variation in tree size, abundance, growth form, biomass accumulation, and stand structure. These findings indicate that carbon storage in the sampled mangrove community was strongly influenced by the presence of structurally dominant species capable of accumulating substantial biomass.

The carbon values observed in the present study were generally higher than those reported for *Rhizophora*-dominated stands in the Verde Passage and Pootol, San Juan, Batangas, as well as *Avicennia*-dominated plots in Catmon, San Juan, Batangas (Gevaña et al., 2008; Gevaña & Pampolina, 2009). They were also higher than values reported for 3- and 9-year-old afforested mangrove stands in Laguindingan, Misamis Oriental (Sharma et al., 2017) and a 22-year-old reforested mangrove stand in Aklan (Castillo & Breva,

2012). In contrast, the estimated carbon stock was lower than those documented in mangrove ecosystems in Sarangani Province (Barcelete et al., 2016; Bigsang et al., 2016), Cotabato City (Dimalen & Rojo, 2019), and a 21-year-old afforested stand in Laguindingan, Misamis Oriental (Sharma et al., 2017). Lower values relative to those reported from plantation and natural mangrove stands on Banacon Island, Bohol (Camacho et al., 2011; Gevaña et al., 2017), and natural and reforested mangrove forests in Samar and Palawan (Abino et al., 2014; Castillo & Breva, 2012; Venturillo, 2016) further demonstrate the substantial spatial variability of mangrove carbon storage across Philippine ecosystems.

Table 4. Estimated carbon stock of the mangrove area being assessed.

Scientific Name	Common Name	Count	AGB (kg)	Carbon (kg)	Total Carbon (kg)
<i>Sonneratia alba</i>	Pagatpat	21	1307.85	614.69	12,908.43
<i>Aegiceras floridum</i>	Saging-saging	15	115.70	54.38	815.67
<i>Rhizophora mucronata</i>	Bakauan babae	16	61.26	28.80	460.65
<i>Rhizophora apiculata</i>	Bakauan lalaki	4	81.62	38.36	153.45
<i>Sonneratia ovata</i>	Pedada	3	48.53	22.81	68.43
<i>Ceriops tagal</i>	Tungog	3	43.98	20.67	62.02
<i>Avicennia marina</i>	Api-api	3	39.70	18.66	55.98
Total Carbon Stored					14,524.63

Such differences in biomass and carbon stocks among mangrove sites can be attributed to variations in environmental conditions, including temperature, rainfall, tidal inundation, freshwater and river discharge, salinity, nutrient availability, and nutrient cycling (Alongi, 2012). Structural characteristics such as tree size, species composition, stand density, and biomass accumulation can likewise influence productivity and carbon storage, while environmental heterogeneity among mangrove habitats may further contribute to differences in ecosystem carbon stocks (Jones et al., 2015; Alavaisha & Mangora, 2016; Kauffman & Bhomia, 2017). Thus, the relatively high carbon contribution of *S. alba* in the present study highlights the importance of conserving mature and structurally developed mangrove stands. At the same time, the variation observed among species and sites emphasizes the need to consider local environmental conditions, stand structure, species composition, and biomass characteristics when evaluating the carbon-storage capacity of mangrove ecosystems and their potential contribution to climate-change mitigation.

3.6. Economic Value of Carbon

The carbon assessment demonstrates a measurable economic dimension to the carbon-storage function of the mangrove forest in Davao Oriental. The estimated 14.52 tC corresponds to 53.29 tCO_{2e}, which, at a conservative carbon-market price of USD 5/tCO_{2e}, represents a potential market value of USD 266.45 (approximately ₱14,921.20) (Table 5). Although this market-based value is relatively modest, it provides a quantitative basis for recognizing carbon storage as an ecosystem service that can potentially be incorporated into voluntary carbon-market and conservation incentive mechanisms (Locatelli et al., 2014). More importantly, applying a social cost of carbon of USD 51/tCO_{2e} results in an estimated value of USD 2717.79 (approximately ₱152,196.24) for the same 53.29 tCO_{2e}. The nearly tenfold difference between these estimates demonstrates that the financial value represented by a market price does not necessarily capture the broader societal value of retaining carbon in mangrove biomass. The SCC-based estimate reflects the potential climate-related damages avoided by preventing the release of stored carbon, although it should be interpreted as a social valuation rather than an amount that would necessarily be received by local communities through carbon markets.

Table 5. Economic Value of Carbon in, Davao Oriental, Philippines.

Metric	Value
Total Carbon Stored	14.52 tC
CO ₂ Equivalent	53.29 tCO _{2e}
Carbon Market Value (USD \$5/tCO _{2e})	\$266.45/₱14,921.20
Social Cost of Carbon (USD \$51/tCO _{2e})	\$2717.79/₱152,196.24

The data therefore provide concrete evidence that the sampled mangrove stand has value beyond its physical biomass, particularly as a natural climate-regulation asset. The ₱14,921.20 market-based estimate

illustrates the potential financial value of carbon under a conservative market scenario, whereas the ₱152,196.24 SCC-based estimate demonstrates the substantially greater societal value associated with avoiding climate-related damages. However, these values represent only the carbon component of the mangrove ecosystem and do not include other important services such as shoreline protection, sediment retention, fisheries support, nutrient cycling, and biodiversity conservation (Alongi, 2012; Primavera et al., 2012). Consequently, the quantified carbon value should be viewed as a conservative component of the ecosystem's overall economic importance. These findings provide useful evidence for incorporating carbon storage into mangrove management, coastal planning, conservation incentives, and ecosystem-based approaches in Davao Oriental, while emphasizing that the full value of mangrove ecosystems requires consideration of both carbon and their wider ecological and socioeconomic functions.

4. Limitations and Recommendations

The study has four principal limitations. First, the 20-plot, 2000-m² field inventory provides a useful characterization of the sampled mangrove stands but is limited for province-wide inference. Second, the supplied study records do not contain a formal quantitative ground-truth accuracy assessment for the remote-sensing classification. Third, the original municipal GIS values require verification before Table 3 and all municipality-specific statements can be finalized. Fourth, the carbon estimate is based on sampled field trees and excludes belowground and soil carbon; the species-specific biomass source or allometric equation should be documented explicitly.

Future work should expand sampling using a stratified design that represents municipalities, mangrove zones, canopy conditions, and disturbance gradients. Georeferenced field plots should be used for independent ground-truth validation of the MVI classification, with an accuracy assessment reported. Repeated surveys would also permit analysis of temporal change and ecological resilience. Finally, community-level socioeconomic data on fisheries, tourism, resource use, and household dependence should be collected to quantify the livelihood implications of mangrove conservation.

5. Conclusions

This study assessed mangrove diversity, aboveground carbon stock, mangrove extent, and carbon economic value in the assessed coastal areas of Davao Oriental, Philippines. Seven mangrove species were recorded, with a Shannon–Wiener diversity index of 1.65 and Pielou's evenness index of 0.85. The revised evenness calculation uses the natural logarithm consistently and remains within the theoretical range of 0–1. *Sonneratia alba* was the most abundant and structurally dominant species and accounted for 12,908.43 kg (88.86%) of the 14,524.63 kg aboveground carbon estimated from the sampled mangrove trees.

Remote sensing produced a current mapped mangrove extent of 3065.82 ha, but municipal-level values require verification against the original GIS output before publication. The remote-sensing extent should not be interpreted as independently accuracy-validated because a formal ground-truth assessment was not available in the supplied study records. Similarly, the carbon estimate applies to the sampled field plots and should not be extrapolated to the mapped provincial extent without additional biomass and spatial-validation procedures.

The findings demonstrate that mangroves provide interconnected ecological and socioeconomic benefits, including biodiversity support, carbon storage, fisheries habitat, shoreline protection, and potential opportunities for nature-based tourism and community conservation. Given the pressures associated with aquaculture, deforestation, and other coastal land-use changes, conservation strategies should combine field-based ecological monitoring, validated remote sensing, habitat protection, restoration where appropriate, and meaningful participation of local communities.

Author Contributions

C.C.C.J.: writing original draft preparation, reviewing and editing, R.G.A.: conceptualization, methodology, software; M.J.T.P.: Data Curation, A.J.T.-E., B.O.P., O.G.C. and S.C.P.: investigation and field works; L.B.J. and E.S.A.: supervision. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

The data supporting the findings of this study, including mangrove species inventory records, aboveground biomass and carbon-stock estimates, and remote-sensing outputs, are available from the corresponding author upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist with language polishing, grammar correction, and improvement of clarity and readability. The authors reviewed and edited the AI-assisted content and take full responsibility for the accuracy, integrity, and originality of the final manuscript. AI was not used to generate or analyze the research data.

References

- Abino, A. C., Castillo, J. A. A., & Lee, Y. J. (2014). Assessment of species diversity, biomass and carbon sequestration potential of a natural mangrove stand in Samar, the Philippines. *Forest Science and Technology*, 10(1), 2–8. <https://doi.org/10.1080/21580103.2013.814593>.
- Alavaisha, E., & Mangora, M. M. (2016). Carbon Stocks in the Small Estuarine Mangroves of Geza and Mtimbwani, Tanga, Tanzania. *International Journal of Forestry Research*, 2016, 1–11. <https://doi.org/10.1155/2016/2068283>.
- Alongi, D. M. (2002). Present state and future of the world's mangrove forests. *Environmental Conservation*, 29(3), 331–349. <https://doi.org/10.1017/s0376892902000231>.
- Alongi, D. M. (2012). Carbon sequestration in mangrove forests. *Carbon Management*, 3(3), 313–322. <https://doi.org/10.4155/cmt.12.20>.
- Ball, M. C., & Pidsley, S. M. (1995). Growth Responses to Salinity in Relation to Distribution of Two Mangrove Species, *Sonneratia alba* and *S. lanceolata*, in Northern Australia. *Functional Ecology*, 9(1), 77–85. <https://doi.org/10.2307/2390093>.
- Baloloy, A. B., Blanco, A. C., Sta. Ana, R. R. C., & Nadaoka, K. (2020). Development and application of a new mangrove vegetation index (MVI) for rapid and accurate mangrove mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, 166, 95–117. <https://doi.org/10.1016/j.isprsjprs.2020.06.001>.
- Barcelete, R. C., Palmero, E. M. F., Buay, B. M. G., Apares, C. B., Dominoto, L. R., Lipae, H., Cabrera, M. L. N., Torres, M. A. J., & Requiron, E. A. (2016). Species diversity and above-ground carbon stock assessments in selected mangrove forests of Malapatan and Glan, Sarangani Province, Philippines. *Journal of Biodiversity and Environmental Sciences*, 8, 265–274.
- Barik, J., Mukhopadhyay, A., Ghosh, T., Mukhopadhyay, S. K., Chowdhury, S. M., & Hazra, S. (2018). Mangrove species distribution and water salinity: An indicator species approach to Sundarban. *Journal of Coastal Conservation*, 22(2), 361–368. <https://doi.org/10.1007/s11852-017-0584-7>.
- Benecario, J. B., Torregosa, K. M. Y., Orbita, M. L. S., & Orbita, R. R. (2016). Composition, abundance and distribution of mangroves in Bacolod, Lanao del Norte, Mindanao, Philippines. *Advances in Environmental Sciences*, 8(1), 42–49. <https://www.cabdirect.org/cabdirect/abstract/20163009576>.

- Bigsang, R. T., Agonia, N. B., Toreta, C. G. D., Nacin, C. J. C. B., Obemio, C. D. G., & Martin, T. T. B. (2016). Community structure and carbon sequestration potential of mangroves in Maasim, Sarangani Province, Philippines. *Advances in Environmental Sciences*, 8(1), 6–13.
- Bitantos, B. L., Abucay, M. D., Dacula, J. A., & Recafort, R. D. (2017). Mangrove in the grove: Diversity, species composition, and habitat in Pamintayan, Dumanquillas Bay, Philippines. *Advances in Environmental Sciences*, 9(3), 183–192.
- Brander, L. M., Wagtendonk, A. J., Hussain, S. S., McVittie, A., Verburg, P. H., de Groot, R. S., & van der Ploeg, S. (2012). Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. *Ecosystem Services*, 1(1), 62–69. <https://doi.org/10.1016/j.ecoser.2012.06.003>.
- Brown, W. H., & Fischer, A. F. (1920). Philippine Mangrove Swamps. In W. H. Brown (Ed.), *Minor products of Philippine forests* (pp. 9–125). Bureau of Printing. <https://doi.org/10.5962/bhl.title.13582>.
- Calumpang, H. C., & Meñez, E. G. (1996). *Field guide to the common mangroves, seagrasses, and algae of the Philippines*. Bookmark. <https://archive.org/details/fieldguidetocomm0000calu>.
- Camacho, L. D., Gevaña, D. T., Carandang, A. P., Camacho, S. C., Combalicer, E. A., Rebugio, L. L., & Youn, Y. C. (2011). Tree biomass and carbon stock of a community-managed mangrove forest in Bohol, Philippines. *Forest Science and Technology*, 7(4), 161–167. <https://doi.org/10.1080/21580103.2011.621377>.
- Cardillo, J., & Novero, A. U. (2018). Assessment of mangrove diversity in Santa Cruz, Davao del Sur, Philippines. *Journal of Biodiversity and Environmental Sciences*, 14(2), 53–62.
- Castillo, J. A. A., & Breva, L. A. (2012). Carbon stock assessment of four mangrove reforestation/plantation stands in the Philippines. In *Proceedings of the 1st ASEAN Congress on Mangrove Research and Development*. Mangrove Research Section, Ecosystems Research and Development, Bureau Forestry Campus.
- Chapman, V. J. (1983). Mangroves in New Zealand. In *Biology and ecology of mangroves* (pp. 81–85). Springer. https://doi.org/10.1007/978-94-017-0914-9_8.
- Cuenca, G. C., Macusi, E. D., Abreo, N. A. S., Ranara, C. T. B., Andam, M. B., Cardona, L. C., & Conserva, G. G. (2015). Mangrove Ecosystems and Associated Fauna with Special Reference to Mangrove Crabs in the Philippines: A Review. *IAMURE International Journal of Ecology and Conservation*, 15(1), 60–110. <https://doi.org/10.7718/ijec.v15i1.998>.
- Curtis, J. T., & McIntosh, R. P. (1951). An Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin. *Ecology*, 32(3), 476–496. <https://doi.org/10.2307/1931725>.
- Das, S., & Vincent, J. R. (2009). Mangroves protected villages and reduced death toll during Indian super cyclone. *Proceedings of the National Academy of Sciences USA*, 106(18), 7357–7360. <https://doi.org/10.1073/pnas.0810440106>.
- Dimalen, F. K., & Rojo, M. J. A. (2019). Carbon stock assessment of a mangrove forest in Cotabato City, Philippines. *Journal of Biodiversity and Environmental Sciences*, 14, 1–8. <https://ssrn.com/abstract=3588114>.
- Dodd, R. S., & Ong, J. E. (2008). Future of mangrove ecosystems to 2025. In *Aquatic Ecosystems: Trends and Global Prospects* (pp. 172–187). Cambridge University Press. <https://doi.org/10.1017/cbo9780511751790.017>.
- Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4(5), 293–297. <https://doi.org/10.1038/ngeo1123>.
- Duke, N. C., Ball, M. C., & Ellison, J. C. (1998). Factors Influencing Biodiversity and Distributional Gradients in Mangroves. *Global Ecology and Biogeography Letters*, 7(1), 27–47. <https://doi.org/10.2307/2997695>.
- Emeterio, C. L., Orbita, M. L. S., Orbita, R. R., Orong, B. C., Valdez, S. A. L., & Dagondon, S. L. (2024). Survey of mangrove habitats in Dumanquillas Bay: Recent observations and findings. *Aquaculture, Aquarium, Conservation & Legislation*, 17(5), 2189–2198.
- Farley, J., Batker, D., de la Torre, I., & Hudspeth, T. (2010). Conserving Mangrove Ecosystems in the Philippines: Transcending Disciplinary and Institutional Borders. *Environmental Management*, 45(1), 39–51. <https://doi.org/10.1007/s00267-009-9379-4>.
- Field, C. D. (1999). Rehabilitation of Mangrove Ecosystems: An Overview. *Marine Pollution Bulletin*, 37(8-12), 383–392. [https://doi.org/10.1016/s0025-326x\(99\)00106-x](https://doi.org/10.1016/s0025-326x(99)00106-x).
- Gevaña, D. T., Camacho, L. D., & Camacho, S. C. (2017). Stand density management and blue carbon stock of monospecific mangrove plantation in Bohol, Philippines. *Forestry Studies*, 66(1), 75–83. <https://doi.org/10.1515/fsmu-2017-0008>.
- Gevaña, D. T., & Pampolina, N. M. (2009). Plant diversity and carbon storage of a *Rhizophora* stand in Verde Passage, San Juan, Batangas, Philippines. *Journal of Environmental Science and Management*, 12(2), 1–10.
- Gevaña, D. T., Pulhin, F. B., & Pampolina, N. M. (2008). Carbon Stock Assessment of a Mangrove Ecosystem in San Juan, Batangas. *Journal of Environmental Science and Management*, 11(1), 15–25.
- Giesen, W., Wulffraat, S., Zieren, M., & Scholten, L. (2007). *Mangrove guidebook for Southeast Asia*. FAO Regional Office for Asia and the Pacific.
- Giffin, A. L., Brown, C. J., Nalau, J., Mackey, B., & Connolly, R. M. (2021). Marine and coastal ecosystem-based adaptation in Asia and Oceania: Review of approaches and integration with marine spatial planning. *Pacific Conservation Biology*, 27(2), 104–117. <https://doi.org/10.1071/pc20025>.

- Giri, C., Ochieng, E., Tieszen, L. L., Zhu, Z., Singh, A., Loveland, T., Masek, J., & Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20(1), 154–159. <https://doi.org/10.1111/j.1466-8238.2010.00584.x>.
- Harborne, A. R., Mumby, P. J., Micheli, F., Perry, C. T., Dahlgren, C. P., Holmes, K. E., & Brumbaugh, D. R. (2006). The Functional Value of Caribbean Coral Reef, Seagrass and Mangrove Habitats to Ecosystem Processes. *Advances in Marine Biology*, 50, 57–189. [https://doi.org/10.1016/s0065-2881\(05\)50002-6](https://doi.org/10.1016/s0065-2881(05)50002-6).
- Hogarth, P. J. (2015). *The Biology of Mangroves and Seagrasses* (3rd ed.). Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780198716549.001.0001>.
- Jones, T., Ratsimba, H., Ravaoarinosihoarana, L., Glass, L., Benson, L., Teoh, M., Carro, A., Cripps, G., Giri, C., Gandhi, S., Andriamahenina, Z., Rakotomanana, R., & Roy, P. F. (2015). The Dynamics, Ecological Variability and Estimated Carbon Stocks of Mangroves in Mahajamba Bay, Madagascar. *Journal of Marine Science and Engineering*, 3(3), 793–820. <https://doi.org/10.3390/jmse3030793>.
- Kathiresan, K., & Bingham, B. L. (2001). Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology*, 40, 81–251. [https://doi.org/10.1016/s0065-2881\(01\)40003-4](https://doi.org/10.1016/s0065-2881(01)40003-4).
- Kauffman, J. B., & Bhomia, R. K. (2017). Ecosystem carbon stocks of mangroves across broad environmental gradients in West-Central Africa: Global and regional comparisons. *PLoS ONE*, 12(11), e0187749. <https://doi.org/10.1371/journal.pone.0187749>.
- Komiyama, A., Poungharn, S., & Kato, S. (2005). Common allometric equations for estimating the tree weight of mangroves. *Journal of Tropical Ecology*, 21(4), 471–477. <https://doi.org/10.1017/s0266467405002476>.
- Lillo, E. P., Malaki, A. B., Alcazar, S. M. T., Rosales, R., Redoblado, B. R., Diaz, J. L. B., Pantinople, E. M., & Nuevo, R. U. (2022). Composition and diversity of mangrove species in Camotes Island, Cebu, Philippines. *Journal of Marine and Island Cultures*, 11(1), 158–174. <https://doi.org/10.21463/jmic.2022.11.1.11>.
- Lillo, E. P., Malaki, A. B., Alcazar, S. M. T., Chavez, M. L. M., Rosales, R., Tomol, C. J. O. Y., Pantinople, E. M., Redoblado, B. R., Margate, M. A., Diaz, J. L. O. U., Isabelo, J. L., Cagara, B. N. R., Abridana, M., Mago, J. E., Cañarijo, D. M., III, Sanchez, I. R. G., Obando, M. E., Belañizo, J., Beceril, R., ... Lillo, E. P. (2024). Mangrove forest composition, diversity, and disturbances in Carcar City and Sibonga Municipality, Southern Cebu Island, Philippines. *Biodiversitas Journal of Biological Diversity*, 25(5), 2035. <https://doi.org/10.13057/biodiv/d250521>.
- Locatelli, T., Binet, T., Kairo, J. G., King, L., Madden, S., Patenaude, G., Upton, C., & Huxham, M. (2014). Turning the Tide: How Blue Carbon and Payments for Ecosystem Services (PES) Might Help Save Mangrove Forests. *Ambio*, 43(8), 981–995. <https://doi.org/10.1007/s13280-014-0530-y>.
- Massel, S. R., Furukawa, K., & Brinkman, R. M. (1999). Surface wave propagation in mangrove forests. *Fluid Dynamics Research*, 24(4), 219–249. [https://doi.org/10.1016/s0169-5983\(98\)00024-0](https://doi.org/10.1016/s0169-5983(98)00024-0).
- Mazda, Y., Magi, M., Ikeda, Y., Kurokawa, T., & Asano, T. (2006). Wave reduction in a mangrove forest dominated by *Sonneratia* sp. *Wetlands Ecology and Management*, 14(4), 365–378. <https://doi.org/10.1007/s11273-005-5388-0>.
- Mazda, Y., Wolanski, E., King, B., Sase, A., Ohtsuka, D., & Magi, M. (1997). Drag force due to vegetation in mangrove swamps. *Mangroves and Salt Marshes*, 1(3), 193–199. <https://doi.org/10.1023/a:1009949411068>.
- Miranda, S. J. M., Reyes, J. O., Tan, A., Villanueva, L. C., Zara, S. M. F., Banaag, A. G., & Rosales, R. (2013). Mangrove Plantation as a Tourist Attraction in San Juan Batangas, Philippines. *International Journal of Academic Research in Business and Social Sciences*, 3(8), 369–375. <https://doi.org/10.6007/ijarbss/v3-i8/158>.
- Natividad, E. M. C., Dalundong, A. R. O., Patriarca, A. B., Banisil, M. A., Hingabay, V. S., Paña, B. H. C., Teofilo, R. C. E., Salvatierra, L. A. J., Dagoc, V., & Jumawan, J. H. (2014). Correlation of soil and mangrove diversity in selected sites of Alabel and Maasim, Sarangani Province, Philippines. *Advances in Agriculture & Botany*, 6(2), 145–153.
- Polidoro, B. A., Carpenter, K. E., Collins, L., Duke, N. C., Ellison, A. M., Ellison, J. C., Farnsworth, E. J., Fernando, E. S., Kathiresan, K., Koedam, N. E., Livingstone, S. R., Miyagi, T., Moore, G. E., Ngoc Nam, V., Ong, J. E., Primavera, J. H., Salmo, S. G., Sanciangco, J. C., Sukardjo, S., ... Yong, J. W. H. (2010). The Loss of Species: Mangrove Extinction Risk and Geographic Areas of Global Concern. *PLoS ONE*, 5(4), e10095. <https://doi.org/10.1371/journal.pone.0010095>.
- Pototan, G. E. C., Rebanco, C. M., Bradecina, R. G., & Landicho, L. D. (2021). Community-based mangrove forest management in Davao Oriental, Philippines: Prospects and challenges. *Journal of Marine and Island Cultures*, 10(1), 14–25. <https://doi.org/10.21463/jmic.2021.10.1.02>.
- Primavera, J. H. (1995). Mangroves and brackishwater pond culture in the Philippines. *Hydrobiologia*, 295(1-3), 303–309. <https://doi.org/10.1007/bf00029137>.
- Primavera, J. H. (1997). Fish predation on mangrove-associated penaeids: The role of structures and substrate. *Journal of Experimental Marine Biology and Ecology*, 215(2), 205–216. [https://doi.org/10.1016/s0022-0981\(97\)00046-4](https://doi.org/10.1016/s0022-0981(97)00046-4).
- Primavera, J. H. (2000). Development and conservation of Philippine mangroves: Institutional issues. *Ecological Economics*, 35(1), 91–106. [https://doi.org/10.1016/s0921-8009\(00\)00170-1](https://doi.org/10.1016/s0921-8009(00)00170-1).

- Primavera, J. H. (2005). Mangroves, Fishponds, and the Quest for Sustainability. *Science*, 310(5745), 57–59. <https://doi.org/10.1126/science.1115179>.
- Primavera, J. H., Sadaba, R. B., Lebata-Ramos, M. J. H., & Altamirano, J. P. (2004). *Handbook of mangroves in the Philippines*. SEAFDEC.
- Primavera, J. H., dela Cruz, M., Montilijao, C., Consunji, H., dela Paz, M., Rollon, R. N., & Blanco, A. C. (2016). Preliminary assessment of post-Haiyan mangrove damage and short-term recovery in Eastern Samar, central Philippines. *Marine Pollution Bulletin*, 109(2), 744–750. <https://doi.org/10.1016/j.marpolbul.2016.05.050>.
- Primavera, J. H., Savaris-Alpino, R., Bajoyo, B. E., Coching, J. D., Curnick, D. J., & Koldewey, H. J. (2012). *Manual on mangrove reversion of abandoned and illegal brackishwater fishponds*. Zoological Society of London and Bureau of Fisheries and Aquatic Resources.
- Raganas, A. F. M., Hadsall, A. S., Pampolina, N. M., Hotes, S., & Magcale-Macandog, D. B. (2020). Regeneration capacity and threats to mangrove areas on the southern coast of Oriental Mindoro, Philippines: Implications to mangrove ecosystem rehabilitation. *Biodiversitas Journal of Biological Diversity*, 21(8), 3625–3636. <https://doi.org/10.13057/biodiv/d210827>.
- Robertson, A. I., Alongi, D. M., & Boto, K. G. (1992). Food chains and carbon fluxes. In A. I. Robertson, & D. M. Alongi (Eds.), *Tropical Mangrove Ecosystems* (pp. 293–326). American Geophysical Union. <https://doi.org/10.1029/ce041p0293>.
- Saenger, P. (2002). *Mangrove Ecology, Silviculture and Conservation*. Springer Dordrecht. <https://doi.org/10.1007/978-94-015-9962-7>.
- Salmo, S. G., Tibbetts, I., & Duke, N. C. (2017). Colonization and shift of mollusc assemblages as a restoration indicator in planted mangroves in the Philippines. *Biodiversity and Conservation*, 26(4), 865–881. <https://doi.org/10.1007/s10531-016-1276-6>.
- Samson, M. S., & Rollon, R. N. (2008). Growth Performance of Planted Mangroves in the Philippines: Revisiting Forest Management Strategies. *AMBIO: A Journal of the Human Environment*, 37(4), 234–240. [https://doi.org/10.1579/0044-7447\(2008\)37\[234:gpopmi\]2.0.co;2](https://doi.org/10.1579/0044-7447(2008)37[234:gpopmi]2.0.co;2).
- Saro, J. M., Litera, E. A., Chua, D. R. C., & Bulay, M. L. (2025). Mangrove Vascular Flora Composition, Distribution, and Diversity in Selected Sites of the Coastal Areas of Surigao del Sur, Philippines. *Asian Journal of Conservation Biology*, 14(1), 12–28. <https://doi.org/10.53562/ajcb.86652>.
- Sharma, S., Nadaoka, K., Nakaoka, M., Uy, W. H., MacKenzie, R. A., Friess, D. A., & Fortes, M. D. (2017). Growth performance and structure of a mangrove afforestation project on a former seagrass bed, Mindanao Island, Philippines. *Hydrobiologia*, 803(1), 359–371. <https://doi.org/10.1007/s10750-017-3252-x>.
- Thampanya, U., Vermaat, J. E., Sinsakul, S., & Panapitukkul, N. (2006). Coastal erosion and mangrove progradation of Southern Thailand. *Estuarine, Coastal and Shelf Science*, 68(1–2), 75–85. <https://doi.org/10.1016/j.ecss.2006.01.011>.
- Tomlinson, P. B. (2016). *The Botany of Mangroves* (2nd ed.). Cambridge University Press. <https://doi.org/10.1017/cbo9781139946575>.
- United States Geological Survey (2018). *How do I use a scale factor with Landsat Level-2 science products?* <https://www.usgs.gov/faqs/how-do-i-use-a-scale-factor-landsat-level-2-science-products>.
- Venturillo, R. M. (2016). Spatio-temporal mapping, biomass and carbon stock assessment of mangrove forest in Aborlan, Palawan, Philippines. *Journal of Nature Studies*, 15, 90–103.
- Williams, A. A., Eastman, S. F., Eash-Loucks, W. E., Kimball, M. E., Lehmann, M. L., & Parker, J. D. (2014). Record Northernmost Endemic Mangroves on the United States Atlantic Coast with a Note on Latitudinal Migration. *Southeastern Naturalist*, 13(1), 56–63. <https://doi.org/10.1656/058.013.0104>.