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Carbon stock assessment of a mangrove forest in Cotabato City, Philippines

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Abstract

The potential of mangrove forests to sequester carbon must be recognized by local government units and other stakeholders. Awareness on this aspect will promote participation among stakeholders in the conservation efforts for this ecosystem. The current study presents the carbon stock assessment of a mangrove forest in Cotabato City, Philippines. There were 3 study sites purposively selected for this study. A total of 12 sampling plots with a size of 5m × 40m each were established in the three study sites. Above ground and below ground biomass were determined. Two soil samples were obtained in each plot for soil carbon analysis. Mean total biomass density is about 605 Mg ha^{-1} with mean total carbon stored of about 491 MgC ha^{-1} and the mean carbon saturation deficit is 0.45. These figures show the importance of this mangrove ecosystem in sequestering substantial amount of atmospheric carbon, thus the coordinated efforts of Local Government Units, residents and private organizations are necessary for the sustainability of these natural resources.

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Introduction

Mangroves not only play a crucial role in global carbon cycle (Cao, 1996) but also in addressing climate change and climate change related problems (Camacho *et al.,* 2011). The ecosystem services mangroves can provide includes bio protection from littoral erosion (Naylor *et al.,* 2002), dissipation of the energy of tsunamis and protection from cyclonic storms (Alongi, 2002) and it also contributes to the diversity, richness and productivity of coastal ecosystems (Albino *et al.,* 2014). However, most often the economic valuations of mangroves include only direct uses and products of mangroves (Zhao and Wu, 2015).

Magrove deforestation and degradation is a worldwide phenomenon (Duke *et al.,* 2007) with an annual rate of 1 to 2% (Wilkie and Fortuna, 2003). In the Philippines, the decreasing trend of mangrove total area (Long *et al.,* 2013; Fortes and Salmo III, 2017) was due to fish pond development (Primavera, 1995) and excessive cutting for firewood and construction materials (Eusebio *et al.,* 1986). Furthermore, the increased population pressures in coastal areas and lack of awareness have led to large scale conversion of mangroves to other uses (Wilkie and Fortuna, 2003).

The Philippines holds at least 50 % mangrove species of the world's approximately 65 species (Garcia *et al.,* 2014) covering 303,387 ha in which 658 ha is located in Cotabato (Philippine Forestry Statistic, 2017). Conserving this natural resource would be beneficial especially to the residence of Cotabato City. Recognizing the blue carbon stock (Gevaña *et al.,* 2018) potential of this mangrove would encourage local government units and residents to participate in mangrove conservation activities. Hence, this study is conducted.

Materials and Methods

Study site

The study was undertaken in a mangrove forest in Cotabato City which is located along the coastal line of three barangays namely; Kalanganan Mother, Kalanganan I and Kalanganan II. This thin strip of mangrove forest area lies within the coordinates of 7°11'30" to 7°15'25"north latitude and 123°59'30" to 124°13'00" east latitude in which a recent study stated that about 38 hectares of the total area remain as mangrove forest. The area extends towards southwest traversing Timako Hill, the highest elevated portion of Cotabato City, Philippines (LGU Cotabato City, 2002). Sample plots were purposively selected to include bakawan-dominated portions of the study site. A total of 12 sampling plots with a size of 5m x 40m (Figure 1) each were established in the three study sites distributed as follows: Kalanganan I- 2 plots, Kalanganan II- 8 plots, and Kalanganan Mother- 2 plots.

Aboveground and belowground biomass

In determining the aboveground and belowground biomass of trees, the following allometric equations developed by Komiyama *et al.,* (2005) were used:

a. Aboveground biomass (W_{top})= 0.251ρ $(D)^{2.46}$

Where:

ρ= wood density of the species, g/cc

D=diameter at breast height, cm

b. Root biomass (W_R) = $0.199\rho^{0.899}$ $(D)^{222}$

Where:

W_R = root biomass or belowground tree weight, kg

ρ = wood density, g/cc

D = diameter beast height, cm

Wood density values were sourced from Saenger (202) as secondary data. Biomass was converted to the equivalent amount of carbon by multiplying biomass by 0.45 which is the average C content value used in the study of Gevaña and Pampolina (2009).

Litter biomass

Nested subplot sizes of 1 x 1 m were established within the 5 x 40 m plot (figure 1). All debris found within the sampled area were collected and weighed for fresh weight. The samples were then air-dried, weighed again and brought to the Soil and Plant Analysis Laboratory (SPAL) of the College of Agriculture of CMU, Musuan, Bukidnon for carbon content analysis. To determine litter biomass, the following formula was used:

$$Total\ fresh\ weight\ (kg/m^2) = \frac{TFW\ xSDW}{SFW\ x\ SA}$$

Where:

TFW = total fresh weight, kg

SDW= subsample dry weight, kg

SFW =subsample fresh weight, kg

SA = sample area, m^2

Soil carbon

Five hundred grams of sediment were randomly taken from 30 cm layer within the 1 × 1 m subplot which was nested within the 5 × 40 m plot. Two soil samples were collected in each plot for texture analysis. The samples were air-dried and mixed and were brought to (SPAL) for soil carbon analysis.

Bulk density was determined by choosing an undisturbed area near the plot, removing debris from the surface and carefully driving into the upper 10cm layer of the soil using a metal core of 5.3 cm in diameter and 30 cm in length .One sample was collected in each plot for physical analysis. The extracted sediment cores were carefully wrapped with foil and placed in a labelled plastic bag and sealed for processing at the SPAL for bulk density determination. The undisturbed cores were immediately weighed and oven-dried. Dry weights were recorded. Bulk density values were computed using this formula:

Bulk density (g/cc) = dry weight of core (g) /volume of cylinder (cc)

$BD = W_2/V$

Where:

W_2 = oven dry weight, g

V = volume of the cylinder, cc

BD =bulk density, g/cc

The dry mass of sediment and the equivalent C stock were determined by using the following formulae:

Sediment mass at specified depth (Mg) = Bulk density at specified depth (Mg/m^3) × 10,000 m^2 × depth (m)

Sediment Cat specified depth (Mg) = Soil mass at specified depth (Mg) x % organic Cat specified depth / 100 Total C storage was estimated by getting the sum of the aboveground, belowground, litter and soil C stocks.

Carbon saturation deficit

Soil texture was analysed to determine carbon saturation deficit of the study sites. The following equation of van Noordwijk*et al.,* (1997) was used:

$C_{satDeficit} = (C_{ref} - C_{org})/(C_{ref}) = 1 - (C_{org}/C_{ref})$

Where:

C_{org}/C_{ref} = SOC content relative to that for forest soils of the same texture and pH

C_{ref} = a reference soil carbon level representative of forest soil

= exp[1.256 + 0.00994 x % clay + 0.00699 x % silt – 0.156 x pH_{KCl} x elevation + 0.834 (if soil is andisol) + 0.363 (for swamp forest on wetland soils)]

If the value of the C_{org}/C_{ref} ratio is 1, this means the soil is similar to that of a forest and basically carbon saturated, and values less than one indicate a carbon deficit relative to the forest soil.

Data analysis

Data obtained in this study were analyzed using SPSS statistical package for analysis of variance (ANOVA) to compare differences in carbon stock among study sites. Differences between carbon stock means were further analyzed using post hoc analysis. All other data were analyzed using descriptive statistics.

Results and discussion

Biomass production and carbon storage

Mean total biomass density is about 605 Mg ha^{-1} with Kalanganan I having the highest with approximately 808 Mg ha^{-1} (Table 1).

Table 1. Biomass production of sampled carbon pools of mangrove forest in the study area.

SITE	TREES, Mg ha^{-1}	LITTER LAYER, Mg ha^{-1}	ROOT, Mg ha^{-1}	TOTAL BIOMASS DENSITY, Mg ha^{-1}
Kalanganan I	560.83	48.4	198.60	807.83
Kalanganan Mother	410.43	37.8	140.48	588.71
Kalanganan II	284.57	31.26	102.46	418.29
Mean	418.61	39.15	147.18	604.94

This observation is highly attributable to large girth of the trees measured in this sampling site. Despite of the fact that Kalanganan II had the most numerous trees, it had the least biomass density at 418 Mg ha^{-1}. This is due to the fact that trees in this sampling site have smaller girths or diameters.

Among sampled carbon pools, trees provided the bulk of produced biomass. This is expected as tree trunks are not only large but also are long-lived such that they can store the most carbon in a particular forest. Root biomass has the second highest among the sampled carbon pools across all study sites ranging from 102 to 199 Mg ha^{-1} with Kalanganan I as the highest. On the other hand, litter biomass in this study has an average of only 39 Mg ha^{-1}. Rate of litter layer formation and decomposition depends on the volume of the growing tree stock and extent of ground vegetation. Litter is broken down by bacteria and fungi in the soil using their enzymes to convert it into forms useful to them (Liski, 2004). In addition, the process of decomposition results to the release of some carbon sequestered in the litter wherein the warmer the day, the faster is the decomposition process. The more litter is left undecomposed, the faster is the rate of carbon storage in the soil.

Table 2. Carbon storage in the sampled carbon pools of a mangrove forest in the study area.

SITE	TREES, MgC ha^{-1}	LITTER, MgC ha^{-1}	ROOT, MgC ha^{-1}	SOIL, MgC ha^{-1}	TOTAL CARBON STORED**, MgC ha^{-1}
Kalanganan I	252.38	24.14	89.37	207.19	573.08[a]
Kalanganan Mother	184.65	11.12	63.22	181.38	440.37[a]
Kalanganan II	128.06	18.89	46.14	265.52	458.61[a]
Mean*	188.38[a]	18.05[b]	66.23[b]	218.03[a]	490.69

* Carbon pool mean values with the same letter superscript (within same row) are not significantly different from each other

** Mean values of total carbon stored among sites having the same letter superscript (within the same column) are not significantly different from each other.

Carbon storage

As shown in Table 2, mean total carbon stored in the study area is about 491 MgC ha^{-1}. Kalanganan I had the highest but the difference is not statistically significant with those of the other two sampling sites. This is much higher compared to the study of Gevaña and Pampolina (2009) wherein the mangrove forest in San Juan, Batangas yielded only an average of 115.45 tC ha^{-1}. Note that one Mg is also equal to one ton. The extent of carbon storage of mangrove forest in this present study which is between 440 to 573 MgC ha^{-1} is rather high and is comparable to that of a natural forest studied by Lasco *et al.,* (2004) whose carbon density reached 518 MgC ha^{-1}. As a general rule, the more biomass produced such as the case in this study, the greater the amount of carbon sequestered. This is expected as physiologically, trees continue to accumulate biomass as it gets older although the rate varies by species.

When comparing carbon pools, trees and soil comprise the highest carbon stock with a mean of about 188 MgC ha^{-1} and 218 MgC ha^{-1}, respectively. These values are statistically higher as compared to carbon stored in litter and roots.

Nevertheless, the mangrove forest's potential to sequester carbon would surely be greatly enhanced as it gets older resulting from the continuous accumulation of biomass. Meanwhile, soil organic carbon generally was found out to be statistically higher in this study ranging from 181 to 265 MgC ha^{-1}. Carbon in the soil is a significant pool as it has the longest residence time among organic carbon pools in the forest (Lugo & Brown, 1993). The soil in the area has probably accumulated already a high amount of organic carbon through the years.

Table 3. Properties of soils in the sampling sites.

Sites	Plot #	Soil Properties			Textural Classification			
		pH	OM,%	SOC,%	%Sand	%Clay	%Silt	Classification
Kalanganan I	1	5.55	5.52	3.21	66.62	4.95	28.43	Sandy loam
	2	5.54	5.21	3.03	39.79	25.81	34.41	Clay loam
Kalanganan	1	6.74	6.29	3.66	65.28	3.68	31.05	Sandy loam
Mother	2	6.47	5.83	3.39	55.20	0.00	44.80	Sandy loam
Kalanganan II	1	5.73	10.73	6.24	40.97	0.00	59.03	Silt loam
	2	5.56	9.97	5.79	54.33	0.00	45.67	Sandy loam
	3	5.53	10.35	6.02	59.49	0.00	40.51	Sandy loam
	4	6.95	6.57	3.82	54.74	0.00	45.26	Sandy loam
	5	7.29	5.91	3.44	64.16	0.00	35.84	Sandy loam
	6	5.49	14.57	8.47	30.71	20.79	48.51	Loam
	7	5.51	6.57	3.82	69.70	3.69	26.62	Sandy loam
	8	5.59	12.32	7.16	69.53	0.00	30.47	Sandy loam
Mean		6.0	8.32	4.84	55.88	4.91	39.22	

Donato *et al.* (2011) even stated that carbon stored in soil accounts for 92% of the total carbon stored. Organic-rich soils which range from 0.5 m to more than 3 m in depth accounts for 49–98% of carbon storage in these systems. Mangroves can trap not only fine sediment and organic matter but also coarse sediment driven by storm waves to form special mangrove sediment (Patil *et al*., 2012).

The mangrove forest's ability to store such large amounts of carbon can be attributed, in part, to the deep organic-rich soils in which it thrives.

Mangrove-sediment carbon stores were on average five times larger than those typically observed in temperate, boreal and tropical terrestrial forests, on a per-unit-area basis (Eng, 2011).

Table 4. Carbon saturation deficit values of soils in the study sites.

STUDY SITE	MEAN C_{ref}	MEAN C_{org}	MEAN C_{org}/C_{ref}	MEAN C_{satdef}
Kalangan I	7.63	3.17	0.42	0.58
Kalangan Mother	5.88	2.46	0.42	0.58
Kalangan II	6.83	5.32	0.80	0.20
Grand Mean	6.78	3.65	0.55	0.45

Meanwhile, between aboveground (trees and litter) and belowground carbon (roots and soil), the latter is higher in this present study. Donato *et al.,* (2011) and Kauffman *et al.,* (2011) reported that belowground carbon is often the largest pool in a mangrove ecosystem and measuring it is important in determining long-term dynamics associated with climate change and/or land management. It usually constitutes over 50% and sometimes over 90% of the total carbon stock of mangrove.

Carbon Saturation Deficit of Soils in the Study Area

Table 3 presents the results of analysis on soil properties in the study area. Soil pH in the area is generally slightly acidic ranging from 5.51 to 7.29 with an average of 6.0. On the other hand, mean organic matter and percent soil organic carbon (SOC) is 8.32% and 4.84%, respectively. Generally, textural classification of soils in the mangrove forest under study is sandy loam.

It is difficult to interpret absolute soil carbon levels considering their variation between soils of different texture and mineralogy under the same land cover types. Van Noordwijk *et al.* (1997) suggested for the determination of carbon saturation deficit which is defined as "the difference between the current organic carbon (C_{org}) content and a reference content, C_{ref}, which is supposed to indicate the undisturbed forest condition". The ratio of the measured C_{org} and a reference C_{org} value for forest (top) soils of the same texture and pH serves as a sustainability indicator.

If the value of the C_{org}/C_{ref} ratio is one, this means the soil is similar to that of a forest and basically carbon saturated, and values less than one indicate a carbon deficit relative to the forest soil.

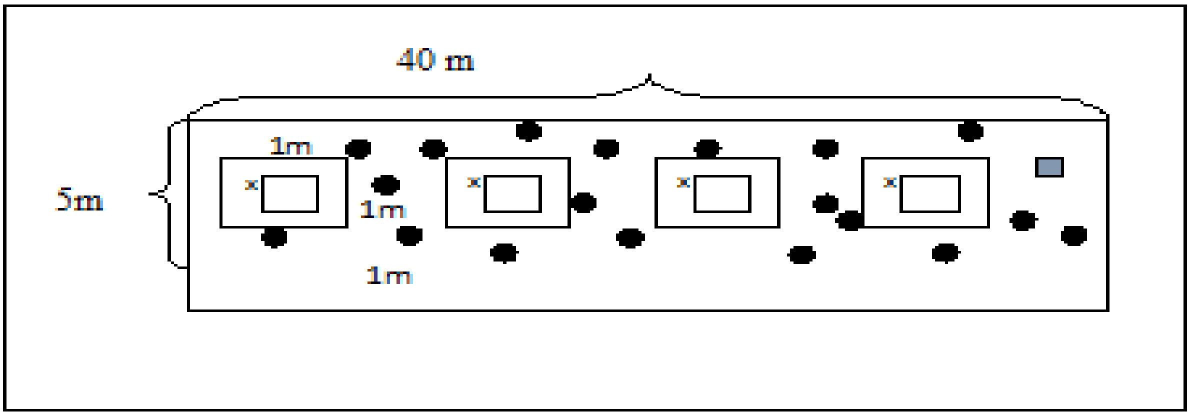

Fig. 1. Diagram of a nested plot used in the study (adopted from Hairiah *et al.*, 2001).

Legend:

trees 5cm & above

soil samples for physical analysis

x-soil samples for chemical analysis.

In this study, mean carbon saturation deficit is 0.45 with Kalangan 2 having the least at 0.2 (Table 4). This indicates that soil in this sampling site is comparable to that of a natural forest in terms of soil organic carbon. This value also conforms to the study of Bajuyo (2012) in which a mangrove forest in El Salvador, Misamis Oriental yielded a carbon saturation deficit of only 0.05.

Conclusion

This study presents the carbon stocks of a mangrove forest in Cotabato City, Phillipines. The study site's soil pH in the area is generally slightly acidic ranging from 5.51 to 7.29 with an average of 6.0. On the other hand, mean organic matter and percent soil organic carbon (SOC) is 8.32% and 4.84%, respectively. Generally, textural classification of soils in the mangrove forest under study is sandy loam.

Mean total biomass density is about 605 Mg $ha^{-1}$with mean total carbon stored in the study area is about 491 MgC ha^{-1} and mean carbon saturation deficit is 0.45.

These figures show the importance of this mangrove ecosystem in sequestering substantial amount of atmospheric carbon, thus the coordinated efforts of Local Government Units, Residents and private organization to conserve this ecosystem is recommended.

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