Species Diversity and Soil Carbon Sequestration Potential of Mangrove Species at *KatungganIt Ibajay* (KII) Eco-Park

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Abstract

The Katunggan It Ibajay (KII) Eco-Park (44.22 hectares) in Bugtongbato, Ibajay, Aklan (11.8047°N, 122.2094°E) in the Philippines was selected to determine the species diversity and quantify the soil carbon sequestration potential of mangrove species. Five (5) plots measuring 20m×20m were laid-out using quadrat sampling technique to identify and record the trees. Diversity index and carbon density equations were utilized to determine species diversity and carbon stocks in the soil. The diversity index (H'=1.760) was very low having a total of thirteen species belonging to four (4) families namely Avicenniacaea, Acanthaceae, Rhizophoraceae, and Sonneratiaceae were recorded; wherein soil pH ranged from acidic to slightly acidic. Despite its lean diversity, this mangrove forest dominated largely by species belonged to family Rhizophoraceae was still regarded for its great potential to sequester and store substantial amount of carbon in the aboveground layer of the soil. Average stored Carbon in the soil was 82.12 tons C ha-1 equivalent to 3,631.35 tons CO2e ha-1. Hence, sustainable management strategies and collective efforts should be made to protect and preserve this pristine ecosystem.

Keywords: *Carbon Stock; Carbon dioxide equivalent; Diversity Index; Katunggan It Ibajay; Mangroves; Species diversity 2*

Introduction

Climate change is one of the primary concerns of humanity today and it has been concluded that a strong evidence that human activities have affected the world's climate attributed to the emission of greenhouse gasses, notably CO2. Forests can be standing stores to sequester atmospheric carbon and as a valuable carbon pool, they draw 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 (CO2) and store carbon in their biomass and sediments have been recently underscored (IPCC, 2001; Murdiyarso *et al.*, 2009; Chen *et al.*, 2012; Kauffman & Donato, 2012).

Mangroves cover only around 0.7% (approximately 140,000 km2) of global tropical forests but they can store up to 20 billion tons of carbon from the atmosphere and oceans which is a little more than twice the annual global CO2 emission and far exceeds the mean carbon stock (C-stock) in tropical upland, temperate, and boreal forests. (Kauffman & Donato as cited by Abino *et al.,* 2014).

Mangrove ecosystems also offer coastal protection through wave attenuation and erosion prevention (Gedan *et al.,* 2011); but they gained more prominence in the aftermath of the

December 2004 Indian Ocean tsunami (Danielsen *et al.,* 2005; Kathiresan & Rajendran, 2005; Alongi, 2008), the November 2013 typhoon *Haiyan* that hit the Philippines (Gross, 2014), and other recent destructive cyclones and hurricanes (Tibbetts, 2006; Williams *et al.*, 2007; Das & Vincent, 2009). These systems also regulate water quality, serve as critical habitats for many fish and shellfish species, provide wood and other products to local populations, and host a diverse array of rare and endangered species (Barbier *et al.*, 2011).

Despite their benefits and services, this ecosystem is one of the most threatened ecosystems on earth, with an estimated 340,000 to 980,000 hectares being destroyed each year (Murray *et al.*, 2011). Although their historical extent is difficult to determine due to dramatic losses which occurred before accurate mapping was possible, statistics showed that an estimated 67% of the historical global mangrove range, 35% of tidal salt marshes, and 29% of sea grasses have been lost. If these trends continue at current rates, a further 30–40% of tidal marshes and sea grasses and nearly all unprotected mangroves could be lost in the next 100 years (Pendleton *et al.,* 2012).

Meanwhile, the continuous decline of mangrove forest is also true in the Philippines. Based on the early estimates, our mangrove forest was recorded to be around 400,000–500,000 ha-1. Recent estimates, however, revealed that this has tremendously been trimmed down to 153,577 ha1, which suggests a huge loss in biodiversity and biomass (Forest Management Bureau as cited by Gevana & Pampolina, 2009). Notably, Lasco and Pulhin as cited by Abino *et al.* (2014) reported that the estimated mean biomass of mangrove forests in the country is around 409 t ha-1 with a corresponding stored carbon of 184 t C ha-1.

A different case may hold for the Katunggan it Ibajay (KII) Eco Park in the town of Ibajay in Aklan, Philippines, home to one of the most diverse mangrove forests in the country. It is a 44.22 ha-1 protected park which boasts a total of 28 true mangrove species or 80% out of the total 35 Philippine mangrove species (Primavera, 2004). The forest is also home to some species of birds and other wildlife like mud lobsters, fiddler crabs, mudskippers and other fauna. Recent studies have been conducted in the area, including the identification of mollusk species, tree species, behaviors and activities of fiddler crabs. However, a study regarding the species diversity and carbon sequestration potential of the mangrove species in KII need to be studied and underscored. 3

The present study, then, set out to evaluate the diversity of the mangrove species in the area and its carbon sequestration potential. Particularly, it aimed to determine where the population structure of a dense cluster of naturally-grown mangrove stands are located. The study also wanted to quantify the amount of carbon stored in the soil and its carbon dioxide equivalent while considering the vital role of mangroves to help mitigate impacts of climate change (Fourqurean *et al.*, 2014). For the researchers believe that the result of the present study can serve as basis for more sustainable management strategies to protect this pristine ecosystem.

Materials and Methods

Study Site

The study was conducted at *Katunggan It Ibajay* (KII) Eco Park (Figure 1) located in Barangays Naisud-Bugtongbato (11.8047°N, 122.2094°E), Ibajay, Aklan, Philippines. It is 36 km north of the capital town of Kalibo and 1 km away from the National Highway. The KII has a total land area of 44.22 hectares with 28 different mangrove species grown in its natural habitat. In addition, the crown jewel of this area is the magnificent stand of century-old mangrove species locally known as *bungalon* or *api-api* (*Avicennia rumphiana*) (Figure 2) with a girth of 3m (10ft), and 30 m (98ft) tall.

Figure 1. *Map of Katunggan It Ibajay (KII) Eco-Park*

A reconnaissance survey revealed that this area is in generally healthy condition because of the active protection being done by the LGU and Peoples' Organization of Ibajay, namely the *Naisud* Mangrove and Aquatic Organization (NAMAO) and Bugtongbato Fisherfolks Association (BFA), against timber poaching activities and fishpond conversion. Mangroves in the area grow mostly in clustered populations dominated by *climax forest of large, old Avicennia rumphiana/Avicennia officinalis surrounded by zones of Ceriops decandra, mixed Avicennia spp., Avicennia marina, Bruguiera sexangula and planted Ceriops tagal (Lebata et. al., 2009).* In addition, a rich canopy is also evident as lianas and epiphytes thrive well in the branches of mangrove trees (Figures 3).

Figure 2. ***Century-old mangrove species in KII***

Figure 3. ***General view of Katunggan It Ibajay (KII) Eco-Park***

Species Diversity and Soil Carbon Stock Assessment

1. **Experimental Design.** This study adopted the protocols developed by Kauffman and Donato (2011) in carbon stock assessment of mangrove forests. Five (5) plots measuring 20 x 20 meters (400m2) each were randomly distributed in the area using strip mapping method with reference to the sea. The plots were laid out with 50 meters distance in between. Inside each plot, all identified species were sequentially recorded and accounted according to their growth structure, such as mangrove seedlings, saplings and matured ones (Figure 1).

2. ***Data Analysis.*** Species diversity was computed using Shannon-Weiner Index (Shannon & Weaver, 1963), which indicates a quantitative description of mangrove habitat in terms of species distribution and evenness. The diversity values for Shannon-Weiner were classified based on the scale developed by Fernando as cited by Gevaña & Pampolina (2009) presented in Table 1. This method was also cited in several studies of Gevaña & Pampolina (2009); Sharma *et al.* (2010); Lumbres *et al.* (2012), and Abino *et al.* (2014). It was calculated using the following formula:

$$(1)\ \boldsymbol{H'} = -\Sigma\ pi.\ln pi$$

where *H'* is the diversity index, *pi* is the proportion of *ith* species individuals to total species individuals, and *ln* is natural logarithm. The relative values to determine the index of diversity are as follows:

Table 1. Diversity index

Relative values*	***H" Values***
Very high	> 3.5000
High	3.0000 – 3.4999
Moderate	2.5000 – 2.9999
Low	2.0000 – 2.4999
Very low	<1.9999

Source: Gevaňa & Pampolina (2009)

Organic Carbon in the soil was determined by collecting 1 kilogram of soil samples in each plot at a depth of 30 cm. The samples were air-dried and sent immediately to the Bureau of Soil and Water Management (BSWM) in Diliman, Quezon City, Philippines for Organic Matter (OM) content and soil carbon analysis. They were analyzed following the methods of Walkley and Black/Loss of Ignition Method. Soil pH from each plot was also determined using a Digital pH meter (*Model: OAKLON*).

Bulk density was determined by choosing an undisturbed spot near the plot, removing debris from the surface and carefully driving into the upper 5-cm layer of the soil metal cylinders of known volume (100cm3). Three (3) samples were collected in each plot. The extracted sediment cores were carefully placed in labeled plastic bags and immediately sealed for later processing in the laboratory. The undisturbed cores were immediately weighed, recorded and oven-dried at 105oC for two days. The dry weights were recorded. Bulk density values were computed using the formula:

$$(2)\, BD\left(\frac{g}{cm^3}\right) = \frac{Oven\ Dry\ Weight}{Volume\ of\ Cylinder}$$

The carbon density for each sampling plots were obtained using the two methods of calculation (Donovan, 2013):

$$(3)\ CT = CF \times D \times V$$

where *CT* is total carbon for the layer in metric tons, *CF* is the fraction of carbon (percentage carbon divided by 100), D is density, and V is the volume of the soil layer in cubic meters. Another shortcut equation giving tons of carbon per hectare is:

$$(4)\ \mathbf{T} = Th_{cm} \times D \times C\ (\%)$$

where T is tons of carbon per hectare, Th*cm* is the thickness of the sampled layer in centimeters, D is density, and C (%) is the percentage of carbon.

Further, results obtained from carbon density calculation were then converted to the total carbon dioxide equivalent expressed in tons per hectare (tons ha-1) to quantify the amount of carbon that would be released into the atmosphere if this ecosystem were left unprotected. This was obtained based on the conversion equivalent suggested by Donovan (2013) where tons of Carbon will be multiplied by 3.67 to get tons of Carbon dioxide (CO2). Total C storage was estimated by getting the sum of the soil C stocks.

Results and Discussion

A. Population Structure and Diversity

Table 2a summarizes the structure & composition of species recorded in the study. It can be gleaned that Plot 5 has the most abundant number of mangrove individuals dominated by species of *C. tagal, C. decandra, and C. philippinensis*. It has been recorded with a total of 8,053 (38.76%) individuals resolved into 7,303 seedlings, 287 saplings, and 463 matured mangrove trees. Plot 2 had the least in count with a total of 822 (3.96%) with 532 seedlings, 184 saplings, and 106 mangrove trees.

Generally, all the plots had a very low diversity index values following a decreasing trend: Plot 2 > Plot 3 > Plot 4 > Plot 5 > Plot 1 (Figure 5). Plot 1 had the lowest index value (*H'*= 0.840) with only four (4) identified species lower compared to Plots 4 (*H'*=0.947) and 5 (*H'*=0.896) even with only three (3) species recorded. The result may be attributed to the number of seedlings present in these plots comparable to

Plot 1. Among the plots, the highest index was found in Plot 2 with a diversity index value of *H'*=1.410 because of its number of species recorded equivalent to six (6) even it had the lowest total abundance.

On the other hand, the total number of species identified in all sampling plots was thirteen dominated by four (4) families namely: *Avicenniaceae*, *Acanthaceae*, *Rhizophoraceae*, and *Sonneratiaceae* with a very low diversity index (*H'*=1.760). Among all the species, *C. decandra* dominated the area of KII with a total of 7,444 (35.84%) individuals (Table 2b & Figure 4).

Comparably, the result of this study was found higher than the recorded species reported by Gevaña and Pampolina (2009) in Verde Passage Corridor in the province of Batangas, Philippines.

This observation suggested a unique formation of mangrove stands wherein a considerable number of species particularly those that belong to Family *Rhizophoraceae* tend to dominate. A similar finding was also reported in the mangroves of Pagbilao and Padre Burgos, Quezon by ENFOR (2004) and Gevaña *et al.* (2009) that observed a very low diversity in the *bakawan* and *Avicennia* (*piapi*) vegetations of the area. This observation may be attributed to some factors that affect the growth of other species in terms of the physical (texture, porosity, bulk density, etc.) and chemical (pH, OM, moisture content) properties of the soil, high salinity, tidal inundation, and weather condition. Several studies also concluded that mangroves had a 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).

Table 2a. *Population Structure And Diversity Per Sampling Plot*

Plot No.	Species*	Population Structure				H'
		Seedling	**Sapling**	**Matured**	**Total**	
1	Ai, Ar, Bg, Ct, Nf	1,303	1,501	38	2,792	0.840
2	Nf, Rm, Rs, Cd, Bp, Cp	532	184	106	822	1.410
3	Aa, Ao, Cd, Cp	1,922	667	952	3,541	1.377
4	Sa, Cd, Cp	2,981	169	2,414	5,564	.947
5	Ct, Cp, Cd	7,303	287	463	8,053	.896

* ***Ai** – *Acanthus ilicifolius*, **Ar** – *Avicennia rumphiana*, **Bg** – *Bruguiera gymnorrhiza*, **Ct** – *Ceriops tagal*, **Nf** – *Nypa fruticans*, **Rm** – *Rhizophora mucronata*, **Rs** – *Rhizophora stylosa*, **Cd** – *Ceriops decandra*, **Bp** – *Bruguiera parviflora*, **Cp** – *Camptostemon philippinensis*, **Aa** – *Avicennia alba*, **Ao** – *Avicennia officinalis*, **Sa** – *Sonneratia alba*

Table 2b. Species diversity of each mangrove species

Family	Species*	*N*	Percent (%)	*H'*
Avicenniaceae	*A. alba*	767	3.69	-0.122
	A. officinalis	764	3.68	-0.121
	A. rumphiana	114	0.55	-0.029
Acanthaceae	*A. illicifolius*	1	0.005	-0.000
Rhizophoraceae	*C. decandra*	7,444	35.84	-0.368
	C. tagal	1,032	4.97	-0.149
	C. philippinensis	6,376	30.70	-0.363
	N. fruticans	1,474	7.10	-0.188
	B. gymnorrhiza	1,282	6.17	-0.172
	B. parviflora	27	0.13	-0.009
	R. mucronata	364	1.75	-0.071
	R. stylosa	56	0.27	-0.016
Sonneratiaceae	*S. alba*	1,071	5.16	-0.153
	TOTAL	**20,772**	**100.00**	**-1.760**

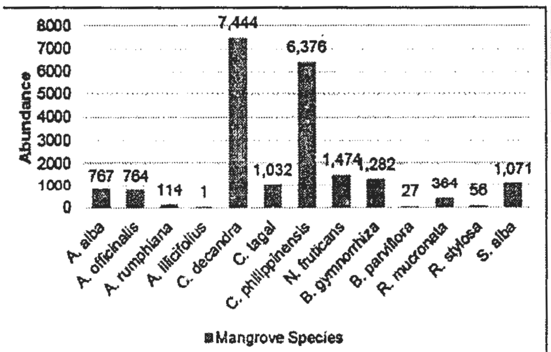

Figure 4. *Total abundance of mangrove species*

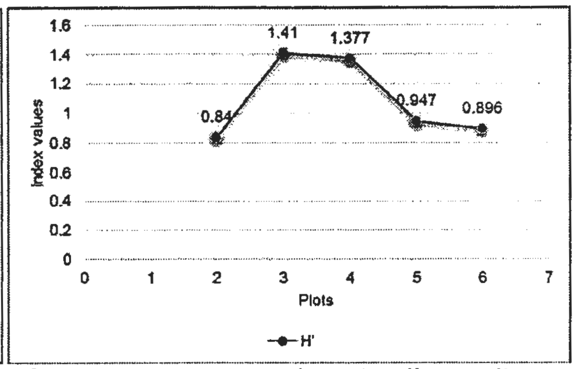

Figure 5. *Diversity indices in all sampling plots*

B. Soil Physicochemical Properties

The physicochemical properties of the soil in *Katunggan It Ibajay* Eco Park were presented in Figure 6. The soils of the area were slightly acidic with an average pH value of 6.09. Among all sampling plots, the lowest pH was 5.79 in Plot 3 (soil under the dominance of *Avicennia spp*). This result was conformed to the findings of some researchers asserted that species of *Avicennia* thrive in mangrove soils with pH ranging from 4.35 to 5.29 (Sukardjo as cited by Arianto, *et al.,* 2015); whereas, the highest pH was 6.51 recorded in Plot 5 under the dominance of *C. decandra*. Generally, the average pH value of this mangrove forest was found higher than the findings reported by Arianto *et al.* (2015) in the mangrove forest in *Awat-Awat* Mangrove Forest in Sarawak, Malaysia.

On the other hand, bulk densities of the soil in the area varied closely in all sampling plots. Highest bulk density recorded was 2.12 g/cm3 found in Plot 2 while Plot 5 has a density of 1.40 g/cm3. The result may be affected by the soil texture and compaction of the soil in different sampling plots. It also suggests that there were only specific species of mangroves that thrive with a required bulk density in soil. Hence, this finding conformed to the assertion of Sitoe *et al.* (2014) in *Sofala* Bay Mangrove Forests that mangrove soils usually have bulk densities ranging from 1.12 g/cm−3 to 1.05 g/cm−3, in 0–30, 30–60, and 60–100cm depth intervals, respectively, and did not differ significantly (p=0.40) across depths.

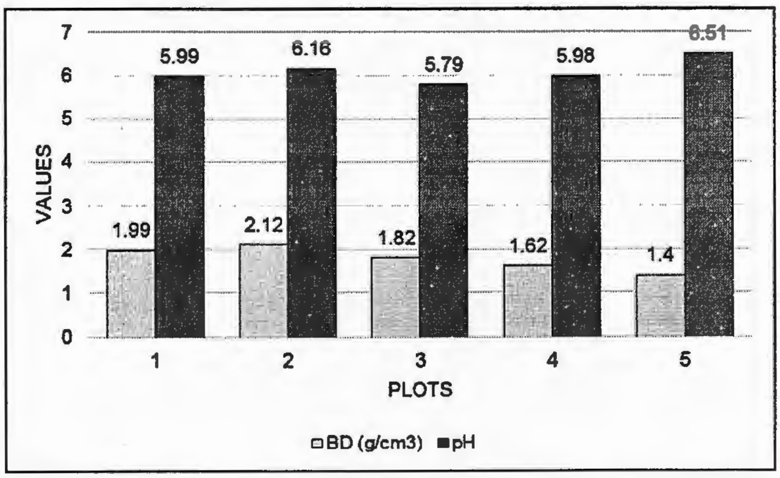

Figure 6. *Soil Physicochemical Properties*

C. Soil Carbon Stock

Results from the analysis of soil gathered in KII were presented in Table 3. It can be noted table that the amount of Carbon (C) concentrated in the area varies from every sampling plots which follows an increasing trend: Plot 1 > Plot 2 > Plot3 > Plot 4 > Plot 5. Among the plots the highest percentage of organic Carbon stored in the soil was found in Plot 5 (2.16%). The result was greatly affected by the amount of bulk density (1.40 g/cm3) and the acidity (6.51) of the soil which was confirmed by Abino et al., (2014) asserted that the lower the bulk density of the soil the higher its organic matter content (percent of Organic Carbon (OC) and other nutrients). Likewise, the result may be associated with the dominance of *C. decandra* species found in this plot.

On the other hand, Plots 3 and 4 had Carbon concentrations of 1.65% and 1.99%, respectively. This result may be attributed with the abundance of *C. philippinensis* that thrive on this plot. Meanwhile, plot 2 dominated mostly by *Rhizophora mucronata* (Bakhaw babae) had 1.21% organic carbon concentrated in the soil. While, plot 1 had the lowest organic Carbon concentration of 0.94% relative to the growth and abundance of *Nypa fructicans* (Nipa) and *Bruguiera gymnorrhiza* (Pototan) species.

Generally, the mean organic Carbon concentration of the area was 1.59% which was considered significant as to the amount of organic matter content of the soil in the area. Whereas, it was affirmed in the study of several researches (Perie & Ouimet, 2008; Hossain *et al.,* 2012, Gevaña & Pampolina, 2009) that soil OM contains about 58% of Organic Carbon; hence, providing enough nutrients to the growth of mangrove trees.

Consequently, it can be noted that the computed carbon density and carbon dioxide equivalents varied closely in each sampling plot following the sequence: Plot 4 > Plot 5 > Plot 3 > Plot 2 > Plot 1 (Figure 7a-b). The highest carbon stored in the soil was found in Plot 4 amounting to 96.71 tons/ha-1 or equivalent to 354.94 tons CO2e/ha-1 among others. This was particularly affected by the amount of bulk density of the soil in this plot which was higher than Plot 5. Comparably, the amount of carbon stored in Plots 3 and 5 were found nearly similar amounting to 90.72% tons/ha-1 (332. 94 tons CO2e/ha-1) and 90.09 tons C/ha- (330.63 tons CO2e/ha-1), respectively. Hence, the computed result was basically affected by the amount of their bulk densities and concentration of soil carbon.

However, Plot 2 dominated largely by *Rhizophora* spp. found to have contributed on the sequestration of carbon in the aboveground layer of the soil to about 76.96 tons C/ha-1 (282.43 tons CO2e/ha-1); while, Plot 1 roughly dominated by Nipa palms (*Nypa fructicans*) had the lowest stored carbon at a rate of 56.12 tons C/ha-1 (205.95 tons CO2e/ha-1).

Overall, the carbon density values obtained in the present study summed up to 410.60 tons C/ha-1 (1,506.89 tons CO2e/ha-1) equivalent to 410.60 Mg C/ha-1 carbon stock. Despite the limitations of the present study and difficulty in comparing soil organic carbon pool of the mangrove ecosystem due to natural variations as well as sampling methodologies, the estimated mean carbon stock was 82.12 tons C/ha-1. The total C-stock of this study was found higher than the findings of Gevaña and Pampolina (2009) which estimated the aboveground layer of mangrove forest in Verde Passage, San Juan Batangas at around 103.50 tons C/ha-1. Likewise, it is worth comparing to the studies undertaken by Abino *et al.* (2014) in *Bahile* mangrove forest in Palawan which is closely estimated to 529.9 tons

C/ha-1. It was also worth comparing with the studies undertaken in the different parts of Asia and Pacific region. The mean above ground C–stock of the study was much higher than that of North Sulawesi (61.4 tons/ha-1, Murdiyarso *et al.,* 2009), Okinawa Japan (80.50 tons/ha-1, Khan et al., 2009), Bengal, India (60.0 tons/ha-1, Kathiresan *et al.*, 2013), and Southern China (55.0 tons C/ha-1, Chen *et al.,* 2012). This is high carbon content as most carbon–pool mangrove forests have 703 MgC/ha-1 (Jardine and Siikamaki, 2014). Apparently, the findings of the present study were similar to the assertion of Fahey *et al.* (2009) that living tree biomass and organic matter stored are the two largest carbon pools in forest ecosystem.

Table 3. Soil Carbon Stock in each sampling plots

Plot	OM* (%)	OC* (%)	C_T (tons ha^{-1})	CO_2e (tons ha^{-1})
1	1.62	0.94	56.12	205.95
2	2.08	1.21	76.96	282.43
3	2.84	1.65	90.09	330.63
4	3.42	1.99	96.71	354.94
5	3.72	2.16	90.72	332.94
Total	**13.68**	**7.95**	**410.6**	**1,506.89**
Mean	**2.74**	**1.59**	**82.12**	**301.38**
SD	**0.84**	**0.51**	**16.22**	**59.55**

**Soil analysis result (BSWM)*

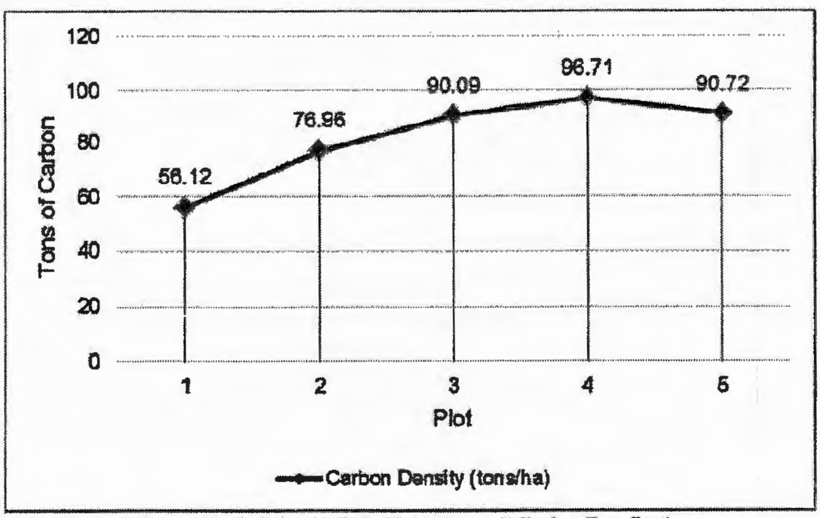

Figure 7a. Soil C-stock in *Katunggan It Ibajay* Eco Park

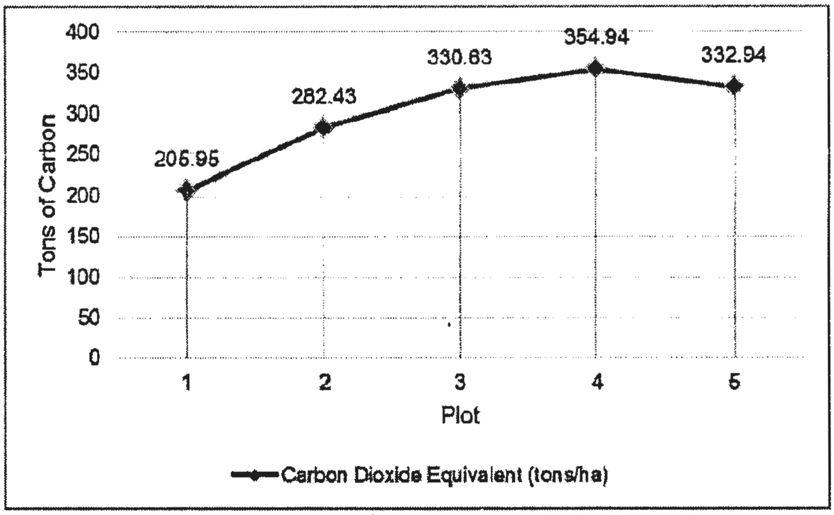

Figure 7a. CO_2 equivalent in *Katunggan It Ibajay* Eco Park

Conclusion

Mangroves play a significant role in sequestering carbon and reducing greenhouse gasses. It can be concluded from the review that mangroves are an important sink for CO2. Despite the very low diversity index recorded from this natural mangrove forest, which covers 44.22 hectares, the researcher notes its potential to sequester and store a substantial quantity of 34.22 tons C/ha-1 per year and an estimated amount of 125.59 tons CO2e/ha-1 per year. Taking into account the amount of CO2 equivalent, this much aboveground carbon stock amounting to 1,506.89 tons/ha-1 was a significant amount which must be managed well. It means that if this mangrove forest would be exposed to deforestation or any other anthropogenic (human) activities, the area can release this much CO2 back into the atmosphere, increasing the already high level of atmospheric Greenhouse Gases (GHGs) and eventually aggravate and worsen the impact of climate change.

Therefore, the renowned array of ecosystem services and ecological functions that people may benefit from these intertidal forests can lead to notable strategies for climate change mitigation in an attempt to balance the conservation of mangrove ecosystems and sustainable livelihood for coastal inhabitants (Abino *et al.*, 2014). It is also vital to explore activities/strategies eligible under Verified Carbon Standard (VCS) such as Reducing Emissions from Deforestation and forest Degradation (REDD+), Reforestation and Revegetation Activities (ARR), Wetlands Restoration or Conservation (WRC), or combinations of these, to provide maximum flexibility and at the same time protect the benefits from these ecosystems.

Acknowledgment

The authors thank the Local Government Unit and the Peoples' Organization (POs) of Ibajay, Aklan for allowing the researchers to conduct this study. They are also grateful for the support from the Department of Environmental Science of Aklan State University-Ibajay Campus.

References

Abino, A. C., J. A. Castillo, Y. J. Lee. (2014). "Species Diversity, Biomass, and Carbon Stock Assessments of a Natural Mangrove Forest in Palawan, Philippines." *Pak. J. Bot.* 46(6): 1955-1962. Available: http://www.pakbs.org/pjbot/PDFs/46%286%29/04.pdf [October 28, 2015]

Alongi, D.M. (2008). "Mangrove forests: resilience, protection from tsunamis, and responses to global climate change." *Estuarine, Coastal and Shelf Science.*; 76, 1–13.

Arianto C. I. *et al.* (2015). "Soil Carbon Storage in dominant species of Mangrove Forest of Sarawak, Malaysia". *Intl. J. Phys. Sci.* 10 (6): 210-214. Available: http://www.academicjournals.org/IJPS [November 24, 2015]

Barbier, E.B. *et al.* (2011). "The value of estuarine and coastal ecosystem services." *Ecological Monographs.* 81: 169–193.

Chen, L. *et al.* (2012). "Comparing carbon sequestration and stand structure of monoculture and mixed mangrove plantations of *Sonneratia caseolaris* and *S. apetala* in Southern China." *For. Ecol. Manage.* 284: 222-229.

Danielsen, F. *et al.* (2005) "The Asian tsunami: a protective role for coastal vegetation." *Science.*310: 643.

Das, S. & Vincent, J.R. (2009). "Mangroves protected villages and reduced death toll during Indian super cyclone." *Proceedings of the National Academy of Sciences.* 106: 7357–7360.

Donovan, P. (2013). "Measuring soil Carbon Change: A flexible, practical, local method. pp. 18, 33-34. Available: soilcarboncoalition.org [November 12, 2015].

ENFOR. (2004). "CO2 storage and sequestration in the Mirant Reforestation Projects in Quezon, Philippines: Year One Progress Report." Environmental Forestry Programme, UP Los Baños.

Fahey, T.J. *et al.* (2009). "Forest carbon storage: ecology, management, and policy." *Front Ecol. Environ.* DOI: 10.1890/080169.

Fourqurean, J. *et al.* (2014). *Coastal Blue Carbon: Methods for assessing carbon stocks and emissions factors in mangroves, tidal salt marshes, and sea grass meadows.* Arlington, Virginia, USA, pp. 25–38.

Gedan, K.B., Silliman, B. & Bertness, M. (2009). "Centuries of human-driven change in salt marsh ecosystems." *Marine Science.* 1: 117–141.

Gevaña, D.T. and N.M. Pampolina. (2009). "Plant diversity and carbon storage of a Rhizopora stand in Verde Passage, San Juan, Batangas, Philippines." *J. Environ. Sci. Manage.* 12 (2): 1-10. ISSN 0119-1144. Available: http://journals.uplb.edu.ph/index.php/JESAM/article/view/338/296 [December 10, 2015].

Gross, M. (2014). "Protect the coasts so they can protect us." *Current Biology.* 24: R51–R53. 14.

Hossain, M.Z., C.B. Aziz and M.L. Saha. (2012). "Relationships between soil physico-chemical properties and total viable bacterial counts in Sunderban mangrove forests, Bangladesh." Dhaka Univ. *J. Biol. Sci.* 21: 169-175.

Intergovernmental Panel on Climate Change (IPCC). Synthesis Report: Third Assessment Report (TAR). Geneva, Switzerland. (2001). Available: https://www.ipcc.ch/ipccreports/tar/ [October 10, 2015]

Kathiresan, K. & Rajendran, N. (2005). "Coastal mangrove forests mitigated tsunami." *Estuarine, Coastal and Shelf Science.* 6: 601–606.

Kathiresan, K., R. Anburaj, V. Gomathi and K. Saravanakumar. (2013). "Carbon sequestration potential of *Rhizophora mucronata* and *Avicennia marina* as influenced by age, season, growth and sediment characteristics in southeast coast of India." *J. Coast Conserv.* DOI 10.1007/s11852-013-0236-5.

Kauffman, J.B. and D.C. Donato. (2012). "*Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests.*" Working Paper 86. CIFOR, Bogor, Indonesia.p.. 40.

Khan, M.N.I., R. Suwa and A. Hagihara. (2009). "Biomass and aboveground net primary production in a subtropical mangrove stand of *Kandelia obovata* (S., L.) Yong at Manko Wetland, Okinawa, Japan." *Wetlands Ecol. Manage.*17: 585-599.

Kovacs, J.M. *et. al.* (2011). "A field based statistical approach for validating a remotely sensed mangrove forest classification scheme." *Wetlands Ecol. Manage.* 19: 409-421.

Lasco, R.D. and Pulhin, F.B. (2000). "Forest land-use change in the Philippines and climate change mitigation." *Mitigation and Adaptation Strategies to Global Change Journal.* 5: 81-97.

Lumbres, R.I.C. et al. (2012). "Floral diversity assessment in Alno communal mixed forest in Benguet, Philippines." *Landsc. Ecol. Eng.* DOI 10.1007/s11355-012-0204-5.

Murdiyarso, D. *et al.* (2009). "Carbon storage in mangrove and peat land ecosystems in Indonesia – a preliminary account from plots in Indonesia." Working Paper 48, Center for International Forestry Research. Bogor, Indonesia, p. 35.

Murray, B.C., Pendleton, L. & Sifleet, S. (2011). "State of the Science on Coastal Blue Carbon: A Summary for Policy Makers. " In: *Nicholas Institute for Environmental Policy Solutions Report. NIR 11-06.* pp. 1–43.

Pendleton, L. *et al.* (2012). "Estimating global 'blue carbon' emissions from conversion and degradation of vegetated coastal ecosystems." *PLoS One.* 7, e43542.

Perie, C. and R. Ouimet. (2008). "Organic carbon, organic matter and bulk density relationships in boreal forest soils." *Can. J. Soil Sci.* 88: 315-325.

Primavera, J. H. (2004). *Handbook of Mangroves in the Philippines- Panay.* Aquaculture Department, Southeast Asian Fisheries Development Center. Tigbuan, Iloilo City, Philippines. 15.

Shannon, C.E. and W. Weaver. (1963). *The mathematical theory of communication.* University of Illinios Press, Urbana, USA. p. 117.

Sharma, C.M. *et al.* (2010). "Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India." *For. Ecol. Manage.* 260: 2170-2179.

Sitoe A., Mandlate L., Guedes B. (2014). "Biomass and Carbon Stocks of Sofala Bay Mangrove Forests". *Forests.5*, 1967-1981; DOI: 10.3390/f5081967. Available: www.mpdi.com/journal/forests [November 25, 2015]

Stanley, O.D. and R.R. Lewis III. (2009). "Strategies for mangrove rehabilitation in an eroded coastline of Selangor, Peninsular Malaysia." *J. Coast. Dev.* 12: 144-155.

Tibbetts, J. (2006). "Louisiana's wetlands: A lesson in nature appreciation." *Environmental Health Perspectives.* 114, A40.

Williams, M.J. *et al.* (2007). "A lesson from cyclone Larry: An untold story of the success of good coastal planning." *Estuarine, Coastal and Shelf Science.* 71: 364–367.