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**Programme:** Bachelor of Science in Forestry

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# Carbon Stocks in the Coastal Mangrove Plantations in Bangladesh: A Case Study in Kuakata National Park

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**Dedicated To…**

**My Beloved Parents**

# ABSTRACT

Bangladesh is a pioneer country in raising successful plantations with *Sonneratia apetala* along the coastal belts. In this study, the biomass and carbon stock per hectare in Khajura beat, Kuakata National Park was investigated. Tree diameter and height of some sample plots were measured from the area, which were converted to biomass and carbon contents using some common allometric equations. The average aboveground carbon was 147.59 Mg $ha^{-1}$ ranging from 80.12 - 215.23 Mg $ha^{-1}$. The average belowground carbon was 68.7375 Mg $ha^{-1}$ ranging from 35.69- 100.73 Mg $ha^{-1}$. The average biomass carbon (includes above and below-ground) was 216.33 Mg $ha^{-1}$. The most suitable allometric model for estimating stand level carbon stocks of *S. apetala* was liner model using Basal area and Mean height as independent variable. The results suggest that *S. apetala* is a suitable species for coastal plantation in terms of carbon stocks.

# ACKNOWLEDGEMENT

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Md. Alvee Shahriar 23.09.18

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**Md. Alvee Shahriar**

# APPROVAL

This is to certify that, Md. Alvee Shahriar, Student ID: 130541 has prepared this thesis entitled "**Carbon Stocks in the Coastal Mangrove Plantations in Bangladesh: A Case Study in Kuakata National Park**" under my direct supervision and guidance. Project thesis submitted to the Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh in partial fulfilment of the requirements for the four years professional B.Sc. (Honours) degree in Forestry. I have approved the style and format of the project thesis.

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# DECLARATION

I, **Md. Alvee Shahriar**, hereby declare that this project thesis is based on my original work except quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Khulna University or other institutions.

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# CHAPTER ONE: INTRODUCTION

## 1.1 Background of the Study:

Mangroves play some important functions in the forest ecosystem which are associated with nearby marine environment and helps to atmospheric carbon sequestration (Eong 1993, Alongi et al. 2001, Khan et al. 2007, Bouillon et al. 2008, Kristensen et al. 2008, Alongi 2011, Donato et al. 2011) and improve socio economic conditions of the neighboring local community (Rönnbäck 1999, Primavera 2005, Kairo et al. 2009). There are many reasons for loss of mangrove forest in the global environment (Valiela et al. 2001, Duke et al. 2007). The possible reasons are habitat destruction through human encroachment, diversion of fresh water for irrigation and land reclamation and conversion for agriculture, aquaculture and urbanization (Primavera 2000, Saenger 2002, Primavera 2005, Kristensen et al. 2008). So it is imperative to find out the possible ways to control the loss of mangroves Therefore, mangrove management has been become an important issues in management of resource and economy in the coastal areas of Bangladesh.

Mangroves provide important goods and services to coastal population such as sequestrating carbon, filtering capacity of pollutants trap and stabilization of sediments (Fromard et al. 1998), indicator of sea level rise (Adame et al. 2013), storm protection (Doyle 1997), support of a diversity of animal species both within the forest and in offshore areas, direct benefits to local communities and indirect benefits to the economy of the region through the contribution to fisheries production and the development of the ecotourism industry (Primavera 2000, Primavera 2005).Mangroves are keystone coastal ecosystems providing numerous environmental services viz. reduce global warming and critical ecological functions, affecting both upland and oceanic resources (Donato et al. 2011). Mangrove forests have been traditionally used as a wide variety of products and services. In the world, many countries are managed the mangrove forest for various purposes such as poles, firewood, construction, timber, charcoal extraction and pulp. Non-timber forest products are recognized as important economic resources, particularly to rural, marginalized communities.

Bangladesh is a tropical maritime nation on the northern border of the Bay of Bengal. The coastal region lies between latitude 21° to 23°N and longitude 89° to 93°E. The coastline is approximately 710 Km long and the coastal zone covers an area of about 2.85 million hectares, which is 23% of the country's total area (Karim 2005). The coastal region includes offshore islands, mudflats, chars and new accretions. However due to the geomorphology of the area, the coastal zone is particularly susceptible to tropical storms and tidal surges which occur frequently in the Bay of Bengal. These natural calamities ravage the area almost regularly and are considered the greatest hindrance to the development of the region and the country as a whole. For this reason, mangroves as coastal shelterbelts are considered most important for the country. The coastal zone has extensive areas of both natural and planted mangrove forest. Natural forest includes the Sundarbans, the Chakaria Sundarbans and fringe mangroves along the eastern coast. The Sundarbans is the world's single largest tract of mangrove forest and in terms of mangrove biodiversity, the richest forest in the world; it is a Ramsar site, part of which has been designated as a World Heritage site. For about a century the Sundarbans has enjoyed the status of Reserved Forest and has been managed for its productive value. After a cyclone devastated the coastal region in the 1960s except for Khulna District, which is protected by the Sundarbans coastal afforestated zone with mangrove species was initiated to protect life and property from cyclones and tidal surges. Later, industrial raw material and fuel wood production, conservation of coastal ecosystem and the environment, protection of wildlife and aquatic resources, protection of agricultural land against salt intrusion, tourism, poverty reduction and enhancing land accretion were added to the objectives of development programmes. In this context, over the last four decades the Forest Department has successfully implemented several massive projects and has established some 148 000 hectares of mangrove plantations scattered over on- and offshore areas mostly along the central part of the coast (Islam. 2006.).

Carbon sequestration is one of the major concerns in this world because there is a huge amount of carbon is releasing day by day from different kinds of industrial and human activities even we continuously produce carbon dioxide by breathe. It is the main element of greenhouse gases that is responsible for global warming that's why carbon measurement and production issues have already became the vital concern to save our planet. To reduce greenhouse gases and balance the amount of carbon in our atmosphere carbon sinking is the best way. Carbon sequestration is intimately related to the existence of living being in our planet and now-a-days, Global warming and biodiversity loss are the two important currently debated issues among the world's scientists and policy makers, caused mainly by fossil fuel burning and deforestation during the last few decades (Van der Werf et al. 2009). The last century finished with an increase in global temperature by 0.74 °C and the atmospheric $CO_2$concentration of 379 ppm (UNFCC 2007, IPCC 2013). Furthermore, atmospheric carbon dioxide would be doubled by 2050 if the current rate of increase continues and will lead to the global temperature rise of up to 2–4 °C (IPCC 2013). Human activities, especially the burning of fossil fuels such as coal, oil, and gas, have caused a substantial increase in the concentration of carbon dioxide ($CO_2$) in the atmosphere. This increase in atmospheric $CO_2$ —from about 280 to more than 380 parts per million (ppm) over the last 250 years—is causing measurable global warming. Potential adverse impacts include sea-level rise; increased frequency and intensity of wildfires, floods, droughts, and tropical storms; changes in the amount, timing, and distribution of rain, snow, and runoff; and disturbance of coastal marine and other ecosystems. A projection by (IPCC 2013) revealed that by the end of 21$^{st}$ century the global sea level will rise by 28–98 cm due to melting of polar ice, which would badly alter low-lying coastal countries (e.g. Bangladesh, Maldives, The Netherlands) existence and livelihoods pattern. Forests retention, coupled with various reforestation and afforestation programmes, tropical in particular, can play an important role in mitigating global climate change through sequestering atmospheric carbon. Tropical forest systems sequester carbon faster, and store more carbon, than comparable temperate and boreal forests. Indeed, tropical forests are responsible for approximately 33% of terrestrial NPP and hold nearly ¼ of above ground terrestrial carbon (Bonan 2008). Species-level tree biomass carbon estimation using diameter at breast height (dbh) with a tree density based allometric model is becoming popular (Rahman et al. 2015). However, for quick calculation of biomass carbon, a basal area based allometric model could be another important option as both basal area and biomass carbon have a strong relation to dbh (Rahman et al. 2015). Studies have made significant contributions in estimating ecosystem level aboveground carbon stocks using basal biomass (Rahman et al. 2015) . The present focus of REDD+ is examining to what extent carbon sequestration through forest restoration and plantation establishment is related to biodiversity conservation, poverty reduction, and carbon sequestration.

## 1.2 Objectives of the Study:

The study is based on the following objectives_

- To measure the biomass of coastal plantation area in Kuakata national park, Patuakhali district.
- To compute the amount of biomass carbon stock per hectare in those plantation area.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Coastal Plantation in Bangladesh

The coastal area of Bangladesh lies within the tropical zone between 21-23°N and 89-93°E (Saenger and Siddiqi 1993). The coastline is approximately 710 km long and the coastal zone covers an area of about 2.85 million hectares, which is 23% of the country's total area. The coastal region includes offshore islands, mudflats, chars and new accretions (Islam 2012).

The coastal areas of Bangladesh have suffered severe cyclone damage almost annually since cyclone recordings began in 1581. During the period from 1960 to 1970, eight severe cyclones were recorded, with the intense cyclone and associated storm surge of November 1970 reported to have caused the deaths of about 300,000 people; current estimates of the April 1991 cyclone yield a similar figure (Saenger and Siddiqi 1993).

The protection from cyclone damage afforded by the Bangladesh Sundarbans mangrove forests, a continuous natural mangrove forest of 5,800 $km^2$ in the southwest of Bangladesh, led the Forest Department in 1966 to commence a programme of planting mangroves outside the protective coastal embankments in order to provide greater protection for inhabited coastal areas. These initial mangrove plantings were highly successful and led to the development of a large-scale mangrove afforestation program. Now the coastal plantations established in the coastal areas are administered by four Coastal Afforestation Divisions namely, from east to west, Chittagong, Noakhali, Barisal and Patuakhali and subdividing into 28 forest Ranges and 198 beats (Drigo 1987). Till 2010, an area of 170,000 ha coastal area has been planted, although there are plantation failures over a considerable area (Aziz 2010). In this context, over the last four decades the Forest Department has successfully implemented several massive projects and has established some 148 000 hectares of mangrove plantations scattered over on and offshore areas mostly along the central part of the coast (Islam 2012).

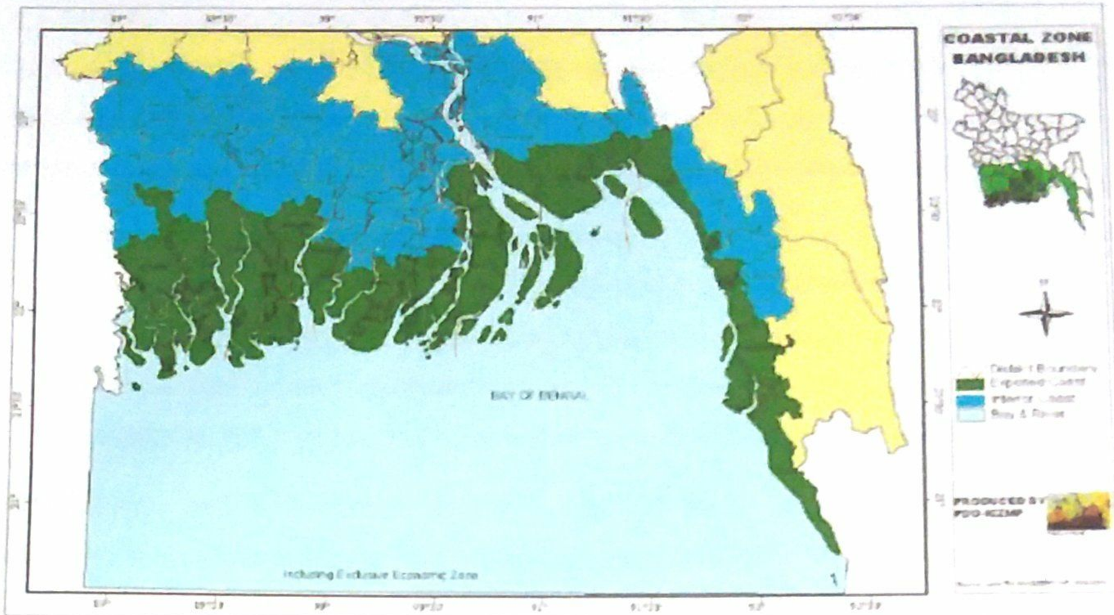


Figure 2.1: Map of Coastal Zones in Bangladesh (Source: Bangladesh Forest Department)

### 2.1.1 Coastal Plantation Projects executed by the Forest Department, Bangladesh

The coastal afforestation program was started in 1965-66 and the Government of Bangladesh has a unique afforestation program on the newly forming lands of the Bay of Bengal. The government has decided that all new accretions in the Bay will be afforested to ensure their stabilizations and to ensure further accretions (Rachid 1977).

The list of coastal plantation projects executed by the forest department was given below:

- Afforestation in the coastal belt and offshore islands (1960–61 to 1964–65).
- Afforestation in the coastal belt and offshore islands (1965–66 to 1969–70).
- Afforestation Project in the coastal regions of Chittagong, Noakhali, Barisal and Patuakhali (1974–75 to 1979–80).
- Mangrove Afforestation Project (1980–81 to 1984–85).
- Second Forestry Project (1985–86 to 1991–92).
- Forest Resources Management Project (1992–93 to 2001–2002).
- Extended Forest Resources Management Project (2002–03 to 2003–04).
- Coastal Green Belt Project (1995–96 to 2001–02).
- Coastal Char Land Afforestation Project (2005–05 to 2009–10).
- Management Support Project for Sundarbans Reserve Forest (2005–06 to 2009 10).

### 2.1.2 Goals and Objectives of Coastal Plantation in Bangladesh

The initial objective of the afforestation program was to create a shelter belt to protect the lives and properties of the coastal communities. The early success of the plantations resulted in the setting of additional objectives for coastal afforestation including to-

- Provide forest products for a range of uses;
- Develop forest shelter-belts to protect life and property inland from tidal surges;
- Inject urgently needed resources into the national economy (i.e. timber and land);
- Create employment opportunities in rural communities;
- Create an environment for wildlife, fishes, and other estuarine and marine fauna.

Conservation and stabilization of newly accreted land, and acceleration of further accretion with the ultimate aim of transferring a large part of this land to agriculture.

## 2.2 Carbon Sequestration

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide (Sedjo and Sohngen 2012). Carbon sequestration involves long-term storage of carbon dioxide or other forms of carbon to mitigate or defer global warming. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels (Hodrien 2008).

The United Nations Framework Convention on climate Change (UNFCCC) defines carbon sequestration as the process of removing carbon from the atmosphere and depositing it in a reservoir. At present, carbon sequestration is valued as a function of credit emission reductions (CERs), based on the difference between the amount of carbon stored in scenario projects and the baseline, current amount of carbon stored in the system (UNFCC 2007).

Through photosynthesis, trees and other plants take up atmospheric carbon dioxide ($CO_2$) and sequester it in their living tissues as biomass. Respiration in forests, both autotrophic (from plants) and heterotrophic (from non-plant organisms), causes the release of $CO_2$ reducing this total sequestration. Carbon (C) moving through a forest ecosystem in a given period of time (termed flux) is by convention considered negative when moving from the atmosphere to biomass (sequestration), and positive when moving from biomass into the atmosphere (release).

Carbon dioxide ($CO_2$) is naturally captured from the atmosphere through biological, chemical, and physical processes Artificial processes have been devised to produce similar effects, (Glossary" 2010) including large-scale, artificial capture and sequestration of industrially produced $CO_2$ using subsurface saline aquifers, reservoirs, ocean water, aging oil fields, or other carbon sinks.

### 2.2.1 Concept of Carbon Trading

It is referred to as emission reduction trading is a relatively simple concept. Carbon trading is an economic tool which allows for several parties to meet total emission reduction requirement as lower costs by working together. Carbon trading allows surplus emission reduction to required limits to be traded to other parties needing to meet emission limits. In theory, if one party can reduce emission at a lower cost than a second party, then first party could maximize emission reductions and sell any surplus reduction to the second party to help to meet its reduction requirements. The aim is to improve the overall flexibility and economic efficiency of obtaining emission reduction (waste concern, UNDP, 2012)

Carbon Trade Exchange (CTX) operates spot exchanges in multiple global environmental commodity markets, including carbon, Renewable Energy Certificates (RECs) and water. Carbon Trade Exchange allows buyers and sellers to trade voluntary credits, carbon as well as those issued by a United Nations program established under the 1997 Kyoto Protocol.

CTX was founded in London by Wayne Sharpe in 2009, after two years of research and development. CTX opened office in Sydney in 2009.

### 2.2.2 Ways of Carbon Sequestration

According to IPCC (2005), $CO_2$ sequestration can be done by the following three ways- One is terrestrial sequestration. it is the natural intake of $CO_2$ by plants, which incorporate it in their wood, leaves, roots and also bind it to the underlying soil and 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 (Brown 2010). This can be enhanced by increasing the growth of land plants through planting tree in any place, mitigating deforestation or for adjusting the forest management practices. In the present time it is the most convenient and effective option for sequestrating carbon.

Geologic sequestration is the second way to sequestrate carbon. It is the process of burring the $CO_2$ deep within earth. It can be done by mechanical capture of $CO_2$ from an emission source(e.g. power plant) and the captured $CO_2$ in injected and sealed into deep rock units (Brown 2010). Deep geological formations such as depleted oil and natural gas fields or deep natural reservoirs filled with saline water (saline aquifers) are the most suitable sites to hide carbon.

Last one is oceanic sequestration. Oceanic sequestration is dumping the co2 into the ocean depths. Pumping $CO_2$ into the deep ocean basins (350-3000m), where it is anticipated it may lakes of liquid, supercritical or solid hydrates. Those are the major type of carbon sequestration.

### 2.3 Concept of Coastal Afforestation and Carbon Sequestration

The delta of Bangladesh is formed by the confluence of the aforesaid mighty rivers and their tributaries. The Ganges unites with the Jamuna (main channel of the Brahmaputra) and later joins the Meghna to eventually empty into the Bay of Bengal.

The alluvial soil deposited by these rivers has created some of the most fertile plains in the world. To stabilize the newly accreted mud flats (locally called 'Chars') at the estuaries of Bay of Bengals, Coastal Forest Divisions of Bangladesh Forest Department have been raising mangrove plantations since 1966. These Mangroves serve as protective barrier against cyclones and tidal surges.

Bangladesh has 710 kilometer long coast line. The coastal zone covers 19 coastal districts (153 Upazilas) & Exclusive Economic Zone (EEZ) in the Bay of Bengal. Out of 19 districts, 12 (51 Upazilas) are exposed coast subject to natural calamities. The landward distance of the delineated coastal zone from the shore is between 30 and 195 km whereas the exposed coast up to 57 km. Land of coastal area is used mainly for agriculture, shrimp and fish farming, forestry, salt production, ship-breaking yards, ports & industries. Land use in the coastal zone is diverse, competitive and often conflicting.

In 1964, the forest department started afforestation in coastal areas. At first, planting was carried out to increase the mangrove shelterbelt. In later years, plantation forestry mainly proceeded on stretches of government land along roads under the social forestry programme a total of 112972 hectares had been planted by 2000.

### 2.3.1 Concept of Plantation

A plantation is a large piece of land usually in a tropical or semi tropical area where one crop is intentionally planted for widespread commercial sale and usually tended by resident laborers. The crop grown include fast growing trees, timber producing trees, cotMg, coffee, tobacco, sugarcane, sisal, oilseeds(e.g. oil palms), rubber trees and various fruits. Protectionist policies and neutral comparative advantage have something's contributed to determining where plantations were located. Among the earliest examples of plantations were the latifundia of the Roman Empire, which produced large quantities of wine and olive oil for export. Plantation agriculture grew rapidly with the increase in international trade and development of a worldwide economy that followed the expansion of European colonial empires. Like every economic, foreign ownership and political influences, and exploitative social system such as indentured labor and slavery (Wikipedia 2007).

## 2.4 Importance of Carbon Sequestration

Carbon dioxide ($CO_2$) capture and sequestration (CCS) could play an important role in reducing greenhouse gas emissions, while enabling low-carbon electricity generation from power plants. It helps to reduce the effect of greenhouse gases and conserves the biodiversity in the earth. An estimated in the U.S. Inventory of Greenhouse Gas Emissions and Sinks, more than 40% of $CO_2$ emissions in the United States are from electric power generation. CCS technologies are currently available and can dramatically reduce (by 80-90%) $CO_2$ emissions from power plants that burn fossil fuels. Applied to a 500 MW coal-fired power plant, which emits roughly 3 million Mgs of $CO_2$ per year, the amount of GHG emissions avoided (with 90% reduction efficiency) would be equivalent to: Planting more than 62 million trees, and waiting at least 10 years for them to grow and Avoiding annual electricity-related emissions from more than 300,000 homes.

## 2.5 Coastal Plantation and Blue Carbon Storage

Coastal strips cover 6% of the earth's forests, but they make up a massive 20% of the deforestation carbon. The mangrove forests also sequester each year a large amount of 'blue carbon'. But with habit degradation very large pools of previously-sequestered carbon residing mostly in sediments, can be released to the atmosphere. Healthy mangrove forests, as well as marshes and sea grass meadows, are important and efficient method for sequestering carbon dioxide as 'blue carbon'. Mangrove losses contributed half the total blue carbon stock reduction.

### 2.6 Forest as a Climate Mitigation

Tool Different types of forest play an important role in the global carbon cycle and forestry can contribute to mitigate the climate change. In two ways the $CO_2$ concentration can possible to reduce in the air;

- Do not allowing $CO_2$ to enter the atmosphere (i.e. control emission or carbon conservation)
- removing some of the excess $CO_2$ already in the atmosphere and sequestrating it where it less harm (Brown 2010).

In those two we can control $CO_2$ and can save our living planet.

### 2.7 Impact of Global Warming

Bangladesh is a low carbon dioxide emitting country. For instance, the per capita carbon dioxide emission is estimated at 0.2 Mg/year, while the average for developing countries is 1.6Mg/year. In USA the per capita emission is 20 Mg/year. The low GHG emission status however provides no relief from the effects of global warming because 1.5 meter rise in sea level would inundate an area of 22000 sq. kilometer of Bangladesh, affecting 17 million people. Obviously Bangladesh is likely to be one of the worst suffers of global warming. The other impacts of global warming would be on: Bio diversity and forestry, Agriculture, Human health, Drainage, Fisheries and Fresh water.

### 2.8 Carbon Cycle in Forest

Carbon is the major component of all cellular life form. Trees utilize carbon as building materials with which to form trunks, roots, stems, branches and leaves. Trees remove (sequester) carbon from the atmosphere through photosynthesis, extracting $CO_2$ from the air, separating the carbon atom from the oxygen atoms and returning oxygen to the atmosphere. In doing so, trees store a tremendous amount of carbon in their structures and annual growth increases the carbon stored within the structure. Photosynthesis is the chemical process by which plants use sunlight to convert nutrients into sugars and carbohydrates. Although individuals plants die and decompose forest eventually reach steady states in which the amount of $CO_2$ released by dying plants in offset by new plants.

## 2.9 Carbon Pool

Carbon pool is a reservoir of carbon that has the capacity to accumulate or release carbon. Carbon pools include above ground biomass, below ground biomass, litter, dead material and soil. Significant amount of carbon and biomass is stored in coastal zone those are created by coastal plantation.

## 2.10 United Nations REDD Programme

REDD+ is a voluntary climate change mitigation approach that has been developed by Parties to the UNFCCC. Aims to incentivize developing countries to reduce emissions from deforestation and forest degradation, conserve forest carbon stocks, sustainably manage forests and enhance forest carbon stocks. The United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation (or UN-REDD Programme) is a collaborative programme of the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP), created in 2008 in response to the UNFCCC decisions on the Bali Action Plan and REDD at COP-13. The overall development goal of the Programme is "to reduce forest emissions and enhance carbon stocks in forests while contributing to national sustainable development". The UN-REDD Programme supports nationally led REDD+ processes and promotes the informed and meaningful involvement of all stakeholders, including indigenous peoples and other forest-dependent communities, in national and international REDD+ implementation. The Programme has expanded steadily since its establishment and now has over 60 official Partner Countries spanning Africa, Asia-Pacific and Latin America Caribbean.

Reducing emissions from deforestation and forest degradation (REDD) is a mechanism that has been under negotiation by the United Nations Framework Convention on Climate Change (UNFCCC) since 2005, with the objective of mitigating climate change through reducing net emissions of greenhouse gases through enhanced forest management in developing countries.

In the last two decades, various studies estimate that land use change, including deforestation and forest degradation, accounts for 12-29% of global greenhouse gas emissions. For this reason the inclusion of reducing emissions from land use change is considered essential to achieve the objectives of the UNFCCC.

### 2.10.1 REDD+ as a climate change mitigation measure

Deforestation and forest degradation account for 17-29% of global greenhouse gas emissions, the reduction of which is estimated to be one of the most cost-efficient climate change mitigation strategies. Regeneration of forest on degraded or deforested lands can remove $CO_2$ from the atmosphere through the build-up of biomass, making forest lands a sink of greenhouse gases. The REDD+ mechanism addresses both issues of emission reduction and enhanced removal of greenhouse gases.

### 2.10.2 Reducing Emissions

Emissions of greenhouse gases from forest land can be reduced by slowing down the rates of deforestation and forest degradation, obviously covered by the first two of the REDD+ eligible activities. Another option would be some form of reduced impact logging in commercial logging, under the REDD+ eligible activity of sustainable management of forests.

Enhancing Removals of greenhouse gases (specifically $CO_2$) from the atmosphere can be achieved through various forest management options, such as replanting degraded or deforested areas or enrichment planting, but also by letting forest land regenerate naturally. Care must be taken to differentiate between what is a purely ecological process of regrowth and what is induced or enhanced through some management intervention.

### 2.10.3 REDD+ and the Carbon Market

In 2009, at COP-15 in Copenhagen, the Copenhagen Accord was reached, noting in section 6 the recognition of the crucial role of REDD and REDD+ and the need to provide positive incentives for such actions by enabling the mobilization of financial resources from developed countries. The Accord goes on to note in section 8 that the collective commitment by developed countries for new and additional resources, including forestry and investments through international institutions, will approach USD 30 billion for the period 2010 - 2012.

The Green Climate Fund (GCF) was established at COP-17 to function as the financial mechanism for the UNFCCC, so including for REDD+ finance. The Warsaw Framework on REDD-plus makes various reference to the GCF, instructing developing country Parties to apply the GCF for result-based finance.

## 2.11 Kyoto Protocol and Carbon Storage

Concept because growing vegetation takes in carbon dioxide, the Kyoto Protocol allows Annex I countries with large areas of growing forests to issue Removal Units to recognize the sequestration of carbon. The additional units make it easier for them to achieve their target emission levels. It is estimated that forests absorb between 10 and 20 Mgs of carbon dioxide per hectare each year, through photosynthetic conversion into starch, cellulose, lignin, and wooden biomass. While this has been well documented for temperate forests and plantations, the fauna of the tropical forests place some limitations for such global estimates.

Some countries seek to trade emission rights in carbon emission markets, purchasing the unused carbon emission allowances of other countries. If overall limits on greenhouse gas emission are put into place, cap and trade market mechanisms are purported to find cost-effective ways to reduce emissions. There is as yet no carbon audit regime for all such markets globally, and none is specified in the Kyoto Protocol. National carbon emissions are self-declared.

In the Clean Development Mechanism (CDM), only afforestation and reforestation are eligible to produce certified emission reductions (CERs) in the first commitment period of the Kyoto Protocol (2008–2012). Forest conservation activities avoiding deforestation, which would result in emission reduction through the conservation of existing carbon stocks, are not eligible at this time. Also, agricultural carbon sequestration is not possible yet.

During the negotiations for the Kyoto Protocol, and then in particular its Clean Development Mechanism (CDM), the inclusion of tropical forest management was debated but eventually dropped due to anticipated methodological difficulties in establishing – in particular – additionally and leakage (detrimental effects outside of the project area attributable to project activities). What remained on forestry was "Afforestation and Reforestation", sectorial scope 14 of the CDM. Under this sectorial scope areas of land that had no forest cover since 1990 could be replanted with commercial or indigenous tree species. In its first eight years of operation, a total of 52 projects have been registered under the "Afforestation and Reforestation" scope of the CDM. The cumbersome administrative procedures and corresponding high transaction costs are often blamed for this slow uptake.

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1 Description of the Study Site

The study site was located in the accreted (char) lands at khajura beat, in Kuakata National Park, Mohipur Range, Patuakhali district, Bangladesh. Initially, most of the commercial mangrove species were planted on newly accreted lands periodically inundated by tides. *Sonneretia appetela* (Keora) is the most successful planted species along the shoreline and *Avicennia officinalis* L. (Baen) is the second most successful species of the coastal mangrove plantations on newly accreted lands.


Figure 3.1: Map of the study site (Khajura, Kuakata, Patuakhali) and Location of sample plots (in Red colours) (Source: Google Map and Google Earth).

### 3.2 Sampling Design and Sample Size Determination

The plantation site of Kuakata National park under Patuakhali district is generally composed of mainly Keora (*Sonneratia apetala*), Gewa (*Excoecaria agallocha*), sometimes Kakra (*Bruguiera gymnorhiza*), Bain (*Avicennia officinalis*) also seen randomly. From those deep areas there are 20 plots selected by randomly to cover all study sites. The size of each sample plot is 20m×20m (400 $m^2$). It's a Keora dominated area but some other older species like Bain, Kakra also present there. In statistical term, all plots are selected by random sampling method.

### 3.3. Research Approach

This research is based on quantitative approach as we take sample plots and trees for further calculation, measurement of dbh, and height. It is the general approach to estimate above ground biomass before statistical analysis. There are several research work have already done by using that approach. This approach is used because this is more convenient and easy to handle into a forest cover area moreover identifying sample and trees are also easy to count.

### 3.4 Data Collection

To complete this project thesis we required two types of data, one is primary data and another is secondary data. Data and its collection methods are discussed below-

#### 3.4.1 Primary Data

Data, those are collected from direct field level and those were not used before is called primary data. To complete my research work tree diameter, tree height, GPS reading is needed that's why we collect those data from this site by manually. By using diameter tape we measure diameter at breast height (1.3 m above from the ground) of trees, height is measured by haga altimeter, measurement tape is used to measure the plot size and a GPS is also used to get geographic location like altitude, latitude, elevation etc.

#### 3.4.2 Secondary Data

The secondary data like total area of plantation those area, specific plantation tree species, plantation area by which we can get to determine the age of tree and by this way we can easily know about growth and height relationship, height and biomass relationship and the growth and development of those site. I have collected official data from the Khajura in Kuakata, Mohipur Range office, Patuakhali and Seminar library of Forestry and Wood Technology Discipline.

### 3.5 Tools/ Equipment's

To complete the research work some equipment's are used such as

- Diameter tape
- Measurement tape
- Haga altimeter
- Geographic Location System (Garmin GPSMAP 76CSx)
- Microsoft office (2010) software

### 3.6 Data Analysis

#### 3.6.1 Biomass and Carbon Measurement

Actually tree biomass includes above ground biomass including shoots, branch, twigs etc. and the below ground biomass includes roots biomass. Aboveground Biomass and carbon of live trees, poles, saplings and dead ones (having stem, branch and twigs) is estimated by the following general equation for mangrove tree species (Chave et al. 2005)

$$\textbf{Above Ground Biomass (AGB)} = \mathbf{0.0509 \times \rho \times D^2 \times H}$$

Here, $\rho$ = wood density ($gmcm^{-3}$) (*Sonneratia apetala* = 0.537) (Zanne et al. 2009), D = Diameter (cm), H = Height (m)

It is needed to convert above ground biomass (AGB) to Above Ground Carbon (AGC) if we want to measure carbon content of mangrove plantation. Above ground carbon is computed by multiplying by 0.47 to the above ground biomass (Feldpausch and Rondon 2004, IPCC 2006, Kauffman and Donato 2012, Kauffman et al. 2016).

$$\textbf{Above Ground Carbon (AGC)} = \mathbf{0.47 \times AGB}$$

Belowground biomass of trees will be computed by using the following general allometric equation for mangroves (Komiyama et al. 2005)

$$\textbf{Below Ground Biomass (BGB)} = \mathbf{0.199 \times \rho^{0.899} \times D^{2.22}}$$

Here, ρ= wood density and D= Diameter (cm).

Below ground carbon is computed by multiplying by 0.47 to the below ground biomass-

$$\textbf{Below Ground Carbon (BGC)} = \mathbf{0.47 \times BGB}$$

**Allometric models tested**

Linear, $y = a + bx$ (1)

Logarithmic, $y = a + b \ln x$ (2)

Exponential, $y = ae^{bx}$ (3)

Power, $y = ax^{b}$ (4)

Polynomial, $y = a + bx + cx^{2}$ (5)

Here y is dependent variable (above and belowground carbon), x = independent variable (BA, Mean H, Max H, BA X Mean H, BA X Max H) and a, b, c are constants.

# CHAPTER FOUR: RESULT

## 4.1 Result

### 4.1.1 Relationship between basal area and Above Ground Carbon (AGC)

This graph shows that the relationship between Basal area and Above Ground Carbon (AGC) and it represents a strong relationship where the value of $R^2$ is 0.9978.

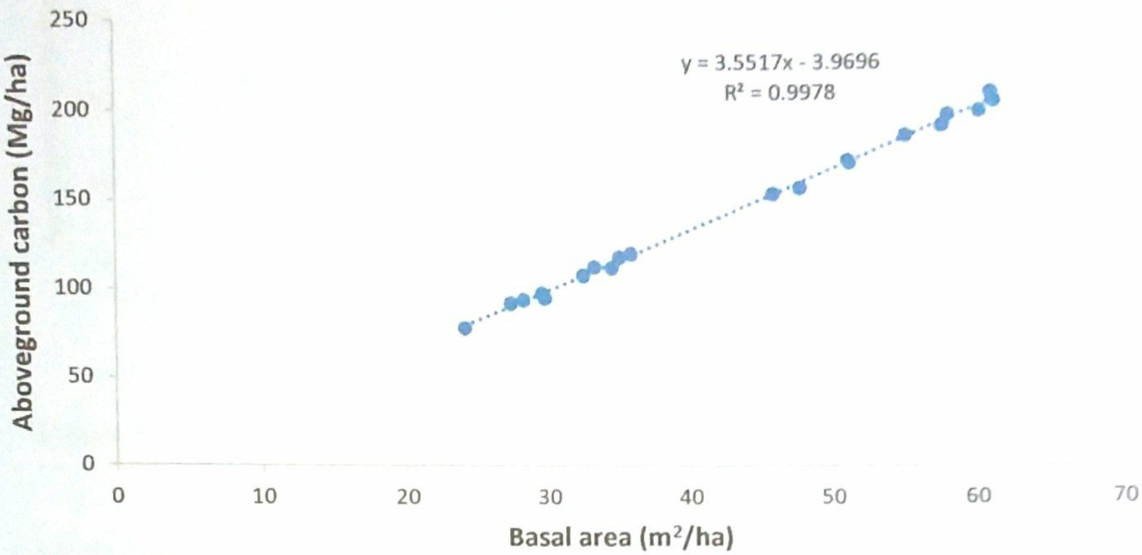


Figure 4.1: Relationship between Basal area and Above Ground Carbon

### 4.1.2 Relationship between basal Area and Below Ground Carbon (BGC)

This graph shows that the relationship between Basal area and Below Ground Carbon (BGC) and it represents a strong relationship where the value of $R^2$ is 0.9994.

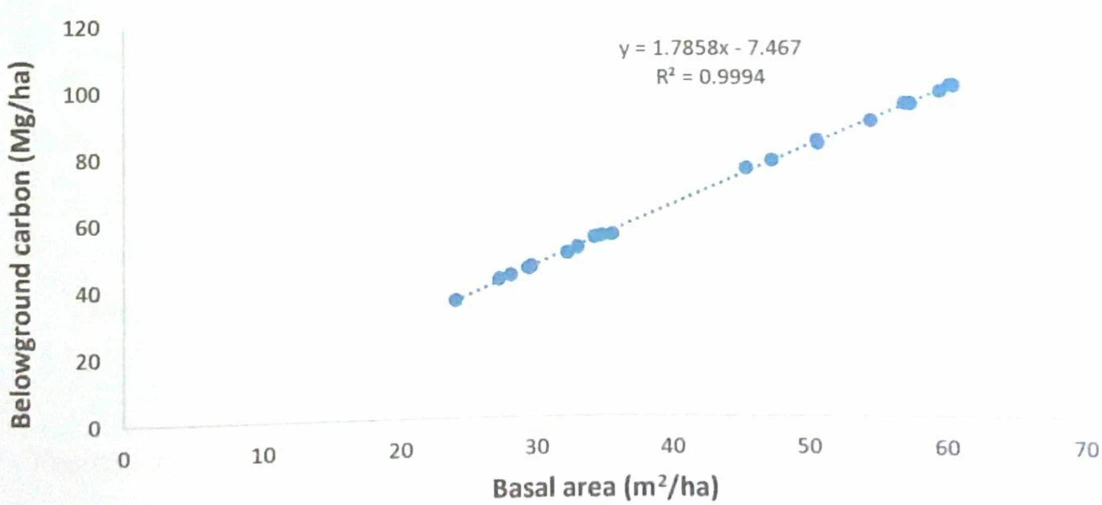


Figure 4.1.2: Relationship between Basal area and Below Ground Carbon

### 4.1.3 Relationship between Maximum Height and Above Ground Carbon (AGC)

This graph shows that the relationship between maximum height and Above Ground Carbon (AGC) and it not represents a strong relationship where the value of $R^2$ is 0.443.

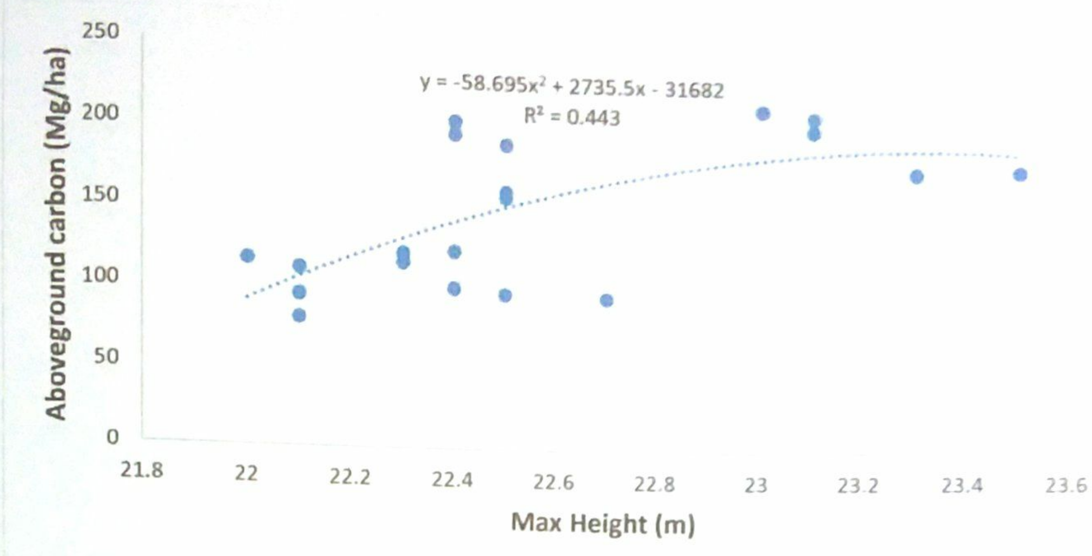


Figure 4.1.3: Relationship between Maximum Height and Above Ground Carbon

### 4.1.4 Relationship between Maximum Height and Below Ground Carbon (BGC)

This graph shows that the relationship between maximum height and Below Ground Carbon (BGC) and it not represents a strong relationship where the value of $R^2$ is 0.4299.

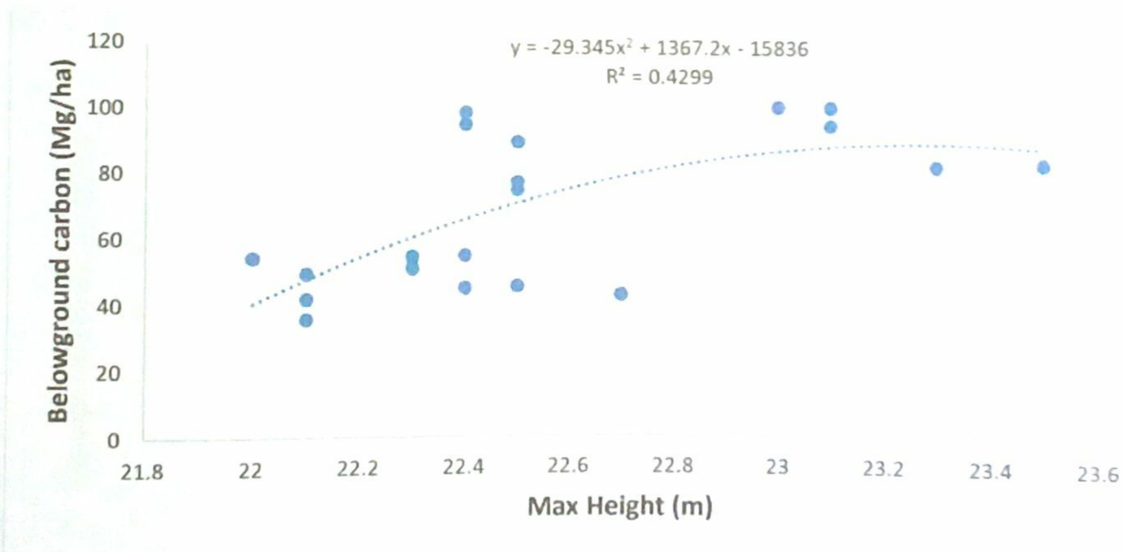


Figure 4.1.4: Relationship between Maximum Height and Below Ground Carbon

### 4.1.5 Relationship between Mean Height and Above Ground Carbon (AGC)

This graph shows that the relationship between mean height and Above Ground Carbon (AGC) and it represents a good relationship where the value of $R^2$ is 0.5586.

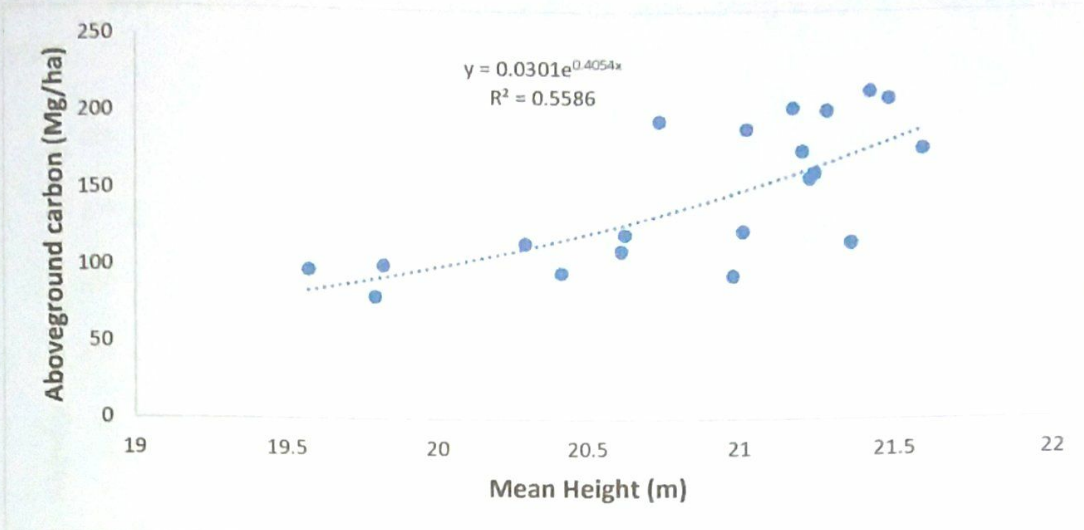


Figure 4.1.5: Relationship between Mean Height and Above Ground Carbon

### 4.1.6 Relationship between Mean Height and Below Ground Carbon (BGC)

This graph shows that the relationship between Mean height and Below Ground Carbon (BGC) and it represents a good relationship where the value of $R^2$ is 0.5253.

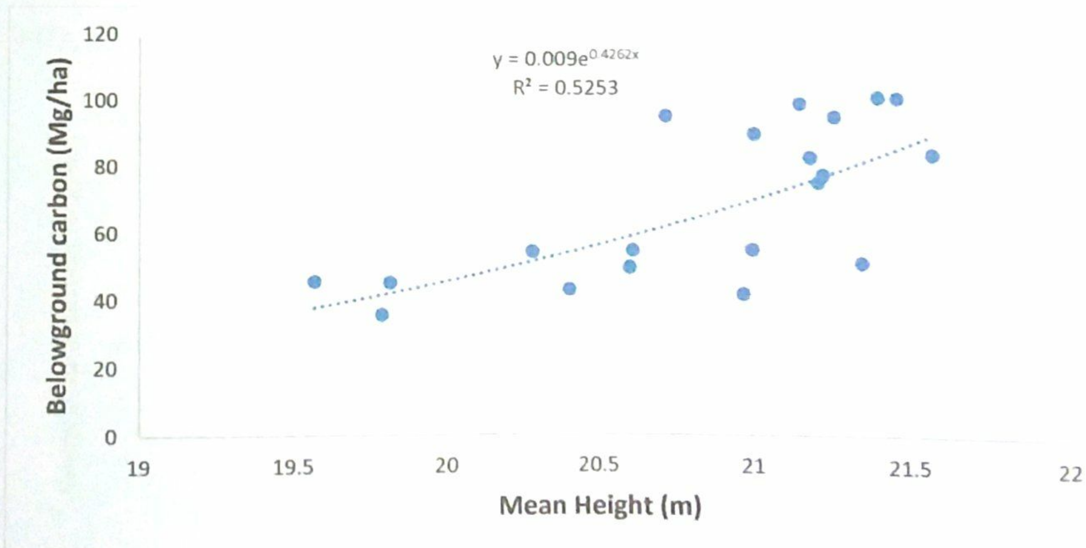


Figure 4.1.6: Relationship between Mean Height and Below Ground Carbon

**4.1.7 Relationship between Basal Area X Max Height and Above Ground Carbon (AGC)**

This graph shows that the relationship between Basal area, Maximum Height and Above Ground Carbon (AGC) and it represents a strong relationship where the value of $R^2$ is 0.9966.

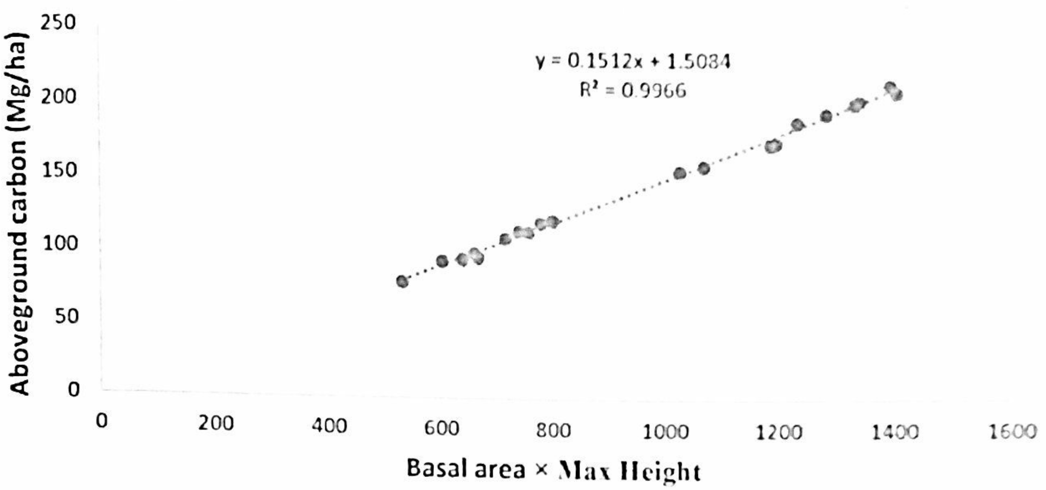


Figure 4.1.7: Relationship between Basal Area x Max Height and Above Ground Carbon

**4.1.8 Relationship between Basal Area X Max Height and Below Ground Carbon (BGC)**

This graph shows that the relationship between Basal area, Maximum Height and Below Ground Carbon (BGC) and it represents a strong relationship where the value of $R^2$ is 0.9973.

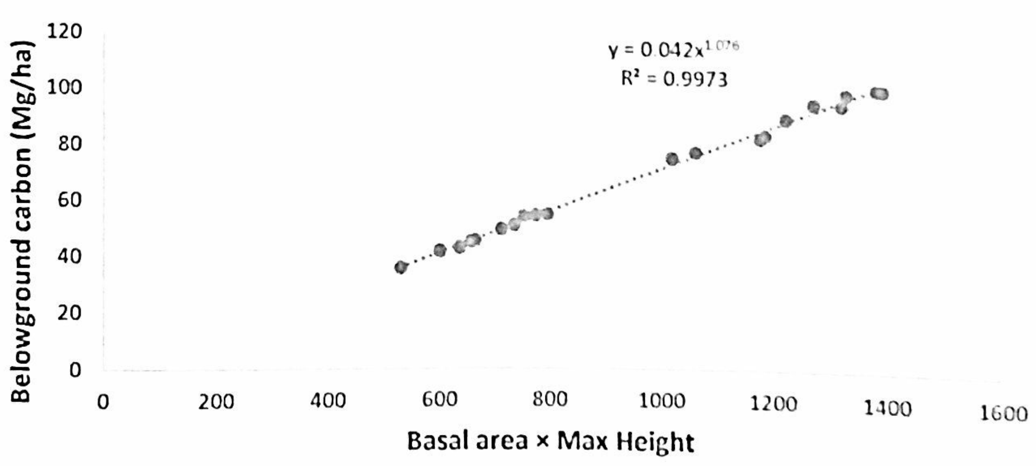


Figure 4.1.8: Relationship between Basal Area × Max Height and Below Ground Carbon

### 4.1.9 Relationship between Basal Area X Mean Height and Above Ground Carbon (AGC)

This graph shows that the relationship between Basal area, Mean Height and Above Ground Carbon (AGC) and it represents a strong relationship where the value of $R^2$ is 0.9982.

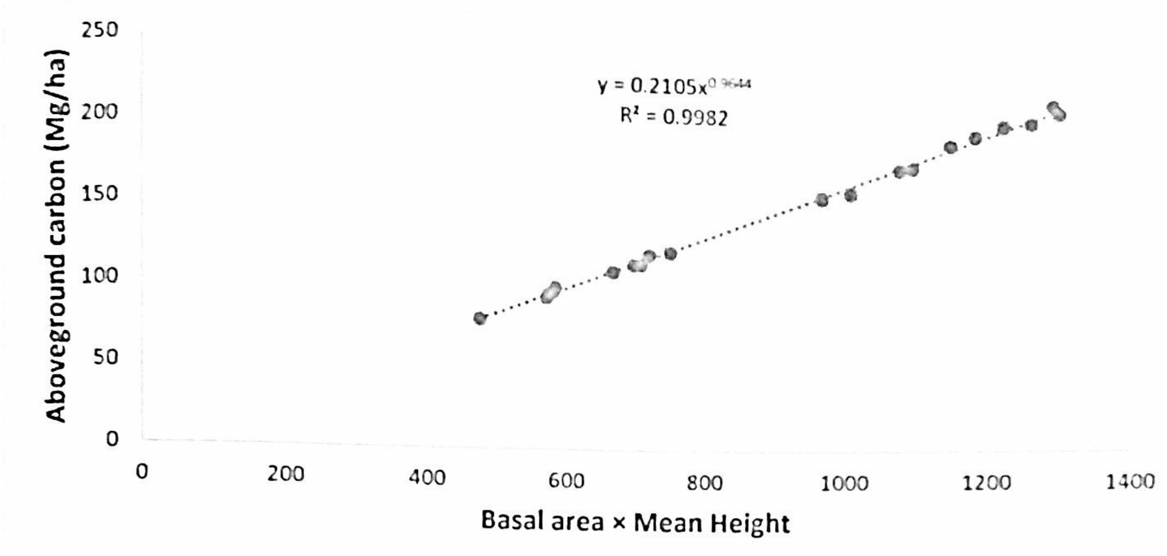


Figure 4.1.9: Relationship between Basal Area X Mean Height and Above Ground Carbon

### 4.1.10 Relationship between Basal Area X Mean Height and Below Ground Carbon (BGC)

This graph shows that the relationship between Basal area, Mean Height and Below Ground Carbon (BGC) and it represents a strong relationship where the value of $R^2$ is 0.9966.

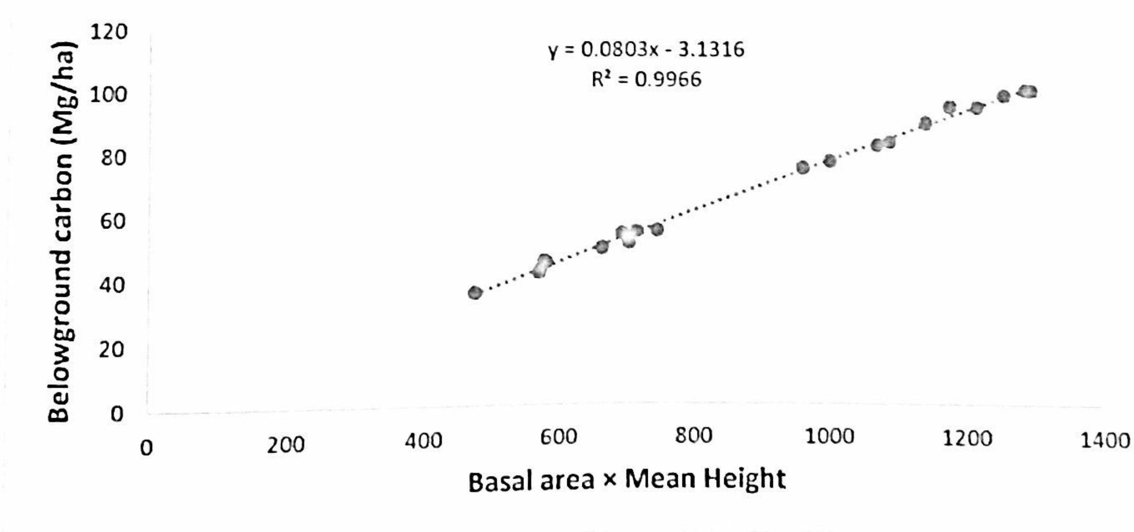


Figure 4.1.10: Relationship between Basal Area X Mean Height and Below Ground Carbon

**Table 4.1:** Comparison of allometric equations of stand carbon stocks in *Sonneratia apetala*. Bold $R^2$ values indicate the highest value in each independent variable.

| Independent variable | Equation type | Dependent variable | |
|---|---|---|---|
| | | Above Ground Carbon | Below Ground Carbon |
| | | $R^2$ | $R^2$ |
| BA | Exponential | 0.9857 | 0.9876 |
| BA | Linear | **0.9978** | **0.9994** |
| BA | Logarithmic | 0.9875 | 0.9883 |
| BA | Polynomial | 0.9978 | 0.9994 |
| BA | Power | 0.9976 | 0.9993 |
| Mean H | Exponential | 0.3881 | 0.3803 |
| Mean H | Linear | 0.3934 | 0.3808 |
| Mean H | Logarithmic | 0.3959 | 0.3832 |
| Mean H | Polynomial | **0.443** | **0.4299** |
| Mean H | Power | 0.3905 | 0.3827 |
| Max H | Exponential | **0.5586** | **0.5253** |
| Max H | Linear | 0.5171 | 0.4891 |
| Max H | Logarithmic | 0.5147 | 0.4867 |
| Max H | Polynomial | 0.5315 | 0.5054 |
| Max H | Power | 0.5567 | 0.5232 |
| BA × Mean H | Exponential | 0.9834 | 0.984 |
| BA × Mean H | Linear | **0.9966** | 0.9964 |
| BA × Mean H | Logarithmic | 0.9871 | 0.9867 |
| BA × Mean H | Polynomial | 0.9966 | 0.9965 |
| BA × Mean H | Power | 0.9963 | **0.9973** |
| BA × Max H | Exponential | 0.9882 | 0.9869 |
| BA × Max H | Linear | 0.9979 | **0.9966** |
| BA × Max H | Logarithmic | 0.9838 | 0.9811 |
| BA × Max H | Polynomial | 0.998 | 0.9967 |
| BA × Max H | Power | **0.9982** | 0.9958 |

## 4.2 Carbon Stock

The average above ground biomass of coastal afforestation area in Khajura beat, Kuakata National Park is 314.03 Mg $ha^{-1}$ ranged between 170.47 Mg $ha^{-1}$ to 457.94 Mg $ha^{-1}$ with lowest and highest value.

On the other hand the below ground biomass and carbon of those study area is lower than the above ground biomass and carbon. The average BGB is 146.25 Mg $ha^{-1}$ and ranged between 75.94 Mg $ha^{-1}$ to 214.32 Mg $ha^{-1}$ with minimum and maximum value.

Average carbon stock in those study area (Khajura beat, Kuakata National Park) is **216.33 Mg $ha^{-1}$** and this is the main finding of my research work.

**Table no. 4.2: List of Important Attributes**

[**AGB**= Above Ground Biomass, **AGC**= Above Ground Carbon, **BGB**= Below Ground Biomass, **BGC**= Below Ground Carbon]

| **Content** | **Minimum ( Mg $ha^{-1}$)** | **Maximum (Mg $ha^{-1}$)** | **Average (Mg $ha^{-1}$)** |
|---|---|---|---|
| **AGB** | 170.4662 | 457.9392 | 314.0265 |
| **BGB** | 75.93212 | 214.3247 | 146.2499 |
| **AGC** | 80.1191 | 215.2314 | 147.5925 |
| **BGC** | 35.6881 | 100.7326 | 68.7375 |
| **TOTAL(AGB+BGB)** | **246.3983** | **672.2639** | **460.2764** |
| **TOTAL(AGC+BGC)** | **115.8072** | **315.964** | **216.33** |

# CHAPTER FIVE: DISCUSSION

There are many research work have already done on carbon stoking in our country except this area so this research works aim to measure the biomass stoking and to find out the potentiality of those kinds of coastal regions capability to hold atmospheric carbon.

The study represents a satisfactory result if we compare to other natural forest region or coastal plantation. The average above ground carbon is 147.59 Mg $ha^{-1}$ with the lowest 80.12 Mg $ha^{-1}$and highest 215.23 Mg $ha^{-1}$ where the above ground carbon stock in Sundarban is between 45.24 Mg $ha^{-1}$ to 152.57 Mg $ha^{-1}$. Again, if we compare those area with the below ground carbon, in Sundarbans has between 11.72 Mg $ha^{-1}$ to 62.37 Mg $ha^{-1}$ and in my study area has 35.68 Mg $ha^{-1}$ to 100.73 Mg $ha^{-1}$. Comparison of different regions of the world results are given below, it clarifies and justifies the finding my research.

**Table 5.1: Comparison of above and below ground carbon in different regions of the world**

| Site | Above Ground Carbon ($Mgha^{-1}$) | Below Ground Carbon ($Mgha^{-1}$) | Source |
|---|---|---|---|
| Khajura Beat, Kuakata National Park | 80.12- 215.23 | 35.68-100.73 | Present Study |
| Sundarban Mangrove Forest, Bangladesh | 45.24-152.57 | 11.72- 196.54 | Rahman et al. 2015 |
| Tropical Coastal Wetlands in the Karstic Landscape of the Mexican Caribbean | 210 ± 33.9 | | Adame et al. 2013 |
| South pacific coast of Mexico | 8.5-145.6 | | Adame et al. 2015 |
| Soloman Island | 190.43 | | Albert et al. 2012 |

The findings of my study will may help the adjacent authority and global scientists for further analysis and they would easily understand the importance of the coastal plantation to sequestrate the atmospheric carbon.

# CHAPTER SIX: CONCLUSION

This study is based on a field data to describe the success, importance and performance of *S. apetala* for the development of monospecific stands in the coastal areas. The average carbon stock (above + below) in those study area (Khajura beat, Kuakata National Park) is 216.33 Mg $ha^{-1}$. The findings of this study would be helpful to understand the importance of the coastal plantation in carbon sequestration. Finally, the expansion of *S. apetala* plantations in the open coastal areas has great potential to sequestrate more C as well as restore the degraded coastal land, although more long-term monitoring and research are still needed to further evaluate biomass and C accumulation of *S. apetala* plantation over time as well as how the increasing distribution of this monoculture plantation will influence the native mangrove forests.

# CHAPTER SEVEN: REFERENCES


Adame, M. F., J. B. Kauffman, I. Medina, J. N. Gamboa, O. Torres, J. P. Caamal, M. Reza, and J. A. Herrera-Silveira. 2013. Carbon Stocks of Tropical Coastal Wetlands within the Karstic Landscape of the Mexican Caribbean. PLOS ONE 8:e56569.

Alongi, D. M. 2011. Carbon payments for mangrove conservation: ecosystem constraints and uncertainties of sequestration potential. Environmental Science & Policy 14:462–470.

Alongi, D. M., G. Wattayakorn, J. Pfitzner, F. Tirendi, I. Zagorskis, G. Brunskill, A. Davidson, and B. Clough. 2001. Organic carbon accumulation and metabolic pathways in sediments of mangrove forests in southern Thailand. Marine Geology 179:85–103.

Aziz, A. 2010. Coastal and marine plant resources of Bangladesh: management and exploitation. Keynote paper, Annual Bot. Conf., Univ. Chittagong, Chittagong.:P. 14.

Bonan, G. B. 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. science 320:1444-1449.

Bouillon, S., A. V. Borges, E. Castañeda-Moya, K. Diele, T. Dittmar, N. C. Duke, E. Kristensen, S. Y. Lee, C. Marchand, J. J. Middelburg, V. H. Rivera-Monroy, T. J. Smith, and R. R. Twilley. 2008. Mangrove production and carbon sinks: A revision of global budget estimates. Global Biogeochemical Cycles 22:1–12.

Brown, D. 2010. Roadside management strategies to reduce greenhouse gases. .11-41.

Chave, J., C. Andalo, S. Brown, M. Cairns, J. Chambers, D. Eamus, H. Fölster, F. Fromard, N. Higuchi, and T. Kira. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145:87-99.

Donato, D. C., J. B. Kauffman, D. Murdiyarso, S. Kurnianto, M. Stidham, and M. Kanninen. 2011. Mangroves among the most carbon-rich forests in the tropics. Nature Geoscience 4:293–297.

Doyle, P. 1997. Modeling Hurricane Effects on Mangrove Ecosystems. USGS Fact Sheet 200:95–97.

Drigo, D., Latif, M.A., Chowdhury, J. A., and Shaheduzzaman, M. 1987. The Maturing Coastal Plantations of the Coastal Afforestation Project. UNDP project BGD/85/085, Dhaka.:Field Document No.2. P. 3.

Duke, N. C., J. O. Meynecke, S. Dittmann, A. M. Ellison, K. Anger, U. Berger, S. Cannicci, K. Diele, K. C. Ewel, C. D. Field, N. Koedam, S. Y. Lee, C. Marchand, I. Nordhaus, and F. Dahdouh-Guebas. 2007. A world without mangroves? Science 317:41–42.

Eong, O. J. 1993. Mangroves - a carbon source and sink. Chemosphere 27:1097–1107.

Feldpausch, T., and M. A. Rondon. 2004. Carbon and nutrient accumulation in secondary forests regenerating on pastures in central Amazonia.

Fromard, F., H. Puig, E. Mougin, G. Marty, J. L. Betoulle, and L. Cadamuro. 1998. Structure, above-ground biomass and dynamics of mangrove ecosystems: new data from French Guiana. Oecologia 115:39–53.

Glossary", S. E. T. 2010. Nebraska Energy Office .

Hodrien, C. 2008. Squaring the circle on carbon capture and storage.*in* Claverton Energy Group Conference.

IPCC. 2006. Default biomass conversion and expansion factors. IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4 – Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change.

IPCC. 2013. Fourth IPCC assesment report: climate change 2013. . Cambridge, UK: Cambridge University press.

Islam, M. 2012. Coastal forest rehabilitation and management in Bangladesh. Retrieved July 11.

Islam., M. M. 2006. Appendix 3. Country papers/presentations about Coastal forest rehabilitation and management in Bangladesh.

Kairo, J. G., C. Wanjiru, and J. Ochiewo. 2009. Net Pay: Economic Analysis of a Replanted Mangrove Plantation in Kenya. Journal of Sustainable Forestry 28:395–414.

Karim, M. R. 2005. Priorities for rehabilitation, current activities and needs for mangroves and other coastal vegetation of Bangladesh: A discussion paper.Presented in the Regional Workshop on Rehabilitation of Tsunami-affected Forest Ecosystems: Strategies and New Directions,7–8 March 2005. Bangkok, Thailand.

Kauffman, J., V. Arifanti, I. Basuki, S. Kurnianto, N. Novita, D. Murdiyarso, D. C. Donato, and M. Warren. 2016. ipProtocols for the measurement, monitoring, and reporting of structure, biomass, carbon stocks and greenhouse gas emissions in tropical peat swamp forests. Working Paper 221. CIFOR, Bogor, Indonesia

Kauffman, J., and D. Donato. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.

Khan, M. N. I., R. Suwa, and A. Hagihara. 2007. Carbon and nitrogen pools in a mangrove stand of *Kandelia obovata* (S., L.) Yong: vertical distribution in the soil–vegetation system. Wetlands Ecology and Management 15:141–153.

Komiyama, A., S. Poungparn, and S. Kato. 2005. Common allometric equations for estimating the tree weight of mangroves. Journal of Tropical Ecology 21:471-477.

Kristensen, E., S. Bouillon, T. Dittmar, and C. Marchand. 2008. Organic carbon dynamics in mangrove ecosystems: A review. Aquatic Botany 89:201–219.

Primavera, J. H. 2000. Development and conservation of Philippine mangroves: institutional issues. Ecological Economics 35:91–106.

Primavera, J. H. 2005. Mangroves, Fishponds, and the Quest for Sustainability. Science 310:57–59.

Rachid, M. 1977. Instruction Manual for Planting on Coastal Area Departmental instruction manual.:P.76.

Rahman, M. M., M. N. I. Khan, A. K. F. Hoque, and I. Ahmed. 2015. Carbon stock in the Sundarbans mangrove forest: spatial variations in vegetation types and salinity zones. Wetlands Ecology and Management 23:269–283.

Rönnbäck, P. 1999. The ecological basis for economic value of seafood production supported by mangrove ecosystems. Ecological Economics 29:235–252.

Saenger, P. 2002. Mangrove ecology, silviculture and conservation.

Saenger, P., and N. Siddiqi. 1993. Land from the sea: the mangrove afforestation program of Bangladesh. Ocean & Coastal Management 20:23-39.

Sedjo, R., and B. Sohngen. 2012. Carbon sequestration in forests and soils. Annu. Rev. Resour. Econ. 4:127-144.

UNFCC. 2007. Climate change : impacts, vulneraties and adaptation in developing countries. Bonn, Germany: climate change secretariat(UNFCCC) Martin luther king street 8.

Valiela, I., J. L. Bowen, and J. K. York. 2001. Mangrove forests: one of the world's threatened major tropical environments. Bioscience 51:807–815.

Van der Werf, G. R., D. C. Morton, R. S. DeFries, J. G. Olivier, P. S. Kasibhatla, R. B. Jackson, G. J. Collatz, and J. T. Randerson. 2009. CO 2 emissions from forest loss. Nature geoscience 2:737.

Zanne, A. E., G. Lopez-Gonzalez, D. A. Coomes, J. Ilic, S. Jansen, S. L. Lewis, R. B. Miller, N. G. Swenson, M. C. Wiemann, and J. Chave. 2009. Global wood density database.