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ANNUAL CARBON SEQUESTRATION IN THE SUNDARBANS: VARIATION IN VEGETATION TYPES

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ANNUAL CARBON SEQUESTRATION IN THE SUNDARBANS: VARIATION IN VEGETATION TYPES

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DECLARATION

I, Gazi A. Rahman Nahid, declare that this thesis is the result of my own work and it has not been submitted or accepted for any degree to other university or institution.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for title and summary to be made available to *Center for Environmental and Geographic Information Services (CEGIS)* and outside organizations with my approval.

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Rahman
8.06.2017

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Gazi A. Rahman Nahid

APPROVAL

This is to certify that the present project entitled "**ANNUAL CARBON SEQUESTRATION IN THE SUNDARBANS: VARIATION IN VEGETATION TYPES**" has been carried out by Gazi A. Rahman Nahid (Student Id: 120537) under my direct supervision at the Forestry and Wood Technology Discipline of Khulna University, Khulna-9208, Bangladesh.

I recommend that the content of the project report can be accepted in the partial fulfillment of the requirement for the Degree of B.Sc. (Honors) in Forestry.

Supervisor

8.6.2017

Dr. Md. Nabiul Islam Khan

Professor

DEDICATION

To my respectful grandfathers, rest in peace

Dr. Motiar Rahman Molla and ***Haji Ahammad Ali Gazi,***

who always inspired me to be an honest man from my childhood.

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ABSTRACT

The Sundarbans is the largest mangrove forest in the world. Forests are very important for sequestering atmospheric carbon and mangroves are amongst the most efficient carbon sequestering device. This study presents the estimation of vegetation carbon (above and belowground) stock and its annual rate in the Sundarbans using three-year time scale data sets collected from systematic transect sample plot in the forest along the Passur river. The variation of carbon stock and the annual rate of carbon sequestration in different vegetation types was investigated. Among five vegetation types, the dominance of *Heritiera fomes* was decreased towards the Bay of Bengal. On the other hand, the dominance of *Excoecaria agallocha* was increased towards the same direction. Both Species were common in every vegetation types of the study sites. The amount of carbon stored varied significantly among vegetation types *($P<0.05$)*. *Excoecaria agallocha* (VT5) dominated vegetation type showed the highest annual carbon sequestration rate (5.08±0.007 Mg ha^{-1} $year^{-1}$) and *Heritiera fomes* (VT1) dominated vegetation type showed the lowest (3.12±0.017 Mg ha^{-1} $year^{-1}$) rate followed by other vegetation types. The yearly average aboveground, belowground and vegetation carbon sequestration rate were found 2.59±0.24 Mg ha^{-1} $year^{-1}$, 1.52±0.14 Mg ha^{-1} $year^{-1}$ and 4.11±0.38 Mg ha^{-1} $year^{-1}$ respectively considering all vegetation types. The mean rate of vegetation carbon sequestration was 4.11±0.38 Mg ha^{-1} $year^{-1}$ which was equivalent to 15.08±1.39 Mg ha^{-1} $year^{-1}$ of CO_2 sequestration (1 Mg C equivalent to 3.67 Mg CO_2). In the total study sites, this amount of sequestration valued to 226.2±20.85 USD ha^{-1} $year^{-1}$ (@15 USD per Mg CO_2). By multiplying total forest cover area (4210 km^2) of the Sunderbans with this annual vegetation carbon sequestration rate (4.11±0.38 Mg ha^{-1} $year^{-1}$), the total vegetation carbon sequestration per year was 1.73±0.16 million Mg which was equivalent to 6.35±0.59 million Mg CO_2 per year. This amount of sequestration valued to 95.25±8.85 million USD per year. With this CO_2 sequestration and other co-benefits, such as biodiversity conservation, the Sundarbans Mangrove Forest greatly contributes to the purpose of REDD+ to reduce the impact of the greenhouse effect, thereby mitigating global climate change.

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ACRONYMS

AGB	Aboveground Biomass
AGC	Aboveground carbon
ASTM	American Society for Testing and Materials
BD	Bulk Density
BGB	Belowground Biomass
BGC	Belowground Carbon
C	Carbon
CBD	Conservation of Biological Diversity
CO_2	Carbon dioxide
CREs	Credit Emission Reductions
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
GHG	Green House Gas
GPS	Global Positioning System
IPCC	Intergovernmental Panel on Climate Change
IVI	Important Value Index
LOI	Loss of Ignition
MDG	Millennium Development Goals
NPK	Nitrogen-Phosphorus-Potassium
REDD+	Reduced Emissions from Deforestation and Forest Degradation "plus"
SFM	Sustainable Forest Management
SOC	Soil Carbon
SRF	Sundarbans Reserved Forest
TSC	Total Site Carbon
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USD	United State Dollar
USGS	United State Geological Survey
VT	Vegetation Type
VTC	Vegetation Carbon

UNITS

cm	Centimeter
ha	Hectare
Kg	Kilogram
m	Meter
m^2	Square meter
Mg	Megagram
Mm	Millimeter
Ppm	Parts Per Million
Pg	Picogram

CHAPTER 1

1 Introduction

1.1 Background and Justification of the Study

Today, the World is facing major challenges responsible by CO_2 causing global warming which occurs mostly due to man-made emissions of greenhouse gases (mainly CO_2) (IPCC 2013, Rahman et al. 2015b). Mangroves are keystone coastal ecosystems providing numerous environmental services viz. reduce global warming and critical ecological functions, affecting both upland and oceanic resources (Kauffman and Donato 2012). Mangroves are defined as an association of halophytic trees, shrubs and other plants growing in brackish to saline tidal waters of tropical and subtropical coastlines (Kauffman and Donato 2012, Mitsch and Gosselink 2007).

The Sundarbans is the largest single tract of mangrove forest in the world (6,017 km^2 in Bangladesh part) (Islam 2011). It is a RAMSAR SITE having three wildlife sanctuaries which are designated as World Heritage by UNESCO during 1997. The forest is, nationally and internationally, of great conservation significance for its environmental services and biodiversity (Seidensticker and Hai 1983, Iftekhar and Saenger 2008). Protecting the world from adverse effects of climate change, the Sundarbans play a crucial ecological role performing as a carbon reservoir and absorbing more than four crore tons of CO_2 from the atmosphere (Paul 2013). The Sundarbans also provide protection from storms and tsunamis (Giesen et al. 2007, Alongi 2009, Kauffman and Donato 2012, Mitsch and Gosselink 2007), provide conservation of biodiversity, including habitats for many rare and endangered species (Duke et al. 2007, Kauffman and Donato 2012). As the Sundarbans become the greatest reservoirs of carbon and environmental shield, therefore for economic and social perspectives, it is essential to study on this topic on the Sundarbans.

Statistics shows that 1.26% of the yearly destruction of forests and remains higher than the world average destruction rate (Mahmood 2014). In this situation, world has focused on a different issue known as carbon trading. The program reduced emissions from deforestation and forest degradation (REDD+) offers the economic incentives for conserving forests and associated carbon stocks and intended to offset the short-term economic factors that promote deforestation (Mahmood 2014). To aid in the conservation of the forest and to benefit from various global initiatives (e.g., carbon trading), an assessment of the carbon sequestration and its annual rate (aboveground, belowground and total vegetation) in the Sundarbans is immensely important. The species distribution in mangroves as well as in the Sundarbans found variation with vegetation types (Iftekhar and Saenger 2008) and site quality (Mahmood 2014). Moreover, the heterogeneity of the mangrove forest in terms of large area of forest cover, salinity zone (Wahid et al. 2007), dominant mangrove vegetation types (Chaffey et al. 1985, Iftekhar and Saenger 2008) which might influence the aboveground and belowground carbon stock would be of great interest to mangrove ecologists.

However, several studies has already done on biodiversity, biomass, vegetation type assessment and carbon stock in Sundarbans but current assessment in the Sundarbans is a considerable issue. By this study, we can quantify the annual carbon sequestration rate with respect to vegetation types. Valuation of yearly carbon sequestration is also done with respect of total Sundarbans. In future, this study will help the Bangladesh Forest Department, Sundarbans researchers and policy makers to take decisions about management of the Sunderbans.

1.2 Objectives

To find out Annual carbon sequestration rate and it's valuation in the Sundarbans Reserved Forest with vegetation types.

1.3 Scopes

I. The Kyoto Protocol of the UNFCCC has introduced Clean Development Mechanism concept among the low-income people who can store carbon through a change in their land uses. It is normally known as carbon trade mechanism. This research will improve knowledge base necessary for country negotiations in the carbon trade mechanism.

II. Under REDD+, developing countries that are effectively protecting their forests through conservation and enhancement of forests carbon stock which will be eligible for carbon payments. Finally, it will fulfill Government's three international treaties like the CBD, Kyoto Protocol and MDG.

CHAPTER 2

2 Literature Review

2.1 Carbon Sequestration

Carbon sequestration refers to the capture and long-term storage of carbon in forests and soils so that the build-up of CO_2 (one of the principles greenhouse gases) in the atmosphere will reduce or slow. The UNFCCC (1992) defines carbon sequestration as the process of removing carbon from the atmosphere and depositing it in a reservoir. According to the U.S. Geological Survey (USGS 2008), The term "carbon sequestration" is used to describe both natural and deliberate processes by which CO_2 is either removed from the atmosphere or diverted from emission sources and stored in the ocean, terrestrial environments (vegetation, soils, and sediments), and geologic formations. At present, carbon sequestration is valued as a function of credit emission reductions (CREs), based on the difference between the amount of carbon stored in scenario projects and baseline, current amount of carbon stored in the system (UNFCCC 2004).

2.2 Types of Carbon Sequestration

According to IPCC (2005), CO_2 sequestration can be done by the following three ways,

I. **Terrestrial sequestration or vegetative sequestration:** Terrestrial sequestration is the natural intake of CO_2 by plants, which incorporate in their wood, leaves, and roots and also bind it to the underlying soil so much of this CO_2 is not released into the atmosphere until the plant is destroyed (by decay or burning) or the soil is tilled and exposed to the atmosphere. This can be enhanced by increasing the growth of land plants through planting trees, mitigating deforestation or adjusting forest management practices. It is the easiest and most immediate option for carbon sequestration at the present time.

II. **Geologic sequestration:** Geosequestration is burying the CO_2 deep within the earth. It can be done by the mechanical capture of CO_2 from an emission source (e.g., a power plant, fossil fuel burning etc.) and the captured CO_2 is injected and sealed into deep rock units. The most suitable sites are deep geological formations, such as depleted oil and natural gas fields or deep natural reservoirs filled with saline water (saline aquifers).

III. **Oceanic sequestration:** Oceanic sequestration is dumping the CO_2 into the depths of the ocean. This uptake is not a result of deliberate sequestration but occurs naturally through chemical reactions between seawater and CO_2 in the atmosphere. While absorbing atmospheric CO_2, these reactions cause the oceans to become more acidic. Many marine organisms and ecosystems depend on the formation of carbonate skeletons and sediments that are vulnerable to dissolution in acidic waters (USGS 2008).

2.3 Carbon Sequestration in Mangrove Forest

Mangrove can trap not only fine sediment and organic matter but also coarse sediment driven by storm waves to form special mangrove sediment. Thus, the rate of sedimentation in mangrove is high. Besides, the litter productivity is also high in Mangroves, which provides more carbon sequestrated in sediments of mangrove, high below ground carbon sequestration. This indicates positive action in mangrove conservation and rehabilitation would contribute immensely to sequestrate CO_2 (Tateda 2005).

Components like NPK, organic carbon export etc. per ha, were estimated in different studies. The global storage of carbon in mangrove biomass is estimated at 4.03 Pg C. The average rate of wood production is 12.08 Mg ha^{-1} $year^{-1}$, which equivalent to a global estimation of 0.16 Pg C $year^{-1}$ stored in mangrove biomass. The net ecosystem production in mangroves is about 0.18 Pg C $year^{-1}$ (Ong 1993). Mangroves are important carbon sinks and sequester approximately 25.5 million tons of carbon every year (IUCN 2009). They also provide more than 10% of essential dissolved organic that is supplied to the global ocean from land (IUCN 2009, Laffoley and Grimsditch 2009). Disturbed mangrove soils release greater than an additional 11 million metric tons of carbon annually.

2.4 Climate Change and its Effects

According to UNFCCC (1992), "Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The main characteristics of climate change are increasing in average global temperature (global warming)(UNFCCC 2007). This increase in atmospheric CO_2 from about 280 to more than 380 parts per million (ppm) over the last 250 years (USGS 2008), and it has been predicted that atmospheric CO_2 will range between 467-555 ppm by the year 2050, and average global temperature will increase by 2-42°C, will causing measurable global warming (IPCC 2007, Anderson and Bows 2011, IPCC 2013).

Coasts are very likely to be exposed to increasing risks, including coastal erosion, due to climate change and sea-level rise. Many millions more people are projected to experience severe flooding every year due to sea-level rise by the 2080s. The numbers affected will be largest in the mega-deltas of Asia and Africa, while small islands are especially vulnerable. Regional changes in the distribution and production of particular fish species are expected due to continued warming, with adverse effects projected for aquaculture and fisheries (UNFCCC 1992).

A 4°C rise could be potentially devastating leading to inundation of coastal areas, increased intensity of tropical cyclones; unprecedented heat waves exacerbated water scarcity; increasing risks for food production potentially leading to higher malnutrition rates; and irreversible loss of biodiversity (Hemani 2014). In the Indian coast past observations on the mean sea level indicates a long-term rising trend of about 1.0 mm $year^{-1}$ on an annual mean basis (Unnikrishnan et al. 2006, Raha et al. 2012).

More than four-fifth (83.9%) of the poor households of the Sundarbans community reported that rainfall has reduced significantly due to climate change. More than two-fifth (43.1%) poor households have experienced inundation of their household due to flood and more than half (56.0%) reported about the flood at the surroundings of their household. More than one-fourth (27.0%) experienced the increasing trend of temperature or feeling hotter than before (Masum 2012). Climate change will have wide-ranging effects on the environment, and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity and coastal zones (UNFCCC 2007).

2.5 Mangroves as a Climate Mitigation Option

About 1.5 tons of carbon per hectare per year that mangroves are able to sequester, this is approximately equivalent to the amount of carbon released from a motor vehicle to the atmosphere each year (assuming each car uses approximately 2500 liters of petrol per year) (Spalding et al. 1997). So forest has an important role in the global carbon cycle and forestry can contribute to climate change mitigation through three different ways like carbon sequestration, carbon conservation and carbon substitution (Pan et al. 2011).

2.5.1 Carbon Sequestration

As they grow, trees absorb CO_2 and through Photosynthesis, sequester carbon to produce wood. Newly established forests (on reforested or afforested sites) and forest re-growth can sequester carbon quickly and will store it for the life of the forest. When trees are harvested efficiently, a large part of the sequestered carbon can be used to produce wood products such as house frames and thus stored in the medium to long term (IPCC 2007). The high rate of carbon allocation in belowground with aboveground carbon makes mangroves as the densest carbon-rich ecosystem in the tropics and contains one an average 937 Mg C ha^{-1} (Donato et al. 2011, Alongi 2012).

2.5.2 Carbon Conservation

The most expensive way to mitigate climate change in the forest is to reduce deforestation and forest degradation, thereby reducing GHG emission. In climate change negotiation, this strategy is usually referred to as "reducing emission from deforestation and degradation" (IPCC 2007).

2.5.3 Carbon Substitution

Forest products can substitute for products from other sectors that have a relatively high GHG emission. Wood-based fuels such as fuelwood, Charcoal, black liquor and ethanol can be used as substitutes for fossil fuels in heating, energy generation and transport. When wood is produced in the forest under a sustainable forest management (SFM) regime, it is effectively carbon-neutral. The production of goods made of steel, aluminum, concrete and plastic consumes a large amount of energy and therefore causes significant GHG emission. The substitution of these products with sustainably produced wood products can, therefore, help reduce GHG emission (IPCC 2005).

2.6 Dynamics of Carbon in the Sundarbans and its Status Along with Vegetation Structure

Mangroves are particularly efficient in sequestering four times carbon per unit area compared with terrestrial forests in the tropics (Khan et al. 2007, Donato et al. 2011, Rahman et al. 2015b). Carbon stock in mangrove ecosystem varies with species (Laffoley and Grimsditch 2009), vegetation type (Laffoley and Grimsditch 2009, Cero´n-Breto´n et al. 2011, Mitra et al. 2011, Sapit et al. 2011, Adame et al. 2013, Rahman et al. 2015b) and salinity (Adame et al. 2013, Rahman et al. 2015b). Aboveground and belowground carbon stock in *Heritiera fomes* dominated area is 152.57 Mg ha^{-1} and 62.37 Mg ha^{-1} respectively which is higher than other vegetation types (Rahman et al. 2015b). The lowest carbon stock of aboveground and belowground are 45.24 Mg ha^{-1} and 11.72 Mg ha^{-1}, found in *Ceriops decandra - Excoecaria agallocha* dominated vegetation type (Rahman et al. 2015b).

In the Sundarbans, *Heritiera fomes*, *Excoecaria agallocha* and *Ceriops decandra* jointly cover 95% of the forest area. The diversity of forest types has been gradually reduced over time, but *Heritiera fomes* and *Excoecaria agallocha* have maintained their dominance over large portions of the forest, are spread over 67% and 74% of the vegetated area of the forest respectively (Iftekhar and Saenger 2008).

Table 2.1 Major vegetation types in the Sundarbans Mangrove Forest

SL No	Vegetation Type	Area %
1	*Heritiera fomes*	21
2	*Heritiera fomes–Excoecaria agallocha*	25.8
3	*Heritiera fomes-Xylocarpus mekongensis-Bruguiera sexangula*	1.7
4	*Xylocarpus mekongensis-Bruguiera sexangula-Avicennia officinalis, Heritiera fomes-Xylocarpus mekongensis-Sonneratia apetala*	2.9
5	*Excoecaria agallocha*	5.2
6	*Excoecaria agallocha-Heritiera fomes*	18.4
7	Non-tree vegetation (NTV)	1.2
8	*Ceriops decandra-Excoecaria agallocha*	13.7
9	*Ceriops decandra*	1.6
10	*Excoecaria agallocha–Ceriops decandra*	8.4

Source: (Chaffey et al. 1985, Iftekhar and Saenger 2008, Rahman et al. 2015b).

CHAPTER 3

3 Materials and Methods

3.1 Description of the study area

The study was carried out in the Sundarbans, which lies between 21°30′ N - 22°30′ N and 89°00′ E - 89°55′ E, in the southwest of Bangladesh. The forest covers an area of 6,017 km^2 of which 4,120 km^2 are covered by the forests and the remaining 1,897 km^2 are in rivers, canals and creeks of varying width and depth (Islam 2011, Rahman et al. 2015b). The soil of the Sundarbans is silty clay loam with alternate layers of clay, silt and sand (Chauhan and Gopal 2014, Rahman et al. 2015b). Five sites were selected purposively for this study. Among them, four sites were along the Passur River at Karomjol, Harbaria, Akram point and Hiron point; another one was near at Sutarkhali forest office (Fig. 3.1). Sites description is shown in table 3.1.

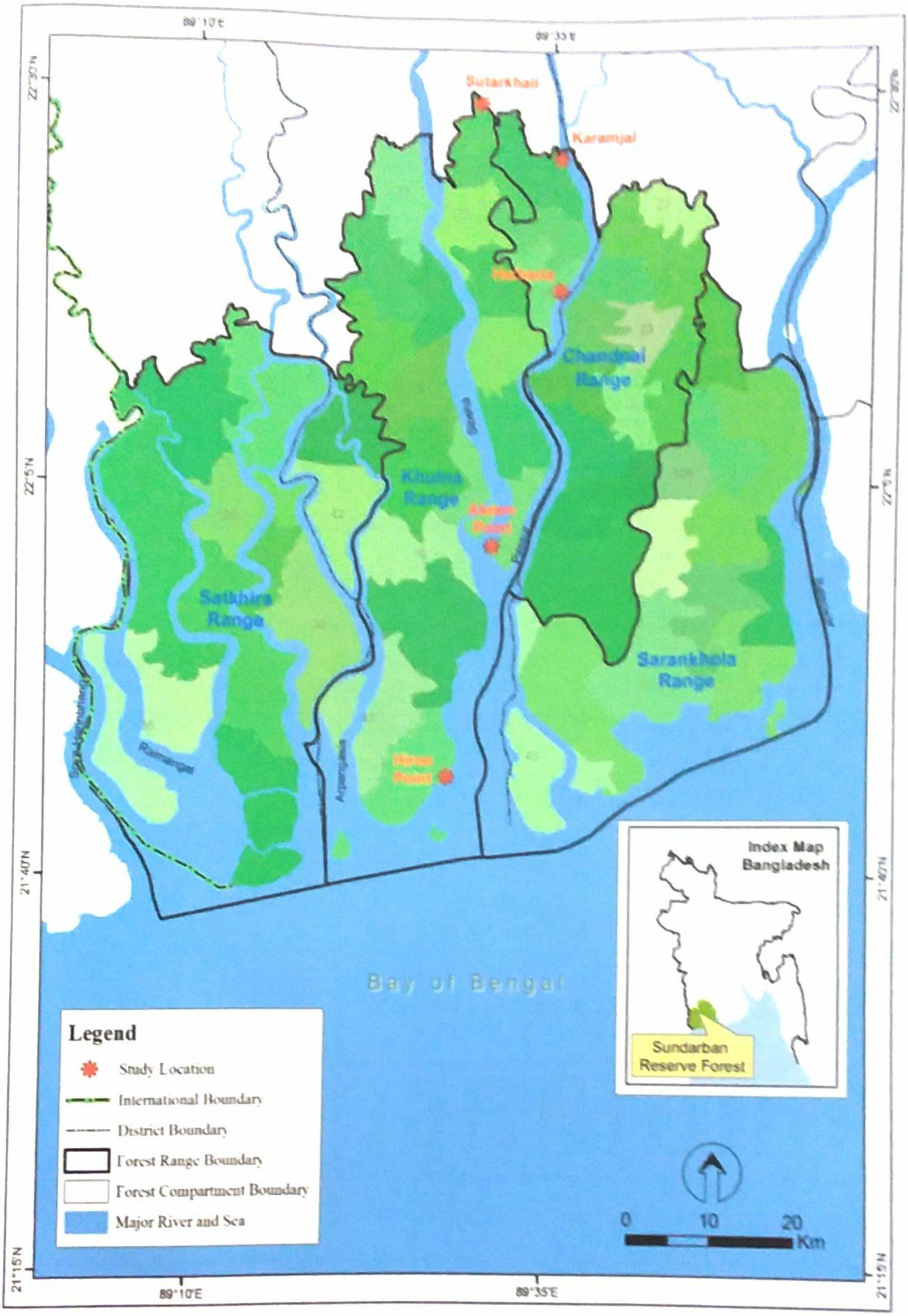
3.1.1 Climatic Condition

In the Sundarbans, April and May are the hottest months, while December and January are the coolest months. The mean annual maximum and minimum temperatures vary between 32°C and 20°C. Mean annual relative humidity varies from 77 to 80 %. The mean annual rainfall ranges between 1900 and 2500 mm (Rahman et al. 2017).

3.2 Methodology

3.2.1 Sampling Design

There were 15 permanent sample plots, the total area of 0.75 ha was taken from five study sites. In each site, a transect line was laid out perpendicular to river or canal bank. Along the transect line, three circular nested plots of 12.62 m radius (plot size 500.34 m^2 each) were laid out at 100 m intervals in order to capture maximum tree species (Fig. 3.2)(Fig. 3.3). Because of variation in species composition in the Sundarbans, observation plots were laid out from coast, river or canal side to landward zone (forest proper side). The location of the first plot was 40 m away from ecotone (riverside) to inner ward of forest in order to save the plot from river bank erosion (Fig. 3.2). GPS reading at the center of each sample plots was also recorded (Table 3.1) (Fig. 3.2).



(Data Source: CEGIS)

Figure 3.1 Study sites in The Sunderbans Reserved Forest

Table 3.1 Description of the study sites

Sites No.	Sites Name	Plot No.	Range	Compartment No.	GPS reading			Topography	Soil Description	Plot Location Notes
					Latitude	Longitude	± (m)			
1	Suterkhali	1	Khulna	32	22.498150	89.487520	3	Flat	Hard Clay	Just opposite from Sutar Khali Forest Station and 40 m SW from Sutar Khali canal
		2	Khulna	32	22.497330	89.487110	3	Flat	Hard Clay	Just opposite from Sutar Khali Forest Station and 140 m SW from Sutar Khali canal
		3	Khulna	32	22.496550	89.486640	3	Flat	Hard Clay	Just opposite from Sutar Khali Forest Station and 240 m SW from Sutar Khali canal
2	Karomjol	4	Chandpai	31	22.425310	89.594390	3	Flat	Hard Clay	Plot centre 40 m west from Passur river
		5	Chandpai	31	22.425210	89.593410	3	Flat	Hard Clay	Plot centre 140 m west from Passur river
		6	Chandpai	31	22.422610	89.592540	3	Flat	Hard Clay	Plot centre 240 m west from Passur river
3	Harbaria	7	Chandpai	29	22.296100	89.592400	4	Flat	Hard Clay	40 m west from passure river
		8	Chandpai	29	22.296240	89.591790	3	Flat	Hard Clay	140 m west from passure river
		9	Chandpai	29	22.296200	89.590800	3	Flat	Muddy	240 m west from passure river
4	Akram point	10	Khulna	17	22.019530	89.512910	3	Flat	Hard Clay	40 M east from shibsha river
		11	Khulna	17	22.018730	89.513440	3	Levee	Clayee	140 M east from shibsha river
		12	Khulna	17	22.018050	89.514080	3	Flat	Hard Clay	240 M east from shibsha river
5	Hiron point	13	Khulna	44	21.775350	89.461060	3	Levee	Sandy	350m east from Gogari canal
		14	Khulna	44	21.777170	89.460560	4	Flat	Sandy	40m north from the Bay of Bengal
		15	Khulna	44	21.776270	89.460820	4	Flat	Hard Clay	648m southeast from Shibsa river

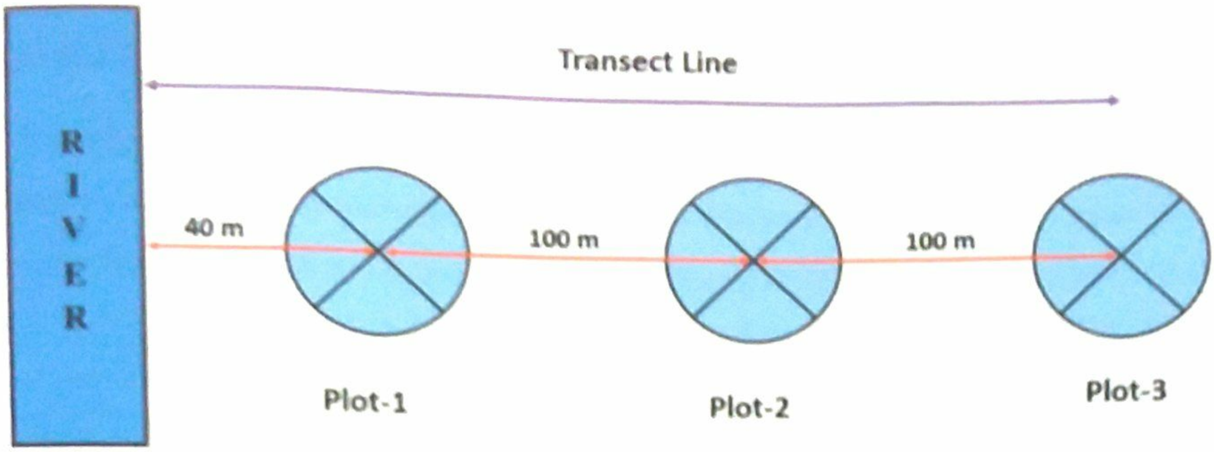


Figure 3.2 Layout of the plots and transect line perpendicular from ecotone (river or canal bank)

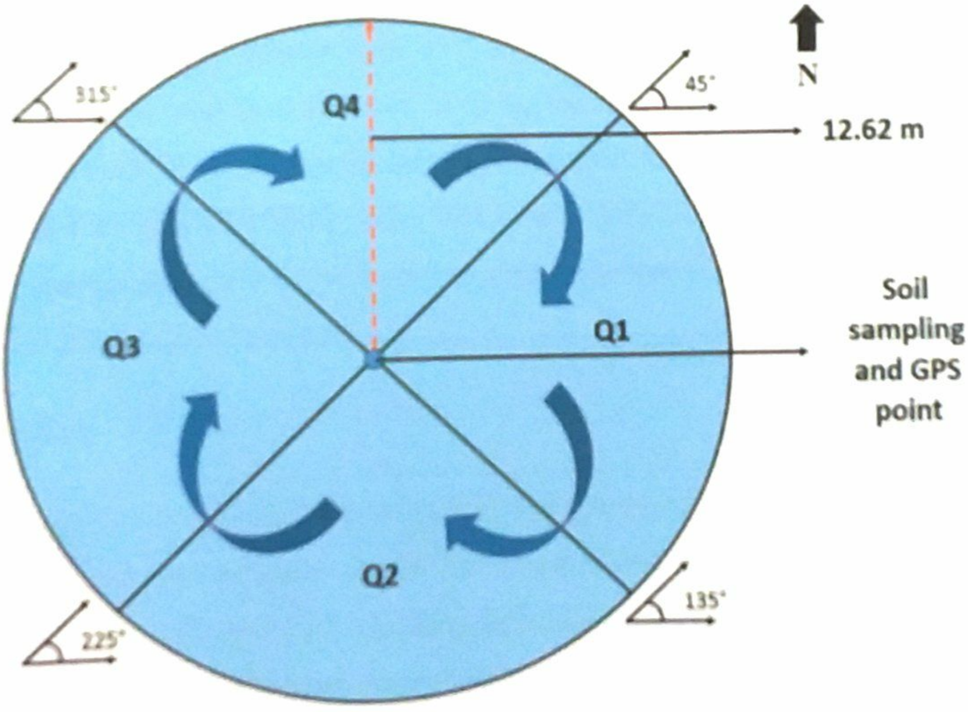


Figure 3.3 Layout of the survey activities in each plot (500.34 m^2)

3.2.2 Field Data Collection

3.2.2.1 Tree Inventory

Trees dominated the aboveground carbon pool and the best indicator of land use change. For this reason, it is essential to measure trees thoroughly and accurately. The basic concept is that measurements of stem diameter are used in allometric equations to compute biomass and carbon stock. A botanical inventory was conducted in the sampling plots of the studied sites. All woody plant species present in the sites of each sampled plot were identified and confirmed from an authentic source(s). Tree inventory was carried out approximately one-year interval since January 2014 to December 2016 (three years). Each and every single tree was tagged with color and numeric code in the 12.62m radius circular plot area. The plot was subdivided by four quadrants facing at 45°, 135°, 225° and 315° from north named Q1, Q2, Q3 and Q4 respectively for collecting vegetation data easily (Fig. 3.3).

3.2.2.2 Measurements

Tree DBH (≥ 5cm and a lean angle greater than 45°) was taken at breast height (above 1.37m from ground) by diameter tape and recorded with their tag number and species name. At every data collection period, besides re-measuring of existing trees, new trees were recruited to the list if they were reached at 5cm or above DBH class. Wood density of every species was collected from secondary data sources such as Global Wood Density Database (Chave et al. 2005, Zanne et al. 2009) and FAO's list of wood densities.

3.2.2.3 Soil Sampling

An open face split auger (1m long) will be used to pull out one-meter long soil core (Kauffman and Donato 2012). Soil core will be taken around the center of the each plot during every data collection. From the 100 cm soil core, a 5 cm long subsample will be taken from the middle point of 0-15, 15-30, 30-50 and 50-100 cm intervals (Kauffman and Donato 2012). Two open sides of cores immediately covered with a rubber cover to resist the moisture going out from the soil samples. Finally, these samples were taken to Nutrient dynamics Laboratory, Khulna University, Khulna to measure bulk density and organic carbon content.

3.2.3 Data Analysis

3.2.3.1 Allometric Computations for Aboveground Biomass

3.2.3.1.1 Live Trees

Aboveground biomass of live trees was estimated by the following general equation for mangrove tree species (Chave et al. 2005).

$$\mathbf{AGB(Kg) = \rho \times exp(-1.349 + 1.980\ lnDBH + 0.207 \times (lnDBH)^2 - 0.0281 \times (lnDBH)^3)}$$

Where, ABG = Aboveground biomass (kg); ρ = Wood density (gcm^{-3});

DBH = Diameter at breast height.

3.2.3.1.2 Standing Dead Trees

The biomass of standing dead trees (which were live at previous data collection period) were determined in two different ways, corresponding to different decay status categories (Kauffman and Donato 2012). The biomass of recently dead trees considering decay Status: 1, those with fine branches still attached, was estimated using live tree equations (Kauffman and Donato 2012). The only difference is that leaves should be subtracted from the biomass estimate. This was accomplished deducting a leaf biomass percentage of 2.5% from AGB of each tree (Kauffman and Donato 2012).

The biomass of Decay Status: 2 (lost some branches in addition to leaves), dead trees was calculated in a similar manner, also subtracting a portion of the biomass; however, because they have also lost some branches in addition to leaves, both leaf biomass and an estimate of branch loss must be factored in (Kauffman and Donato 2012). Commonly, a total 15% of biomass (accounting for both leaves and some branches) was subtracted from AGB in the same manner of recently dead trees (Kauffman and Donato 2012).

3.2.3.2 Allometric Computations for Belowground Biomass

Belowground biomass of trees was computed by using the general mangrove equation of Komiyama et al. (2005),

$$\mathbf{BGB(Kg) = 0.199 \times \rho^{0.899} \times DBH^{2.22}}$$

Where, BGB = Belowground biomass (kg); ρ = Wood density (gcm^{-3});

DBH = Diameter at breast height (cm)

3.2.3.3 Conversion of Biomass to Carbon

Estimated biomass from the allometric relationship was multiplied by the wood carbon content (50%). As almost a carbon measurement projects in the tropical forest assume all tissues (i.e. wood, leaves and roots) consist of 50% carbon on a dry mass basis (Chave et al. 2005, Kauffman and Donato 2012).

Carbon (Mg) = Biomass estimated by allometric equation × Wood carbon content %

= Biomass estimated by allometric equation × 0.5 (Kauffman and Donato 2012)

3.2.3.4 Conversion of Carbon to Molecular CO_2

Following IPCC (2003) protocol for tracking changes in carbon stock, the amount of carbon stock was converted to molecular CO_2 by multiplying 3.67 (the value reflects the ratio of molecular weights between carbon dioxide and carbon) (Pearson et al. 2007, Pendleton et al. 2012).

3.2.3.5 Soil Carbon Calculation

Soil carbon storage was calculated as the product of soil carbon concentration (% of dry mass determined by wet carbon oxidation techniques), soil bulk density and soil depth range.

Soil C (Mg/ha) = Depth interval (cm) × Bulk Density (gcm^{-3}) × OC% (Kauffman and Donato 2012)

3.2.3.5.1 Bulk Density

Bulk density was measured according to Maynard and Curran (2007). Collected samples were oven-dried at 105°C until constant weight by using an air flow oven (Wisd, WOF-W305, Korea). The oven-dried samples were weighted and the corresponding volume of the core was measured and bulk density (BD) of the soil sample was calculated with the following equation:

$$\text{Bulk Density (BD)} = Wt105°C/Vcore$$

$$Vcore = \pi \times Dcore^2/4 \times Lcore$$

Where Wt105°C is the weight of oven dried soil, Vcore is the volume of the core, Dcore is the inner diameter of the core and Lcore is the length of the core.

3.2.3.5.2 Soil Organic Content

Loss on ignition (LOI) method was followed to measure organic carbon in the soil sample (Allen 1974). One gram of soil was taken in a pre-weighted porcelain cup and oven-dried at 105°C for 24 hours. The oven-dried sample was then placed in a digital Muffle furnace (WiseTherm F, Wisd, Korea) at 450°C for four hours. After ignition, the sample was then placed in desiccators to allow it to room temperature and weight it again to calculate the loss on ignition (LOI %) using the following formula

$$LOI\% = (Wt105°C - Wt450°C)/Wt105°C$$

Where Wt105°C is the weight of soil at 105°C and Wt450°C is the weight of soil at 450°C.

The LOI% is usually accounted as organic matter percentage. A total of 50% of LOI% or ash-free mass was considered as the C content in the sample (ASTM 2013).

3.2.3.6 Carbon Stock

Vegetation Carbon Stock (VTC) = AGB carbon + BGB Carbon

Total Carbon Stock (TSC) = Vegetation Carbon Stock + Soil Carbon

3.2.3.7 Important Value Index (IVI) Calculation for Vegetation Types Assessment

For describing floristic composition species of study area the basal area, relative density, relative dominance, relative frequency and important value index (IVI) were calculated. Following the formulas of Moore and Chapman (1986), quantitative structure parameters of investigated trees were calculated:

a. **Relative density (%)** $= \frac{\text{Total no.individuals of one species in 3 plots of each site}}{\text{All no individual of all species in each site}} \times 100$

b. **Relative Frequency (%)** $= \frac{\text{Frequency of one species in 3 plots in each site}}{\text{Sum of frequency of all species in 3 plots in each site}} \times 100$

c. **Relative basal area (%)** $= \frac{\text{Basal area of each specie in 3 plots in each site}}{\text{Total basal area of all species in 3 plots in each site}} \times 100$

d. **Important value index (%) = (Relative density + Relative frequency + Relative dominance)/3**

3.2.3.8 Statistical Analysis

The normality of distribution of carbon stock and rates (aboveground, belowground, vegetation and soil) for the entire data sets were tested Kolmogorov–Smirnov test (K–S test). When and if distributions were approximately normally distributed, One-Way ANOVA was performed to explore the significant difference between vegetation types and aboveground, belowground, vegetation and soil carbon stock and rates..Test of Homogeneity of Variances (Homogeneous subsets) was done with Tukey B[a] test. Descriptive analysis was done to explore minimum, maximum and mean value of different parameters. Analysis was performed using SPSS-23 and Microsoft Excel 2013.

CHAPTER 4

4 Results and Discussions

4.1 Results

4.1.1 Vegetation types

A total of 13 species (Table 4.1) were found in 5 study sites from 15 plots of total 0.75 ha area. Among them, there were 5 species (Table 4.2) namely *Avicennia officinalis*, *Bruguiera sexangula*, *Excoecaria agallocha*, *Heritiera fomes* and *Xylocarpus mekongensis* were most important according to Important Value Index (IVI %). Vegetation types were prepared considering IVI% value. Species which have more than 50 and 25 of IVI value were considered as principal and associated contributor to vegetation types respectively (Chaffey et al. 1985, Iftekhar and Saenger 2008, Rahman et al. 2015b).

Table 4.1 List of floral species found in total study area at the Sundarbans Reserved Forest

Serial No.	Local Name	Initial	Scientific name	Family
1	Amoor	AMCU	*Amoora cucullata*	Meliaceae
2	Baen	AVOF	*Avicennia officinalis*	Avicenniaceae
3	Kankra	BRSE	*Bruguiera sexangula*	Rhizophoraceae
4	Goran	CEDE	*Ceriops decandra*	Rhizophoraceae
5	Lakur,Honai	DOLI	*Dolichandrone spathacea*	Bignoniaceae
6	Gewa	EXAG	*Excoecaria agallocha*	Euphorbiaceae
7	Sundri	HEFO	*Heritiera fomes*	Malvaceae
8	Bhola, Bola	HITI	*Hibiscus tiliaceus*	Malvaceae
9	Bhaila	INBI	*Intsia bijuga*	Leguminosae
10	Narikili,Bhutbutta	PERO	*Petunga roxberghii*	Rubiaceae
11	Hurmui, Batley	SAIN	*Sapium indicum*	Euphorbiaceae
12	Keora	SOAP	*Sonneratia apetala*	Lythraceae
13	Passur	XYME	*Xylocarpus mekongensis*	Meliaceae

In addition, among five sites, two sites shows less than 50% of IVI value and vegetation types were considered by all species. Species in a site were not taken into account which did not have 10 (out of 100) of IVI value. There were five different vegetation types have found in this study (Table 4.2). They were *Heritiera fomes*, *Bruguiera sexangula–Heritiera fomes–Avicennia officinalis–Excoecaria agallocha–Xylocarpus mekongensis*, *Heritiera fomes–Excoecaria agallocha*, *Excoecaria agallocha–Heritiera fomes* and *Excoecaria agallocha* which were coded as VT1, VT2, VT3, VT4 and VT5 respectively. Vegetation type VT1 and VT5 were only single species composition of *Heritiera fomes* and *Excoecaria agallocha* respectively.

Table 4.2 Vegetation Types of study area based on IVI %

Sites	Code	Importance Value Index (%)					Vegetation types
		AVOF	BRSE	EXAG	HEFO	XYME	
1	VT1			17.29	58.93	20.22	HEFO
2	VT2	18.25	27.21	16.31	18.32	10.88	BRSE-HEFO-AVOF-EXAG-XYME
3	VT3			36.15	45.31		HEFO-EXAG
4	VT4			56.52	38.40		EXAG-HEFO
5	VT5			67.27	20.34		EXAG

4.1.2 Aboveground Carbon Stock

The aboveground carbon stock (AGC) data under the vegetation types showed normal distribution as tested with Kolmogorov–Smirnov test (K–S test). There was a significant difference *(P<0.05)* in AGC among three years and the vegetation types tested with one-way ANOVA. Among the vegetation types, VT5 showed significantly higher *(P<0.05)* mean AGC (75.05 Mg ha^{-1}) than all other vegetation types whereas VT3 also showed significantly higher *(P<0.05)* mean AGC (66.58 Mg ha^{-1}) followed by VT1, VT2 and VT4. The lowest mean AGC was found in VT4 (56.34 Mg ha^{-1}). There was no significant difference *(P>0.05)* in mean AGC within VT1, VT2 and VT4 tested with Tukey B[a] test.

Table 4.3 ANOVA table for AGC (Mgha^{-1})

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Between Groups	982.024	4	245.506	20.948	.000
Within Groups	175.797	15	11.720		
Total	1157.821	19			

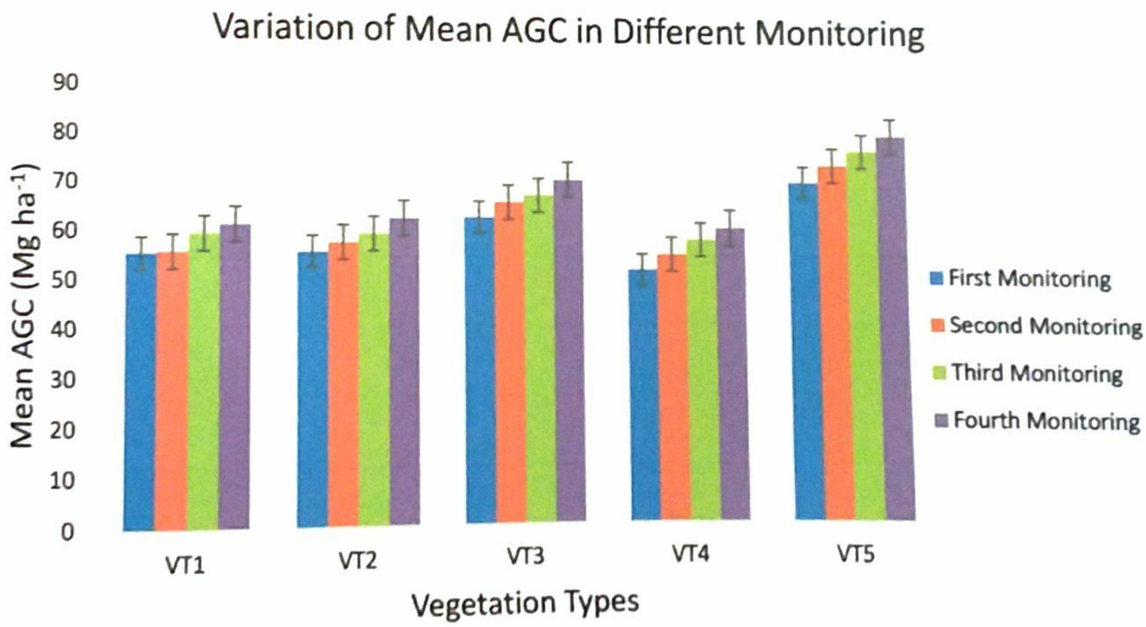


Figure 4.1 Variation of mean AGC in different monitoring

4.1.3 Belowground Carbon Stock

The belowground carbon stock (BGC) data under the vegetation types showed normal distribution as tested with Kolmogorov–Smirnov test (K–S test). There was a significant difference *(P<0.05)* in BGC among three years and the vegetation types tested with one-way ANOVA. As like mean AGC, among the vegetation types, VT5 showed significantly higher *(P<0.05)* mean BGC (42.80 Mg ha^{-1}) than all other vegetation types whereas VT3 also showed significantly higher *(P<0.05)* mean AGC (37.11 Mg ha^{-1}) than VT2. The lowest mean BGC was found in VT2 (31.77 Mg ha^{-1}). There was no significant difference *(P>0.05)* in mean AGC within VT1 and VT4 tested with Tukey B^a test.

Table 4.4 ANOVA table for BGC (Mgha^{-1})

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Between Groups	299.388	4	74.847	18.445	.000
Within Groups	60.869	15	4.058		
Total	360.257	19			

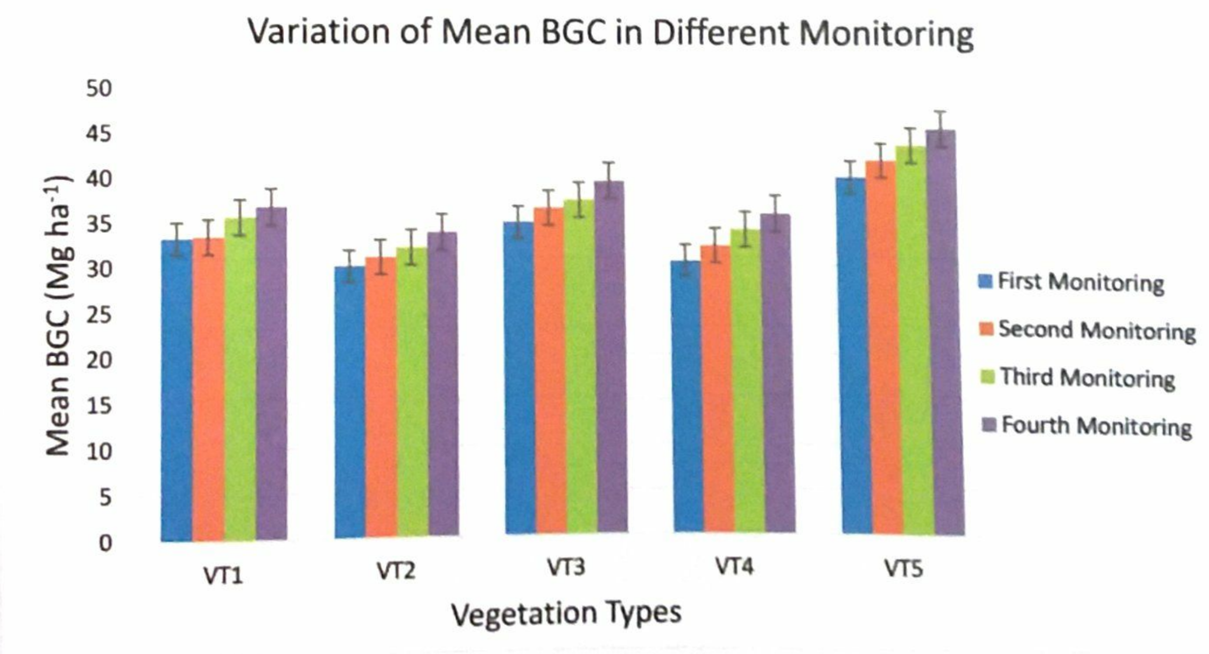


Figure 4.2 Variation of mean BGC in different monitoring

4.1.4 Vegetation Carbon Stock

The vegetation carbon stock (VTC) comprises with aboveground carbon stock (AGC) and belowground carbon stock (BGC), data under the vegetation types showed normal distribution as tested with Kolmogorov–Smirnov test (K–S test). There was significant difference *($P<0.05$)* in VTC among three years and the vegetation types tested with one-way ANOVA. Among the vegetation types, VT5 showed significantly higher *($P<0.05$)* mean VTC (117.85 Mg ha^{-1}) than all other vegetation types whereas VT3 also showed significantly higher *($P<0.05$)* mean VTC (103.68 Mg ha^{-1}) followed by VT1, VT2 and VT4. The lowest mean VTC was found in VT4 (89.51 Mg ha^{-1}). There was no significant difference *($P>0.05$)* in mean VTC within VT1, VT2 and VT4 tested with Tukey B[a] test.

Table 4.5 ANOVA table for VTC (Mgha^{-1})

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Between Groups	2311.968	4	577.992	19.561	.000
Within Groups	443.226	15	29.548		
Total	2755.194	19			

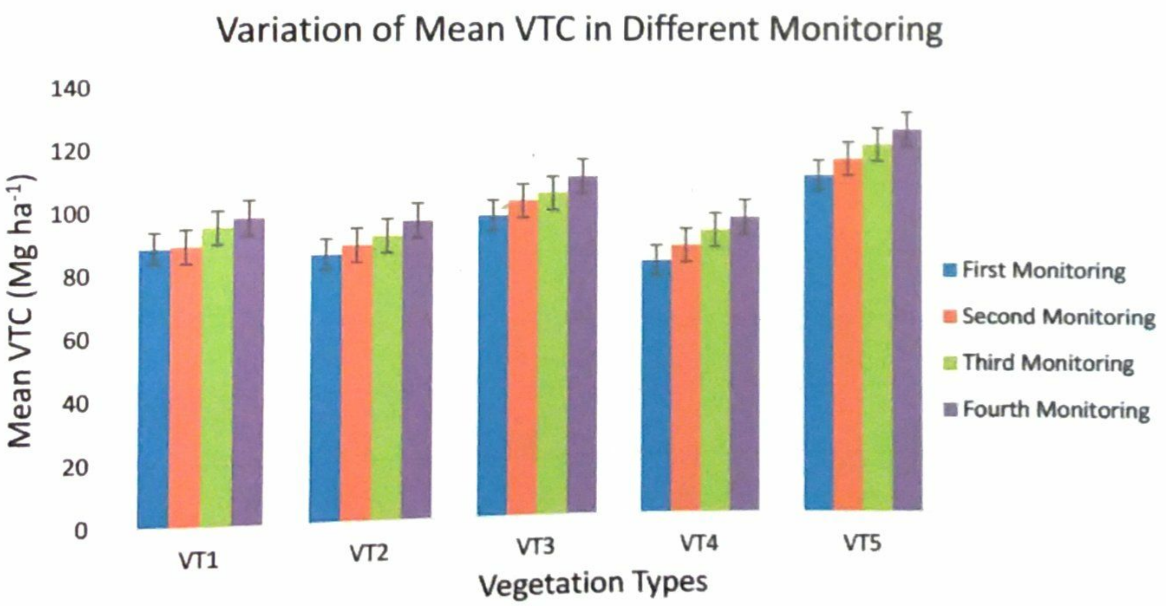


Figure 4.3 Variation of mean VTC in different monitoring

4.1.5 Soil Carbon Stock

The soil carbon stock (SOC) data under the vegetation types showed normal distribution as tested with Kolmogorov–Smirnov test (K–S test). There was significant difference *(P<0.05)* in SOC among three years and the vegetation types tested with one-way ANOVA. Among the vegetation types, VT2, VT3 and VT4 showed significantly higher *(P<0.05)* mean SOC than VT5. Among VT2, VT3 and VT4, mean SOC was higher in VT2 (454.09 Mg ha^{-1}). The lowest mean SOC was found in VT5 (332.92 Mg ha^{-1}). There were no significant difference *(P>0.05)* in mean SOC within VT1, VT2, VT3 and VT4 whereas there were also no significant difference *(P>0.05)* in mean SOC between VT1 and VT5 tested with Tukey B[a] test.

Table 4.6 ANOVA table for SOC (Mgha^{-1})

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Between Groups	32555.796	4	8138.949	6.698	.003
Within Groups	18227.742	15	1215.183		
Total	50783.538	19			

Graph shows, soil carbon was highly variable and no regular change over time. It was fluctuating dramatically.

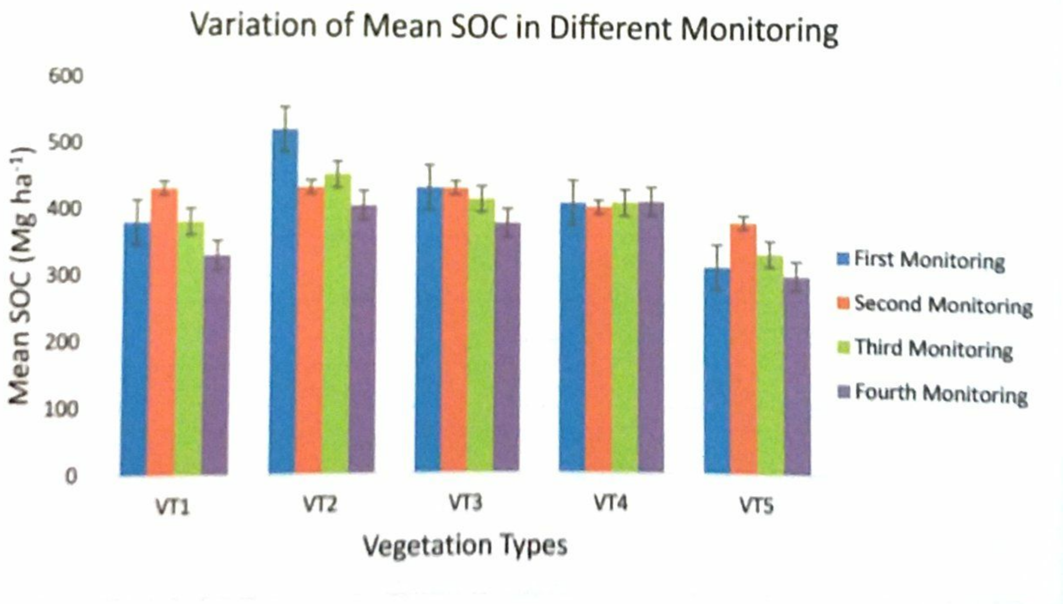


Figure 4.4 Variation of mean SOC in different monitoring

4.1.6 Total Site Carbon Stock

The total site carbon stock (TSC) comprises with aboveground carbon stock (AGC), belowground carbon stock (BGC) and Soil carbon stock (SOC) data under the vegetation types showed normal distribution as tested with Kolmogorov–Smirnov test (K–S test). There was significant difference *($P<0.05$)* in TSC among three years and the vegetation types tested with one-way ANOVA. Among the vegetation types, VT2 showed significantly higher *($P<0.05$)* mean TSC (544.62 Mg ha^{-1}) than VT1 and VT5 whereas VT3 also showed significantly higher *($P<0.05$)* mean VTC (519.81 Mg ha^{-1}) followed by VT1, VT4 and VT5. The lowest mean TSC was found in VT5 (450.78 Mg ha^{-1}). There was no significant difference *($P>0.05$)* in mean TSC within VT1, VT4 and VT5. There was also no significant difference *($P>0.05$)* in mean TSC within VT1, VT3 and VT4. The Same trend was found in mean TSC within VT2, VT3 and VT4 tested with Tukey B^a test.

Table 4.7 ANOVA table for TSC (Mgha^{-1})

Source of Variation	*Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*
Between Groups	21829.196	4	5457.299	5.254	.008
Within Groups	15580.164	15	1038.678		
Total	37409.360	19			

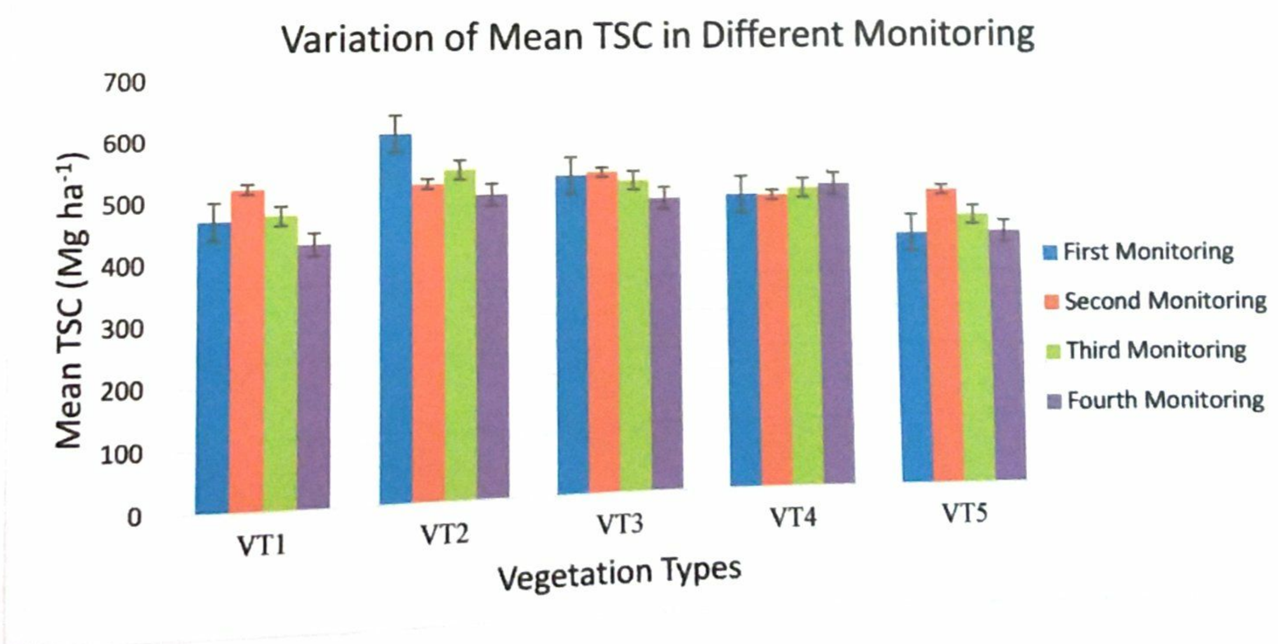


Figure 4.5 Variation of mean TSC in different monitoring

4.1.7 Annual Carbon Sequestration Rate

Annual carbon Sequestration rate was assessed by considering yearly carbon stock increment. Descriptive statistical analysis showed maximum yearly aboveground carbon Sequestration rate (3.74 Mg ha^{-1} $year^{-1}$) was found on the second year whereas minimum rate (0.34 Mg ha^{-1} $year^{-1}$) was found on the first year at VT1 among all vegetation types and monitoring year. Among all vegetation types, the mean yearly aboveground carbon Sequestration rate were 2.40 ± 0.59 Mg ha^{-1} $year^{-1}$, 2.62 ± 0.42 Mg ha^{-1} $year^{-1}$ and 2.76 ± 0.28 Mg ha^{-1} $year^{-1}$ at first, second and third year respectively.

On the other hand, yearly maximum belowground carbon Sequestration rate (2.17 Mg ha^{-1} $year^{-1}$) was found on the second year at VT1 whereas minimum rate (0.18 Mg ha^{-1} $year^{-1}$) was found on the first year at VT1 among all vegetation types and monitoring year. Among all vegetation types, the mean yearly belowground carbon Sequestration rate were 1.28 ± 0.31 Mg ha^{-1} $year^{-1}$, 1.54 ± 0.24 Mg ha^{-1} $year^{-1}$ and 1.74 ± 0.17 Mg ha^{-1} $year^{-1}$ at first, second and third year respectively.

In the case of yearly vegetation carbon Sequestration rate, VT1 showed maximum (5.92 Mg ha^{-1} $year^{-1}$) and minimum (0.52 Mg ha^{-1} $year^{-1}$) at second year and first year respectively among all vegetation types and monitoring year. Among all vegetation types, the mean yearly vegetation carbon Sequestration rate were 3.68 ± 0.91 Mg ha^{-1} $year^{-1}$, 4.17 ± 0.66 Mg ha^{-1} $year^{-1}$ and 4.5 ± 0.43 Mg ha^{-1} $year^{-1}$ at first, second and third year respectively.

Finally, yearly average aboveground, belowground and vegetation carbon sequestration rate were found 2.59 ± 0.24 Mg ha^{-1} $year^{-1}$, 1.52 ± 0.14 Mg ha^{-1} $year^{-1}$ and 4.11 ± 0.38 Mg ha^{-1} $year^{-1}$ respectively

Table 4.8 Variation of carbon sequestration rate (Mg ha^{-1} $year^{-1}$) in three years in five vegetation (VT) types in the Sundarbans Reserve Forest

VT Types	First Year			Second Year			Third Year		
	AGC	BGC	VTC	AGC	BGC	VTC	AGC	BGC	VTC
VT1	0.34±0.016	0.18±0.011	0.52±0.015	3.74±0.008	2.17±0.005	5.92±0.011	1.80±0.024	1.14±0.017	2.94±0.026
VT2	1.82±0.023	1.00±0.027	2.82±0.022	1.81±0.011	1.10±0.01	2.91±0.006	3.13±0.034	1.69±0.036	4.83±0.028
VT3	3.10±0.019	1.63±0.043	4.73±0.025	1.48±0.005	0.88±0.023	2.36±0.002	3.23±0.024	2.17±0.065	5.40±0.027
VT4	3.21±0.057	1.71±0.047	4.92±0.006	3.06±0.026	1.84±0.029	4.91±0.005	2.47±0.084	1.78±0.075	4.25±0.001
VT5	3.52±0.007	1.90±0.001	5.42±0.007	3.01±0.001	1.74±0.003	4.75±0.004	3.16±0.008	1.90±0.005	5.07±0.011

Table 4.9 Average annual carbon sequestration rate (Mg ha^{-1} $year^{-1}$) in five vegetation (VT) types in the Sundarbans Reserve Forest

VT Types	AGC	BGC	VTC
VT1	1.96±0.016	1.16±0.011	3.12±0.017
VT2	2.25±0.022	1.26±0.024	3.52±0.018
VT3	2.60±0.016	1.56±0.044	4.16±0.018
VT4	2.91±0.056	1.78±0.05	4.69±0.0004
VT5	3.23±0.005	1.85±0.003	5.08±0.007

4.1.8 Annual Carbon dioxide (CO_2) Sequestration Rate and Valuation

The rate of vegetation carbon sequestration during the three years period (2014 to 2016) showed increasing trend from all vegetation study area (Fig. 4.2). In the whole study area, the mean rate of vegetation carbon sequestration was 4.11±0.38 Mg ha^{-1} $year^{-1}$ which was equivalent to 15.08±1.39 Mg ha^{-1} $year^{-1}$ of CO_2 sequestration (1 Mg C equivalent to 3.67 Mg CO_2) (Pearson et al. 2007, Pendleton et al. 2012) (Table 4.5). In the total study area, this amount of sequestration valued to 226.2±20.85 USD ha^{-1} $year^{-1}$ (@15 USD 15 per Mg CO_2) (Tvinnereim and Røine 2010). By multiplying total forest cover area (4210 km^2) of the Sunderbans with this annual vegetation carbon sequestration rate (4.11±0.38 Mg ha^{-1} $year^{-1}$), the total annual vegetation carbon sequestration per year was 1.73±0.16 million Mg which was equivalent to 6.35±0.59 million Mg CO_2 per year. This huge amount of sequestration valued to 95.25±8.85 million USD per year.

Table 4.10 CO_2 sequestration and valuation with respect to carbon pools

Carbon Pool	Area (ha)	C sequestration	CO_2 sequestration	Valuation
Vegetation carbon (study area)	0.75	4.11±0.38 Mg ha^{-1} $year^{-1}$	15.08±1.39 Mg ha^{-1} $year^{-1}$	226.2±20.85 \$ ha^{-1} $year^{-1}$
Total Sundarbans vegetation carbon (forest Cover only)	421000	1.73±0.16 million Mg $year^{-1}$	6.35±0.59 million Mg $year^{-1}$	95.25±8.85 million \$ $year^{-1}$

4.2 Discussion

4.2.1 Vegetation Types

There were 5 different vegetation types found in study sites whereas, in the respect of total Sunderbans Reserved Forest, 10 vegetation types in Rahman et al. (2015b) and 13 in Chaffey et al. (1985) were reported. In this study, among all vegetation types, the dominance of *Heritiera fomes* was decreased towards the Bay of Bengal. On the other hand, the dominance of *Excoecaria agallocha* was increased towards the same direction. Both Species were common in every vegetation types of the study sites.

4.2.2 Carbon Sequestration Rate in Relation to Vegetation Types

Excoecaria agallocha (VT5) dominated site showed average yearly higher vegetation carbon sequestration rate (5.08±0.007 Mg ha^{-1} $year^{-1}$) among all vegetation types whereas *Heritiera fomes* (VT1) dominated vegetation types showed lower (3.12±0.017 Mg ha^{-1} $year^{-1}$) followed by *Bruguiera sexangula–Heritiera fomes–Avicennia officinalis–Excoecaria agallocha–Xylocarpus mekongensis* (VT2), *Heritiera fomes–Excoecaria agallocha* (VT3) and *Excoecaria agallocha–Heritiera fomes* (VT4) vegetation types. Carbon sequestration rate also increased association with *Excoecaria agallocha* species in vegetation. *Heritiera fomes* (VT1) dominated vegetation types showed dramatic increment (0.52±0.015 to 5.92±0.011 Mg ha^{-1} $year^{-1}$) in vegetation carbon sequestration rate from second monitoring to third (second year). It might happen because of huge recruitment of tree (a tree which reached DBH 5cm from lesser). All other vegetation carbon sequestration rates were normal with respect to time and vegetation types.

In a comparison of carbon sequestration rate on local and global perspective, it should go into details about the carbon inventory methods and computation procedure. The richness of mangrove tree species in Sundarbans restricts the use of species wise allometric equations for biomass estimation (Rahman et al. 2015b). In this study, universal allometric equations (Chave et al. 2005, Komiyama et al. 2005) were used for estimating the above and below ground biomass of tree species using the variables tree DBH and wood density, in order to avoid destructive sampling of trees (Rahman et al. 2015b). However, due to the difference in analyzing method and sampling depth variance in different studies like 0->300 cm depth (Donato et al. 2011) or 0–100 cm (Rahman et al. 2015b), a large difference in soil carbon stocks were observed in different studies (Rahman et al. 2017). These inconstancies in carbon measurement restrict to compare our result from a global perspective.

On the other hand, Rahman et al. (2017) estimated total carbon sequestration rate (3.93 Mg ha^{-1} $year^{-1}$) including aboveground, belowground, soil, woody debris, seedling and sapling carbon at three wildlife sanctuaries in the Sundarbans Reserved Forest. This study conducted considering only aboveground and belowground carbon and found carbon sequestration rate 4.11±0.38 Mg ha^{-1} $year^{-1}$. Findings of this study show higher annual carbon sequestration rate than three wildlife sanctuaries reported at Rahman et al. (2017).

4.2.3 Carbon Valuation and Prospect of Climate Change

Fighting with global climate change in the post-Kyoto Protocol period, scientific community and policy makers have come to consensus to adopt a new strategy reducing emissions from deforestation and forest degradation and enhancing forest carbon stocks in developing countries (REDD+) (Gardner et al. 2012, Rahman et al. 2015a, Rahman et al. 2017). Like other terrestrial forests, mangrove forests can be a potential site for Carbon Trading program implementation since it can sequestrate atmospheric CO_2 with a higher rate (Donato et al. 2011, Rahman et al. 2017). However, globally the mangrove forest has drastically reduced over the last 50 years, which not only intensify the social and economic damage but also influence climate change and loss of biodiversity (Alongi 2002).

These scenarios have changed by creating mangrove protected areas as it would sequestrate atmospheric carbon which ultimately is converted into official carbon credits (Grimsditch 2011, Rahman et al. 2017). These credits can be sold under the UNFCCC Carbon Trading programs. While the mangroves are decreasing globally, the Sundarbans Reserved Forest, however, has slightly increased (52 km^2) from 1989 to 2014 (Kanak and Rahman 2015). Thus the Sundarbans Reserved Forest have greatly contributed to reducing atmospheric CO_2 through photosynthesis which stored in the form of plant biomass and soil organic carbon (Rahman et al. 2017). In this present study, the CO_2 (vegetation biomass carbon) sequestration of forest cover area of the Sunderbans was 6.35±0.59 million Mg $year^{-1}$ (study period Jan 2014 to Dec 2016) which valued 95.25±8.85 million USD $year^{-1}$. With this huge CO_2 sequestration and other co-benefits, such as biodiversity conservation, the Sundarbans Mangrove Forest greatly contributes to the purpose of REDD+ to reduce the impact of the greenhouse effect, thereby mitigating global climate change.

4.3 Limitations of the Study

The dataset used in this study was solely from the permanent sample plot of Center for Environmental and Geographic Information Services (CEGIS). They have only five permanent sampling station along the Passur River. Those stations do not cover all salinity zones in Sundarbans. It would be better if we cover all salinity zones for the present study. But the vegetation types I have found from IVI% value, there was sufficient variation in vegetation types. The variation may increase if all salinity zones were covered.

CHAPTER 5

5 Conclusion

The present study estimated the carbon sequestration rate in Sundarbans over a 3-year period. The amount of carbon stored varied significantly among vegetation types. *Excoecaria agallocha* dominated vegetation type showed the highest annual carbon sequestration rate (5.08±0.007 Mg ha^{-1} $year^{-1}$) and *Heritiera fomes* dominated vegetation type showed the lowest (3.12±0.017 Mg ha^{-1} $year^{-1}$) rate. The yearly average vegetation carbon sequestration rate was 4.11±0.38 Mg ha^{-1} $year^{-1}$ considering all vegetation types. The total amount of carbon sequestration considering whole Sundarbans can be valued to 95.25±8.85 million USD per year. The findings of this study can be useful in updating carbon valuation of Sundarbans regarding UNFCCC REDD+ project by negotiating with parties who are interested in buying carbon offset.

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APPENDIX

Homogeneous Subsets from Tukey B[a] Test

AGC (Mg/ha)

Vegetation Types	N	Subset for alpha = 0.05		
		1	2	3
VT4	4	56.3383		
VT1	4	57.9881		
VT2	4	58.7616		
VT3	4		66.5792	
VT5	4			75.0520

BGC (Mg/ha)

Vegetation Types	N	Subset for alpha = 0.05		
		1	2	3
VT2	4	31.7685		
VT4	4	33.1764	33.1764	
VT1	4	34.7694	34.7694	
VT3	4		37.1054	
VT5	4			42.8015

VTC (Mg/ha)

Vegetation Types	N	Subset for alpha = 0.05		
		1	2	3
VT4	4	89.5146		
VT2	4	90.5301		
VT1	4	92.7575		
VT3	4		103.6846	
VT5	4			117.8535

SOC (Mg/ha)

Vegetation Types	N	Subset for alpha = 0.05	
		1	2
VT5	4	332.9225	
VT1	4	381.2825	381.2825
VT4	4		410.4100
VT3	4		416.1300
VT2	4		454.0925

TSC (Mg/ha)

Vegetation Types	N	Subset for alpha = 0.05		
		1	2	3
VT5	4	450.7760		
VT1	4	474.0400	474.0400	
VT4	4	499.9246	499.9246	499.9246
VT3	4		519.8146	519.8146
VT2	4			544.6226