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ASSESSMENT OF CARBON SEQUESTRATION POTENTIAL OF MANGROVE FORESTS IN THE TALON-TALON AND MAMPANG TREEVOLUTION SITES OF ZAMBOANGA CITY

Terminal Report

BUILDING LOW EMISSION ALTERNATIVES TO DEVELOP ECONOMIC RESILIENCE AND SUSTAINABILITY PROJECT
(B-LEADERS)

August 2017

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AFOLU	Agriculture, Forestry and Other Land Use
AGB	Above ground biomass
BGB	Below ground biomass
B-LEADERS	Building Low Emission Alternatives to Develop Economic Resilience and Sustainability
CENRO	Community Environment and Natural Resources Office
CO_2e	Carbon dioxide equivalent
DBH	Diameter at breast height
DENR	Department of Environment and Natural Resources
FAO	Food and Agriculture Organization (United Nations)
MinDA	Mindanao Development Authority
NGP	National Greening Program
OCENR	Office of the City Environment and Natural Resources
USAID	United States Agency for International Development

EXECUTIVE SUMMARY

Mangrove ecosystems, like other forest ecosystems, represent natural capital capable of producing a wide range of goods and services. These ecosystems protect shorelines from damaging storm and hurricane winds, waves, and floods. Mangroves also help prevent erosion by stabilizing sediments with their root systems. They maintain water quality and clarity, filtering pollutants and trapping sediments originating from land. Furthermore, they provide a critical source of food and economic benefit to local communities through aquaculture, apiculture, and the provisioning of fuelwood and timber. Mangrove forests also support fisheries production and act as a carbon sink by sequestering atmospheric carbon, and reduce pollution through water filtration.

In the Philippines, a large portion of the population depends on the mangroves for food, livelihood, and shelter derived from the mangrove ecosystem. Primavera (2000) reported that approximately half of the country's towns and local communities depend on these mangrove habitats for food and other goods and services.

In spite of being a valuable resource, mangrove forests in the Philippines are under severe pressure resulting in its deterioration due to overexploitation, uncontrolled extraction, and conversion to other land uses, primarily for fishponds. This resulted in the widespread degradation and generally poor condition of mangrove forests in the country.

This study presents a carbon sequestration assessment of two mangrove restoration sites around Zamboanga City in the barangays of Talon-talon and Mampang. Both mangrove restoration sites were replanted in 2014 as a part of the "Treevolution" program, managed[1] by both the Community and Environment and Natural Resources Office (CENRO) of the Department of Environment and Natural Resources (DENR) and the Office of the City of Environment and Natural Resources (OCENR) of Zamboanga City. Human activities heavily impact the mangrove forests in both barangays, particularly through cutting/harvesting primarily for firewood, both for local consumption and for commercial purposes.

Zamboanga City is located in the southwestern part of Mindanao with a population of 861,799. Mangrove forests occupy the southeastern sides of the city. The city's boundary stretches far south and constitutes the south most part of the Mindanao Island. Because the city's boundary in the south, east and west are coastal areas with no adjoining land areas, the city is exposed to tidal waves and other similar risks faced by islands. Mangrove forests in Zamboanga City are important because they can serve as protection against possible coastal risks such as waves and strong storm surges.

The mangrove sites examined in this study are close to two barangays which are heavily populated and highly dependent on the mangrove for their livelihood such as salt making, fishing for lapu-lapu, bangus, prawns and fingerlings. The demand for fuelwood is also high, both for local and commercial uses. The heavy pressure placed on the mangrove forests due to these high impact human activities was one of the main reasons for the selection of these sites as part of the Treevolution program. Monitoring the general condition of the forests, including their biomass and carbon sequestration potential is important in these areas in order to assess their health and overall sustainability.

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[1] Treevolution was a Mindanao-wide campaign called, "Treevolution Greening MindaNow', which was a massive tree planting activity conducted in September 26, 2014.

The Mindanao Development Authority (MinDA), in collaboration with the USAID-funded Building Low Emission Alternatives to Develop Economic Resilience and Sustainability (B-LEADERS) program, DENR regional offices, local government units, and private sector groups agreed to conduct an assessment of the amount of carbon stock in mangrove forests at the two local barangays. The primary purpose of the assessment is two-fold: to generate baseline data on the amount of carbon stock within the mangrove forests of the two barangays and to estimate the carbon sequestration potential of the mangrove forests within the two Treevolution sites.

To establish a carbon assessment baseline, the team collected data from 54 sample plots within the two mangrove sites. Using a systematic stratified random sampling design, sample plots were selected. Stratification was based on canopy cover, management agency (DENR and Office of the City Environment and Natural Resources, OCENR), location (i.e. barangays), and management regimes. The study team identified potential sample plots using a systematic grid of 100 x 100 meters where each grid center or node is a potential sample plot. Finally, the study team selected sample plots within each stratum randomly from among the set of nodes within the boundary of the stratum.

Carbon assessment focused on the three major carbon stocks that comprise the total carbon pool of a mangrove ecosystem: above ground biomass (AGB), below ground biomass (BGB), and carbon imbedded in soil sediments.

From the 54 sample plots, the team measured 2,636 individual trees and stems. These constituted the dataset of trees to estimate total biomass (AGB and BGB). The average number of trees and stems[2] per plot is 48.

There were five mangrove species found in the two areas, namely: *Rhizophora mucronata* dominate with a total of 1,356 individuals, followed by *Rhizophora stylosa*, *Avicennia marina*, *Sonneratia alba* and *Rhizophora apiculate*. As expected in sites dominated by planted species, the Shannon index, which is a widely used index characterize species diversity in a community and accounts for both abundance and evenness of the species present, is relatively low (1.29) mainly due to low species richness (only 5 species) and dominance (high relative abundance) of *Rhizophora mucronata* relative to the others (e.g. *Rhizophora apiculata*).

Compared to other plantation mangroves studied in the Philippines, the average diameter of the trees measured is relatively small with an average diameter at breast height (DBH) of 6.88cm (Camacho et al, 2011; Abino et al, 2012). This is in part because the mangrove forests in the two sites are mostly from 'plantation areas' where trees are younger (9-14 years) than those reported in the published literature on plantation mangroves in the Philippines. These plantation areas were planted using assisted natural regeneration where new mangrove trees were planted between 'residual' trees that were left after heavy cutting in the past.

The team used three allometric equations for three species groups to estimate AGB, and one general allometric model to estimate the BGB. These models were adopted because they are the most appropriate since they represent the closest in terms of geographical region (i.e. Southeast Asia) where the data and models were obtained and developed.

The estimated average AGB of the two sites is 32.1 tons[3] per hectare, while the estimated average BGB is 19 tons per hectare. Hence, the average total biomass (AGB and BGB) is approximately 51.1 tons per hectare. The total area of the mangrove forests for Talon-talon and Mampang is 857 hectares. Hence, the total AGB and BGB for the two sites are 27,509 tons and 16,283 tons of AGB and BGB, respectively, or a total biomass of 43,707 tons.

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[2] Trees refer to individual trees with no coppices; stems refer to coppices of the same tree resulting from heavy cutting.

[3] Unit of measure used in this study is in Metric tons.

To determine the total carbon sequestered in the trees and the forests, biomass is 'converted' to carbon by multiplying biomass by its carbon density. Carbon density of mangrove trees in the Philippines is estimated at 46% and 39% for above ground biomass and below ground biomass, respectively. Hence, the total carbon for the 857 hectares of mangrove forest is estimated at 12.6 tons of carbon (tC) and 6.3 tC for above ground and below ground biomass, respectively. Furthermore, in terms of carbon dioxide equivalent (usually calculated so that carbon sequestered can be compared with other greenhouse gases), tC is converted to carbon dioxide equivalent (CO_2 e) by multiplying the amount of carbon by its weight equivalent of 3.67. Therefore, the total CO_2 e of the biomass sequestered from the 857 hectares are 46.2 tons of carbon dioxide (tCO_2 e)and 23.1 tC, or a total of 69.3 tCO_2e for the two sites. These amounts are also summarized in the table below. The slight differences in these estimates of total values compared to the values shown in the table below are primarily due to the difference in the areas of the two sites.

Table ES-1 below shows a summary of the carbon sequestration potential of mangrove forests for the two Treevolution sites. The table describes the carbon stocks and the carbon dioxide equivalent from the three carbon pools (i.e. above ground biomass, below ground biomass, and soil sediments) from the two barangays coming. The results show that soil sediments constitute the largest source of carbon in mangrove forests, which is consistent with the results of other studies in southeast Asia.

Table ES-1: Total Carbon Sequestration Potential

Mangrove Site	**Area (ha)^{a}**	**Total^{d} Above Ground Carbon (tC)**	**Total CO_2 Equivalent)^{b} of AG (tCO_2e)**	**Total Below Ground Carbon (tC)**	**Total BG (tCO_2e)**	**Total Sediment Carbon (tC)**	**Sediment (tCO_2e)^{c}**	**Total ecosystem^{e} (tCO_2e)**
Talon-talon	525	8,661.88	31,789.10	4,149.23	15,227.67	320,595.50	1,176,583.65	1,223,600.42
Mampang	332.00	4,184.52	15,357.19	2,256.18	8,280.18	197,779.04	725,848.93	749,486.30
TOTAL	857	12,846.40	47,146.29	6,405.41	23,507.85	518,374.54	1,902,432.58	1,973,086.72

[a] Areas are estimated based on mangrove forests delineated according to NAMRIA 2010 map and barangay boundaries data obtained from PhilGIS (http://philgis.org/country-barangay/country-barangays-file)

[b] Total Carbon (tC) is converted to tCO_2 equivalent by multiplying the amount of carbon (tC) by carbon's CO_2 equivalent weight (3.67)

[c] Based on sample plots located within each barangay (i.e. 610tC/ha for Talon-talon and 595.72 tC for Mampang)

[d] Total refers to the whole barangay. Calculated based on the Above Ground Biomass and Below-ground Biomass shown in Table 5 and a carbon conversion rate of 0.46 and 0.39 for AGB and BGB.

[e] This includes tCO_2e from the three carbon pools (Above-Ground, Below Ground and Sediments)

The team collected soil samples from 39 of the 54 sample plots at two soil depth ranges each, namely at 0-40 and 40-100 centimeters to test for bulk density and to estimate the percentage of carbon concentration. The estimated average amount of carbon from soil sediments is 606.836 tons of carbon (tC) per hectare.

The estimated average bulk densities and percentage of carbon concentrations were not significant between the two soil depths. This implies that soil compaction did not increase or change significantly with soil depth and carbon concentration did not increase significantly with deeper soil depth.

The total ecosystem carbon per hectare, calculated by aggregating AGB, BGB, and soil carbon is 629 tC per hectare.

This study also explored the correlation of the amount of soil carbon and above ground and below ground biomass measures. This analysis is conducted to understand the relationship of AGB and BGB to soil carbon, which if strongly correlated, can be used to model total carbon density of the ecosystem without the need for soil sampling. Results show weak correlation between soil carbon and biomass. This is partly because of the heavy cutting in the past that may have significantly impacted the mangrove forest ecosystem. In other words, the normal plant-soil dynamic interactions in a natural undisturbed ecosystem were heavily impacted resulting in the possible distortion or disturbance of the biomass and soil carbon relationship.

In addition to establishing the baseline, this report also describes projected carbon sequestration reflecting the carbon sequestration potential of the mangrove forests. The team used the USAID AFOLU (Agriculture, Forestry and Other Land Use) Carbon Calculator[4] to project future carbon benefits and describe three scenarios representing different management regimes or levels of interventions. The first scenario projects future[5] carbon sequestration of the 857-hectare mangrove forests from the two sites if the areas are successfully protected from deforestation. This means no deforestation, or 100% management effectiveness; thus, representing the true carbon sequestration potential of the mangrove forests. This scenario adopts the 'default' data on deforestation rates provided by the AFOLU calculator based primarily on analysis of global remote sensing data. Currently, there is no study or data on deforestation rates specific to the Philippines; hence, the AFOLU default data is adopted in the first scenario.

The second scenario assumes similar conditions to the first scenario, albeit with a higher assumed historical deforestation rate (i.e. 2% instead of 0.8%). The 2% deforestation rate is adopted in the second scenario, the only for illustrative and comparative purposes. The projected carbon benefits[6] are higher due to the higher expected benefits from 'avoided' deforestation, resulting from the reduction due to high historical deforestation rate. The third scenario assumes reforesting 85 hectares of mangrove forests. The carbon benefit includes the expected growth in biomass over a 10 year growth period from 2017-2027.

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[4] The USAID AFOLU Carbon calculator was developed, on behalf of USAID, by Winrock, International and is intended for USAID supported Projects to calculated and report the carbon benefits generated by the projects

[5] Mid-term projection of 10 years was made and described in the results.

[6] The term 'carbon benefit' is the term used by the AFOLU calculator; hence the term is also adopted here for consistency. However, it should be noted that the calculated carbon benefits essentially reflect the carbon sequestration potential of an area.

1. INTRODUCTION

Mangrove forests play an important role in sequestering carbon in biomass and soil sediments, as recently highlighted in a number of publications (Murdiyarso et al., 2010; Chen et al., 2012; Kauffman & Donato, 2012). Moreover, mangroves also provide a variety of economic and environmental benefits both to humans and other organisms. Mangrove forests provide various products used as food, source of herbs with medicinal value, and other timber and wood products, including firewood and building poles. Mangrove ecosystems also serve as critical nesting grounds for many bird species, as well as a shelter to a wide variety of mammals, amphibian, fish, crabs, shrimps, and other invertebrates (Nagelkerken et al. 2008).

Mangroves ecosystems are ecologically valuable for a variety of reasons. They provide complex habitat structure for numerous juvenile fish species. In addition, the extensive rooting system of mangrove ecosystems stabilize near shore sediments and therefore help mitigate coastal erosion. Mangroves also provide water filtration benefits as well as protection to local communities and ecosystems during storm events by minimizing the impact of storm surge, winds, and erosion.

Equally important is the economic value of mangroves as one of nature's largest carbon sinks (Nellemann et al., 2009). In a recent study, Brandera et al (2012) examined the value of ecosystem services provided by mangroves using meta-analysis of the economic valuation literature, and then applied the estimated value function to assess the value of mangroves in Southeast Asia. They reported that the mean economic value of mangrove forests is US$4,185 ha/year. They also reported that, "the values of mangrove ecosystem services are highly variable across study sites due to, amongst other factors, the bio-physical characteristics of the site and the socio-economic characteristics of the beneficiaries of ecosystem services".

In the Philippines, Spaninks and Beukering (1997) described how mangrove ecosystems provide a range of non-market as well as marketed goods and services both on and off-site. Their study concluded that the "full value of mangrove products is not easily recognized, and is, therefore, often neglected in development planning". Such incomplete valuation of mangroves resulted in the conversion of mangroves to other uses that generate directly marketable products, such as aquaculture. Subsequently, they proposed an "economic valuation method that offers a more comprehensive assessment of the many goods and services provided by mangrove ecosystems, and hence may contribute to more informed decision-making".

In the Philippines, published reports indicate that the country is home to at least 42 species of mangroves belonging to 18 families (Polidoro et al., 2010). Consequently, the Philippines is been recognized as 16th most mangrove rich country in the world (Siikamaki et al., 2012).

A large part of its population depends on the mangroves for food, livelihood, and shelter derived from the mangrove ecosystem. Primavera (2000) has reported that approximately half of the country's towns and local communities depend on these mangrove habitats for food and other goods and services.

Despite the importance of mangroves, they are among the least studied, most threatened, and rapidly disappearing natural environments in the world. The Food and Agriculture Organization (FAO) reported in 2007 that global mangrove coverage declined from 18.8 million hectares in 1980 to 15.2 million hectares by the end of 2025. In the Philippines, the total area of mangroves was estimated at 259,600 hectares in 2010 (Siikamaki et al., 2012). Large areas of mangroves in the country have experienced natural and human-induced deforestation specifically conversion to fish and shrimp ponds (Lawrence, 2012). In addition, intensive harvesting and cutting primarily for firewood have also significantly degraded large areas of mangrove area.

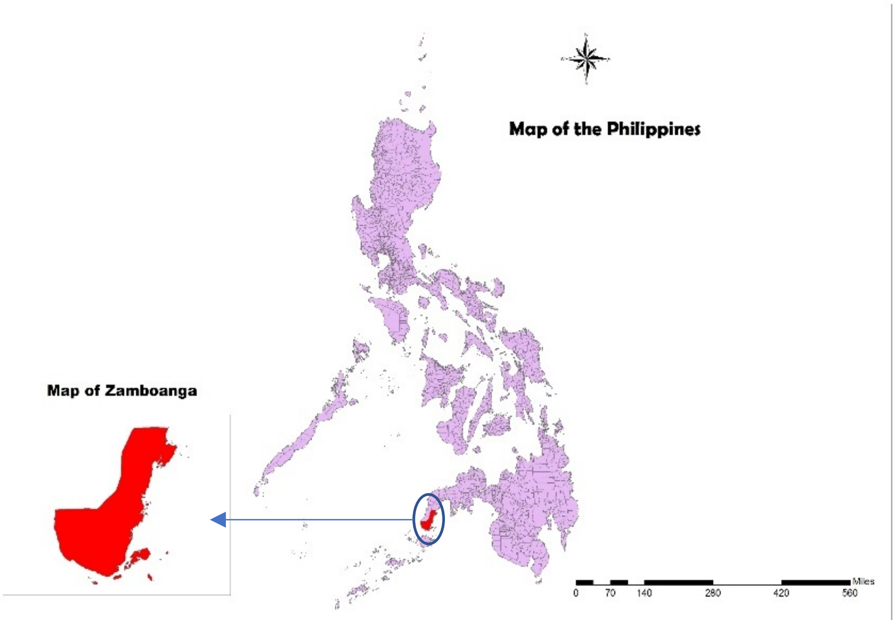
Treevolution was a Mindanao-wide campaign, whose full name is "Treevolution Greening MindaNow'—a massive tree planting activity conducted in September 26, 2014. Organized by the Office of the City Environment and Natural Resources (OCENR) in Zamboanga City, the activity focused on the Talon-talon mangrove area, the designated national greening program (NGP) site for the city. In addition, in Zamboanga City, the Community Environment and Natural Resource Office (CENRO) of Zamboanga East planted 92,011 seedlings with 1,412 planters in 36.80 hectares. CENRO Zamboanga West planted 220,241 seedlings with 2,500 planters in 88.08 hectares[7].

The Mindanao Development Authority (MinDA) in collaboration with the USAID Building Low Emission Alternatives to Develop Economic Resilience and Sustainability (B-LEADERS) Project, DENR Regional Offices, Local Government Units, and private sector groups agreed to conduct an assessment of the amount of carbon stock in Mangrove forests at two local Barangays, namely: Talon-talon and Mampang. These areas are also two of the Treevolution sites within the City of Zamboanga.

This study describes the results of a carbon assessment study of the mangrove forests from these two sites. Figure 1 shows the location of the Zamboanga Mangrove Forests.

Zamboanga City is located in the southwestern part of Mindanao with a population of 861,799. Mangrove forests occupy the southeastern sides of the city. The city's boundary stretches far south and constitutes the south most part of the Mindanao Island. Because the city's boundary in the south, east and west are coastal areas with no adjoining land areas, the city is exposed to tidal waves and other similar risks faced by islands. Mangrove forests in Zamboanga City are important because they can serve as protection against possible coastal risks such as waves and strong storm surges.

Figure 1: Location of the Study Sites



The mangrove sites examined in this study are close to two barangays which are heavily populated and highly dependent on the mangrove for their livelihood such as salt making, fishing for lapu-lapu, bangus, prawns

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[7] http://r9.denr.gov.ph/index.php/86-region-news-items/238-denr-ix-releases-partial-tally-of-treevolution

and fingerlings. The demand for fuelwood is also high, both for local and commercial uses. The heavy pressure placed on the mangrove forests due to these high impact human activities was one of the main reasons for the selection of these sites as part of the Treevolution program. Monitoring the general condition of the forests, including their biomass and carbon sequestration potential is important in these areas in order to assess their health and overall sustainability.

1.1 OBJECTIVES OF THE ASSESSMENT

The objectives of the assessment are:

- To generate baseline data on the amount of carbon stock within the mangrove forests of the two barangays
- To characterize the mangrove forests in terms of species composition, stand structure, and other ecosystem-based characteristics
- To determine the carbon sequestration potential of the mangrove forest within the two areas, including the Treevolution sites

1.2 GENERAL SOCIO-ECONOMIC AND BIOPHYSICAL CONDITIONS OF THE SITES

The two barangays share some characteristics that make them suitable as Treevolution sites. They lie in close proximity to the mangrove areas. In fact, the boundaries of the two barangays extend up to the coast where the mangrove forests are located. Hence, the two barangays are most likely going to provide the agents that can either cause negative impacts to the mangrove forests, or be the partners for its protection and sustainable management.

During a scoping review conducted by B-LEADERS, the team noted the following observations that are worth mentioning in this report: the total area of the mangrove forests within the two barangay is approximately 860 hectares; in both barangays, National Greening Program (NGP) areas were established in 2012 (2 hectares), 2013 (16 hectares), 2014 (150 hectares) and 2015 (148 hectares).

The total population in Talon-Talon and Mampang are 35,000 and 7,000, respectively. The communities around the mangrove areas benefit directly and indirectly from the Treevolution mangrove restoration through paid labor during the restoration/planting/protection/maintenance activities, hired forest guards, ability to harvest prawns and fingerlings of bangus, lapu-lapu, and crablets, right to fish in the Tabon channel and in the mangrove waterways, and ability set up seaweed farms in the city water areas. In addition, communities also benefit from the mangrove forests by seaweed farming for those with access to financing as well as prawn gathering, salt panning, and fishing.

There are physical indications of some illegal and abandoned fish ponds within the mangrove areas, particularly those within the jurisdiction of Department of Environment and Natural Resources (DENR) planting areas. The estimated area of these abandoned fishponds is approximately 15 hectares.

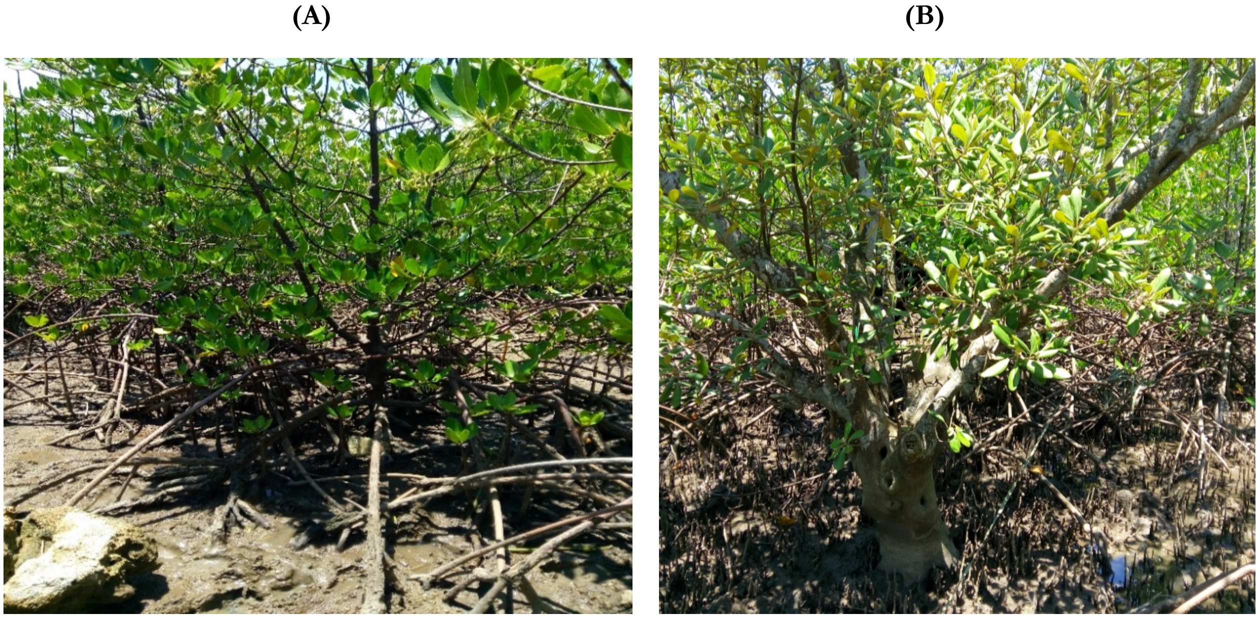
1.3 GENERAL CHARACTERISTICS OF THE MANGROVE FORESTS IN THE TWO SITES

Human activities heavily impact the mangrove forests of Talon-talon and Mampang, particularly cutting and harvesting of mangrove trees for primarily for fuelwood and conversion to other land uses mainly fishponds. Harvesting occurs both by clear-cutting trees as well as selective harvest of branches and stems. As a result, the team observed a significant amount of coppicing or re-branching in many of the sampling plot, particularly among two dominant species: *Sonneratia alba* (Pagatpat) and *Avicennia marina* (Bungalon). Many of these 'coppices' or branches were the result of earlier cutting as shown in the photos (Figure 2 A-B below).

The mangrove species were mainly planted through assisted regeneration, where new mangrove seedlings are planted among existing stands of older mangrove trees which were left after heavy cutting in the past.. The trees appear very healthy and well suited for the general mangrove ecosystem conditions and characteristics. Natural regeneration is also apparent throughout the two sites.

The two sites were planted at different years since the 1990s primarily by the DENR. Chosen plantation species are growing well as shown by the vigor of the trees, high regeneration rates, and the presence of naturally regenerating seedlings and saplings in the understory.

Figure 2: Coppicing and Major Branching of Mangrove Species


(A)

(B)

To represent the sampling area covering the two sites, the entire area is divided into strata (i.e. categories). One of the most important bases for stratification is on canopy cover (i.e. open, relatively open, and closed) as shown in the photos in Figure 3.

Figure 3: Sample Plots from Different Canopy Covers

A) Open **B) Relatively Open** **C) Closed**

The Treevolution areas planted recently appear in excellent health and vigor with very high survival rates and they are growing well even at different spacing. Saplings are also growing uniformly: a sign that the saplings are not undergoing any significant disturbance and stress as shown by the photos in Figure 4.

Figure 4: Saplings under the Canopy of Mangrove Trees

The hydrological conditions of the sites allow for sufficient natural flow of water and nutrients, making both sites favorable for mangrove forests as shown by the photo in

Figure 5. Because the local communities cleared waterways to access open water provide, the study team could directly access the mangrove forests for sampling. Despite the presence of a local community inside the mangrove area (close to Talon-talon) and good accessibility, there was no sign of negative impacts (e.g. cutting), signaling the mangrove forests are well-protected.

Figure 5: Waterways Scattered over the Mangrove Forests

Mangroves are viviparous, bringing forth live young and dispersing propagules via water, rather than producing dormant seeds like most flowering plants. These propagules allow for natural regeneration of the mangroves. Propagules were found throughout the mangrove areas and most likely dispersed via water with varying degrees of vivipary or embryonic development.

Five mangrove species dominate much of the mangrove forests in the two sites, namely: *Rhizophora mucronata* (B. Babae), *Rhizophora apiculata* (B. Lalake), *Rhizophora stylosa* (B. Bangkaw); *Sonneratia alba*, *Avicennia marina*. *Rhizophora mucronata* is the most found species in the two sites. Hence, the forest floor is characterized by significant above ground roots, as shown in the photos in Figure 6.

Figure 6: Significant Above Ground Rooting System of Rhizophora Spp

2. METHODOLOGY: SAMPLING, DATA COLLECTION, AND ANALYSIS

Protocol on carbon assessment for mangrove guided data collection, as outlined in the monograph written by Kauffman and Donato (2012). Their tools also informed the) guided the general methodology adopted in this study. .T) guided the procedures used in the data collection process and the methods adopted in the analysis of the data.

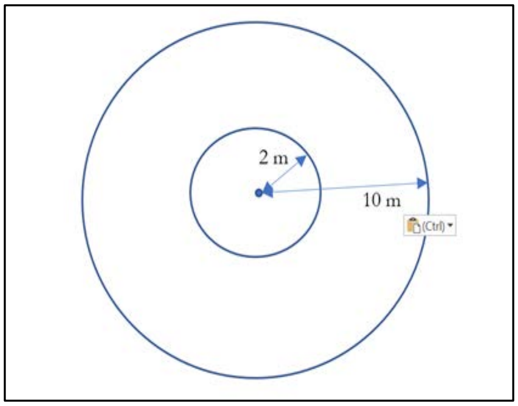
2.1. SAMPLING DESIGN AND PLOTS

Following the protocol recommended by Kauffman and Donato (2012), the team adopted two ‘nested’ circular sample plots. The first, larger plot is a 10-meter radius plot where data from trees/stems were collected to serve as the primary dataset for estimating biomass, both above ground biomass (AGB) and below ground biomass (BGB). Soil samples from some of these circular plots were also collected to estimate the soil carbon content of the mangrove areas.

Following the inventory protocol for estimating biomass, the team measured and recorded the diameter of all trees equal or greater than 5 cm were. Diameter at breast height (DBH) (approximately 1.3 meters) were measured for these trees/stems, while species with heavy above ground rooting system, particularly *Rhizophora spp*, measured at 30 cm above the highest stilt.

The second circular plot is a 2-meter radius plot taken from the same plot center of the 10-meter radius plot as shown in Figure 7.

Figure 7: Circular Sampling Design



The 2-meter radius plot serves as the regeneration plot for collecting data on saplings and seedling. The saplings and seedlings are too small to count toward biomass estimation, as they are less than 5 centimeters.

The sampling scheme adopted was systematic stratified random sampling. As shown in the succeeding sections, it is systematic because the potential sample plots are generated based on a systematic grid of 100 x 100 meters. The nodes generated serve as the center of the sample plots. Hence, there can be as many possible sample plots as there are nodes within the grid. Sampling scheme is also stratified because the sampling area covering the two barangays of Talon-talon and Mampang were stratified based on canopy cover, management regime, management agency, and location. Each category can have more than one stratum. Hence, the number of possible sample plots within a stratum is the number of nodes encapsulated by the boundaries of each stratum. Sampling is random because for each stratum, sample plots were randomly selected from among the potential grid points (sample plot centers).

The systematic stratified random sampling is appropriate because it can best address the objectives of this study. Specifically, it allows for the unbiased estimation of the amount of carbon sequestered in the mangrove areas, and it also enables an in-depth characterization of the mangrove areas in terms of canopy cover, location, and management regime.

2.2 STEPS IN SAMPLING AND DATA COLLECTION.

Sampling and data collection included the following series of steps.

Step 1: Identify the extent and scope of general area where sampling will occur

Figure 8-A shows a GIS map of the extent of mangrove areas in Zamboanga City; Figure 8-B shows the mangrove areas of Talon-talon and Mampang imported and displayed on Google Earth, and Figure 8-C shows the map of mangrove areas according to the mangrove map of 2010 generated by NAMRIA.

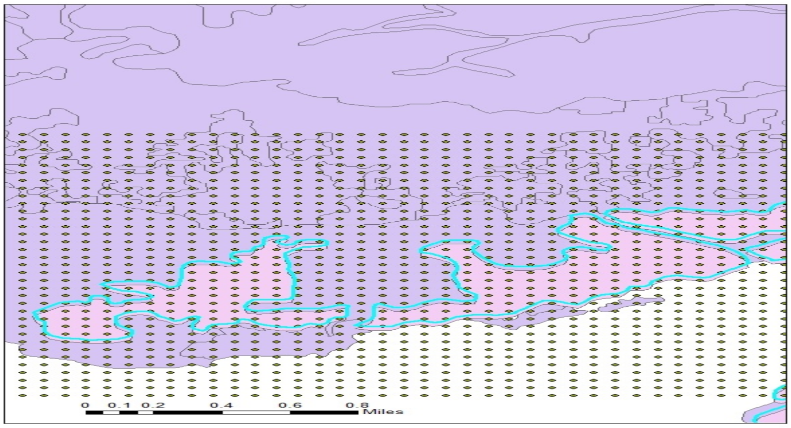
Figure 8: Map of (A) Mangrove Areas in Zamboanga City, (B) Mampang and Talon-talon on Google Earth and (C) the Barangays from NAMRIA 2010 Data


(A) (B) (C)

Step 2: Generate a sampling grid, as grid centers will be potential 'center' of a sample plot

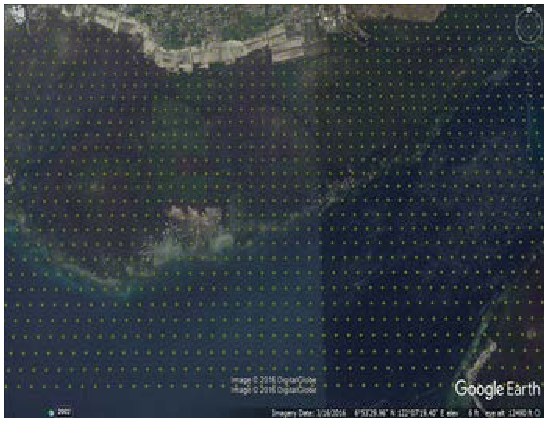
Figure 9 shows the sampling grid, which served as a guide to identify potential locations of the sample plots. Each grid point serves as potential sample plot that can be selected through random sampling.

Figure 9: Sampling Grid (100 x 100 meters) Generated in ArcMap



Step 3: Display sampling grid in Google Maps, which contains the most recent map or aerial photo available

Figure 10: Sampling Grid Imported into Google Earth



The grids in Google Earth provide an aerial view of the possible sample locations. Again, each point in the grid represents a possible sample plot location during sampling. The aerial view provided by Google Earth enables the preliminary or approximate identification and delineation of canopy cover.

The aerial photo also shows the location of waterways that can guide the plot location by disregarding randomly selected plots or plots with a node located within waterways.

Step 4: Pre-stratify the sampling area

Stratification generally provides more efficient and accurate estimates. Stratification can incorporate several factors such as canopy cover (open, relatively open, close). Figure 11 shows the different strata used in sampling. In addition to canopy cover, other strata were identified using management regimes (NGP, non-NGP, co-managed, Treevolution sites), location (Talon-talon, Mampang), and management agencies (CENRO/DENR, OCENR).

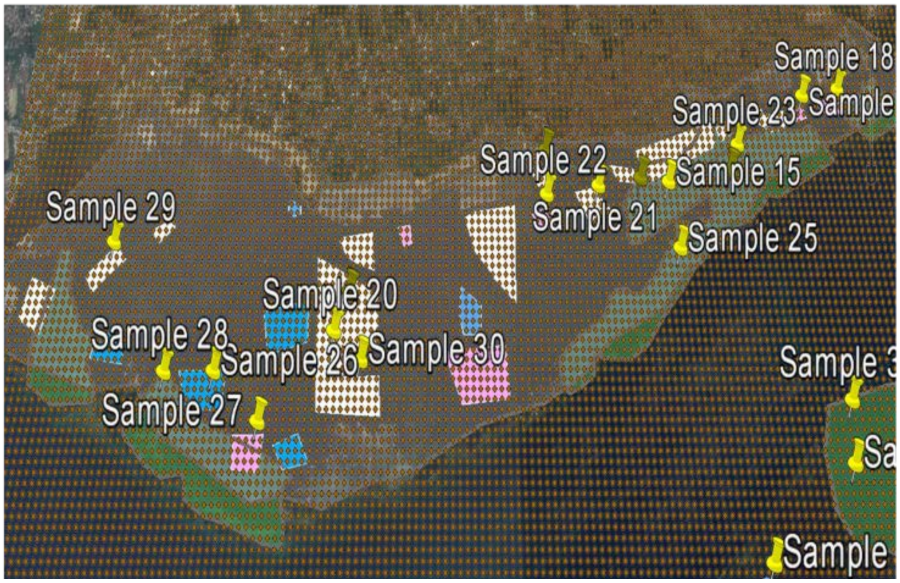
Figure 11: Stratification using Canopy Cover, Location, and Management Regime

The stratification scheme also allows the generation of summary data and information for each relevant stratum. For example, one can summarize canopy cover data according to canopy cover, such as closed, relatively open and open, and summary data according to location such as for each barangay, namely Talon-talon and Mampang; or by management regime such as NGP and non-NGP areas.

Step 5: Randomly select sample plots

In the absence of previous sampling in the selected Treevolution sites, the team selected and located sampling plots randomly as shown in Figure 12. Random selection of grids or sample plot centers removes possible bias in sample selection. In this case, the team used a heuristic approach using numbered grid points within each stratum to identify and locate randomly selected sample plots.

Figure 12: Sample Locations of Systematically Stratified and Randomly Selected Sample Plots



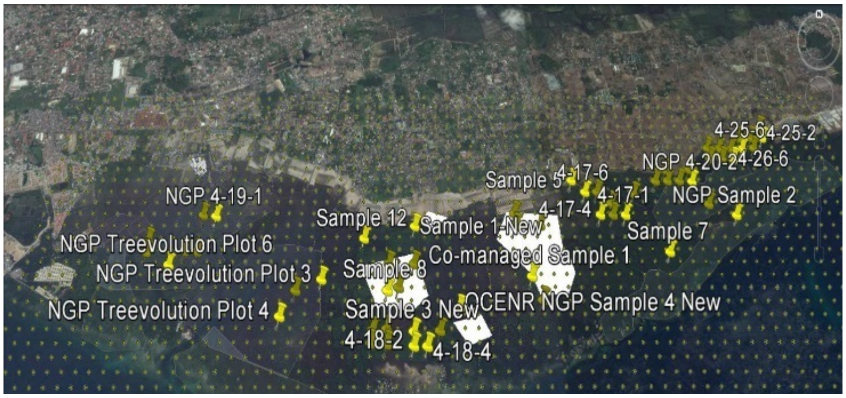
The selection of sample plots was iterative. First, the team completed preliminary selection randomly using only the potential grid points (or nodes) as shown in Figure 10. As described in Step 4 and shown in Figure 11, the entire sampling area is stratified using geospatial data, such as shapefiles, to identify the boundaries of each stratum.

To make sure that each stratum received representation, the team completed a random selection of sample plots within each stratum. Because no previous data was available, it was not possible to statistically determine the number of sample plots and optimally allocate them to each stratum. Consequently, the team allocated a minimum of three sample plots *a priori* for each stratum. The preselected sample plots are then validated using Google Earth and validated or ground-truthed with local partners. The team replaced preselected sample plots if they were on ‘clear’ areas (such as waterways) where no mangrove trees exist.

Step 6: Collect samples from randomly selected sample plots

Figure 13 shows an example of the randomly located sample plots identified based on the date of the actual survey.

Figure 13: Location of Sample Plots Identified Based on Date of Sampling, Group and Plot Number



To make sure that sample plots are uniquely identified, the following naming convention was adopted: group number, date of sampling, and sample number. This naming convention replaced the Plot ID originally adopted in the preselection process.

Data collected from the plot include: the diameter of all trees, the height of selected trees, the species, and the number of saplings and seedlings. Diameter is measured at breast height, which is generally about 1.3 meters above ground for independently growing trees and species. Alternatively, for species that have extensive above ground root systems such as *Rhizophora mucronata*, diameter was measured at 30 cm above the highest stilt.

3. CARBON POOLS IN MANGROVE AREAS

Like other forest types, carbon sources from mangroves come from five carbon pools: (1) AGB of live vegetation; (2) BGB of live vegetation; (3) dead wood; (4) forest floor (litter); and (5) soil. Kauffman and Donato (2012) recommended that, "a pool should be measured if it is: (1) large; (2) if it is likely to be affected by land use; (3) if the future land-uses are uncertain; and (4) if the pool size is uncertain. Small pools or those unlikely to be affected by land use change may be excluded or sampled less frequently. In mangroves, non-tree vegetation and litter are usually minor ecosystem components and can often be excluded from measurements without compromising the accuracy of the sample.

In terms of magnitude, the three largest carbon pools in mangrove forests are AGB, BGB or root biomass, and soil. Consequently, this study sampled all these carbon pools. The final total carbon calculation may include the others, but based only on estimates from earlier or previously published works. The sub-sections below describe estimations of the three major carbon pools.

3.1 ESTIMATION OF ABOVE GROUND BIOMASS AND ITS CARBON CONTENT

The team estimated above ground biomass using allometric equations developed specifically for mangrove forests and corresponding to species or species groups.

This study adopted three allometric models based on the models described in Kauffman and Donato (2012). The three types of allometric models adopted for each species/species groups are:

- For common or general models applicable to all species not included in the other two models:
  $AGB = 0.251 * \rho * DBH^{2.46}$
- For *Rhizophora spp*:
  $AGB = 0.105 * DBH^{2.68}$
- For *Sonneratia Alba*
  $AGB = 0.168 * \rho * DBH^{2.31}$

In these models, AGB is the above ground biomass; DBH is the diameter at breast height (measured at 1.3 meters from the ground, or 30 centimeters from the highest stilt for *Rhizophora Spp*); and ρ is the wood density of the species.

The first allometric equation is the general model for most mangrove species adopted from Komiyama et al (2005), as reported and cited in Kauffman and Donato (2012). This model is used quite extensively especially in Southeast Asia.

The first model is considered general because the dataset in model development came from 104 sample trees representing 10 mangrove species (*Rhizophora mucronata Lamk., R. apiculata Bl., Bruguiera gymnorrhiza (L.) Lamk., B. cylindrica (L.) Bl., Ceriops tagal (Perr.) C. B. Robinson, Avicennia alba Bl., Sonneratia alba J. Smith., S. caseolaris (L.)*

Engler, Xylocarpus granatum K¨onig and X. moluccensis (Lamk.) Roem). This study used sample trees with a diameter (DBH at 30 cm above highest stilt) larger than 5.0 cm in the analysis. in the study Five study sites in Thailand and Indonesia generated the dataset. In light of these conditions, and in view of the geographical location that supplied the data, the study adopted the model.

The second allometric model for *Rhizophora spp* came from Clough and Scott (1989), as reviewed in Komiyama et al (2008). The team adopted this model because it was developed for a group of *Rhizophora* species group, which included *Rhizophora stylosa*, *Rhizophora apiculata* and *Rhizophora mucronate—mucronata* -- the same species found in the two mangrove sites examined in this study.

Finally, the third allometric model for *Sonneratia alba* came from Chave (2005). The team adopted this model because, as reported by Kauffman and Donato (2012), it represents an average model, i.e. within the range of the high and low estimates provided by other allometric models for *Sonneratia alba*.

The estimation using allometric models only provides AGB and still needs to be converted to its equivalent carbon content by multiplying the AGB by its specific carbon concentration (percentage). Kauffmann and Donato (2012) quoted previous studies in its reporting on the carbon concentration of the wood of *Bruguiera gymnorrhiza* as 46.3%, *Rhizophora apiculata* as 45.9%, and Sonneratia *alba* as 47.1%. They also reported that the carbon concentration of wood is usually a little less than 50%, hence, it is a common practice to convert biomass to carbon by multiplying by 0.46–0.5, if local or species-specific values are not available (Kauffman and Donato (2012). This study adopted a more conservative estimate of 0.46.

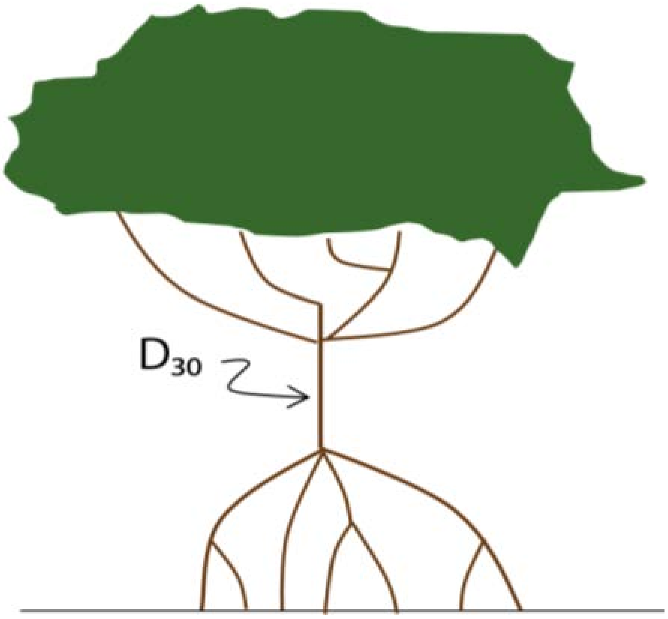
3.2 ESTIMATION OF ROOT BIOMASS

Komiyama et al (2008) reported that root biomass is an important component in mangroves because it comprises a relatively high proportion of the ecosystem compared to upland forests, including its carbon content. Unlike AGB, there are few allometric equations developed for root biomass of forests, especially and especially for mangroves because they are among the least studied forests (Kauffman and Donato (2012). Komiyama et al (2008) provides a useful reference for below ground allometric equations for mangroves. The team adapted the Komiyama et al (2008) model here:

$$BGB = 0.199 * \varrho^{8.99} * D^{2.22}$$

In this mode, BGB is the tree's below ground biomass (kg), ϱ is wood density (g/cm3), and D is the tree diameter at breast height (cm), or as described above, tree diameter at 30 cm above the highest stilt for *Rhizophora spp* as shown (D_{30}) in Figure 14.

Figure 14: Diameter at Breast Height Measured at 30 cm Above the Highest Stilt



Like AGB, the carbon content of root biomass is the product of root biomass and root carbon concentration. Kauffman and Donato (2012) reported that, "Carbon concentrations of roots are typically lower than that of above ground tree components. For example, Jaramillo et al. (2003a) reported carbon concentration of roots in tropical forests as 36– 42%. A defensible default value for root carbon concentration would be 39%. The results should be scaled to a per-hectare basis to report carbon pool estimates".

The World Agroforestry Center (2011) provided the wood densities for the calculation, as reviewed by Kauffman and Donato (2012).

3.3. CARBON CONTENT OF ABOVE-GROUND AND BELOW GROUND BIOMASS

Section 3.1 and 3.2 describe how allometric models can be used to estimate AGB and BGB that requiring data only on diameter size, wood density, and species/species groups. Biomass, in general, is the total mass of a given area or volume. Forest biomass, in particular, refers to the total mass of all vegetative elements in a forest. Hence, to estimate the carbon equivalent of biomass, it is necessary to determine the carbon concentration of the biomass source (e.g. wood, leaves, roots, etc.). As pointed out in Section 3.1, carbon concentration in wood and other AGB is approximately 46%. On the other hand, carbon concentration in root biomass is about 39%. Hence, as described in Sections 3.1 and 3.2, to convert biomass to carbon, multiply the biomass source by its carbon concentration.

3.4 ESTIMATION OF SOIL CARBON

Below ground carbon is often the largest pool in a mangrove, usually constituting over 50% to upwards of 90% of the total ecosystem carbon stock of mangroves (Donato et al. 2011). To accurately measure the soil carbon pool, three parameters are required: soil depth, soil bulk density, and organic carbon concentration.

3.4.1 BULK DENSITY

Technically, bulk density is the weight of soil in a given volume. In general, soils with a bulk density higher than 1.6 g/cm^3 tend to restrict root growth. Moreover, bulk density increases with compaction and tends to increase with depth.

To calculate bulk density, soil samples should be oven-dried to a constant mass at 60 °C. Kauffman and Donato (2012) determined that it requires at least 48 hours for samples to attain a constant dry mass when dried at 60 °C. Caution must be taken to ensure that samples are thoroughly dried before calculating bulk density.

After the drying process, bulk density is determined by dividing the oven-dry soil sample by the sample volume using the following equation:

$$\text{Soil bulk density } (g\ cm^3) = \text{Oven-dry sample mass } (g) / \text{ Sample Volume } (m^3)$$

3.4.2 CARBON CONCENTRATION

Kauffman and Donato (2012) described two basic approaches to quantify total carbon in soils: dry combustion with an elemental analyzer and wet combustion (Nelson and Sommers 1996, Schumacher 2002).

3.4.3 SOIL DEPTH

Soil depth refers to the depth, in centimeters, at which soil samples are collected and analyzed. Kauffman and Donato (2012) reported that mangroves often have organic-rich soils with organic horizons ranging in depth from 0.10 m to >3 m. Consequently, they recommended that when mangrove soils are deeper than 1 m, to sample at least the top 100 cm. Minimally, collect soil samples at 0–30 cm depth, plus additional samples representing the 30–100 cm depth range. Kauffman et al. (2011) and Donato et al. (2011) sampled mangrove soils at depths of 0–15 cm, 15–30 cm, 30–50 cm, 50–100 cm, and >100 cm.

This study collected soil samples at depths 0-40, and 40 to 60 cm in order characterize the soil content at these two depth ranges and provide a robust data set that correlates soil depth (at different ranges) with biomass (AGB, BGB, or total) as described in Section 4.4.

3.4.4 TOTAL SOIL CARBON CONTENT

Total soil carbon content is determined by summing the mass of each sampled soil depth. In this study, the team determined the total soil carbon pool by partitioning the soil horizon into depth intervals of 0–40 cm and 40–100 cm, taking measurements of bulk density and carbon concentration at each layer/depth.

Calculations of the soil carbon mass at each depth interval used the following equation:

$$\text{Soil carbon } (Mg/ha) = \text{Sediment Mass} * \%\ C$$

$$\text{Sediment Mass} = \text{Bulk density} * \text{soil depth interval } (m) * 10000\ m^2$$

In the equation, %C is the carbon concentration. Finally, the total soil carbon pool is the sum of the carbon mass of each of the sampled soil depths (i.e. for 0–40 cm and 40–60 cm).

3.5. TOTAL CARBON CONTENT OF THE MANGROVE FORESTS

The previous sub-sections describe the methods and principles to estimating AGB (Section 3.1), root biomass (Section 3.2), carbon content of the total biomass (Section 3.3), and the soil carbon (Section 3.4). Given these estimates, the following equation calculates the total carbon content of a mangrove forest:

$$\text{Total carbon stock (Mg ha-1) of the sampled stand} = C_{treeAGB} + C_{treeBGB} + C_{soil}$$

In the equation, $C_{treeAGB}$ is the amount of above ground carbon pools of trees, $C_{treeBGB}$ is the amount of below ground tree carbon pool, and C_{soil} is the total soil carbon pool.

4. SUMMARY OF RESULTS

Table 1 shows a summary of the general information generated from the results of the study.

Table 1: General Results and Summary Statistics

Measurement	Amount
Total number of plots sampled/measured	54
Total number of mangrove trees/stems measured	2636
Average number of stems/plot	48.70
Number of plots with soil samples	39
Average Diameter of trees/stems (cm)	6.88
Average Above Ground Biomass (Kgs/ha)	32,104 (STD[8] = 26,516)
Average Carbon from AGB (Kgs/ha)	14,767
Average Below Ground Biomass (Kgs/ha)	19,003 (STD = 14,968)
Average Carbon from Below Ground (Kgs/ha)	7,411
Average Total Biomass (Kgs/ha)	51,108.40
Total Carbon from Biomass (kgs/ha)	22,178
Average Soil Carbon (Kgs/ha)	606,836.724 (STD =172,558.69)
Total Carbon from all carbon pools (kgs/ha)	629,014

The team measured a significant number of trees (2,636). The average number of trees and stems (major coppice or branch with DBH > 5 cm) is 48.7 per plot. The study considers coppice or major branch from the same tree that have diameters $\geq$ 5 cm as individual stems for purposes of carbon assessment. For instance, a tree with three coppices or branches that has diameter greater than or equal to 5 cm (within the DBH range) are considered three individual stems. Hence, their AGB and BGB are calculated using their respective allometric models, as described in Sections 3.1 and 3.2.

As shown in Table 1, the trees/stems of the mangrove forests are rather small (6.88 cm average). This is mainly because both sites are essentially 'plantation areas' with average age between 9–14 years. These areas were reforested after heavy cutting in the past. The sampling plots are within areas that were replanted through assisted regeneration in various stages; some as early as 1992, although most were planted between 2003 and 2008.

The estimated average total biomass (AGB and BGB) per hectare of the 54 sample plots measured is 51.1 tons per hectare. This amount is consistent or comparable with the results of published reports, including Kauffman and Donato (2012) and Castillo and Breva (2012).

The total biomass is 32.1 tons per hectare (62.8%) and 19.0 tons per hectare (37.2%) for AGB and BGB, respectively. In a similar study conducted by Castillo and Breva (2012) for four mangrove plantations from four different areas in the Philippines (Bataan, Palawan, Aklan and Samar), the AGB ranged from 5 –282 tons per hectare with an average of 137.86 tons per hectare. However, the plantations from these four mangrove plantations are older (between 15 to 27 years old); hence, the trees are larger (5-32 centimeter DBH) and therefore the average AGB is higher. The total biomass per hectare (AGB and BGB) in the four mangrove

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[8] STD=Standard Deviation

sites is 184 tons per hectare, which is higher compared to the estimate of 51 tons per hectare for the two mangrove areas assessed in this study.

The BGB is approximately 62% of the AGB for each plot. The percentage ranges from a low of 35% to a high of 74% of the AGB. This is consistent and comparable with the percentages observed in Castillo and Breva (2012).

4.1 SUMMARY DATA FOR BIOMASS

Table 2 shows a summary of the data collected from the 54 sample plots measured. It provides summary information of the measured 54 plots classified into different categories: canopy cover, location, management agency, and management regimes. The table also shows the number stems per plot, the average diameter of each stem/tree per plot, AGB, BGB, and total biomass of each plot adjusted on a per hectare basis.

Table 2: Summary Data of Each Sample Plot

Plot ID	N (No. of Stems)	Average DBH	Above Ground Biomass(Kg) per hectare	Below Ground Biomass (Kg per hectare)	Total Biomass (Kg per hectare)	Canopy Cover	DENR/OCENR	Location	NGP/Non-NGP	Co-Managed/OCENR/Treevolution
s1-g1	9	5.28	2,626.1298	1,922.1333	4,548.2631	Relatively Open	OCENR	Talon-talon	NNGP	COM
s2-g1	41	9.60	74,230.6456	36,115.5856	110,346.2313	Close	OCENR	Talon-talon	NGP	
s1-g2	81	6.02	34,598.8945	23,435.3710	58,034.2655	Close	OCENR	Talon-talon	NGP	COM
S2-G3	20	6.74	10,935.4487	6,336.5749	17,272.0237	Close	OCENR	Talon-talon	NNGP	COM
S1-G3	32	9.16	33,416.0044	21,034.9500	54,450.9544	Relatively Open	OCENR	Talon-talon	NNGP	COM
S3-G1	6	8.07	6,522.7614	3,528.7475	10,051.5089	Open	OCENR	Talon-talon	NNGP	COM
D1 Plot 2	**50**	7.29	24,600.9974	17,554.2925	42,155.2900	Open	OCENR	Talon-talon	NGP	
G2-04-17-17-Plot 2	54	6.08	24,742.0179	14,953.3242	39,695.3420	Relatively Open	OCENR	Talon-talon	NNGP	COM
G2-04-17-17-Plot 4	44	6.06	21,331.6442	11,537.4033	32,869.0475	Relatively Open	OCENR	Talon-talon	NNGP	COM
G2-04-18-17-Plot 5	72	6.54	40,245.8890	26,452.8215	66,698.7105	Close	DENR	Talon-talon	NGP	
G2-04-18-17-Plot 6	183	6.65	105,291.9864	67,321.4766	172,613.4630	Close	DENR	Talon-talon	NNGP	
G2-04-19-17-Plot 5	70	6.55	48,523.0505	23,481.9007	72,004.9512	Close	DENR	Talon-talon	NGP	Treevolution
G2-04-19-17-Plot 6	**52**	8.19	72,852.5399	32,381.9827	105,234.5226	Open	DENR	Talon-talon	NGP	Treevolution
G2-04-20-17-Plot 2	107	5.67	38,334.6156	26,897.1715	65,231.7872	Close	DENR	Mampang	NGP	
G2-04-20-17-Plot 4	28	6.17	15,973.7317	8,413.8640	24,387.5956	Relatively Open	DENR	Mampang	NNGP	Treevolution
G1-04-17-17-Plot 1	86	5.88	34,045.2101	23,503.4680	57,548.6781	Close	OCENR	Talon-talon	NNGP	COM
G1-04-17-17-Plot 2	21	6.50	13,876.1701	6,795.3035	20,671.4736	Relatively Open	OCENR	Talon-talon	NNGP	COM
G1-04-18-17-Plot 1	58	5.79	22,561.6357	15,353.9154	37,915.5512	Close	DENR	Talon-talon	NGP	
G1-04-18-17-Plot 2	27	8.87	46,597.8159	21,181.9791	67,779.7950	Close	DENR	Talon-talon	NNGP	
G1-04-19-17-Plot 1	13	9.14	18,268.5919	10,724.9113	28,993.5032	Open	DENR	Talon-talon	NGP	Treevolution
G1-04-19-17-Plot 2	32	5.94	13,182.5018	9,010.3603	22,192.8621	Close	DENR	Talon-talon	NGP	
G1-04-20-17-Plot 1	12	5.45	3,831.0872	2,756.1050	6,587.1922	Close	DENR	Mampang	NNGP	
G1-04-20-17-Plot 2	63	5.77	27,889.6486	17,679.5004	45,569.1491	Relatively Open	DENR	Mampang	NNGP	
G3-04-17-17-Plot 1	36	5.81	14,079.5943	9,694.4720	23,774.0663	Close	OCENR	Talon-talon	NNGP	COM
G3-04-17-17-Plot 3	36	6.79	23,731.9344	13,514.5137	37,246.4480	Close	OCENR	Talon-talon	NNGP	COM
G3-04-18-17-Plot 2	114	6.89	72,973.9885	45,605.8348	118,579.8233	Close	DENR	Talon-talon	NNGP	
G3-04-18-17-Plot 4	76	6.18	35,196.9490	23,505.1718	58,702.1208	Close	DENR	Talon-talon	NGP	
G3-04-19-17-Plot 3	20	10.63	96,051.8683	33,770.0709	129,821.9392	Relatively Open	DENR	Talon-talon	NNGP	Treevolution
G3-04-19-17-Plot 4	20	6.72	13,940.3528	7,078.0849	21,018.4377	Relatively Open	DENR	Talon-talon	NNGP	
G3-04-20-17-Plot 1	64	6.32	32,190.4037	21,059.0990	53,249.5027	Close	DENR	Mampang	NGP	
G3-04-20-17-Plot 2	59	6.07	25,599.2299	17,357.3744	42,956.6043	Close	DENR	Mampang	NGP	
G1-04-21-17-Plot 1	113	6.99	82,297.1660	48,994.4010	131,291.5670	Close	DENR	Mampang	NGP	
G2-04-21-17-Plot 2	25	5.97	10,464.2067	7,127.9124	17,592.1191	Open	DENR	Mampang	NGP	
G3-04-12-17-Plot 1	67	6.05	28,801.8478	19,569.9198	48,371.7676	Close	OCENR	Talon-talon	NNGP	Treevolution
G1-04-12-17-Plot2	23	6.19	11,049.2477	7,271.9533	18,321.2010	Relatively Open	OCENR	Talon-talon	NNGP	
G2-04-12-17-Plot 3	24	6.49	15,820.3466	8,693.6824	24,514.0289	Relatively Open	OCENR	Talon-talon	NGP	
G2-04-21-17-Plot 1	90	7.28	67,514.6803	40,922.9319	108,437.6121	Close	DENR	Mampang	NGP	
G1-04-21-17-Plot 2	77	7.46	62,931.4783	37,269.9848	100,201.4630	Close	DENR	Mampang	NNGP	
G1-04-25-17-Plot 1	20	8.97	28,770.6896	16,500.4317	45,271.1213	Open	DENR	Mampang	NGP	
G1-04-25-17-Plot 2	22	6.15	7,067.7046	5,288.7053	12,356.4100	Open	DENR	Mampang	NGP	
G1-04-25A-17-S	38	7.90	23,858.4314	16,460.1129	40,318.5443	Open	DENR	Mampang	NGP	
G1-04-26-17-Plot 1	22	5.34	6,568.6386	4,795.5330	11,364.1715	Close	DENR	Mampang	NNGP	
G1-04-26-17-Plot 4	29	5.54	9,761.5681	6,941.6506	16,703.2187	Close	DENR	Mampang	NGP	
G1-04-27-17-Plot 1	48	6.32	32,182.6319	17,186.7404	49,369.3724	Close	DENR	Talon-talon	NNGP	
G3-04-25-17-Plot 4	13	5.34	3,966.7607	2,869.9693	6,836.7300	Open	DENR	Mampang	NNGP	
G3-04-25-17-Plot 6	7	5.48	2,259.7050	1,624.1338	3,883.8388	Open	DENR	Mampang	NNGP	
G3-04-26-17-Plot 3	8	13.92	20,363.9349	12,066.6657	32,430.6005	Open	DENR	Mampang	NNGP	
G3-04-26-17-Plot 6	140	6.62	78,920.6454	50,714.6919	129,635.3373	Close	DENR	Mampang	NNGP	
G3-04-27-17-Plot 3	43	11.57	83,752.1176	49,477.3645	133,229.4821	Relatively Open	OCENR	Talon-talon	NGP	
G2-04-25-17-Plot 3	31	5.52	9,410.0542	6,917.6878	16,327.7420	Relatively Open	DENR	Mampang	NGP	
G2-04/25/17-Plot 5	20	5.83	8,252.0946	5,515.8052	13,767.8998	Relatively Open	DENR	Mampang	NGP	
G2-04-26-17-Plot 2	6	5.14	1,621.0457	1,205.4823	2,826.5280	Open	DENR	Mampang	NGP	
G2-04-26-17-Plot 5	60	6.46	32,545.6399	21,095.0769	53,640.7168	Relatively Open	DENR	Mampang	NGP	
G2-04-27-17-Plot 2	118	6.26	57,224.7512	37,736.5980	94,961.3493	Relatively Open	DENR	Mampang	NGP	

NNGP = Non-NGP; OCENR = Office of the City of Environment and Natural Resources; COM = Co-managed Program under the OCENR

4.2 DISTRIBUTION AND AVERAGE VALUES FROM SAMPLE PLOTS

Table 2 provides a summary table with the relevant information shown, particularly the AGB, BGB and total biomass. The sections that follow provide a more detailed summary for the different categories.

4.2.1 BY CANOPY COVER

Table 3: Summary Table Showing Results Based on Canopy Cover

Canopy Cover	No. of Plots	Average number of Stems)/plot	Average DBH of stems/plot	Average Above Ground Biomass/plot	Average Ground Biomass (Kgs/ha)	Total Biomass (Kgs/ha)
Closed	26	67.69	6.5142	40,197.2800	24,576.12	**64,773.40**
Relatively Open	16	38.13	6.9175	29,243.8600	16,243.30	**45,487.16**
Open	12	21.67	7.6312	18,384.7800	10,611.11	**28,995.89**

[1] *Close - Canopy cover is approximately 60% or greater; Relatively Open – Canopy cover between 30-60%; Open – Canopy Cover is less 30%.*

In Table 3, it is clear that 'closed' forests have the highest total biomass per hectare. The average size of the trees increases with decreasing canopy cover. The increasing diameter size relative to decreasing canopy cover is likely due to two reasons: (1) the size of 'older' trees that were residual trees after heavy cutting in the past; and (2) more 'open' canopy space for trees to grow; hence larger trees with more open canopy cover. The high total biomass for closed forests are likely due to the high number of trees/stems per plot (67.7) compared to the other canopy covers, at 38.13 and 21.67 trees/stems per hectare for relatively open and open forests, respectively.

4.2.2 BY MANAGEMENT AGENCY

Table 4: Summary Table Showing Basic Data/Information by Management Agency

Agency	No. of Plots	Average number of Stems)/plot	Average DBH of stems/plot	Average Above Ground Biomass/plot	Average Ground Biomass (Kgs/ha)	Total Biomass (Kgs/ha)
OCENR	17	39.58	7.0300	26,950.6400	16,172.88	**43,123.52**
DENR	37	52.15	6.89	34,826.3600	20,330.26	**55,156.62**

Table 4 is for informational purposes and not intended to serve as basis for comparison or inference regarding the two management agencies. Results show that the average total biomass per hectare is higher in the DENR-managed areas even though the trees are relatively smaller. The difference is likely because there are more trees sampled in DENR-managed plots.

4.2.3 BY LOCATION

Table 5: Summary Data Based on Location/Barangay

Location	**No. of Plots**	**Average number of Stems)/plot**	**Average DBH of stems/plot**	**Average Above Ground Biomass (Kgs/ha)**	**Average Below Ground Biomass (Kgs/ha)**	**Total Biomass (Kgs/ha)**
Talon-talon	30	48.60	7.1300	35,867.6900	20,266.470	**56,134.1600**
Mampang	24	48.83	6.5700	27,400.7400	17,425.45	**44,826.1900**

Table 5 is for informational purposes and not intended to serve as a basis for comparison or inference regarding the two Barangay sites. The results show that, on the average, the number of trees sampled per plot is the same, but the average total biomass per hectare is higher in Talon-talon mainly because the trees are larger.

4.2.4 BY MANAGEMENT REGIME

Table 6: Summary Data Based on Management Regime

Management Regime	**No. of Plots**	**Average number of Stems)/plot**	**Average DBH of stems/plot**	**Average Above Ground Biomass/plot**	**Average Ground Biomass (Kgs/ha)**	**Total Biomass (Kgs/ha)**
NGP	27	52.37	6.8700	34,027.6400	20,600.28	**54,627.92**
Non-NGP	27	45.03	6.9000	30,181.5600	17,407.13	**47,588.69**
Others						
Co-management	11	38.63	6.5800	19,991.4300	12,386.00	**32,377.43**
Treevolution Sites[9]	7	41.66	7.7900	46,745.0000	21,390.46	**68,135.46**

Again, the values for each management regime in Table 6 are not intended to compare or make inferences relative to each category. They are for the general purpose of providing information for each management regime.

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[9] These are sites identified by OCENR and DENR as Treevolution areas which were planted recently using assisted natural regeneration. This means planting between residual trees that were left after heavy cutting in the past,

The average total biomass per hectare is higher in NGP areas most likely because of the high number of trees sampled. The average total biomass in Treevolution sites is higher because of bigger trees sampled and more trees per plot at the Treevolution sites.

4.3 SOIL CARBON CONTENT

As described in Sections 3.3.1 to 3.3.4, the team collected soil data from 39 plots to determine the amount of carbon sequestered in the soil sediments below the mangrove forests. For this, the team used a 1 m soil auger that was custom-made with a circumference of 5 cm.

The study collected four soil samples from each selected plot; two samples from each soil depth of 0-40 cm and 40-100 cm. For each depth range, the team collected two soil samples: one for bulk density and the other for carbon content/concentration analyses.

The team collected soil samples from 39 out of the 54 sample plots. Then a total of 156 soil samples were analyzed for bulk density and carbon content at Central Mindanao State University. Table 7 shows the results of the soil carbon analysis.

Table 7: Carbon Content from Each Selected Plot Sampled

Plot ID	Soil Depth (0-40 cm)			Soil Depth (40-100 cm)			Total Soil Carbon (Kgs/ha)
	Bulk Density	Carbon Content	Soil Carbon (Kgs/ha)	Bulk Density	Carbon Content	Soil Carbon (Kgs/ha)	
G3-04-12-17-PLOT 1	1.193	7.083	338,000.760	1.052	6.205	391,659.600	729,660.360
G1-04-12-17-PLOT 2	1.017	7.777	316,368.360	1.052	7.695	485,708.400	802,076.760
G3-04-17-17-PLOT 1	1.245	6.714	334,357.200	1.108	2.589	172,116.720	506,473.920
G2-04-17-17-PLOT 2	1.236	5.655	279,583.200	1.127	5.336	360,820.320	640,403.520
G3-04-17-17-PLOT 3	1.242	6.901	342,841.680	1.063	7.983	509,155.740	851,997.420
G1-04-18-17-PLOT 1	1.073	3.975	170,607.000	1.136	5.253	358,044.480	528,651.480
G3-04-18-17-PLOT 4	1.140	5.506	251,073.600	1.154	6.308	436,765.920	687,839.520
G2-04-18-17-PLOT 5	1.356	5.980	324,355.200	1.032	6.767	419,012.640	743,367.840
G1-04-19-17-PLOT 1	1.011	4.794	193,869.360	0.957	5.504	316,039.680	509,909.040
G3-04-19-17-PLOT 3	1.229	4.920	241,867.200	1.198	5.481	393,974.280	635,841.480
G2-04-19-17-PLOT 5	1.189	6.505	309,377.800	1.140	8.017	548,362.800	857,740.600
G1-04-20-17-PLOT 1	1.387	3.661	203,112.280	1.299	5.028	391,882.320	594,994.600
G2-04-20-17-PLOT 2	1.212	5.201	252,144.480	0.998	5.683	340,298.040	592,442.520
G2-04-20-17-PLOT 4	1.138	6.880	313,177.600	1.058	6.673	423,602.040	736,779.640
G3-04-20-17-PLOT 1	1.131	5.199	235,202.760	1.000	8.297	497,820.000	733,022.760
G3-04-21-17-	0.950	5.416	205,808.000	1.226	3.505	257,827.800	463,635.800

PLOT 1							
G1-04-21-17-PLOT 2	1.214	5.841	283,638.960	1.021	4.769	292,148.940	575,787.900
G1-04-25-17-PLOT 1	1.230	3.752	184,598.400	1.220	6.702	490,586.400	675,184.800
G1-04-25-17-PLOT 2	1.123	3.854	173,121.680	0.997	6.598	394,692.360	567,814.040
G2-04-25-17-PLOT 3	1.130	2.876	129,995.200	1.190	4.854	346,575.600	476,570.800
G3-04-25-17-PLOT 4	1.624	1.433	93,087.680	1.321	4.983	394,952.580	488,040.260
G2-04-25-17-PLOT 5	1.089	5.214	227,121.840	1.158	4.781	332,183.880	559,305.720
G3-04-25-17-PLOT 6	1.319	5.251	277,042.760	1.156	0.649	45,014.640	322,057.400
G1-04-25A-17-S	1.086	4.275	185,706.000	1.066	5.615	359,135.400	544,841.400
G1-04-26-17-PLOT 1	1.356	1.894	102,730.560	1.268	2.631	200,166.480	302,897.040
G2-04-26-17-PLOT 2	1.246	2.410	120,114.400	1.070	6.339	406,963.800	527,078.200
G3-04-26-17-PLOT 3	1.148	3.310	151,995.200	1.412	5.419	459,097.680	611,092.880
G1-04-26-17-PLOT 4	0.834	3.080	102,748.800	1.286	2.647	204,242.520	306,991.320
G3-04-26-17-PLOT 6	1.229	4.543	223,333.880	1.120	3.822	256,838.400	480,172.280
G1-04-27-17-PLOT 1	1.166	8.511	396,953.040	1.220	6.453	472,359.600	869,312.640
G2-04-27-17-PLOT 2	1.187	7.282	345,749.360	1.477	7.002	620,517.240	966,266.600
G3-04-27-17-PLOT 3	1.510	3.199	193,219.600	1.169	4.149	291,010.860	484,230.460
S1 – G1	1.067	6.347	270,889.960	1.436	6.045	520,837.200	791,727.160
S1 – G2	1.148	5.671	260,412.320	1.106	7.009	465,117.240	725,529.560
S1 – G1	1.170	7.135	333,918.000	1.672	5.746	576,438.720	910,356.720
S2 – G1	1.175	5.239	246,233.000	1.510	3.559	322,445.400	568,678.400
S3 – G1	1.286	1.358	69,855.520	1.154	2.063	142,842.120	212,697.640
DAY 1 PLOT 1	1.118	5.290	236,568.800	1.077	4.621	298,609.020	535,177.820
G1-04-21-17-PLOT 1	1.084	5.572	241,601.920	0.998	5.150	308,382.000	549,983.920
Average	**1.187**	**5.013**	**234,932.907**	**1.172**	**5.332**	**371,903.817**	**606,836.724**
Std. Dev.	**0.142**	**1.740**	**80,692.267**	**0.159**	**1.724**	**122,732.388**	**172,558.695**

The average soil carbon per hectare is higher than those in the four mangrove plantations in the Philippines, as reported in Castillo and Breva (2012). In their study, the soil carbon from the four plantations ranged from 57 to 158 tons per hectare and had an average of 113.4 tons per hectare. These soil carbon estimates used soil depths from 0-30 cm. In comparison, in this study, the estimated average soil carbon per hectare from the two mangrove areas ranged from 69.8 to 396.8 and had an average of 234.9 tons per hectare for the soil depth of 0-40 cm. The higher estimate is partly due to the deeper soil depth, i.e. 0-30 cm in the Castillo and Breva (2012) study compared to the 0-40 cm in this study. In other words, carbon estimates in the 30-40 cm depths are included in this study, but not included in the Castillo and Breva (2010) study. Compared to the results reported in Kauffman and Donato (2012) for Micronesia and Mudiyarso, et al. (2010) for Indonesia, the soil carbon estimates for the two soil depths are also higher as summarized in Table 8.

Table 8: Comparison of Soil Carbon*

Source/Study	Depth (cm)	Average Soil Carbon (tons/ha)
Kauffman and Donato (2012) for Micronesia	0-50	205
	50-100	206
	Total	**411**
This study	0-40	234.9
	40-10	371.9
	Total	**606.8**
Castillo and Breva (2012)	0-30	113.4
Mudiyarso et al (2010) for Indonesia	0-50	141.9
	50-100	156.3
	Total	**298.2**

* *Comparisons with respect to soil carbon and other soil properties from different studies are for general information only. Conditions in the forests being compared may be different (e.g. natural vs plantation, disturbed or undisturbed, stand density, etc.)*

The percent carbon concentration in this study is slightly lower relative to those reported in Castillo and Breva (2012). In their study, the average percent carbon concentration is about 9.12% while the estimated average in this study is 5.13% (for the 0-40 cm soil depth) as shown in Table 7. Again, note that the soil depth examined in the previous study is from 0-30 cm, while the soil depths examined in this study are 0-40 cm and 40-60 cm. Also, the 5.13% carbon concentration in this study is close to similar studies reported for Malaysia (Arianto 2015) for the same soil depth (0-40 cm), which ranged from 1.73% to 4.08%.

The percent carbon concentration in this study did not change significantly between the two depth ranges, i.e. 5.013% and 5.332% for 0-40 cm and 40-100 cm soil depths, respectively. The estimates are slightly lower than those reported in Donato, et al. (2011) which noted average carbon concentrations of 7.9% and 14.6% for estuarine and oceanic mangrove forests, respectively.

In terms of bulk density, the estimates for soil depths at 0-40 cm and 40-60 cm are 1.18 and 1.17 (see Table 7), respectively. This suggests that the soils are not necessarily more compact in deeper soils. In fact, on the average, the soils are almost equally compact between 0-40 cm and 40-60 cm ranges as shown by their bulk densities. The bulk densities are higher than the results noted by Lunstrum and Chen (2014), which reported a range of bulk densities between 0.71 to 1.04 for soil depths between 0-100 cm.

4.4 TOTAL CARBON STOCK (ECOSYSTEM CARBON) FROM ALL CARBON POOLS

As shown in Section 3.5, the total carbon stock from the measured major carbon pools is the sum of all carbon stocks from AGB, BGB, and soil carbon. Using the corresponding carbon concentration factors for both AGB and BGB will convert them to carbon (see Table 9).

Table 9: Average Total Carbon per Hectare and the CO2e

Carbon Pools	Average Amount of Carbon per Hectare (KgC)	CO_2 Equivalent (Kg CO_2e)
Above Ground	14,767	54,194.89
Below Ground	7,411	27198.37
Soil Sediments	606,836	2,227,088.12
Total	**629,014**	**2,308,481.38**

The average amount of carbon per hectare from AGB is obtained by multiplying the average AGB per hectare (32,104.6, see Table 1) by the carbon concentration of the AGB (0.46, see Section 3.1). Similarly, the average amount of carbon per hectare from the BGB is estimated by multiplying the average BGB per hectare (19,003.8, see Table 1) by the carbon concentration of the BGB (0.39, see Section 3.2).

Note that a significant amount of the ecosystem pool is due to carbon from soil sediments, and the soil carbon estimate is for soil depth up to 1 m.

The carbon dioxide equivalent (CO_2e) is a term for describing different greenhouse gases in a common unit. For any quantity and type of greenhouse gas, CO_2e signifies the amount of CO_2 that would have the equivalent global warming impact. Technically, this is the ratio of molecular weights between carbon dioxide [44] and carbon [12]. In this case, the CO_2e of carbon is 3.67; hence, multiply the amount of carbon by 3.67 to calculate the CO_2e for carbon, as shown in Table 9.

Table 10 shows a comparison between the three studies on the total ecosystem pool, which includes AGB, BGB, and soil carbon for soil depths of 0-100[10] cm. The estimated total ecosystem carbon of Zamboanga city is within the range of the two other ecosystems in Micronesia and Indonesia.

Table 10: Comparison of Ecosystem Carbon from Three Studies

Source (Report)	Amount of Ecosystem Carbon (tons/ha)*
Kauffman and Donato (2012) for Micronesia	761
Mudiyarso et al (2010) for Indonesia	479
This Study for Zamboanga City	629

**Includes only carbon from AGB, BGB and soil carbon at 0-100 centimeter depth for the three studies*

4.4 RELATIONSHIP OF SOIL CARBON WITH BIOMASS

Mangrove scientists have recently expressed interest in establishing the relationship between the amount of soil carbon and biomass. This relationship is important because it can make the assessment of total carbon in mangrove forests more efficient and less costly. Estimating soil carbon in mangrove forest is tedious and laborious and therefore quite costly. The study team experienced this firsthand while collecting soil samples at different soil depths for this study. Even with a custom-made soil auger developed by Kauffman and Donato (2012), soil sample collection was challenging as it was difficult to collect soil samples that were intact. Mangrove soils are very muddy and soft, making it difficult to extract intact or unbroken soil. In most instances, the team had to attempt several tries before extracting a complete soil sample.

Besides the difficulty of collecting soil samples, the cost of soil analysis can be prohibitively expensive. It is also time consuming, as soil samples must be air dried before soil analysis for bulk density and carbon content.

If there is a satisfactory correlation model between soil carbon and biomass, then it is possible to estimate total carbon in an area without collecting and analyzing soil samples. Instead, the correlation model with biomass can estimate soil carbon without having to collect soil samples.

Literature provides mixed results concerning the relationship or correlation between soil and biomass. Kaufmann and Donato (2012) reported that the correlation is weak. However, more recently, Sahu et al

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[10] The study of Castillo and Breva (2012) was not included in the comparison because their study included only soil depth up to 30 cm.

(2016) reported a strong positive correlation (r = 87) between vegetation biomass and soil organic carbon in the surface soil (0–30 cm). These mixed results may be an indication that the correlation is site-specific and depends on a number of factors—the most important of which could be land use pattern and history and adjacent landscape and its condition.

This study attempted to explore such correlation by collecting data from the 39 out of the 54 soil plots. Table 11 shows a summary of the soil carbon and biomass estimates from each of the 39 plots. Table 12 shows the correlation matrix of the results.

Table 11: Soil Carbon and Vegetation Biomass

Plot ID	Soil carbon (tons/ha)			Above Ground Biomass		
	0-40 cm	40-100 cm	Total	Above Ground Biomass tons/ha	Below ground biomass (tons/ha)	Total biomass (tons/ha)
G3-04-12-17-PLOT 1	338,000.760	391,659.600	729,660.360	28,801.85	19,569.92	48,371.77
G1-04-12-17-PLOT 2	316,368.360	485,708.400	802,076.760	11,049.25	7,271.95	18,321.20
G3-04-17-17-PLOT 1	334,357.200	172,116.720	506,473.920	14,079.59	9,694.47	23,774.07
G2-04-17-17-PLOT 2	279,583.200	360,820.320	640,403.520	24,742.02	14,953.32	39,695.34
G3-04-17-17-PLOT 3	342,841.680	509,155.740	851,997.420	23,731.93	13,514.51	37,246.45
G1-04-18-17-PLOT 1	170,607.000	358,044.480	528,651.480	22,561.64	15,353.92	37,915.55
G3-04-18-17-PLOT 4	251,073.600	436,765.920	687,839.520	72,973.99	45,605.83	118,579.82
G2-04-18-17-PLOT 5	324,355.200	419,012.640	743,367.840	40,245.89	26,452.82	66,698.71
G1-04-19-17-PLOT 1	193,869.360	316,039.680	509,909.040	18,268.59	10,724.91	28,993.50
G3-04-19-17-PLOT 3	241,867.200	393,974.280	635,841.480	96,051.87	33,770.07	129,821.94
G2-04-19-17-PLOT 5	309,377.800	548,362.800	857,740.600	48,523.05	23,481.90	72,004.95
G1-04-20-17-PLOT 1	203,112.280	391,882.320	594,994.600	3,831.09	2,756.10	6,587.19
G2-04-20-17-PLOT 2	252,144.480	340,298.040	592,442.520	38,334.62	26,897.17	65,231.79
G2-04-	313,177.600	423,602.04	736,779.64	15,973.73	8,413.86	24,387.60

20-17-PLOT 4						
G3-04-20-17-PLOT 1	235,202.760	497,820.000	733,022.760	32,190.40	21,059.10	53,249.50
G3-04-21-17-PLOT 1	205,808.000	257,827.800	463,635.800	28,801.85	19,569.92	48,371.77
G1-04-21-17-PLOT 2	283,638.960	292,148.940	575,787.900	62,931.48	37,269.98	100,201.46
G1-04-25-17-PLOT 1	184,598.400	490,586.400	675,184.800	28,770.69	16,500.43	45,271.12
G1-04-25-17-PLOT 2	173,121.680	394,692.360	567,814.040	7,067.70	5,288.71	12,356.41
G2-04-25-17-PLOT 3	129,995.200	346,575.600	476,570.800	9,410.05	6,917.69	16,327.74
G3-04-25-17-PLOT 4	93,087.680	394,952.580	488,040.260	3,966.76	2,869.97	6,836.73
G2-04-25-17-PLOT 5	227,121.840	332,183.880	559,305.720	8,252.09	5,515.81	13,767.90
G3-04-25-17-PLOT 6	277,042.760	45,014.640	322,057.400	2,259.70	1,624.13	3,883.84
G1-04-25A-17-S	185,706.000	359,135.400	544,841.400	23,858.43	16,460.11	40,318.54
G1-04-26-17-PLOT 1	102,730.560	200,166.480	302,897.040	6,568.64	4,795.53	11,364.17
G2-04-26-17-PLOT 2	120,114.400	406,963.800	527,078.200	1,621.05	1,205.48	2,826.53
G3-04-26-17-PLOT 3	151,995.200	459,097.680	611,092.880	20,363.93	12,066.67	32,430.60
G1-04-26-17-PLOT 4	102,748.800	204,242.520	306,991.320	9,761.57	6,941.65	16,703.22
G3-04-26-17-PLOT 6	223,333.880	256,838.400	480,172.280	78,920.65	50,714.69	129,635.34
G1-04-27-17-PLOT 1	396,953.040	472,359.600	869,312.640	32,182.63	17,186.74	49,369.37
G2-04-27-17-PLOT 2	345,749.360	620,517.240	966,266.600	57,224.75	37,736.60	94,961.35
G3-04-27-17-PLOT 3	193,219.600	291,010.860	484,230.460	83,752.12	49,477.36	133,229.48
S1 – G1	270,889.960	520,837.200	791,727.160	2,626.13	1,922.13	4,548.26

S1 – G2	260,412.320	465,117.240	725,529.560	34,598.89	23,435.37	58,034.27
S1 – G1	333,918.000	576,438.720	910,356.720	33,416.00	21,034.95	54,450.95
S2 – G1	246,233.000	322,445.400	568,678.400	74,230.65	36,115.59	110,346.23
S3 – G1	69,855.520	142,842.120	212,697.640	6,522.76	3,528.75	10,051.51
DAY 1 PLOT 1	236,568.800	298,609.020	535,177.820	24,601.00	17,554.29	42,155.29
G1-04-21-17-PLOT 1	241,601.920	308,382.000	549,983.920	82,297.17	48,994.40	131,291.57

The study team estimated correlation coefficients, measuring the degree to which soil carbon and vegetation biomass are closely associated. Correlation values can range from -1.0 to 1.0. A correlation of -1.0 indicates a perfect negative correlation and a 1.0 value indicates a perfect positive correlation. Using the parameter values summarized in Table 11, the team derived the correlation values, shown in Table 13.

Table 12: Correlation Matrix Between Soil Carbon and Vegetation Biomass (Kgs/ha)

S Carbon 0-40	0.284485242	0.295476541	0.291094168
S Carbon 40-100	0.117193353	0.111095034	0.116111684
Total C	0.216385381	0.217187726	0.218706524

From the correlation matrix, it is clear that soil carbon parameters weakly correlate with any of the biomass measures. This observation is consistent with the observations reported in Kauffman and Donato (2012). Significant impact by human activities in the past, mainly heavy cutting, may contribute to the weak correlation between them. Consequently, the dynamics of the entire mangrove ecosystem was disturbed enough; hence the weak correlation of the soil carbon and biomass of the trees.

5. BIODIVERSITY AND STAND STRUCTURE

Forest managers and ecologists are becoming increasingly interested and concerned with biodiversity, resulting in the proposal of numerous approaches and ways of quantifying species diversity. Species diversity itself has two separate components: (1) the number of species present (species richness), and (2) their relative abundances (sometimes referred to as dominance or evenness), or how close in ‘number’ the species are.

5.1 BIODIVERSITY INDEX

There are different measures (or indices) of biodiversity in addition to richness and relative abundance or evenness. The most commonly used index is the Shannon Index (H’, also termed as the Shannon-Wiener index) as described below.

The idea behind the Shannon Index is to reflect species composition beyond species richness (i.e. the number of species present) to also include the relative abundance and evenness of each species. Hence, the following equation calculates the Shannon index:

$$H' = -\sum p_i \, Ln \, p_i$$

In this equation, H’ is the Shannon Index, p_i is the proportion of individuals found in species.

The index reflects (or incorporates) both species richness (i=1, 2, … S (number of species)) and relative abundance reflected in p_i.

All p_i values must be between zero and one, by definition, meaning the natural log makes all terms of the summation negative, which is why we take the inverse of the sum or multiplying the sum by negative 1.

Typical values are generally between 1.3 and 3.5, and the index is rarely greater than 4. The Shannon Index increases as both the richness and evenness of the community increase. In other words, the index increases as the number of species increase, and as the relative abundance of each species are similar. Incorporating both components of biodiversity (i.e. species richness and relative abundance) can be a positive and a negative. It is a positive because it provides a simple, synthetic summary, but it is also a negative because it makes it difficult to compare community richness. For instance, two communities may have a high Shannon Index value, but one has higher species richness; the difference in species richness was ‘compensated’ by relative abundance, resulting in a high Shannon Index value for both communities despite the difference in species richness.

For the two mangrove sites, the Shannon Indices are in Table 13.

Table 13: Shannon Index of the Two Mangrove Sites

Species	Scientific Name	Number of individuals	Relative abundance	Ln p_i
B. Babae	Rhizophora mucronata	1,356	0.51	-0.3419
B. Bangkaw	Rihizophora stylosa	572	0.22	-0.3315
B. Lalake	Rhizophora apiculata	96	0.04	-0.1206
Bungalon	Avicennia marina	319	0.12	-0.2556
Pagatpat	Sonneratia alba	293	0.11	-0.2442
Total		**2,636**	**Diversity Index**	**H' = 1.2939**

Table 13 shows the five species found in the two mangrove sites. *Rhizophora mucronata* dominates with a total of 1,356 individuals, followed by *Rhizophora stylosa, Avicennia marina, Sonneratia alba and Rhizophora apiculate.* The Shannon Index is relatively low (1.29) mainly due to low species richness (only five species) and dominance (high relative abundance) of *Rhizophora mucronata* relative to other species (e.g. *Rhizophora apiculata*).

5.2. STAND STRUCTURE OF THE MANGROVE FORESTS

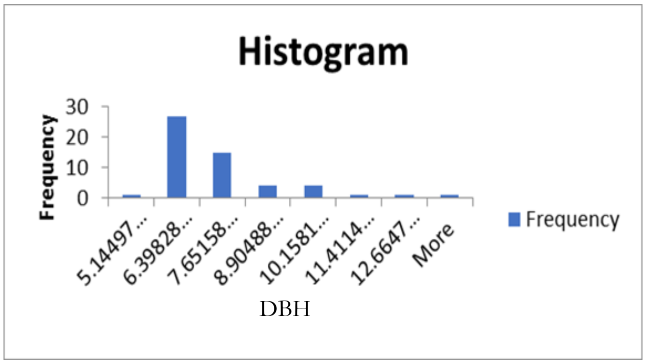
Stand structure refers to the distribution of individual trees by diameter sizes. This is a typical way to characterize a forest by looking at the number of individual trees for each diameter size. Typically, diameter sizes correspond to intervals, like in a frequency distribution. This measure is useful in natural uneven aged forests because they typically exhibit an inverse J-shape distribution (i.e. more trees in the smaller diameter size and fewer trees in bigger diameter size).

As pointed out earlier, the mangrove forests in the two sites are essentially 'plantation' forests planted using assisted natural regeneration where new mangrove species were planted under, or in spaces between, 'residual' trees that were left after heavy cutting in the past. Hence, stand structure in these mangrove plantation forests may not have much relevance as a tool for forest management. However, the concept of stand structure is still meaningful for characterizing the forest.

In Table 14, it shows that for the number of forests 'planted', the distribution is rather 'uniform', rather than the typical J-shape of natural forests, and skews in the 'smaller' average size.

Table 14: Stand Structure of the Mangrove Forests

Diameter (Middle)	Lower limit	Upper limit	Number of trees
5.144976745	4.5183251	5.77162839	1
6.398280035	5.77162839	7.024931679	27
7.651583324	7.024931679	8.278234969	15
.904886614	8.278234969	9.531538259	4
10.1581899	9.531538259	10.78484155	4
11.41149319	10.78484155	12.03814484	1
12.66479648	12.03814484	13.29144813	1
>13.29			1



As expected, the second and third diameter classes dominate in terms of number, as shown in the histogram.

6. EVALUATION OF CARBON SEQUESTRATION POTENTIAL

Sections 1 through 5 provide an assessment of baseline data on the amount of carbon sequestered within the mangrove forests of Zamboanga City, specifically within the two Treevolution areas at the barangays of Talon-talon and Mampang. While this baseline estimate is meaningful and informative, it is rather 'static'; that is, it is only a baseline estimate and does not entirely reflect the sequestration potential of the mangrove forests. Sequestration potential should not only reflect baseline estimation, but also its 'potential' or capability to sequester carbon in the future. Hence, beyond baseline assessment of the amount of carbon currently sequestered, it is also meaningful and informative to estimate the projected amount of carbon sequestered by the mangrove forests as they grow and mature.

6.1 THE USAID AFOLU CARBON CALCULATOR

In its effort to help mitigate climate change, USAID developed a tool to assess the impacts of land use and land management activities that have direct, significant, and positive impacts on the climate. USAID developed and adopted this tool because of its ability to estimate and translate the impacts of these land use and management activities into reportable, quantifiable estimates and measures of carbon benefits.

The tool, called the AFOLU (Agriculture, Forestry and Other Land Uses) Calculator, "employs Intergovernmental Panel on Climate Change-based accounting methods that allow users to estimate the CO_2 benefits and potential climate impacts of eight different types of land-based project activities: forest protection, forest management, afforestation/reforestation, agroforestry, cropland management, grazing land management, forest degradation by fuelwood, and support/development of policies"[11]. Each of the tools in the AFOLU Calculator are adequately documented with manuals and online documents describing the methods and assumptions. They also present the underlying data along with its associated sources of uncertainties.

6.2 PROJECTING CARBON SEQUESTRATION POTENTIAL OF THE MANGROVE FORESTS: A DEMONSTRATIVE EXAMPLE

The AFOLU Calculator is capable of projecting carbon benefits from eight different activities. In this example, the Calculator projects carbon sequestration potential based only on the most passive management activity: forest protection. In other words, the Calculator estimates sequestration potential only under the

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[11] http://afolucarbon.org/

assumption that the mangrove forests are protected and no other intervention activities, such as reforestation/afforestation or active forest management, are conducted. Moreover, carbon sequestration is also estimated under assumption of optimal or maximum management effectiveness; hence a reflection of the 'true' sequestration potential.

6.2.1 MANAGEMENT EFFECTIVENESS IN CARBON SEQUESTRATION POTENTIAL ESTIMATION

Estimating carbon sequestration 'potential' also portends 'effectiveness' in terms of whether the full (maximum) sequestration capacity is reached. AFOLU has a facility or provision that is capable of embracing the 'degree of effectiveness' in carbon benefit calculation.

AFOLU includes an *Effectiveness Guide* built into the AFOLU Carbon Calculator's tools. As described in the manual, "the Effectiveness Guide generates an effectiveness rating for project activities, which is an estimated measure of the overall success of a project activity. For example, for an avoided deforestation project to be considered 100% effective, it would successfully prevent 100% of projected baseline deforestation in the project area, thus avoiding 100% of potential emissions caused by deforestation. However, few projects are likely to achieve 100% success".

This study assumes 100% effectiveness to reflect the maximum carbon sequestration potential of the mangrove forests. Hence, forest protection is conducted under optimal conditions–e.g. no deforestation or degradation, no encroachment or conversion, and in-place institutional and policy infrastructure such as control or regulation on cutting.

Fundamentally, the management effectiveness factor serves as an adjustment mechanism to reduce or adjust the carbon sequestration potential by the degree of management effectiveness. For example, if the management effectiveness is 80%, then the 'realistic' estimate of the 'actual' sequestration is only 80% of the maximum or 'estimated potential'; i.e. reduce the realistic estimate of carbon benefit by 20% of the estimated potential.

6.2.2 CARBON BENEFITS FROM AVOIDED DEFORESTATION

As stated in Section 7.2, the projection of carbon sequestration potential examined in this study is for forest protection only, i.e. no additional intervention activities. Hence, carbon benefits are from avoided deforestation; that is carbon sequestered from the growth of mangrove trees that will not be deforested throughout the projection period.

To realistically estimate the benefits from avoided deforestation, it must incorporate two things: current deforestation rate and projected deforestation rate. Clearly, the benefits from avoided deforestation must reflect the following: growth of trees not deforested and growth of trees resulting from reduced deforestation.

6.2.3 DATA NEEDED/USED FOR PROJECTION

The following are the data/parameters used in the projection:

Area:	857 hectares of mangrove forests (area of Talon-talon and Mampang mangrove forests
Avoided Action	Deforestation

Management Effectiveness (ME)	100%
Average Age of the Mangrove	12 years
Historical Deforestation rate	0.8 (Default data obtained from global data set representing percent of total area)
Number of years to 100% ME	1 year
Deforestation Rate after 1 year	0% (because management effectiveness is 100%)
Average Annual Growth of forest	4.65 tons carbon/hectare (default data obtained from global dataset generated specifically for Zamboanga City
Above Ground and Below Ground Carbon	629 tons carbon/hectare (based on data in Table 10)

Except for *Historical Deforestation Rate* and *Average Annual Growth*, all the other data are user-specified, i.e. they reflect the best estimates specific to the mangrove forests of the two sites. *Historical deforestation rate* and average *Annual Growth* used in this projection are 'default' values obtained by AFOLU from external data sources based on global data set estimated through geospatial techniques and methods (e.g. geographic information systems and remote sensing, land use change estimates using image processing and analyses). These data sets are field-validated or verified using other datasets (e.g. FAO).

6.2.4 ESTIMATED CARBON SEQUESTRATION POTENTIAL (BENEFITS) OF THE MANGROVE FORESTS PROTECTED FROM DEFORESTATION

Under the assumptions or conditions outlined above, the AFOLU Calculator can project the potential carbon benefits of the mangrove forests, with the results summarized in Table 15. Note that results from this study's carbon assessment inform the carbon sequestration data in the projection. In other words, this study uses data and results from the two mangrove sites to inform the estimates of carbon content per hectare of a mangrove forest. Hence, the data and information are site-specific and therefore a realistic estimate of the carbon sequestration potential and future carbon benefits.

As seen in Table 15, the carbon benefit in 2017 is 15,929 tons. This represents the amount of carbon sequestered for one year based on the growth of the protected forest. Estimated benefits for the next year, 2018, are 16,046 tons, again representing the benefit for one year. The growth is higher because the growing stock in year 2 has increased. The 15,929 tons represent only the growth (sequestration potential); it does not include the carbon stored in the total biomass 'sequestered' in the trees themselves. Again, these benefits also reflect the impact of reducing the deforestation rate from the historical deforestation rate of 0.8% to 0 (as a result of forest protection activity and 100% management effectiveness).

Table 15: Projected Carbon Benefits from Avoided Deforestation (Deforestation Rate = 0.8%)

Year	Management Effectiveness (%)	Annual benefit from avoided mangrove deforestation (tCO_2)	Total Annual Benefit (tCO_2)	Cumulative Benefit (tCO_2)
2017	100	15,929	15,929	15,929
2018	100	16,046	16,046	31,975
2019	100	16,163	16,163	48,138
2020	100	16,280	16,280	64,419
2021	100	16,397	16,397	80,816
2022	100	16,514	16,514	97,330
2023	100	16,631	16,631	113,961
2024	100	16,748	16,748	130,709
2025	100	16,865	16,865	147,574
2026	100	16,982	16,982	164,556
2027	100	17,099	17,099	181,654

To illustrate the effect of the deforestation rate, Table 16 presents a corollary scenario. Suppose the historical deforestation rate is higher, going from 0.8% to 2%. All things being equal, the projected carbon benefit is a result of reducing the deforestation rate from 2% to 0 (due to forest protection).

Table 16: Projected Carbon Benefits from Avoided Deforestation (Deforestation Rate = 2%)

Year	Annual benefit from avoided mangrove deforestation (tCO_2)	Total Annual Benefit (tCO_2)	Cumulative Benefit (tCO_2)
2017	39,823	39,823	39,823
2018	40,115	40,115	79,938
2019	40,408	40,408	120,346
2020	40,700	40,700	161,046
2021	40,993	40,993	202,039
2022	41,285	41,285	243,324
2023	41,578	41,578	284,902
2024	41,870	41,870	326,772
2025	42,162	42,162	368,934
2026	42,455	42,455	411,389
2027	42,747	42,747	454,136

The results in Table 16 show that if the historical deforestation rate was 2% instead of 0.8%, all things being equal, carbon benefit for the first year is 39,823 tons—more than twice the previous estimate of 15,929 tons. The increase in carbon benefit is because of the increase in avoided deforestation from forest protection having reduced deforestation rate from 2% to 0% after year 1 and thereafter, instead of from 0.8% to 0% as described in Table 15.

6.2.5 PROJECTING POTENTIAL CARBON BENEFITS FOR OTHER MANAGEMENT SCENARIOS

The projected benefits were estimated under the assumption that passive forest protection is the only management intervention. In other words, the projection did not include any other forest management activity except for protecting the forests.

This section presents a management scenario where additional areas of mangrove are reforested, such as the case of the five hectare Treevolution sites managed by OCENR. This scenario is for illustrative purposes only and to demonstrate the carbon sequestration potential of mangroves, including other activities to consider or plan in the future.

From the 2015 scoping review conducted by B-LEADERS, there is significant interest in the Treevolution activity. In fact, DENR and the local government unit of Zamboanga City agreed that the latter should restore about 85 hectares adjacent to the 65 hectares of mangrove conservation area. Hence, the scenario examined here will be based on the following: (1) the new Treevolution sites for replanting are close to the Talon-talon and Mampang areas or adjacent to the conservation area; (2) the carbon stock value in the scenario is from the study; (3) in terms of expected growth, default data will be used in the absence of growth data on mangrove from the same area; and (4) management effectiveness is determined following the guidelines developed for AFOLU.

In the scenario, AFOLU determined the Effectiveness Guide based on responses to these questions:

- Is this a policy initiative? **No**
- Are the project's activities best described as large scale/commercial, or small scale/small holder led operations? **Small**
- Will smallholders receive technical support/extension and access to inputs? **Yes**
- How are the climate and soil conditions relative to the requirements of the species selected? **Optimal**
- Will fertilizers and irrigation be available and be applied where required? **Not applicable**
- Will the plantation(s) be managed by people who have received adequate training and capacity building? **Yes**
- Based on the answers provided, it is estimated that the project will be 100% effective in reducing emissions compared to project that was optimally designed?
- The following deductions were made to your total maximum estimated effectiveness:
    - A 10% effectiveness addition has been made because the managers of the plantation have received capacity building that enables them to manage the plantations effectively in the long run.
    - Adjustments resulted in (110%) effectiveness, which was set to 100%. Hence, for this scenario, ME is determined by AFOLU to be 100%

Table 17 shows the scenario results, assuming a conversion rate of 46% (46% of biomass growth is carbon) and an annual growth rate similar to the default value in the previous scenarios (4.65 tons) .

Table 17: Projected Carbon Benefits from Proposed 85-hectare Plantation

Year	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Cumulative benefit (tCO_2)	477	953	1,430	1,907	2,383	2,860	3,337	3,813	4,290	4,767	5,243

7. SUMMARY AND RECOMMENDATIONS

This study's results show carbon stock estimates of three major carbon pools of mangrove forests—above ground biomass, below ground biomass, and soil carbon—using two barangay sites of Zamboanga City: Talon-talon and Mampang. These two sites are designated Treevolution sites, which planted mangroves in the areas in 2014.

In general, the estimated total biomass is consistent or comparable with published reports on similar mangrove areas, although they are relatively lower than published results of plantation areas in the Philippines, as reported in Castillo, et al. (2012). Because there were smaller, younger trees in the two sites in Zamboanga City, the team calculated a low AGB relative to existing literature.

Results of the analysis presented in this report include summary data based on relevant categories/strata such as: canopy cover, management agency, management regime, and location. Some of these summary data are relative to each category for general information and characterization and are not meant to make inferences or comparative analysis between categories, but rather to provide general characterization of the area and categories.

Table 18 below shows a summary of the carbon sequestration potential of mangrove forests in the two Treevolution sites. The table describes the carbon stocks and the carbon dioxide equivalent from the three carbon pools (i.e. above ground biomass, below ground biomass, and soil sediments) from the two barangays coming. The results show that soil sediments constitute the largest source of carbon in mangrove forests, which is consistent with the results of other studies in southeast Asia.

Table 18: Total Carbon Sequestration Potential

Mangrove Site	**Area (ha)[a]**	**Total[d] Above Ground Carbon (tC)**	**Total CO_2 Equivalent)[b] of AG (tCO_2e)**	**Total Below Ground Carbon (tC)**	**Total BG (tCO_2e)**	**Total Sediment Carbon (tC)**	**Sediment (tCO_2e)[c]**	**Total ecosystem[e] (tCO_2e)**
Talon-talon	525	8,661.88	31,789.10	4,149.23	15,227.67	320,595.50	1,176,583.65	1,223,600.42
Mampang	332.00	4,184.52	15,357.19	2,256.18	8,280.18	197,779.04	725,848.93	749,486.30
TOTAL	857	12,846.40	47,146.29	6,405.41	23,507.85	518,374.54	1,902,432.58	1,973,086.72

[a] Areas are estimated based on mangrove forests delineated according to NAMRIA 2010 map and barangay boundaries data obtained from PhilGIS (http://philgis.org/country-barangay/country-barangays-file)

[b] Total Carbon (tC) is converted to tCO_2 equivalent by multiplying the amount of carbon (tC) by carbon's CO_2 equivalent weight (3.67)

[c] Based on sample plots located within each barangay (i.e. 610tC/ha for Talon-talon and 595.72 tC for Mampang)

[d] Total refers to the whole barangay. Calculated based on the Above Ground Biomass and Below-ground Biomass shown in Table 5 and a carbon conversion rate of 0.46 and 0.39 for AGB and BGB.

[e] This includes tCO_2e from the three carbon pools (Above-Ground, Below Ground and Sediments)

The total CO_2 equivalent sequestered in the 857 hectares from the two barangays 1.97 M tons distributed as follows: 1.22 M tons and 0.75 M tons for Talon-talon and Mampang, respectively. Carbon in the soil sediments constitutes the biggest source of the total carbon sequestered which amounted to 1.9 M tons distributed as follows: 1.17 M and 0.73 M tons for Talon-talon and Mampang, respectively.

The sampling system adopted was a combination of systematic, stratified, and random sampling. It allows general characterization of the areas into categories, provides unbiased estimates of the biomass, and enables samples to be collected from areas that represent the general landscape of the mangrove forests. This implies pre-stratifying the area (to make sure relevant strata are represented in the sample). It is systematically done by gridding the sampling area into 100 x 100-meter grid allowing each grid node as a possible sample plot. Finally, selection of sample plots is random; within each selected stratum, random plot selection occurs from the potential grid points or nodes.

Results show that the average biomass is 32.1 tons (62%) and 19.0 tons (38%) per hectare for above ground and below ground (root), respectively. Hence, the average total biomass is 51.1 tons per hectare.

The trees/stems sampled are relatively small (average DBH is 6.88). The forests are predominantly planted using assisted natural regeneration where mangrove species are planted in rows under, or between, residual trees left from heavy cutting in the past.

The average estimated carbon amount found in the soil sediments from the 39 plots samples is 606,836 kgC or 606.836 tons of carbon per hectare. This is higher than the estimated soil carbon per hectare observed in four similar mangrove plantations, as reported by Castillo and Breva (2012) and Kauffman and Donato (2012) for Micronesia and Mudiyarso, et al. (2010) for Indonesia.

The total ecosystem carbon of Zamboanga City mangroves per hectare is 629 tons. This estimate is within the range of total ecosystem carbons of the two other ecosystems in Micronesia and Indonesia, which is reported to be 761 and 479 tons of carbon per hectare, respectively (Kauffman and Donato 2012; Mudiyarso et al 2010).

Biodiversity in the two sites is relatively low, as *Rhizophora spp.* dominates the area, particularly *Rhizophora mucronata*. The team found only five mangrove species in the area. The estimated Shannon Index is also quite low mainly because of low species richness and number (5 total) and relative low evenness (high variation in relative abundance of species, as *Rhizophora mucronata* had 1,356 individuals while *Rhizophora apiculata* had only 96 individuals).

This report also describes projections showing the carbon sequestration potential of, and future carbon benefits from, the mangrove forests. It examined and presented three projection scenarios: forest protection from avoided deforestation using historical deforestation rates (0.8%); a corollary scenario using a different deforestation rate (higher at 2%), and an option to plant 85 hectares of mangrove forests, which Zamboanga City is considering. The projections show the carbon sequestration potential, or expected carbon benefits, within the midterm (1 to 10 years). The report analyzes and presents these projections for illustrative purposes to demonstrate the carbon sequestration potential of the mangrove forests under different management regimes and interventions—from a relatively passive intervention (e.g. forest protection) to a more active intervention (e.g. reforestation).

In general, the mangrove forests show low carbon stock in its total biomass (51.1 tons of carbon per hectare). This is mainly because the forests are still young and growing. As shown in the management scenarios examined and presented in Table 15, the carbon benefits of simply protecting them and avoiding deforestation is approximately 15.9 tons of carbon in 2017, or up to 181.6 tons of carbon after 10 years. These projected carbon benefits reflect the carbon sequestered from the biomass growth of the trees that were protected and therefore not reforested. They do not include the carbon stored in the growing stock of the mangrove forests.

The sampling design adopted was systematic (gridded sample area) stratified (sampling area classified into strata), and contained random sampling (samples selected randomly from each stratum). The report suggests any succeeding measurements adopt a purely stratified random sampling approach, as most of the mangrove areas are planted through assisted natural regeneration; hence, the strata can be identified or classified based on the year of establishment (planting). Hence, the whole area should be divided into strata based on the year of planting to make each stratum sufficiently uniform. Sample plots should be selected so that each stratum is represented. Since most of the strata are uniform, the number of plots can be the same for all strata.

Zamboanga City has conducted a greenhouse gas inventory of its emissions from different sectors such as; agriculture and forestry, transportation, industry, and energy. Results from the inventory provide a very useful baseline data to then begin planning and policy formulation. Baseline data is meaningful and informative; but its value is mostly demonstrated when used as reference in support of planning and policy formulation. For instance, the City can examine its emission as well as its general carbon sequestration potential based on the result of this study, and make inferences regarding its carbon neutrality. Moreover, to take full advantage of the greenhouse gas inventory initiative, the City should consider promulgating local ordinances that will encourage, incentivize, control, or regulate the amount of greenhouse gas emissions from the different sector. For instance, carbon offsets can be a core component of such ordinances, incentives, or local regulations. Such offsets can be at the center of a City policy which allows carbon exchange, either financially, or in partnership between the managers of the carbon sink (i.e. sequestered carbon), and the carbon source (i.e. emitter), with the city serving as the broker of the exchange. The exchange can be mandatory or voluntary. Mandatory implies local policies (e.g. City ordinance) regulating the amount of emission (e.g. setting an emission quota/target for an industry or firm). Voluntary means the exchange is through incentives like providing certificates to firms that either voluntarily limits its emission, or provide assistance to forest communities that protect the forests that sequester the carbon emitted by the firms.

There are several areas in the mangrove forests that are highly degraded and in need of rehabilitation through assisted natural regeneration. The report recommends these areas be replanted. Much of the mangrove forests seem to be growing vigorously, indicating that the site is optimal for reforestation. The management scenario described in Section 6.2.5. can give an indication of the expected carbon benefits for reforested areas.

Protecting the mangrove forests will help ensure that the carbon benefits are sustained and also enable the forests to continue to deliver benefits to local communities dependent on the mangroves for the ecosystem services they provide such as provisioning (e.g. food), building materials, income sources, and protection from storm surges and strong waves. It is recommended that the current practice of engaging local communities in protecting the mangrove forests be sustained. Partnership between the local government units such as the OCENR and barangay officials, should be strengthened from its current level. Similarly, current cooperation between DENR and barangay officials should be continued or even increased. This tripartite three-way cooperation has positively impacted the establishment, development and management of the mangrove forests in and around Zamboanga City and should therefore be strengthened. Currently, these partnerships are rather temporary and 'ad hoc' through short term contracts and job orders. The large geographic extent of the mangrove forests in Zamboanga City, along with their economic, ecological and protective values, present a compelling case for making these partnerships more permanent and institutionalized.

In addition to LGUs, barangay officials, and the DENR, local communities and academe play an important role in ensuring the long-term survival of mangrove forests. It is important to educate local communities on the economic and financial benefits mangroves provide so they can better understand the need to protect mangroves from clear-cutting and degradation. This training can include best practices for sustainable harvest, waste management, fishing, and aquaculture. The academe can also play an important role in providing technical support for the sustainable management of the mangrove forests, including the assessment and monitoring of the development of the mangrove forests. As a part of this activity, the B-LEADERS team trained students on appropriate methodology for field sampling of the mangroves, necessary to continue monitoring the health and growth of the mangrove forests. Continued capacity building and training is needed to ensure sustainability of mangrove monitoring.

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