DESCRIBING THE GREENHOUSE GAS REDUCTION CAPACITY OF MANGROVES BY CARBON STOCK ASSESSMENT USING ALLOMETRIC DATA IN SUKOL RIVER, BONGABONG, ORIENTAL MINDORO, PHILIPPINES

RANDY A. QUITAIN
https://orcid.org/0000-0001-7457-9789
quitainrandy@gmail.com
Mindoro State University
Labasan, Bongabong, Oriental Mindoro, Philippines

ABSTRACT

Enhanced Greenhouse Gas (GHG) emission becomes a massive problem across the Earth due to anthropogenic activities. This event caused natural disturbance in the atmosphere that resulted into various natural hazards such as flooding, rise of sea level, drought, heat waves, increased storm intensity and occurrence. Mitigation for this environmental concern can be done by protecting, conserving or restoring forests, coastal wetlands, and peat lands that improve carbon sequestration. Thus, these actions helped in reducing enormous Greenhouse Gas (GHG) emissions in the atmosphere. Mangroves is one of the efficient ecosystems that sequester GHG from a particular source. In order to provide details of their efficiency as reservoir of these gases, allometric data regarding their physiology were estimated in the study. The sampling of mangroves was done using a circular plot method. The main procedure for this approach is to establish a 125 meter transect line in the designated sampling stations of the study site. Along the overlaid transect line, 6 circular plots with 7 meter radius were placed lengthwise with 25 meters interval. The mangroves within the 7 meter radius plot having a 2 meters height and above were measured according to their girth diameter, stem diameter and tallness. The Tree Density, Species, Girth (GBH), Stem Diameter and Height were computed based on the standard formula used for Aboveground Biomass (AGB) and Belowground Biomass (BGB) estimation for mangroves. A total biomass of 5,905.88 Mg·Ha^{-1} is recorded from the combined biomass of aboveground and belowground carbon pools. The total estimated carbon stock is 2,775.76 Mg·Ha^{-1} which is equivalent to 10,187.05 Mg·Ha^{-1} of absorbed carbon. Moreover, the results for the computation of oxygen release of mangroves in the study site average 7,402.04 Mg·Ha^{-1}·year^{-1}. These results from allometric data provides the confirmation that mangroves are efficient sinks of carbons that can possibly develop to a greenhouse gas reaching the atmosphere reinforcing global warming.

Keywords: mangroves; natural hazards; greenhouse gas; allometric data

INTRODUCTION

The Greenhouse Gas (GHG) provides the blanket that holds the heat within the Earth's atmosphere averting the escape of this energy out in the space. The greenhouse gases such as water vapor, carbon dioxide, methane and nitrous oxide creates a regulated temperature for the biotic factors of the planet and mobilize biogeochemical cycles to support life forms. Maintaining the condition of the temperature in a stable manner made living things in the planet productive, and set abiotic processes in balance. However, anomalies in temperature are associated with greenhouse gases because of their enhancement in the atmosphere. The flux reaches the threshold that the atmosphere should only contain due to anthropogenic activities. Fossil fuel production and consumption, utilization of agricultural chemicals, burning, incineration, and other human activities increased the greenhouse gases in the atmosphere. In the long run, anthropogenic activities double up the amount of greenhouse gases especially the carbon dioxide (Everuss & Lever-Tracy, 2020). The effect of these accumulations of greenhouse gases totally ensnared the radiated heat from the surface of the planet that caused global warming. This phenomena impact the world's climate that leads to various hazard like flooding, sea level rise, drought, extreme heat and amplified storm intensity and occurrence. According to the review of Showstack (2017), there is an intensification of temperature by 0.2 degree Celsius per decade. Considering this increase since pre-industrial period, disorder of temperature in the atmosphere will be hardly felt within the surface of the earth.

According to Duarte et al. (2013) and Busch et al. (2015), mitigation of climate change is possible through forests conservation and restoration including coastal wetlands and peat lands that improve carbon sequestration, and avoiding deforestation and change of landscape. These preventions help in reducing massive greenhouse gas emissions in the atmosphere. Relative to this, there are undergoing studies to support the worldwide drive in diminishing the impact of global warming in the reservoir of carbons to capture the human derived greenhouse gases. Governments, altogether started to formulate their own scheme, system, and alternatives to avoid excessive greenhouse gas emissions. As an example of the strategy by governing body working on the environment level and prevention of disaster caused by natural hazards, the Hyogo Framework was formulated. According to the study of Madu et al. (2020), the abovementioned framework was the spearhead and basis of the Disaster Risk Reduction (DRR) synergies. Part of the framework was reinforcing the protection of different ecosystems and their services to lessened the impact of natural hazards, this includes the effects of global warming. Considering the implementation of the Hyogo Framework across countries halt in 2015, supporting frameworks took effect. packaged with different agreements and strategies. As of today, one of the strategies identified in making effort to protect and restore the environment for the purpose of mitigating the possible impact of natural hazards is the Ecosystem-based Disaster Risk Reduction (Eco-DRR) Framework. The framework created and enhanced policies on global warming, climate change adaptation and environmental protection (Birch, 2014). The framework recognized ecosystem services as reducer of the impact of natural hazards that may lead to disaster. In addition, the Eco-DRR concept were empowered by the different agreements in the international level, such as Paris Agreement Framework and Sustainable Development Goals, the Sendai Framework and CBD Strategic Plan for Biodiversity. Most of these approaches work on the safeguarding of the environment for the provision of ecosystem services (Sanchez-Rodriguez et al., 2018).

One of the natural mechanisms in storing carbons are absorption by upland forest or aquatic vegetated ecosystem. Acres of forest, both terrestrial and aquatic ecosystems contribute in regulating the emissions of greenhouse gas. Consequently, these reservoirs are subjugated because of human interests. Mangrove can be considered as one of the most effective carbon storages yet exploited ecosystem due to consumptions and conversions for commercial use despite their capacity in mitigating excessive greenhouse gas emission.

According to Alongi (2012), mangroves are coastal ecosystems that provide immeasurable ecological services and significant functions that aid upland and ocean biodiversity. These trees are known for their complex roots system that captures substances and minerals from the soil. They are valuable in terms of storm and tsunami protection, maintenance of water quality, habitat for the different species of fish and shellfish, source of wood fuel and other forest goods. Mangrove ecosystems are sources of nutrient and energy for other marine ecosystem such as seagrass and coral reefs. On the other hand, mangroves also help in the mitigation of global warming because they lessen the possible carbon dioxide that will be released in the atmosphere. This is done by storing carbon within their body and surrounding substrate preventing these elements to be oxidized and reach the atmosphere in a gaseous state.

According to the discussion of Tengku et al. (2021), despite the ecosystem services provided by the mangroves for the benefit of humans and other living organisms, globally, 35 percent of their forest area decline during the period of 1980s and 1990s. The destruction was due to aquaculture, agriculture, urbanization and wood extraction. In 1970s and succeeding year, venture for aquaculture caused almost 28 percent of mangroves lost in Asia covering the country of Bangladesh, India, China, Thailand, Vietnam, and Indonesia, and in South America; Ecuador, Brazil and Peru. Furthermore, in South East Asia mangrove damage in terms of land cover was nearly 1.66 million hectares. Summing up the global economic loss of mangroves due to aquaculture was 3.78–17.01billion/year US dollar.

Meanwhile, the main cause of mangrove loss in the Philippines was aquaculture due to occupation, food security and business. In the study of Garcia et al. (2013), during the year 1920s, there were 400,000 – 500,000 hectares of mangroves covering the riverine and intertidal system of the Philippines but decreased to 120,000 hectares in 1994. The depletions of mangroves were caused by over-exploitation of coastal people for household and commercial use, conversion to agricultural lands, industrial activities and settlement expansion. If this trend continues, this could deplete the mangrove resources in the country for the following years. With the current situation of mangroves not only in the Philippines but also around the world, there is a necessity to provide actions that will help them recover from over-exploitation.

Mangroves are efficient carbon storage in the coastal ecosystem. Understanding their biomass production is the proper way of describing their nutrient cycling activities, and even participating in the biogeochemical cycle. Relative to these processes of mangroves, there is a need to analyze the pathways of substances and nutrients in their live biomass for accurate assessment of their sequestration activities especially the capturing of carbons. Determining the carbon stock of mangroves justify their importance in resolving carbon dioxide emissions. The information regarding the rate of mangroves carbon sequestration can be a support to strictly implement policies and laws that protect these trees. Furthermore, this also provide a spectrum of figures to describe the abilities of mangroves in global warming or climate change mitigation.

OBJECTIVES OF THE STUDY

This study aimed to describe the significance of mangrove ecosystem in reducing the emissions of greenhouse gas in the atmosphere. Specifically, it sought to answer the following objectives: 1) determine the biomass amount of the mangroves in the study area; 2.) compute the carbon stock of mangroves in the study area and carbon dioxide equivalent; 3.) determine the oxygen release of the mangroves in the study site; 4.) provide discussion on the importance of the collected allometric data of mangroves in the context of global warming.

METHODOLOGY

The study identified three mangrove sampling stations along Sukol River, Bongabong, Oriental Mindoro. The mangroves included in the sampling sets were selected through circular plot method. This was done by establishing a 125 meter transect line in the three selected sampling stations of the study site. After overlaying the transect line, 6 circular plots with 7 meter radius were placed along this line with 25 meters interval. The mangroves covered by the 7 meter radius plot having a height of 2 meters and above were measured according to their girth diameter, stem diameter and height. The Tree Density, Species, Girth (GBH), Stem Diameter and Height were computed based on the standard formula used by Kauffman and Donato (2012), for Aboveground Biomass (AGB) and Belowground Biomass (BGB). After the three sampling stations were already surveyed, the total Aboveground and Belowground Biomass were combined. Then afterwards, the AGB and BGB of the three sampling stations were added together to achieve the total live biomass.

Figure 1. The map of the study site, Sukol River, Bongabong, Oriental Mindoro

The study was done in Sukol River, (121.48935 E,12.74399 N) which is surrounded by the communities of barangay Aplaya, sitio K.I. of barangay Poblacion and sitio Asiatic of barangay Ipil, Municipality of Bongabong, Oriental Mindoro. Based on Figure 1, the site is riverine and intertidal in characteristic inhabited by diverse mangrove species.

The equations below were used for acquiring AGB and BGB:

a Aboveground Biomass $(AGB)=0.0509*\rho*D^2*H$
b. Belowground Biomass $(BGB)=0.199*\rho^{0.899}*D^{2.22}$

The species code and standard estimates of wood density necessary to compute for the AGB and BGB of the mangroves were listed in Table 1.

Table 1
The Wood Density of Different Mangrove Species (p) (Kauffman & Donato, 2012)

Scientific Name	Species Code	Wood density (g/cm3)
Bruguiera gymnorrhiza	Bg	0.741
Rhizophora apiculata	Ra	1.065
Rhizophora mucronate	Rm	0.77
Rhizophora stylosa	Rs	0.94
Sonneratia alba	Sa	0.78
Avicennia marina	Am	0.69
Avicennia rumphiana	Ar	0.7367
Avicennia officinalis	Ao	0.62
Bruguiera sexangula	Bs	0.92
Ceriops decandra	Cd	0.96
Excoecaria agallocha	Ea	0.45
Heritiera littoralis	Hl	1.074
Avicennia alba	Aa	0.6987
Xylocarpus granatum	Xg	0.7

Moreover, the equations below were used to compute for the Carbon Stock and Carbon Dioxide Equivalent (Schöngart et al., 2011):

1. *Carbon sequestration= Carbon fraction (0.47 value) x biomass*
2. *CO_2-eq = (44/12) x carbon stock*

In addition, the equation below was used by the study to get the Net Oxygen Release of the mangroves from the study site:

3. *Net O_2 release = Net Carbon sequestration (tonnes/ha/yr) × 32 / 12* (Mitra, 2019)

RESULTS AND DISCUSSION

1.Computation of Aboveground and Belowground Biomass

A total of 430 trees belonging to six true mangrove species were assessed, comprising a total estimated biomass of 5,905.88 Mg·Ha^{-1} from aboveground and belowground biomass based on Table 2, Results for Mangrove Aboveground and Belowground Biomass Data. The mangrove species *Sonneratia alba* exhibit the greatest amount of aboveground (5,087.36 Mg·Ha^{-1}) and belowground biomass, 19.4 Mg·Ha^{-1}. The *Brugiera sexangula* has the least amount of aboveground biomass with 2.79 Mg·Ha^{-1} and 0.0106 Mg·Ha^{-1} for the computation of their belowground biomass.

Table 2
Results for Mangrove Aboveground and Belowground Biomass Data

Mangrove Station	Mangrove Species	Tree Density	Range DBH (cm)	Mean DBH (cm)	Total Aboveground Biomass (Mg·Ha^{-1})	Total Belowground Biomass (Mg·Ha-1)
1	*Sonneratia alba*	98	3.12-60.80	17.84	3,721.9	13.5
	Rhizophora mucronata	68	3.18-17.13	7.67	328.7	1.3
	Rhizophora apiculata	7	6.68-18.14	13.19	135.2	0.5
	Avicennia marina	14	3.82-19.74	6.97	29.4	0.3
	Avicennia officinalis	1	6.05	6.05	1.6	0
	Bruguiera sexangula	2	4.46-4.62	4.54	2.8	0
2	*Sonneratia alba*	48	2.42-35.01	13.44	895.9	3.6
	Rhizophora mucronata	14	5.35-8.50	6.49	22.8	0.1
	Rhizophora apiculata	38	2.55-11.24	5.26	81.2	0.4
	Avicennia marina	23	2.86-11.46	5.94	24.6	0.2
	Avicennia officinalis	9	3.82-33.42	10.13	104	0.4
3	*Sonneratia alba*	74	2.71-30.72	9.2	469.6	2.3
	Rhizophora mucronata	14	2.55-11.46	5.46	18.3	0.1
	Rhizophora apiculata	2	4.14	4.14	1.1	0
	Avicennia marina	15	2.39-13.37	8.35	40.1	0.3
	Avicennia officinalis	3	4.62-12.10	9.23	5.5	0.1
	Total	**23.89**			**5,882.70**	**23.1**

2. Carbon Stock- Computation of Carbon Sequestration and Carbon Dioxide Equivalent (CO2-eq)

A total biomass of 5,905.88 Mg·Ha^{-1} is recorded from the combined biomass of aboveground and belowground carbon pools based on Table 3, Results for the Carbon Stock and Carbon Dioxide Equivalent in the mangrove forest in Sukol River, Bongabong, Oriental Mindoro. Almost 87 percent of the total biomass is contributed by *Sonneratia alba* (5,106.74 Mg·Ha^{-1}) trees which is probably due to their high density and the existence of large girth individual trees.

Table 3
Results for the Carbon Stock and Carbon Dioxide Equivalent (CO_2-Eq)

Mangrove Species	Total Aboveground Biomass ($Mg \cdot Ha^{-1}$)	Total Belowground Biomass ($Mg \cdot Ha^{-1}$)	Total Biomass ($Mg \cdot Ha^{-1}$)	Net Carbon Sequestration ($Mg \cdot Ha^{-1}$)	Total CO_2-Eq ($Mg \cdot Ha^{-1}$)
Sonneratia alba	5,087.36	19.38	5,106.74	2,400.17	8,808.62
Rhizophora mucronate	369.77	1.61	371.38	174.55	640.59
Rhizophora apiculate	217.55	0.91	218.46	102.68	376.83
Avicennia marina	94.17	0.74	94.91	44.61	163.7
Avicennia officinalis	111.1	0.49	111.59	52.45	192.48
Bruguiera sexangular	2.79	0.0106	2.8	1.32	4.83
Total	**5,882.70**	**23.1**	**5,905.88**	**2,775.76**	**10,187.05**

The total estimated carbon stock is 2,775.76 $Mg \cdot Ha^{-1}$ which is equivalent to 10,187.05 $Mg \cdot Ha^{-1}$ of absorbed carbon dioxide. Highest biomass and carbon stock are exhibited by large girthed trees of *S. alba* (total biomass=5,106.74 $Mg \cdot Ha^{-1}$; net carbon sequestration = $Mg \cdot Ha^{-1}$), which has absorbed an estimated amount of 8,808.62 $Mg \cdot Ha^{-1}$ carbon dioxide.

3. Computation of Net Oxygen Release

Table 4
Results for the Computation of Net Oxygen Release

Mangrove Species	Total Biomass (Mg·Ha-1)	Net Carbon Sequestration ($Mg \cdot Ha^{-1}$)	Net Oxygen Release (Mg·Ha-1·year-1)
Sonneratia alba	5,106.74	2,400.17	6, 400.45
Rhizophora mucronate	371.38	174.55	465.46
Rhizophora apiculate	218.46	102.68	273.81
Avicennia marina	94.91	44.61	118.95
Avicennia officinalis	111.59	52.45	139.86
Bruguiera sexangular	2.8	1.32	3.51
Total	**5,905.88**	**2,775.76**	**7,402.04**

The dominant mangrove species in Sukol River can release an average of 7,402.04 $Mg \cdot Ha^{1} \cdot year^{-1}$ oxygen based on Table 4, Results for the Computation of Net Oxygen Release. The mangroves of the study site are unique oxygen generator as justified by the results of *Sonneratia alba* (6,400.45 $Mg \cdot Ha^{-1} \cdot year^{-1}$), *Rhizophora mucronata* (465.46 $Mg \cdot Ha^{-1} \cdot year^{-1}$), *Rhizophora apiculata* (273.81 $Mg \cdot Ha^{-1} \cdot year^{-1}$) and other mangrove species.

4. Mangrove Allometric Data in the Context of Global Warming

4.1. Aboveground and Belowground Biomass

The total estimated biomass of the study site is 5,905.88 $Mg \cdot Ha^{-1}$. The aboveground and belowground live biomass of mangroves are reliable factors to describe the amount of captured carbon and carbon stock of this ecosystem. The higher amount of computed live biomass of mangroves is an implication of their effectiveness in capturing carbon.

The process of achieving the data for biomass computation was effective due to the appropriate parameters used in the study. Moreover, the result of individual biomass for each mangrove are also presented for sole analysis of the amount of carbon and other organic materials they can capture. Understanding of the capacities of each mangrove species in terms of biomass stocking is an important parameter for analyzing the possible carbons they can store. The process of biomass accumulations in this ecosystem has implication in projecting measures how much possible greenhouse gas are prevented to reach the atmosphere. The aboveground and belowground biomass computation provide data that can be used in annual monitoring of mangrove carbon stock which is essential in describing the greenhouse gas reduction capacity of mangroves as climate regulators.

4.2. Carbon Stock and Carbon Dioxide Equivalent (CO2-eq)

The total estimated carbon stock is 2,775.76 Mg·Ha^{-1} which is equivalent to 10,187.05 Mg·Ha^{-1} of absorbed carbon. Highest biomass and carbon stock are exhibited by large girth trees of *S. alba* (total biomass=5,106.74 Mg·Ha^{-1}; net carbon sequestration = Mg·Ha^{-1}) which has absorbed an estimated amount of 8,808.62 Mg·Ha^{-1} carbon dioxide.

Mangroves store the captured carbon within their leaves, trunks, branches and belowground, and hanging roots. Mangroves can contain 1083 ± 378 MgC·ha^{-1} of carbons greater than the upland forests ecosystem. Unlike other research studies of mangrove monitoring with relation to carbon stock that were just utilized to describe the development of mangroves and growth. This study used the difference in carbon stock (net carbon sequestered) of each mangrove species to infer the amount of possible carbon dioxide they can prevent in reaching the atmosphere (Murdiyarso et al.,2015).

Considering that climate change bolsters natural hazards such as extreme temperature, rainfall regime getting heavier frequency of strong typhoon and prevalent drought, these issues became the greatest challenge of nations across the entire planet. The collected numerical data that represented the carbon stock of mangroves are used to validate their role in the climate change mitigation. The harnessed data are suitable parameter in discussing policy enhancement, programs and projects for the mangrove ecosystem with relation to mitigation of climate change planning and Disaster Risk Reduction and Management (DRRM) program.

4.3. Net Oxygen Release

The results for the computation of oxygen release the dominant mangrove species in the study site, can release an average of 7,402.04 Mg·Ha^{-1}·year^{-1}. The overall results for the oxygen released were useful to describe the photosynthetic process' benefits for other living things in the context of global warming. This process captured the carbon dioxide which helps to regulate temperature and contribute in arresting greenhouse gases in the atmosphere. The amount of oxygen released by the mangroves of Sukol River is produced from the 2,775.76 Mg·Ha^{-1} of carbon sequestered through the process of photosynthesis. This reveals the importance of understanding the mangroves' net oxygen release for they serve as indicator of effective carbon confinement from different sources.

In general, allometric data can be used to describe the significance of mangroves in reducing the greenhouse gas that can reach the atmosphere. The biomass is an effective parameter to achieve data in describing the amount of possible greenhouse gas, specifically carbon dioxide, a mangrove can store. The oxygen released by the mangroves were also consumed by the dead mangrove trees, litter and detritus to initiate decomposition. The decomposition helps in storing carbons that reach the marine ecosystem from a high gradient source (Mitra, 2019).

CONCLUSIONS

The biomass computation of mangroves can be used as a given data in estimating the amount of carbon and possible volume of carbon dioxide they can sequester from a source. Carbon stock of mangroves can be utilized in estimating the amount of carbon dioxide they can contain in the biomass level that might reach the atmosphere, and oxygen release. In addition, the results on the assessment of mangroves allometric parameters are useful in justifying the importance of this ecosystem to global warming or climate change mitigation. Due to their carbon sequestration activities, they prevented the conversion of the mentioned elements into carbon dioxide. Carbons, when they reached the atmosphere are no longer simple element, it became a greenhouse gas that impact the atmosphere due to heat repression. Fundamentally, the approach of proving the significance of mangroves to lessen the effect of global warming using allometric data is reliable.

RECOMMENDATIONS

The allometric data of mangroves should be presented in a wider spectrum emphasizing their worth in the context of greenhouse gas reduction and global warming. The importance of describing their abilities to prevent the accumulation of greenhouse gases in the atmosphere are necessary so that conservation drive for these saline trees will be prioritized. Assessment tool to describe mangroves' greenhouse gas reduction capacity should be developed for a more allometric data utilization. The interpreted data should also be transpired to the policy makers and decision-makers for better planning and implementation of various mangrove restoration projects. Data on research regarding the capacities of mangroves to mitigate global warming must be considered by the world government. Considering the figures on allometric analysis of mangroves, they are dependable for conservation procedures.

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AUTHOR'S PROFILE

Dr. Randy A. Quitain is a faculty researcher of Mindoro State University (MinSU) , a state university based on the island of Oriental Mindoro, Philippines. He is a graduate of Doctor of Philosophy in Environmental Management and Studies at the Miriam College, a well-known institution in the Philippines working in environmental management and education. The author before having his Ph.D. was trained in studying mangrove, and other marine ecosystem for the purpose of effective coastal resource management. Today, Dr. Quitain had expanded his works on municipal development plan and tourism, addressing environmental impact of projects in various ecosystem

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