Article

Aboveground carbon storage and species diversity of mangrove stand in Leyte Island, Philippines

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Abstract

Mangroves are commonly found along sheltered coastlines in the tropics and sub-tropics, fulfilling essential socio-economic and environmental functions. However, because of Super Typhoon Haiyan in 2013, the studied mangrove stand was severely affected. After three years, this study determined the current mangrove species diversity and the amount of carbon sequestered. The study employed a nondestructive quadrat technique to determine species composition and forest structure. An allometric equation was used in c-stocks estimation. Three (3) mangrove species were identified, namely, *Rhizophora apiculata*, *Sonneratia alba,* and *Avicenna marina*, in sixty-four plots with 10x10 m size. Results showed species frequency of 1.41, species density of 22.89, and diversity index of 1.245. *R. apiculata* rendered the highest IVI values (228.5%), followed by *A. marina* (49.3%) and *S. alba* (22.2%). The overall means of biomass, C-stocks and CO_{2eq} of the mangrove stand in the whole research area of 6.46 ha were 10.89 MgB ha^{-1}, 5.99 MgC ha^{-1}, and 21.99 Mg ha^{-1} CO_{2eq}, respectively. Such results are quite low compared to mangrove stands in Asia but indicated that it could sequester substantial atmospheric with intensified protection and conversation despite less species diversity.

Key Words: *Rhizophora apiculate, Sonneratia alba, Avicenna marina, C-stocks,* CO_2 *Sequestration*

Introduction

One of the widely distributed ecotypes in tropical coastlines are the mangrove forest which covers only 0.5% of the Earth's coastal areas (Ardiansyah et al. 2019; Asadi et al. 2018; Alongi, 2014). The archipelagic nature of the Philippines has endowed it with rich mangrove forest scatter in some of 7,100 islands. However, it has gradually been reduced through the years. In the previous century, the mangrove forest in the country stood at 400,000-500,000 ha (Faridha-Hanum et al., 2011). Almost a century later, the area covered by the mangrove is down to an estimated 117,000 ha or roughly less than 30% of the original extent (Melana et al., 2000). However, present statistics show that among the mangrove-rich countries, the Philippines ranked 16th with an area of 259,600 ha representing 1.9% of the global mangrove system (Siikamaki et al. 2012). Additionally, there are seventy (70) true mangrove species, and forty-two (42) mangrove species that belong to 18 families are found in the Philippines (Samson and Rollon, 2011).

The Philippines is usually visited with Tropical Typhoons where the mangrove stand serves as natural breakwaters and dissipates the waves' energy and storm surge (Polidoro et al., 2010). Tacloban City, Philippines, was severely devastated by Super Typhoon Haiyan last November 13, 2013, and a storm surge passed thru Cancabato Bay. To that, restoration and rehabilitation of the said mangrove stand are one of the current initiatives of the Philippine government. It has been prioritized that mangrove plantation and rehabilitate degraded and damaged mangrove areas are products of careful assessment and planning enrich with the experience brought about the Super Typhoon Haiyan and other calamities besetting our country (CENRO Palo, Leyte, 2014).

Moreover, mangrove forest could store three (3) times more organic C than terrestrial forest (Kauffman et al. 2016) and has found to have a high capacity in sequestering CO_2 and C storage which is a basic form of blue C (Alongi, 2016). Such data can be used for carbon credits trading, which applies to the REDD+ scheme as mangrove rehabilitation and conservation are already included (Wylie et al., 2016). Nevertheless, there is still a lack of data on C-stocks of mangrove forests (Brander et al., 2012). Especially in a highly urbanized city such as Tacloban City, Philippines, which was seriously affected by a super typhoon and still prone to extreme weather events, linked to climate change and inventory of carbon in the biomass, especially in mangrove areas. Therefore, this study aims to assess the mangrove forest structure in terms of species diversity and estimate biomass, C-stocks, and the amount of CO_2 sequestered.

Methodology

Study sites

The study area was located in Barangay 83-A Burayan, San Jose, along the Cancabato Bay, Tacloban City, Leyte Island, the Philippines, with GPS coordinates 11.211885”N and 125.014443“E and with 6.46 hectares of mangrove forest (Figure 1). The site selection is primarily based on mangrove stands that were severely affected by Super Typhoon Haiyan. The topography of the urban area along the coastline of Tacloban City is characterized by the flat and low-lying area of the Leyte plain. Most of the urban area was below 5 m asl, critically damaged by 5.65 m of storm surge. The area belongs to the Type IV climate Coronas classification system (Philippine Atmospheric, Geophysical and Astronomical Services Administration [PAGASA], 2014).

Figure 1. Study site in Cancabato Bay, Barangay 83-A Burayan, San Jose, Tacloban City, Leyte Island, Philippines

Inventory design

Fieldwork was performed in November 2016. Field Guide to Philippine Mangroves by Primavera (2009) was used in identifying mangrove species and was verified by OML Center for Climate Change Adaptation and Management Foundation, Inc. The study employed a nondestructive quadrat technique to determine species composition and forest structure. Sixty-four (64) representative sampling plots were established with a size of 10mx10m was laid in areas with sufficient mangrove cover (Natividad et al. 2015) and perpendicular to the shore. All mangrove species were identified and recorded inside each plot. The measurement of diameter at breast height (DBH) (cm) was measured at 1.3 m above the ground (Kauffman et al. 2014 and Bautista et al., 2018). For Rhizophora, DBH was measured 30 cm above the buttress and highest prop root. The DBH was measured using a measuring tape and vernier caliper (Aheto et al., 2011).

Forest structure and biomass calculation

The importance value index (IVI), which indicates the structural importance of each species in the community, was obtained by adding the percentage values of frequency (F), dominance (Dom), density (D) where:

$$\textit{Frequency} = \frac{\textit{Number of plots where one species is found}}{\textit{Total number of plots of all species}}$$

$$\textit{Dominance} = \frac{\textit{Total basal area of the species}}{\textit{Total basal area of all the species}}$$

$$\textit{Density} = \frac{\textit{Total number of individual species}}{\textit{Total number of plots of all individual species}}$$

Diversity Index was determined using the Shannon-Wiener Index (H'). This index indicates a quantitative description of mangrove habitat in terms of species distribution and evenness, including mangrove forest (Abino et al. 2014; Tang et al. 2012) and was calculated using this formula:

$$H' = -\sum pi \ln pi$$

where *H'* is the diversity index and *ρi* is the proportion of i^{th} species individuals to total species individuals and ln natural logarithm.

In computing the trees' above-ground biomass (kg), allometric equations developed by Komiyama et al. (2005) were employed. The following formulas were used: aboveground biomass (W_{top}) = $0.251\rho D^{2.46}$ (Komiyama et al., 2005; Abino et al., 2014); root biomass (W_R)= $0.199 \rho^{0.899} D^{2.22}$ (Abino et al., 2014); carbon conversion factor = 0.55 (Alemayehu et al., 2014); and CO_2 Equivalent = 3.67 (Asadi and Pambudi, 2020). The study also utilized the global wood density database of Zanne et al. (2009) as the basis of wood density calculation. One-way analysis of variance (ANOVA) and Scheffé's Post Hoc multivariate analysis were use to evaluate statistical difference between species.

Results and Discussion

Forest Structure

Mangrove forests face extinction due to population growth and conversion for industrial use and urban settlements (FAO, 2007). It has been estimated that the loss of mangroves may reach 60% by 2030 (Simard et al. 2008). The mangrove forests resources of the Philippines have deteriorated significantly during the last 50 years. The country has now less than 120,000 ha of mangroves remaining, and much of that is only secondary growth and by no means pristine (Primavera, 2008). Moreover, the devastating effect of Super Typhoon Yolanda has drastically affected the mangrove forest in Leyte Island.

The species composition of mangrove forest in Cancabato Bay three (3) years after Super Typhoon Yolanda is shown in Table 1. A total of 1,466 trees from three (3) species of true mangroves was recorded from 64 (10mx10m) plots. *Rhizophora apiculata*, belonging to the *Rhizophoraceae* family, was observed in 62 of 64 plots, with 1,316 total individuals and mean DBH 0.848 cm. This was followed by *Avicenna marina* and *Sonneratia alba* with 127 and 23 total individuals, observed in 11 and 17 of 64 plots and mean DBH of 3.820 cm and 1.052 cm, respectively.

Table 1. IVI and Shannon-Weiner diversity index of mangroves in Cancabato Bay, Leyte Island

Species	Mean DBH (cm)	n	No. of plots where one species found	Total Basal Area of species	F	RF (%)	D	Rdom (%)	Density	RD (%)	IVI (%)	H'
Rhizophora apiculata	0.848	1316	62	1270.99	0.97	68.9	0.698	69.9	20.54	89.7	228.5	0.969
Sonneratia alba	1.052	23	17	31.53	0.27	18.9	0.017	1.7	0.36	1.6	22.2	0.065
Avicenna marina	3.820	127	11	517.09	0.17	12.2	0.284	28.4	1.98	8.7	49.3	0.211
Total	1.907	1466		1819.61	1.41	100	1	100	22.89	100	300	1.245

Note: Total Plots: 64; DBH – diameter at breast height; n = No. of Individuals; F = Frequency; RF = Relative Frequency; D = Dominance; Rdom = Relative Dominance; RD = Relative Density; IVI = Importance Value Index; *H'* = Diversity Index

R. apiculata had the highest relative frequency (RF) (68.9%), relative dominance (Rdom) of 69.9% and relative density (RD) of 89.7%, resulting in the highest importance value index (IVI) of 228.5%. The importance value of a species was determined based on the total contribution that a species made to the community to the number of plants within the 10mx10m plots (relative abundance), its influence on the other species through its competition, shading, or aggressiveness (relative dominance), and its contribution to the community by means of distribution (relative frequency) in a study plot (Faridha-Hanum et al. 2012; Rotaquio et al. 2007). *R. apiculata* got the highest analysis percentage among the other species because it occurred in large numbers in the study area. The said species was abundant because some concerned agencies and organizations replanted it since it can easily thrive and withstand high currents and tides. The said species was found in almost all plots because it grows at the interface between land and sea. It is also well adapted in dealing with natural stress (e.g., temperature, salinity, anoxia, and ultraviolet rays). The same result was obtained in the mangrove forest situated 60 km south of the protected Ranong Biosphere Reserve in Thailand, where *R. apiculata* rendered the highest importance value of 151.30% (Jachowski et al., 2013). However, because they live close to their tolerance limits, they may be particularly vulnerable to disturbances like those anthropogenic (Gevaña and Pampolina, 2009). The area experienced a decline in *S. alba* and *A. marina* due to the lack of replantation activities.

The second highest IVI (49.3%) was rendered by *A. marina (Verbenaceae family)* with RF, Rdom, and RD of 12.2%, 28.4%, and 8.7%, respectively. In contrast, *S. alba*, which belongs to the *Lythraceae family*, rendered the lowest IVI (22.2%) among the three species with 18.9%, 1.7%, and 1.6% RF, Rdom, and RD, respectively. These results are closely related to findings in a 15-ha privately-owned natural mangrove stand in Verde Passage, San Juan, Batangas, the Philippines, where the *Rhizophoraceae family* has the most significant number of species enormous diameter value followed by the *Avicenniaceae family* (Gevaña and Pampolina 2009). Moreover, a natural old-growth mangrove forest in Palawan, Avicenna officinalis, was observed in almost all plots, followed by *Sonneratia alba* and other five *Rhizophora* species, including *Rhizophora apiculata* (Abino et al., 2014).

Shannon-Weiner diversity (H') of *R. apiculata, A.marina,* and *S. alba* rendered very low diversity scale of 0.969, 0.211, and 0.065, respectively. The overall diversity index (H') of 1.245 was considered very low based on the diversity scale reported by Gevaña and Pampolina (2009). This is primarily due to the lack of species variation in the mangrove stands. On the other hand, these three mangrove species in Cancabato Bay are commonly found in the Philippines. These mangrove species grow only in a mangrove environment and reproductively adapted to saline, brackish, waterlogged and anaerobic conditions, according to FAO (2007). Globally, the importance value was relatively different than that of *Avicenna officinalis* in Botoc, Pinabacdao, Samar (Abino et al., 2014) and relatively the same as that of *R. apiculata* and *R. mucronata* in Southwest Thailand (Jachowski et al., 2013) and *R. mangle* in Mexico (Adame et al., 2015).

Mangrove Biomass and Carbon Stock Estimation

The mangrove forest in Cancabato Bay with an estimated 6.46 ha rendered total aboveground biomass of 7.33 Mg ha^{-1} while roots attributed 3.56 Mg ha^{-1} (Figure 2). Terrestrial forest usually accounts for 90% of the total tree's biomass (Bobon-Carnice and Lina, 2017 and 2021). However, mangrove trees in estuarine and intertidal areas have an aerial root system and extensive underground to support anchorage due to soft muddy soils and waterlogged environments (Sinacore et al., 2017). Hence, biomass accumulated 32.7% on its roots compared to its aboveground (67.3%). Nevertheless, such results are still very low compared to mangrove stands in Palawan on its aboveground (562.2 t ha^{-1}) and roots (196.5 t ha^{-1}). Though the same dominant species (*R. apiculata*) can be found in both areas, the average DBH in Palawan is 39.5 cm (Abino et al., 2014). Meanwhile, *R. apiculata*, *Avicenna marina*, and *Sonneratia alba* in Cancabato Bay had only an average DBH of 0.848 cm, 3.820 cm and 1.052 cm, respectively. According to some locals interviewed during the sampling, the area before the Super Typhoon Haiyan last November 8, 2013 was thick. It is even not passable, not unless passing through the Burayan River. However, this is no longer the case during the sampling, which was visible evidence that the storm surge indeed destroyed the mangrove forest. Most of the mangroves here are wildlings and regrowth from the last mangrove stand while some sampled plots were replanted seedlings.

The aboveground biomass and root-biomass ratio (T/R Ratio) rendered 2.06, consistent with the values indicated by Komiyama et al. (2008). However, this was higher than the mangrove stands in the Bay of Bengal, India (Kathiresan et al. 2013). Upland/terrestrial forest have higher TR ratio compared to mangrove forest since it needs to have a heavy root system to support aboveground weight aside from coping with environmental stresses such as salty water and high-water table (Kathiresan et al. 2013; Chandra et al. 2011).

The mean C-stocks of mangrove stand rendered 5.99 Mg C ha^{-1}, where roots and aboveground contributed 1.96 Mg C ha^{-1}, and 4.03 Mg C ha^{-1}, respectively. The low C-stock accumulation was due to small and still re-growing mangrove tree stands. Mangrove forest in Botoc, Pinabacdao, Samar contained 1091.53 t ha^{-1} aboveground biomass and 513.02 t C ha^{-1} C-stocks (Abino et al., 2014) which is very high compare to the results above (Figure 2). Relatedly, the mangrove forest in Sofala Bay has a total C-stock of 218.34 Mg ha^{-1}, 85% of which was stored belowground (185.2 Mg ha^{-1}) (soil and roots) (Sitoe et al. 2014). These values show the role of mangrove soil as a vital carbon pool and the total aboveground C. To have a better C-stock estimation, it should include live and dead trees, herbaceous, pneumatophores, and litter (Sitoe et al. 2014) (Bobon-Carnice and Lina, 2017 and 2021).

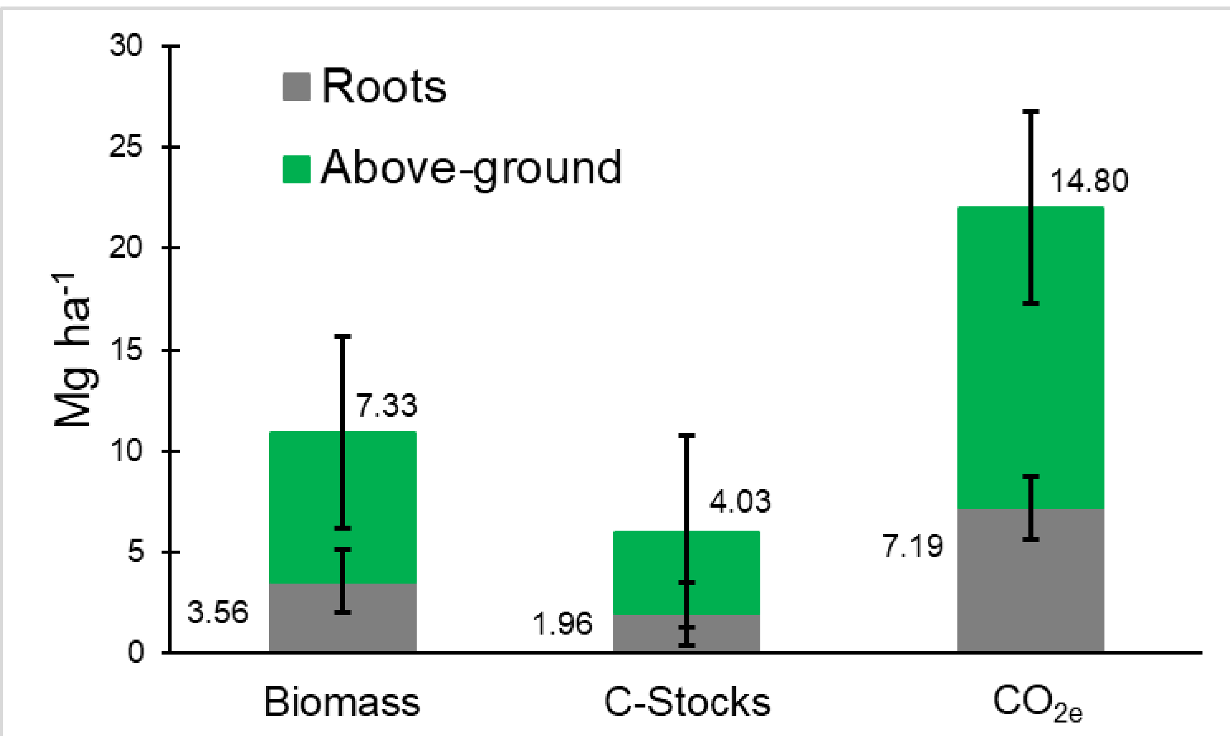

Figure 2. Biomass, C-stocks, and CO_{2e} sequestration of mangrove forest in Cancabato Bay, Tacloban City, Leyte Island, Philippines

Despite less species diversity and low DBH values, the Cancabato Bay mangrove stand could sequester C. The aboveground accumulated

14.8 Mg CO_{2e} ha^{-1}, while roots rendered 7.19 Mg CO_{2e} ha^{-1}, totaling 21.99 Mg CO_{2e} ha^{-1}. The indicated results are comparable with the mangrove stand study in Panay Island, wherein the mangrove area could sequester 9.44 Mg CO_{2e} ha^{-1} (Thompson et al. 2014). In contrast, the mangrove forest in Indonesia could sequester as much as 880 Mg CO_{2e} ha^{-1}, further implying that mangrove forests could play an important role in sequestering carbon dioxide from the atmosphere. Based on the mean values of the service of carbon sequestration for fringe forest (low intertidal, Estrada et al. 2015), the Cancabato Bay mangrove stand has a potential value of 1,809.34 US$ ha^{-1} yr^{-1}. It will be increasing as the mangrove stand grows. This further implies that the said mangrove stand can be further reforested and traded in voluntary carbon markets in the context of the Reducing Emissions from Deforestation and Forest Degradation (REDD) methodology.

The allometric method for biomass estimation is the most common as it is non-destructive than other methods (Kridiborworn et al., 2012). In particular, the allometric equations (Komiyama et al., 2005) used in this study only employ stem diameter which is easily quantifiable. *Avicenna marina*, locally known as piapi has the highest aboveground biomass, C-stocks, and CO_{2e} sequestration among species (Figure 3), rendering 0.497 MgB ha^{-1}, 0.273 Mg C ha^{-1}, 1.002 Mg CO_{2e} ha^{-1}, respectively. Such results could be attributed to its mean (3.820 cm) and highest DBH (27.80 cm). Such results are statistically significantly different (p=2.1735E-29) with the *Rhizophora apiculata* and *Sonneratia alba*, which rendered 0.012 Mg ha^{-1} and 0.021 Mg ha^{-1} for aboveground biomass, respectively, where estimation of biomass is critical in describing the status of mangroves and essential component of carbon sequestration estimation (Kirui et al. 2006). C-stocks of the two species are not significantly different, *R. apiculata* with 0.007 Mg C ha^{-1} and *Sonneratia alba* with 0.011 Mg C ha^{-1} (Figure 3). Although *R. apiculata*, locally known as *pagatpat*, has 1,316 individuals, its mean and highest DBH was 0.848 cm and 7.452 cm, respectively, resulting in low C-stock. The same with *Sonneratia alba*, locally known as *pagatpat*, with mean and highest DBH of 1.052 cm and 3.503 cm, respectively.

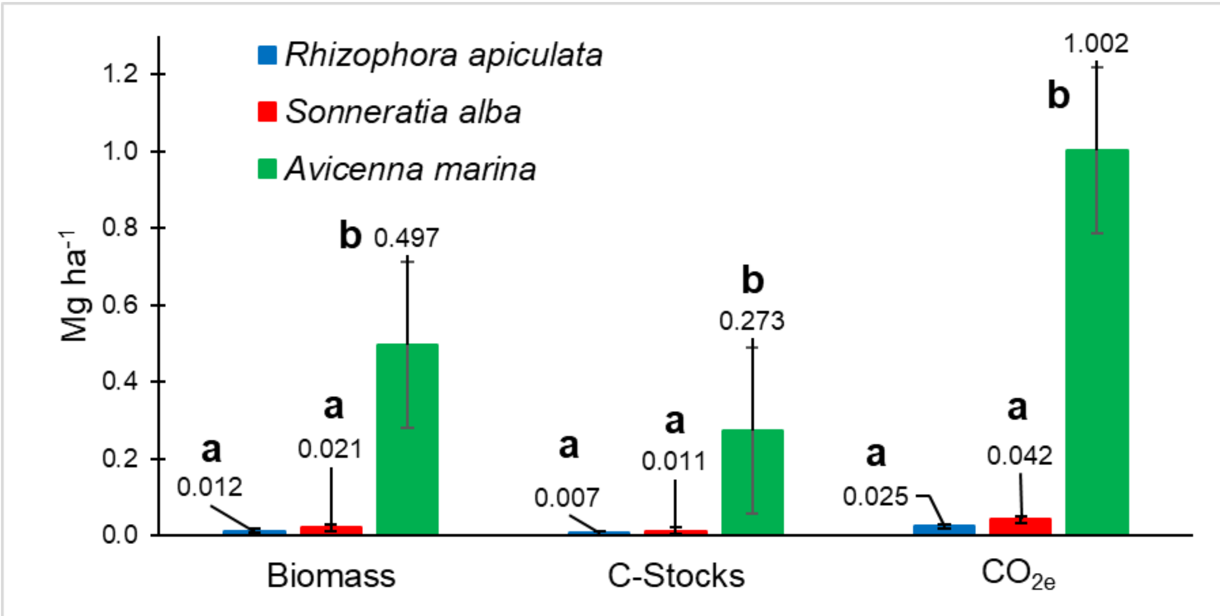

Figure 3. Biomass, C-stocks, and CO_{2e} sequestration of three (3) mangrove species found in in Cancabato Bay, Tacloban City, Leyte Island, Philippines. Different letters indicate statistically significant differences at $p < 0.05$

The results above are very low compared to those *Avicenna marinas, Rhizophora apiculate*, and *Sonneratia alba* that were studied in Verde Passage, Batangas, Philippines which has a DBH range of 56 cm, 11.5 – 24.0 cm, and 39.0 – 45.5 cm, respectively. Thus, it rendered higher aboveground and belowground biomass of 372.71 t ha^{-1} (Gevana and Pampolina, 2009). In a similar study in Rufiji River District, Tanzania, *R. mucronata* stored the highest amount of carbon per unit area of 39.87%, followed by *A. marina* with 28.06% of the total carbon (Lupembe, 2014). However, the biomass accumulation rate is mainly influenced by age of mangrove tree, species, management regime, and climate (Kairo et al. 2020).

Conclusions

The mangrove stand in Cancabato Bay has the remarkable capacity to store C-stocks and sequester CO_2. DBH, biomass, C-stocks, and CO_2 sequestered of the mangrove's species are considered low, and rehabilitation and conservation efforts should be intensified. In addition, to consider the whole mangrove ecosystem in estimating C-stocks, belowground C-stocks such as mangrove C-soil should be estimated. It can play a massive factor in storing a high amount of C. Further; a study should be conducted after 5-10 years to know the condition and amount of C-stored mangrove stand.

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