Pak. J. Bot., 46(6): 1955-1962, 2014.

SPECIES DIVERSITY, BIOMASS, AND CARBON STOCK ASSESSMENTS OF A NATURAL MANGROVE FOREST IN PALAWAN, PHILIPPINES

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Abstract

Philippines claims international recognition for its mangrove-rich ecosystem which play significant functions from the viewpoint of ecosystem services and climate change mitigation. In this study, we assessed the species diversity of the natural mangrove forest of Bahile, Puerto Princesa City, Palawan and evaluated its potential to sequester and store carbon. Sixteen plots with a size of 10 m × 10 m were established using quadrat sampling technique to identify, record, and measure the trees. Diversity index and allometric equations were utilized to determine species diversity, and biomass and carbon stocks. Sediment samples in undisturbed portions using a 30 cm high and 5 cm diameter corer were collected in all plots to determine near-surface sediment carbon. The diversity index (H' = 0.9918) was very low having a total of five true mangrove species identified dominated by *Rhizophora apiculata* Bl. with an importance value index of 148.1%. Among the stands, 74% of the total biomass was attributed to the above-ground (561.2 t ha^{-1}) while 26% was credited to the roots (196.5 t ha^{-1}). The total carbon sequestered and stored in the above-ground and root biomass were 263.8 t C ha^{-1} (50%) and 92.3 t C ha^{-1} (17%), respectively. Sediments contained 33% (173.75 t C ha^{-1}) of the mangrove C-stocks. Stored carbon was equivalent to 1944.5 t CO_2 ha^{-1}. These values suggest that Bahile natural mangrove forest has a potential to sequester and store substantial amounts of atmospheric carbon, hence the need for sustainable management and protection of this important coastal ecosystem.

Key words: Allometric equation; Carbon stock; Diversity index; *Rhizophora apiculata*; Sediment organic carbon.

Introduction

Forests are known as standing stores of sequestered atmospheric carbon. Given the increased importance of a forest ecosystem as valuable carbon pool, it draws significant attention as the global community becomes progressively more concerned about climate change. Of these ecosystems, the roles of mangrove forests to sequester substantial amounts of atmospheric carbon dioxide (CO_2) and store carbon in its biomass and sediments have been recently underscored (Murdiyarso *et al.*, 2009; Chen *et al.*, 2012; Kauffman & Donato, 2012). Moreover, the economic significance of mangroves as efficient blue carbon sink is also becoming popular (Nellemann *et al.*, 2009; Lawrence, 2012). While mangroves cover only around 0.7% (approximately 140000 km^2) of global tropical forests (Giri *et al.*, 2011), they store up to 20 billion t C which is a little more than twice the annual global CO_2 emission and far exceeds the mean carbon stock (C-stock) in tropical upland, temperate, and boreal forests (Donato *et al.*, 2011).

In terms of floral and faunal regimes, mangrove forests are among the most productive and biologically complex ecosystems. The Philippine mangroves alone harbour at least 42 species of trees belonging to 18 families out of around 70 true mangrove species in the world (Polidoro *et al.*, 2010; Samson & Rollon, 2011). The country also claims international recognition being ranked 16th among the most mangrove-rich countries with an area of 259600 ha representing 1.9% of the global mangrove (Siikamaki *et al.*, 2012). Nutrients, heavy metals and sediments that find their way from the uplands down to the estuaries through the tributaries are absorbed by these mangroves (Ellison, 2008; Khattak *et al.*, 2012; Latiff, 2012), aside from serving as natural breakwaters, dissipating the energy of the waves and tsunamis and protection from cyclonic storms (Alongi, 2008; Polidoro *et al.*, 2010).

Despite their strategic importance, mangroves are among the most threatened and rapidly disappearing natural environments in the world. The Food and Agriculture Organization (FAO) reported in 2007 that global mangrove coverage had declined from 18.8 million ha in 1980 to 15.2 million ha by the end of 2005, corresponding to approximately 20% of the mangrove existing worldwide in 1980. This component of wetlands is under constant flux attributed to immense pressure from unsustainable anthropogenic activities and their vulnerability to the impacts of climate change such as sea-level rise (Anon., 2007; Giri *et al.*, 2011). In the Philippines, the total area of mangroves has decreased by almost half, from 400000-500000 ha recorded several decades ago (Brown & Fischer, 1920; Primavera, 2000) to the current estimate of 259600 ha (Siikamaki *et al.*, 2012). Vast areas of mangroves in this country have been subjected to natural and human-induced degradations specifically conversion to fish and shrimp ponds (Lawrence, 2012). This ecosystem is made up of carbon-based life forms in plant biomass and soil through litter fall. Hence, the loss of mangrove cover predicates the tremendous reduction in forest biomass augmenting the concentration of CO_2 in the atmosphere.

The province of Palawan contains around 22% of the total mangrove cover of the Philippines (Anon., 2011). The province capital, Puerto Princesa, is a city in the country where the total area of mangrove forests does not decline, but is increasing due to the sustained commitment on coastal reforestation and afforestation of the community. Lasco and Pulhin (2004) reported that the estimated mean biomass of mangrove forests in the Philippines is around 409 t ha^{-1} with a corresponding stored carbon of 184 t C ha^{-1}. Consequently, a huge percentage of the total carbon sequestered and stored in the biomass and sediment of the mangroves are attributed to the stands located in the province of Palawan.

Most of the studies on carbon storage and sequestration conducted in the Philippines center on terrestrial vegetation like second-growth forests, plantation forests, and agroforestry. There is, however, lack of information on carbon sequestration and storage of Philippine coastal vegetation in general and mangrove forest in particular. Therefore, this study aims to assess species diversity as well as to estimate above-ground and root biomass, and C-stocks in one of the coastal zones in Philippine archipelago with the largest remaining natural mangrove stands, particularly the province of Palawan.

Materials and Methods

Study site: This study was carried out in the natural mangrove stand situated in the coast of Bahile Village (10°3'3"N 118°43'2"E) which is located 77 km north of the geographical center of the 450 km-long island of Palawan, the main land mass of the westernmost province of the Philippines (Fig. 1). This site was selected based on accessibility and safety in going to and from the natural mangrove stands. The natural mangrove formation is dominated by *Rhizophora apiculata* Bl. in association with *Rhizophora mucronat*a Lamk. and *Bruguiera gymnorrhiza* (L.) Lamk.. *Lumnitzera littorea* (Jack) Voigt. and *Xylocarpus granatum* Koen. were rarely observed in the mangrove stand.

On the basis of the Puerto Princesa City profile (2012), the west coast which encompasses the Bahile Village has equal lengths of dry and rainy seasons. Dry season starts in November and ends until April while the rainy months begin in May and lasts in October. The highest amount of rainfall is observed during September while February is the most dry. The mean annual precipitation (MAP) is 1148 mm while the mean annual temperature (MAT) is 29°C. The soil formations in Bahile village are mostly alluvial which is characterized by high fertility.

Data collection: Sixteen plots of size 10 × 10m were established through a nondestructive quadrat sampling technique to determine the species composition and structure in the study area. The plots were laid with 20 to 30 m distance in between depending on vegetation characteristics and landscape. Inside each plot, all trees with at least 5 cm in diameter were identified, and measured the trunk diameters (cm) and total height (m). We measured the trunk diameters at 30 cm above the highest prop root for *Rhizophora* species, 30 cm above the buttress for big *Bruguiera* species, whereas the rest were measured at DBH (130 cm above ground). Branch bark and stem (6-8 cm diameter, 10-20 cm long) samples of the three dominant mangrove species in the study site were taken to the laboratory for carbon content analysis.

The sediments were sampled for bulk density (BD) and organic matter (OM) content determination. Soil samples were randomly collected within each plot in undisturbed portions using a 30 cm high and 5 cm diameter corer, with the aim of determining the near-surface sediment carbon storage. The core samples were stored separately in labeled and sealed plastic bags for fresh weight determination, drying, and BD and OM content analysis.

Data analysis: The importance value index (IVI) which indicates the structural importance of each species in the community was obtained by adding the percentage values of relative frequency (RF), relative dominance (RDom) and relative density (RD), where:

$$RF = \frac{Number\ \ of\ \ occurrence\ \ of\ \ the\ \ species}{Number\ \ of\ \ occurrence\ \ of\ \ all\ \ the\ \ species} \times 100 \qquad (1)$$

$$RDom = \frac{Total\ \ basal\ \ area\ \ of\ \ the\ \ species}{Total\ \ basal\ \ area\ \ of\ \ all\ \ the\ \ species} \times 100 \qquad (2)$$

$$RD = \frac{Number\ \ of\ \ individual\ \ of\ \ the\ \ species}{Number\ \ of\ \ individual\ \ of\ \ all\ \ the\ \ species} \times 100 \qquad (3)$$

Diversity index, determined in this study using the Shannon-Wiener's Index (Shannon & Weaver, 1963), indicates a quantitative description of mangrove habitat in terms of species distribution and evenness. This species diversity index was used in several studies (Gevaña & Pampolina, 2009; Sharma *et al.*, 2010; Lumbres *et al.*, 2012) and was calculated using the following form:

$$H' = -\sum p_i \ln p_i \qquad (4)$$

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

To measure the carbon stored in the mangrove ecosystems, two pools of carbon were considered: the carbon present in the biomass (above-ground and roots) and the carbon stored in the sediment. Estimates of above-ground biomass (W_{top}) and root biomass (W_R) were calculated using the allometric equations for mangroves developed by Komiyama *et al.* (2005) for Southeast Asian mangroves. The maximum diameter of trees included in the derivation of these equations was 49 cm with a total number of 104 trees. These allometric equations which use diameter and wood density as predictive variables have a coefficient of determination (R^2) of 0.979 and 0.954, respectively, and are comparably reliable with allometric equations derived for natural stands (Chave *et al.*, 2005; Hossain *et al.*, 2008; Kauffman & Cole, 2010). The following common allometric equations were used:

$$W_{top} = 0.251 \rho D^{2.46} \qquad (5)$$

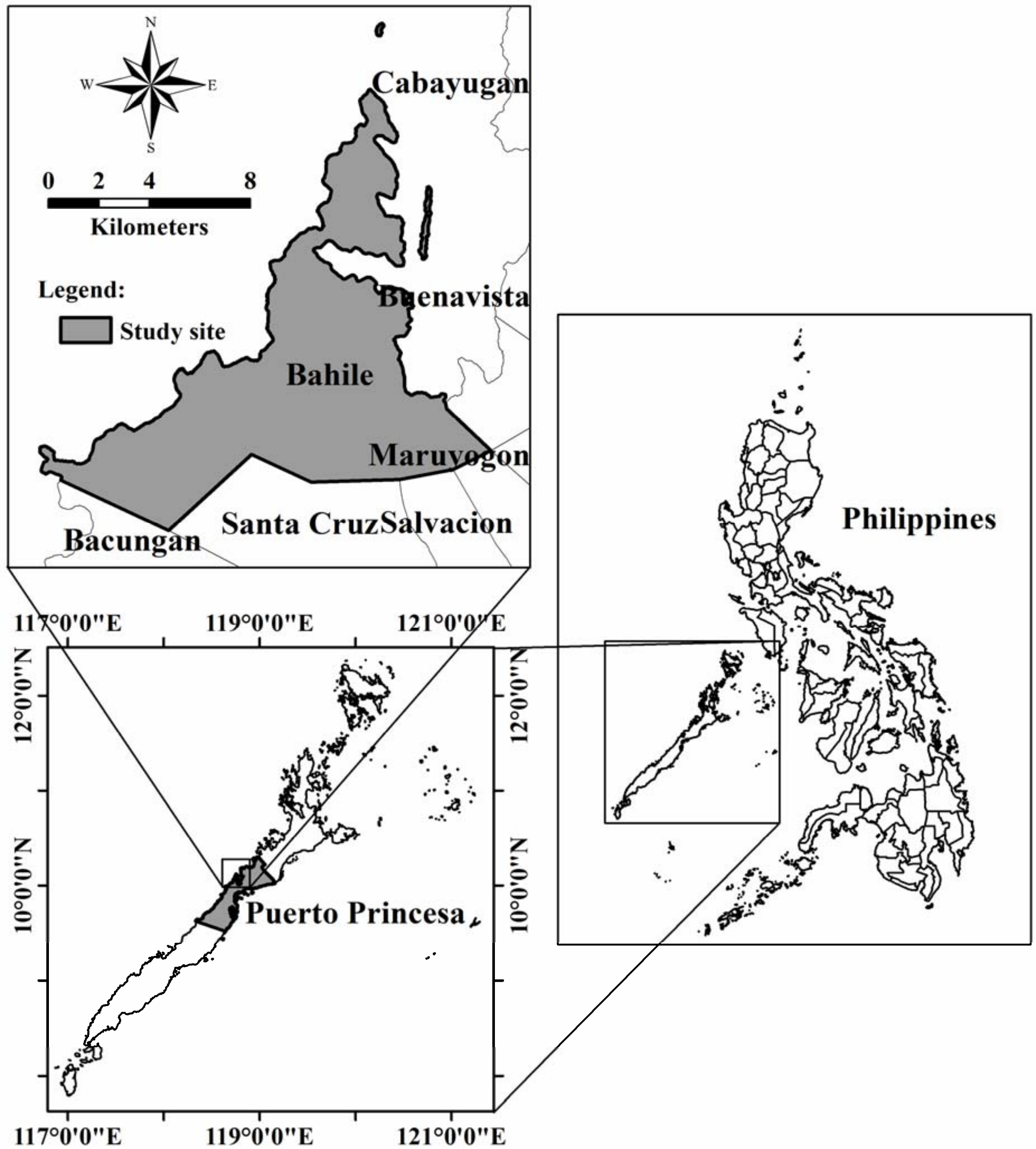

Fig. 1. Location map of the study site in Bahile, Puerto Princesa City, Palawan, Philippines.

$$W_R = 0.199\rho^{0.899} D^{2.22} \quad (6)$$

where W_{top} is the above-ground biomass (kg); W_R is the root biomass (kg); ρ is the wood density of the species; and D is the diameter at breast height. The values of total biomass (above-ground and root) per plot was summed for all plots and averaged to get the mean stand biomass which was then converted to tons per hectare. Carbon pools of the above-ground and root components were calculated as the product of biomass multiplied by the carbon concentration. The carbon fraction was determined through analysis of stem and branch bark samples of the three dominant mangrove species. Samples were oven dried at 105°C until constant weights were attained (within 48 hours). Carbon contents of the oven dried samples (10-20 g) were analyzed via the automated carbon analysis-mass spectrometry continuous flow technique at the International Rice Research Institute (IRRI) Analytical Services Laboratory, and resulted to an average of 47% carbon fraction.

For near-surface sediment carbon determination, sediment cores were brought to the laboratory for fresh weight determination. Samples were placed in an oven at

105°C and dried until constant weights were attained (within 48 hours). BD was calculated as the ratio between the dry weight of the core sample divided by the volume of the sample. BD of the soil and height of corer were used to compute the soil mass per hectare. To determine the soil OM content, sediment samples were analyzed following the methods of Walkley & Black (1934). Soil organic carbon was calculated as the OM concentration (percentage) divided by 1.724 (Van Bemmelen factor), based on the assumption that the soil OM contains about 58% organic carbon (Perie & Ouimet, 2008; Hossain *et al.*, 2012). The BD, soil mass and soil/sediment carbon per hectare were determined using the following forms (Gevaña & Pampolina, 2009):

$$\text{BD (g cm}^{-3}) = \frac{\text{Dry weight of core (g)}}{\text{Volume of cylinder (cm}^3)} \quad (7)$$

$$\text{Sediment mass per ha at specified depth (t ha}^{-1}) = \text{BD at specified depth (g cm}^{-3}) * 10{,}000 \text{ m}^2 * \text{depth (m)} \quad (8)$$

$$\text{Sediment C per ha at specified depth (t C ha}^{-1}) = \text{Soil mass at specified depth (t ha}^{-1}) * \text{\% organic C at specified depth}/100 \quad (9)$$

The total sediment carbon pool was determined by summing the carbon mass per plot and averaged to get the mean sediment C-stock of the stand. The total C-stock was estimated by adding the biomass and sediment C-stocks. The ratio of molecular weight of CO_2 to carbon was utilized in the conversion of biomass and sediment C-stocks to their CO_2 equivalent. According to Kauffman & Donato (2012), greenhouse gas inventories and emissions are often reported in units of CO_2 equivalents since it is the most common greenhouse gas form of carbon.

Results and Discussion

Species diversity: A total of 146 sample trees representing five true mangrove species, namely: *R. apiculata*, *R. mucronat*a, *B. gymnorrhiza*, *L. littorea* and *X. granatum*, belonging to three families were recorded at the natural mangrove stand of Bahile (Table 1). True mangrove species are those that are exclusively restricted to tropical intertidal habitats and do not extend into terrestrial plant community and are morphologically, physiologically and reproductively adapted to saline, waterlogged and anaerobic condition (Anon., 2007; Polidoro *et al.*, 2010). The DBH of the mangroves ranging from 5.5 cm to 48.5 cm, total height varying between 4.0 m and 25.0 m, with average of 19.9 cm and 9.9 m. *B. gymnorrhiza* registered the largest girth while *R. mucronat*a was the tallest. The average density of mangroves in the study site was 913 trees ha^{-1}.

Among the species recorded in the mangrove stand, *R. apiculata* was found dominating the mangrove forest with an IVI of 148.1%; 93 individuals of this species occurred in 15 plots (Table 2). It was followed by *R. mucronat*a (80.3%) and *B. gymnorrhiza* (56.0%). All species with the highest importance values belonged to the family Rhizophoraceae. The importance value of a species was determined based on the total contribution that a species made to the community in relation to the number of plants within the quadrats (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 (Faridah-Hanum *et al.*, 2012).

Table 1. Species composition and stand structure of the natural mangrove forest in Bahile, Puerto Princesa City, Palawan, Philippines.

Plot	No. of trees	Species	DBH (cm)				Height (m)			
			Mean	Min.	Max.	SD	Mean	Min.	Max.	SD
1.	2	Rm	39.5	38.8	40.3	-	24.0	23.0	25.0	-
2.	6	Rm, Ra	31.7	25.0	38.0	5.4	18.7	17.0	22.0	1.9
3.	5	Ra, Rm	19.9	15.0	24.3	3.7	11.9	8.0	14.0	2.5
4.	7	Ra, Rm, Bg	32.4	10.3	48.5	15.2	14.7	6.0	20.0	5.9
5.	12	Rm, Bg, Ra	23.3	7.0	41.0	11.8	11.0	5.5	17.0	3.4
6.	8	Rm, Ra	20.3	8.0	39.0	11.8	9.9	5.0	13.0	2.7
7.	8	Ra, Rm	21.5	7.5	34.8	11.1	10.1	4.8	16.0	3.4
8.	12	Ra	16.9	11.3	26.5	4.1	5.3	4.0	7.0	0.9
9.	9	Rm, Ra, Bg	17.1	5.5	44.8	13.7	8.2	4.0	14.0	3.9
10.	8	Ra, Bg	16.8	8.0	35.0	8.5	8.6	4.5	13.0	3.0
11.	14	Ra, Xg, Bg, Ll	12.3	5.5	29.8	7.1	7.0	4.0	13.0	2.7
12.	8	Ra	22.9	21.0	26.0	1.5	10.3	9.0	11.0	0.7
13.	9	Ra, Bg	24.5	11.5	39.5	10.2	11.3	7.0	14.0	2.3
14.	17	Ra, Bg, Rm	14.9	6.4	33.6	7.1	8.8	4.5	14.0	2.5
15.	5	Bg, Rm, Ra	35.8	23.2	42.2	7.6	13.5	13.0	14.0	0.5
16.	16	Ll, Ra, Bg, Rm	11.9	5.5	39.0	9.9	7.4	4.5	14.0	3.4

Note: Rm = *Rhizophora mucronata*, Ra = *Rhizophora apiculata*, Bg = *Bruguiera gymnorrhiza*, Xg = *Xylocarpus granatum*, Ll = *Lumnitzera littorea*

Table 2. Analyses of importance value and Shannon-Weiner diversity index of the natural mangrove forest in Bahile, Puerto Princesa City, Palawan, Philippines.

Family	Species	No. of individual	RF (%)	RDom (%)	RD (%)	IVI (%)	*H'*
Rhizophoraceae	*Rhizophora mucronata*	30	28.2	31.6	20.6	80.3	0.3252
	Rhizophora apiculata	93	38.5	46.0	63.7	148.1	0.2873
	Bruguiera gymnorrhiza	19	23.1	19.9	13.0	56.0	0.2654
Meliaceae	*Xylocarpus granatum*	1	2.6	0.2	0.7	3.5	0.0341
Combretaceae	*Lumnitzera littorea*	3	7.7	2.4	2.1	12.1	0.0798
	Total	**146**	**100.0**	**100.0**	**100.0**	**300.0**	**0.9918**

Note: RF = Relative Frequency, RDom = Relative Dominance, RD = Relative Density, IV = Importance Value Index, *H'* = Diversity index

The calculated diversity index (Shannon-Wiener's index), as shown in Table 2, was *H'*=0.9918 which was considered very low based on the diversity scale used by Gevaña & Pampolina (2009). This could be attributed to the dominance of few species, specifically those belonging to the family Rhizophoraceae, over other species in terms of frequency, basal area (dominance), and density. Several studies coincidentally concluded that the mangroves had very low diversity indices attributed to their unique stands formation in contrast to other tropical forest ecosystems (Gevaña & Pampolina, 2009; Stanley & Lewis, 2009; Kovacs *et al.*, 2011).

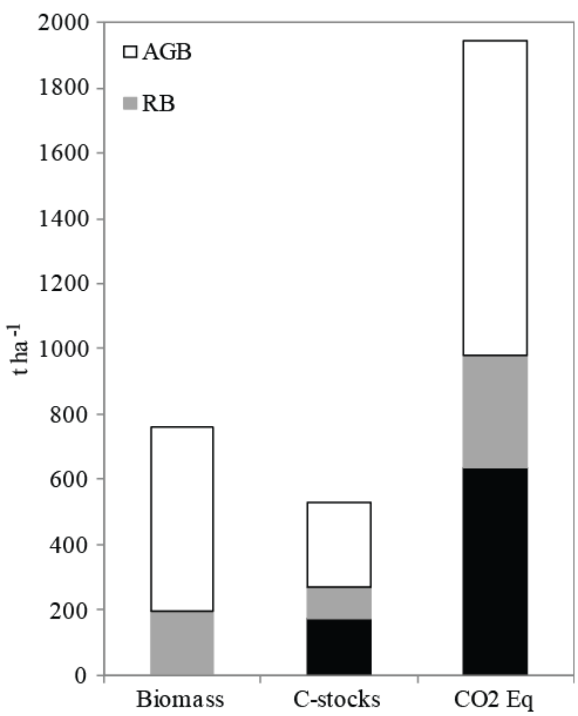

Fig. 2. Biomass, C-stocks and equivalent CO_2 potential of natural mangrove forest in Bahile, Puerto Princesa City, Palawan, Philippines. AGB = above-ground biomass, RB = root biomass, C-stocks = carbon stocks, CO_2 Eq = carbon dioxide equivalent.

Biomass and C-stock: The trunk diameter, commonly the DBH, is used as an independent variable in determining the mangrove biomass via the use of allometric equations (Kirui *et al.*, 2006; Kridiborworn *et al.*, 2012). On the stand level, the Bahile mangrove forest has a total biomass of 757.7 t ha^{-1} ranging from 291.0 to 1578.6 t ha^{-1} (Fig. 2). Based on the carbon concentrations, the total biomass C-stock varied from 136.8 to as high as 741.9 t C ha^{-1} with a mean of 356.1 t C ha^{-1}. This was equivalent to 501.9 to 2722.9 t CO_2 ha^{-1} with an average of 1306.9 t CO_2 ha^{-1} which was sequestered and stored in the biomass, both above-ground and roots. In detail, the above-ground biomass ranged from 210.6 to 1190.6 t ha^{-1}, with a mean of 561.2 t ha^{-1} and mean C-stock of 263.8 t C ha^{-1} which is equivalent to 968.0 t CO_2 ha^{-1}. The root biomass varied from 80.4 to 388.0 t ha^{-1}, with an average of 196.5 t ha^{-1} and mean C-stock of 92.3 t C ha^{-1} which is equivalent to 338.9 t CO_2 ha^{-1}. Among the established sample plots, huge quantities of biomass and stored carbon were estimated in those plots with large tree girths and high species wood density.

While extensive literatures are available on the above-ground biomass of coastal forests (Komiyama *et al.*, 2008; Khan *et al.* 2009; Murdiyarso *et al.*, 2009; Chandra *et al.*, 2011; Kauffman *et al.*, 2011; Chen *et al.*, 2012; Kridiborworn *et al.*, 2012; Kathiresan *et al.*, 2013), fewer studies have been conducted on below-ground biomass including both roots and sediments (Tamooh *et al.*, 2008; Nguyen *et al.*, 2009; Donato *et al.*, 2011), attributed to the logistical difficulties involved (Tamooh *et al.*, 2008) and time consuming experiments. The biomass estimates acquired in this study is worth comparing to the studies undertaken in different parts of Asia and the Pacific region. The mean above-ground biomass in this study was much higher than that of North Sulawesi (61.4 t ha^{-1}, Murdiyarso *et al.*, 2009), Okinawa, Japan (80.5 t ha^{-1}, Khan *et al.,* 2009), and Sarawak Mangrove Forest in Malaysia (116.8 t ha^{-1}, Chandra *et al.* 2011). The findings in the Bahile mangrove was also relatively higher than that of Micronesian coastal fringes of Yap (363.0 t ha^{-1}) and Palau (225.0 t ha^{-1}) (Kauffman *et al.*, 2011), and estuarine complex along the Bay of Bengal, India (60.0-117.7 t ha^{-1}, Kathiresan *et al.*, 2013). Carbon pools of the above-ground biomass estimated by Kauffman *et al.* (2011) in the Micronesian mangrove forests ranged from 104.4 t C ha^{-1} (Palau) to 169.2 t C ha^{-1} (Yap) were lower than the C-stock obtained in this study (263.8 t C ha^{-1}). Moreover, the above-ground C-stocks estimated in Southern China (55.0 t C ha^{-1}, Chen *et al.*, 2012) and Thailand (140.5 4 t C ha^{-1}, Kridiborworn *et al.*, 2012) were also lower compared to that of the present study. Comparatively, the estimated mean above-ground biomass and C-stock estimated in the Bahile mangrove was also substantial compared to the reported densities in various coastal ecosystems in the Philippines such as San Juan, Batangas (Gevaña & Pampolina, 2009) and Banacon, Bohol (Camacho *et al.*, 2011).

The estimated mean root biomass in this study solely depends on predictive variables used in the common allometric equation developed by Komiyama *et al.* (2005). Although derived for Southeast Asian mangroves, the size range of trunk diameters in this present study was within the sample diameter range of Komiyama *et al.* (2005). The findings for mean root biomass (196.5 t ha^{-1}) and its C-stock (92.3 t C ha^{-1}) in Bahile mangrove was comparable to a mangrove forest in Palau (171.0 t ha^{-1} and 80.0 t C ha^{-1}) but much lower than those obtained in Yap (312.0 t ha^{-1} and 144.0 t C ha^{-1}) (Kauffman *et al.*, 2011). Furthermore, Bahile shows comparatively higher C-stock than mangrove plantations in Northern Vietnam (10.7 t C ha^{-1}, Nguyen *et al.*, 2009), Bohol, Philippines (69.6 t C ha^{-1}, Camacho *et al.*, 2011), Southern China (21.4 t C ha^{-1}, Chen *et al.*, 2012) and Tamil Nadu, India (18.1-12.9 t C ha^{-1} Kathiresan *et al.*, 2013).

The above-ground and root biomass ratio (T/R Ratio) of the present study ranged from 2.6 to 3.1 or an average of 2.8. The result was consistent with the value given in Komiyama *et al.,* (2008) which varied from 1.1 to 4.4, although higher than that of Rhizophora stand in Bay of Bengal, India (Kathiresan *et al.*, 2013). According to Komiyama *et al.,* (2008), the mangrove forests' T/R ratio was significantly lower than upland/terrestrial forests because a large amount of biomass tended to be allocated in the roots system in order to maintain a bottom-heavy tree form to stand upright in wet and soft mud. Khan *et al.,* (2009) likewise stated that T/R ratio is the typical basis to judge the biomass allocation pattern to the underground part of a forest. In terms of biomass allocation of Bahile mangrove forest, the estimated above-ground biomass represented 74% of the total, while the remaining 26% was accounted for the roots. The above-ground and root biomass differs greatly per species but also on geographical location, plant density and ecology (Komiyama *et al.*, 2008; Chandra *et al.*, 2011).

Sediment C-stock: The carbon stored as well as the CO_2 equivalent in the upper 30 cm depth of the sediment of the mangrove stand studied was presented in Fig. 2. The sediment C-stock in this study was estimated to range from 89.0 to 344.3 t C ha^{-1} with an average of 173.8 t C ha^{-1}. The sediment of a mangrove ecosystem is an important carbon pool (Donato *et al.*, 2011; Kauffman *et al.*, 2011; Kauffman & Donato, 2012), as was substantiated in the present study where estimated sediment C-stock was 49% of the biomass C-stock. The mean sediment C-stock value was equivalent to 637. 7 t CO_2 ha^{-1} which if excavated, as in the case of fish ponds and similar coastal disturbances and land use changes, would be oxidized and reverted into the atmosphere (Samson & Rollon, 2011). The near-surface sediment C-stock which was estimated from the upper 30 cm in this study is an indicative amount of the carbon stored in the sediment of the Bahile natural mangrove stand. Hence, further studies that will account the total depth of sediment deposits and analysis of carbon content in different depth intervals from multiple samples per plot are suggested specifically in the light of blue carbon trading that gives emphasis on the sediment as vast carbon reservoirs (Nellemann *et al.*, 2009; Lawrence, 2012).

Despite the limitation of the present study and the difficulty in comparing soil organic carbon pool of mangrove ecosystem due to natural variations as well as differences in sampling methodologies, the estimated mean sediment C-stock (173.8 t C ha^{-1}) was close to that obtained values from same depth in the Micronesian coastal fringes of Palau (128.1 t C ha^{-1}) and Yap (119.5 t C ha^{-1}) (Kauffman *et al.*, 2011). Moreover, findings of this study were substantially higher compared to obtained values at 1 m sediment depth in Okinawa, Japan (57.3 t C ha^{-1}, Khan *et al.*, 2007) and Northern Vietnam (68.5 t C ha^{-1}, Nguyen *et al.*, 2009), and 20 cm depth in Southeast Australia (57.3-94.2 t C ha^{-1}, Howe *et al.*, 2009). However, the result of this study was much lower than the 822.1 t C ha^{-1} recorded in North Sulawesi, Indonesia taken from an average depth of 1.22 m (Murdiyarso *et al.*, 2009). Based on previous studies, density of carbon in the sediment decreased with increasing soil depth (Nguyen *et al.*, 2009) and showed minimum values after 30 cm depth (Khan *et al.*, 2007; Cerón-Bretón *et al.*, 2011). The exposure to long periods of inundation that maintained the anoxic conditions in coastal areas slows down the decomposition of OM and accelerates carbon accumulation at 30cm depth (Nguyen *et al.*, 2009; Cerón-Bretón *et al.*, 2011).

Total C-stocks: Based on the combined mean C-stocks in the biomass and sediment, the natural mangrove stand in Bahile, Puerto Princesa stored a high of 529.9 t C ha^{-1} which was equivalent to 1944.5 t CO_2 ha^{-1}. This is a significant amount which must be managed well. The highest percentage of C-stocks was accounted to the above-ground biomass (50%), followed by the sediment (35%), while the least contributor was the root biomass (15%). Apparently, the findings in this study were similar to the assertion of Fahey *et al.,* (2009) that living tree biomass and organic matter stored in soil are the two largest carbon pools in forest ecosystems.

Recognizing the entire natural mangrove stands of the province which covers 53678 ha (Forest Management Bureau, 2011), we grasp its potential to sequester and store a substantial quantity of 28.4 million t C and an estimated amount of 104.4 million t CO_2.The renowned array of ecosystem services and ecological functions that we may benefit from these intertidal forests can lead to notable strategies for climate change mitigation. Moreover, the window for blue carbon trading is a significant mitigation opportunity in an attempt to balance the conservation of mangrove ecosystems and sustainable livelihood for coastal inhabitants. Lawrence (2012) specified coastal ecosystems, mangroves in particular, as blue carbon sinks attributing its ability to transfer and store carbon on their sediments and within plant parts at rates far greater than those of terrestrial forests. It is not surprising that great attention is now focused on forests, including mangroves, to offset carbon emission due to their cheap cost compared to pollution control devices, their high potential rates of carbon uptake, and their environmental and social benefits (Warren-Rhodes *et al.*, 2011).

Conclusions

A very low diversity index was observed in the natural mangrove stand in Bahile, Puerto Princesa City, Palawan attributed to the dominance of few species, specifically those belonging to the family Rhizophoraceae. Nonetheless, because of the large tree girths and high density of species observed in this forest as well as the litter fall buried in mangrove sediment over time, it has the potential to sequester and store large amount of atmospheric carbon. Taking into account the estimated values of C-stocks and equivalent CO_2 from biomass and sediment, it is noteworthy to explore the implementation of mangrove carbon credit systems such as payment for ecosystem services (PES) and the blue carbon fund as sustainable management schemes to sustain the livelihood of coastal residents and at the same time protect the global mangrove carbon sinks. A follow-up study on developing site-specific and species-specific biomass equation applicable to wide DBH classes of Philippine mangroves is also deemed essential for a more precise quantification of tree biomass in view of carbon trading as significant climate change mitigation opportunity.

Acknowledgements

Profound gratitude is given by the authors to the local government unit as well as to the coastal communities of Bahile, Puerto Princesa City, Palawan, Philippines for allowing us to conduct this research. This study was carried out with the support of Kongju National University and the Forest Science and Technology Projects (Project No. S211314L020130) provided by the Korea Forest Service.

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(Received for publication 10 June 2013)