Khulna University
Life Science School
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Title: Biodiversity, Biomass and Carbon Stock of a Mature Mangrove Stand in the Sundarbans, Bangladesh

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Programme: Masters of Science in Forestry

BIODIVERSITY, BIOMASS AND CARBON STOCK OF A MATURE MANGROVE STAND IN THE SUNDARBANS, BANGLADESH

TECHNOLOGY

CIENCE SCH

KHULNA UNIVERS

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BANGLADESH

2015

BIODIVERSITY, BIOMASS AND CARBON STOCK OF A MATURE MANGROVE STAND IN THE SUNDARBANS, BANGLADESH

Course Title: Project Thesis

Course no: FWT-5112

[This paper has been prepared and submitted to Forestry and Wood Technology Discipline, Khulna University, Khulna, Bangladesh for the partial fulfillment of the requirements for the professional degree of M.Sc in Forestry and Wood Technology]

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I, Manabendra Baral, declare that this thesis is the result of my own works and that it has not been submitted or accepted for a degree in other university.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans and for the title and summary to be made available to outside organizations.

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Dedicated To

My Beloved Uncle Who Always Loves and Inspires Me.

ACKNOWLEDGEMENTS

At first all my admiration goes to the supreme creator and ruler of the universe, God, for his great mercy to create me alive and enables me to pursue my education in Forestry and Wood Technology Discipline and to complete my thesis for the degree of M.Sc in Forestry and Wood Technology.

I am delighted to convey my cordial respect and gratitude to my honorable supervisor **Dr. Md. Mahmood Hossain,** Professor Forestry and Wood Technology Discipline, Khulna University, Khulna for his cordial co-operation, inspection, guidance and caring allowed me to prepare this report successfully My sincere thanks are also to my respectable teacher **S.M. Rubaiot Abdullah** for his affection, advice and teaching.

I am also grateful to the lab technician Ujjal Kundu, senior brother Md. Mostafizur Rahman Shaon and senior sister Roksana Jahan Munia for their valuable cooperation in the time of measuring of carbon content.

Special thanks to my friend Md. Najmus Sayadat Pitol for giving his laptop to write this thesis paper. I am also thankful to some of my friends particularly Mandal Falgunee Kumar, Mamunur Rashid, Abu Wabaeid Hasan and all of my classmates for their valuable cooperation to bring out my project thesis work.

Finally, I am deeply indebted and grateful to my parents and all of my family members for their encouragement sacrifice, affection and blessing that paved the way to my higher education.

ABSTRACT

The goal of this study was to estimate biodiversity, biomass and carbon stock of a mature stand in Sundarbans. Although there has been some research on both tropical and sub-tropical mangroves of the world, there is limited information on the biodiversity, biomass and carbon stock of mangroves in Sundarbans which is the largest single mangrove forest in the world. The vegetation structure, species richness, biomass and carbon stock of mangroves of root, soil and litter stand in kolagachia area of Sundarbans were estimated. The above ground biomass and carbon stock were estimated from the dbh and wood density of mature tree species. Below ground biomass and carbon stock were estimated from the mass of roots in three pits. Tolal biomass and carbon stock were estimated from above ground biomass, below ground biomass and litter standing biomass. Total 12 species was found which belonged to 11 genera and 8 plant families in tree, sapling and regeneration stage among them 7 tree species was found belonged to 7 genera and 6 plant families are found. *Excoecaria agallocha* showed highest stand density (932 ha^{-1}) and *Sonneratia apetala* and *Bruguiera sexangula* showed lowest stand density (21 ha^{-1}). Basal area of this stand was 16.44 m^2ha^{-1}. Highest basal area was shown by *Xylocarpus mekongensis.* Among trees above ground biomass was highest for *Xylocarpus mekongensis* and lowest for *Ceriops decandra* although the hihgt wood density was for *Bruguiera sexangula.* Total biomass of this stand was calculated 205.22 t ha^{-1}. Among trees, highest above ground carbon was for *Xylocarpus mekongensis.* The total amount of carbon in this mangrove stand was 275.29 t ha^{-1}. This study shows species diversity for seedling, sapling and tree stage of a mature mangrove stand, total biomass and carbon stock which can help for making a better management plan and sustainable use of mangrove products.

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1.1 Background of the study

Forest degradation is a serious problem now-a-days. There are many reasons for forest degradation but human activities are the main reason. For this reason biodiversity of forest is lost. Mangrove disappearance is no exception (Mahmood *et al.* 2013).

The Convention on Biological Diversity (CBD), defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

Ecosystem services form the basis of human survival. They help to meet the livelihood needs of the farmers, fisher folk, forest dwellers, craft persons and others. So, ecological security and livelihood security in Bangladesh are critically dependent on biodiversity and its components (Islam, 2011).

Mangrove forests are the ecosystems of great complexity. They are open environments, where significant linkages occur between the land (lithosphere and hydrosphere), the estuary (basin physiography), and the ocean and atmospheric (climate) systems (Marília Cunha-Lignon *et al.*, 2009). Mangroves are woody plants which grow at the inter face between land and sea on tropical and sub-tropical sheltered coast. Mangrove trees grow in a soil that is more or less permanently water logged (Peter, 1999).

As a complex ecosystem the ecological succession process of mangrove also unique. Ecological succession is the observed process of change in the species structure of an ecological community over time. The community begins with relatively few pioneering plants and develops through increasing complexity until it becomes stable or self-perpetuating as a climax community.

The biomass of mangrove forests varies with age, dominant species, and locality. In primary mangrove forests, the above-ground biomass tends to be relatively low near the sea and increases inland. On a global scale, mangrove forests in the tropics have much higher above-ground biomass than those in temperate areas. Mangroves often accumulate large amounts of biomass in their roots, and the above-ground biomass to below-ground biomass ratio of mangrove forests is significantly low compared to that of upland forests (Komiyama *et al.* 2008).

Biodiversity in Bangladesh contributes significantly to the country's economy. The people of Bangladesh depend on biodiversity for their day-to-day sustenance as well as overall livelihood security. For example, of the sector's contribution to the GDP, approximately 7.1% is covered by the forestry. The various forestry-related projects in the country together generate 90 million person-days of job opportunities every year. The Sundarbans provides livelihood and employment to an estimated 112,000 people (Khan 2001).

The over-extraction of resources for livelihood sustenance is a major reason for the depletion of biodiversity in Bangladesh. Along with that, development initiatives that do not consider biodiversity can also be held responsible for this loss. At the same time, ecological threats from climate change, water and air pollution, and build-up of solid wastes will degrade the ecosystems, which ultimately exacerbate the social costs of poverty. Hence there exists a direct link between poverty and biodiversity in Bangladesh. Conserving biodiversity poses a formidable challenge without considering alleviation of poverty simultaneously (National Biodiversity Strategy and Action Plan for Bangladesh, 2005).

So, biodiversity conservation is very much important for our country as well as whole world. For this reason estimation of biodiversity and biomass of forest land is essential.

Mangroves help people in their livelihood by providing timber, fire-wood, and charcoal, fishing poles, pulp and tannin (Hamilton and Snedaker 1984; Nagelkerken *et al.* 2008). On the other hand they also reduce coastal erosion, flooding and run-off, and provide nutrients (Mahmood *et al.* 2003).

But now-a-days mangrove forests are degrading rapidly. The world has lost about 5 million ha of mangroves over 20 year period from 1990 to 2000 (FAO, 2003). About 90% of global mangroves are growing in developing countries and they are critically endangered. So biodiversity conservation in mangrove forest is important.

To consider all aspects I estimate the biodiversity and biomass of the community and carbon stock of the area in my study.

1.2 Objective of the study

- To estimate the biodiversity of the mature stand at the saline water zone of the Sundarbans.
- To estimate above and below-ground biomass of a mature stand at the saline water zone of the Sundarbans.
- To estimate carbon pool of a mature stand at the saline water zone of the Sundarbans.

2.1 The Concept of Bio-diversity

Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992). Biological diversity has recently become one of the most popular topics of discussion both in scientific and political forum at local, national, regional and global level.

2.1.1 Types of Bio-diversity

The term biodiversity includes three different but closely related aspects,

I) **Genetic diversity:** It refers to the variation of genes within species. This constitutes distinct population of the same species or genetic variation within population or varieties within a species (Rahman, 2009).

II) **Species diversity:** It refers to the variety of species within a region. Such diversity could be measured on the basis of number of species in a region (Rahman, 2009).

III) **Ecosystem diversity:** In an ecosystem, there may exist different landforms, each of which supports different and specific vegetation. Ecosystem diversity in contrast to genetic and species diversity is difficult to measure since the boundaries of the communities which constitute the various sub-ecosystems are elusive. Ecosystem diversity could best be understood if one studies the communities in various ecological niches within the given ecosystem; each community is associated with definite species complexes. These complexes are related to composition and structure of the biodiversity (Rahman, 2009).

2.1.2 Status of Bio-diversity in Bangladesh

Bangladesh is the world largest deltaic region, lies in the northeastern part of South Asia (Hossain, 2001). The majority of country's land is formed by alluvium deposition from the Ganges and the Brahmaputra Rivers and their tributaries and consists mostly of flood plains (80%), with some hilly areas (12%) (Islam, 2003). Bangladesh has a sub-tropical monsoon climate; its natural forests are classified into three major vegetation types occurring in three distinctly different land types: hill forest (evergreen to semi-evergreen), plain land Sal *(Shorea robusta)* forests and mangrove forests. There is contradictory information on the actual forest extent of Bangladesh. According to the Bangladesh Forest Department and some other sources (Khan *et al.*, 2007, & Hossain, 2005), forest cover is about 2.53 million ha, representing approximately 17.5% of the country's total surface area, but according to FAO's FRA-2005, forest extent is only about 0.87 million ha (FAO, 2006) Officially the FD manages 1.53 million hectares of forest land of the country (Roy, 2005).

Bangladesh is part of the Indo-Burma region, which is one of the ten global hot-spot areas for biodiversity, with 7000 endemic plant species (Mittermeier *et al.*, 1998). Due to its unique geo-physical location and characteristics, Bangladesh is characterized by an exceptionally rich biological diversity (Hossain, 2001, Nishat *et al.*, 2002 & Barua *et al.*, 2001). Its flora includes as estimated 5,700 species of angiosperms alone, including 68 woody legume species, 130 species of fibre yielding plants, 500 medicinal plant species, 29 orchid species, three species of gymnosperms and 1,700 pteridophytes (Firoz *et al.*, 2004 & Khan, 1977). Some 2,260 plant species have been reported from the hilly region of Chittagong alone, which falls between two major floristic regions of Asia (Anno, 1992). The homestead forests are usually composed of multipurpose fast growing trees, fruits trees, bamboo, rattan, medicinal and some aquatic plants. There are about 8000 varieties of rice and nearly 3000 varieties of other miscellaneous crops in Bangladesh (Hassan, 1995).

2.1.3 Biodiversity and forest structure of Mangrove

A group of taxonomically heterogeneous woody shrubs and trees growing in the intertidal zone of tropical and subtropical coasts is expressed as "Mangrove". Consequently three dimensions of biodiversity- species, gene and ecosystem. Worldwide there are 114 species of true mangroves belonging to 66 genera with species richness being greatest in the Indo-Pacific region (Tomlinson, 1986). Sundarbans in Bangladesh covered about 3% of the world Mangroves. Mangrove ecosystem services play a crucial role in the maintenance of biodiversity, waste assimilation, cleansing, recycling, and renewal, as well as in protecting coastal areas from disturbance events (Basu, 2013).

Species composition in mangroves is influenced by the environmental parameters, light intensity, competition, soil fertility, P^H (Koch and Snider, 1997; Utpong, 1997; Sherman et al., 1998; Tam and Wang, 1998). Short trees with small diameters show low basal areas and high density but larger trees shows low density with high basal area (Joshi andGhose, 2014). Fromardet al. (1998) observed that higher density (17,333 N ha^{-1}) for *Avicennia*spp. in the pioneer stage than mature stage (558 N ha^{-1}) in French Guiana. According to Singh et al. (1990) and Singh and Odaki (2004), higher complexity Index values are observed for undisturbed (87.1 to 260) site compared to disturbed site. Nazrul-Islam (1995) reported slightly higher heterogeneity and evenness (2.74 and 0.82) were for the mangroves of Bangladesh Sundarbans. In relatively low species communities where in a single environmental factor predominates so that only one species is best fit to survive and becomes numerically dominant (Whittaker, 1975).

2.1.4 Deforestation and diminishing global biodiversity

According to the World Resources Institute (WRI), the world has lost about half of itsforest cover from 62 million km2 to 33 million km2 (Sundrlin et. al. 2005; Kaimowitz and Angelson, 1998). The magnitude of global biodiversity situation is undoubtedly threatened million times higher than any time of its history. Over 15 million ha of natural forest are lost in the tropic every year which is more than the area of Nepal or Arkansas in the United States (FAO, 2006), again the present rate of species extinction is estimated to be between 1000 and 10,000 times the historical (pre 10,000 years BP) rate (Wilson, 1988). According to '2004 IUCN Red List' currently 15,589 species are threatened with extinction; 12% of world's known birds, 23% of mammals, and 32% of amphibians are also threatened (Baillie et. al. 2004). Most recent form of deforestation takes place in developing countries, particularly in tropical areas. Deforestation and forest degradation directly threatens the life and living of 400 million people out of which 50 million are forest indigenous people- who depend on forests for subsistence.

Interestingly, most of the world's biodiversity have been hold by majority of theeconomically poorest countries (Koziell, 2001; Blockhus et. al. 1992) where the peopledepend most immediately upon local ecosystems for their livelihoods are somehowresponsible for the degradation of biodiversity and will mostly affected by the consequence of this biodiversity loss (CBD, 2006 and 2007). Biodiversity conservation is however essential to improve and alter this crisis. Biodiversity conservation through environmental sustainability is one of the prime objectives of Millennium Development

Goals which strongly linked with its first objective, i.e., eradication of poverty and hunger. To date, various international treaties andconventions with intergovernmental bodies have been formed to work on biodiversity issues in national, regional and international level.

2.2 The Concept of Biomass

The word "biomass" consist of "bio"+"mass", and originally used in the field of ecology simply referring to amount and plant. There is no strict definition of biomass, and the definition differs from one field to another field. Biomass is organic matter that can be converted into energy. Common examples of biomass include food crops, crops for energy (e.g., switchgrass or prairie perennials), crop residues (e.g.,corn stover), wood waste and byproducts (both mill residues and traditionally noncommercial biomass in the woods), and animal manure.

Woody biomass has received special attention because of its widespread availability, but to date has been of limited use for energy production except for wood wastes at sawmills. Wood can be burned directly, usually to produce both heat or steam and electricity (called combined heat and power, or CHP), or digested to produce liquid fuels. Biomass from forests, as opposed to mill wastes, has been of particular interest, because it is widely accepted that many forests have excessive levels of biomass (compared to historic levels) called hazardous fuels that can contribute to catastrophic wildfires (Bracmort, 2012).

2.2.1 Biomass of Mangroves

2.2.1.1 Standing Biomass

Biomass of plants includes total dry weight of leaves, buds, flowers, fruits, branches, stems, above and below-ground roots in a certain time. The estimation of standing biomass and analysis of stand structure of mangrove forests are important for their management and often used for the comparison of potential forest productivity (Golley*etal.*, 1975; Clough and Attiwill, 1982; Aksornkoae, 1993).

Mangrove species at different places showed wide range of standing biomass from 460 t/ha in tall *Rhizophora* spp. dominated forest in Matang, Malaysia (Putz and Chan, 1986) to 6.80 t/ha in low *Avicenniamarina* communities in Tuff Crater, New Zealand (Woodroffe, 1985). In general, tropical mangroves have higher standing biomass and more complicated structure than sub-tropical mangroves (Chapman, 1976; Saenger and Snedaker, 1993; Tam *et al.*, 1995b). Moreover, standing biomass and their proportion in the above and below-ground components of mangrove plants are not only affected by the geographical location and microclimates but also vary with the species, stand structure and age of stand (Lugo and Snedakar, 1974; Woodroffe, 1985; Steinke *et al.*, 1995; Tam *et al.*, 1995b).

2.2.1.2 Species and Stand Structure

The above and below-ground biomass of *Avicennia marina* (mean height 3.5 m) in Westernport Bay, Victoria, Australia were 8.60 t/ha and 14.60 t/ha, which made up 37.11 and 62.89% of total biomass, respectively (Clough and Attiwill, 1975). In a similar study, Briggs (1977) observed higher standing biomass of *A. marina* (mean height 7.5 m) at two different sites in a mangrove community near Sydney, Australia. The above-ground biomass varied from 100.20 to 129.50 t/ha and below-ground biomass varied from 144.40 to 160.20 t/ha and the proportion of above and below-ground biomass varied from 41.52-49.49% and 50.51-58.48%, respectively. The above and below-ground biomassof *A. marina* (4.56 m, 4.19 cm and 4500 stem/ha) in Beachwood mangrove forest, South Africa were estimated at 94.49 and 9.69 t/ha and the biomass proportion in above and below-ground components were 88.51 and 11.49%, respectively (Steinke *et al.*, 1995).

The above ground biomass of *A. germinans* in two different places of Campeche, Mexico varied from 17.40 to 73.00 t/ha, where mean height, mean DBH and density in two sites varied from 4 to 6 m, 4.90-7.70 cm, and 1590-1720 stem/ha, respectively (Day *et al.*, 1996).

The total above and below-ground biomass of *A. corniculatum* (mean height 3.85 m, mean DBH 19.56 cm and density of 794 stem/ha) and *Kandeliacandel* (mean height 4.2 m, mean DBH 7.76 cm and density of 117 stem/ha) in Futin Natural Reserve, Shenzhen, China were 87.1 and 121.40 t/ha, respectively and the biomass proportion in above and below-ground components of *A. corniculatum* and *K. candel* were 71.26% and 28.74%; 63.05% and 36.95%, respectively (Tam *et al.*, 1995b). Li (1997) reported that *A. corniculatum* and *K. candel* in Shenzhen, South China together constituted 108.26 t/ha of above-ground biomass.

The above and below-ground biomass of *Bruguiera* spp. (mean height 10.69 m, mean DBH 9.33 cm and density of 208 tree/ha) in KhongNgaoHatsaikao, Ranong, Thailand were 28.43 and 6.06 t/ha and made up 92% and 8% of total standing biomass, respectively (Tamai*et al.*, 1986). Steinke *et al.* (1995) reported that the above and below-ground biomass of *B. gymnorrhiza* (mean height 2.31 m, mean DBH 2.31 cm and density of 42500 stem/ha) in

Beachwood mangrove forest, South Africa were higher of 74.67 t/ha and 9.69 t/ha, respectively, and the above and below-ground components contained 90.70 and 9.30%, respectively of total standing biomass.

Komiyama *et al.* (2000) reported that the above and below-ground biomass of *Ceriopstagal* (mean height 5.20 m, mean DBH 4.20 cm, density of 10010 stem/ha) in Satun Province, southern Thailand were 94.24 and 87.51 t/ha, which made up 51.85 and 48.15% of total biomass, respectively. The above-ground biomass of mixed mangrove (mean height 13.09 m, Mean DBH 12.15 cm, density of 849 stem/ha) in Pulau Langkawi, Malaysia was 115.56 t/ha (Norhayati and Latiff, 2001).

Rhizophoraapiculata (mean height 10.57 m, mean DBH 11.1 cm and density of 998 tree/ha) in KhongNgaoHatsaikao, Ranong, Thailand was estimated to produce 252.74 and 111.57 t/ha of above and below-ground biomass, respectively, and biomass proportion in shoot to roots was 69 and 31%, respectively (Tamai*et al.*, 1986). In a similar study, Gong and Ong (1990) reported that the above and below-ground biomass of *R. apiculata* (DBH range 1.11 to 24.51 cm) in Matang Mangrove Reserve, Peninsular Malaysia were 185.30 and 17.20 t/ha, respectively. The biomass proportion in leaves, branches, stems, stilts roots and below-ground roots were 1.6-25.7%, 1.1-23.0%, 16.5-85.2%, 4.5-46.7% and 3.3-19.7% respectively. The above-ground biomass of *R. mucronata* (mean height 7.20, mean DBH 26.40, density 2200 stem/ha) in Erumathivu, Dutch bay, Sri Lanka was higher of 240 t/ha (Amarasinghe and Balasubramaniam, 1992a).

2.2.1.3 Stand Age

Stand age appears as an important determinant of standing biomass in mangroves. Different aged (5 to 25 years) planted *R. apiculata* in Matang Mangrove Reserve, Peninsular Malaysia showed wide range (16 to 300 t/ha) of above-ground biomass (Ong *et al.*, 1985a). But, Putz and Chan (1986) reported much higher range (270-460 t/ha) of above-ground biomass of *R. apiculata* in 80 years old mixed mangroves at Pulau Kecil, Matang Mangrove forest, Peninsular Malaysia. Sukardjo and Yamada (1992) estimated 93.73 t/ha of above-ground biomass of 7 years old planted *R. mucronata*in Tritih, Java, Indonesia.

2.2.1.4 Factors Influencing the Biomass Proportion in Plant Components

Different mangrove species showed different trends of biomass allocation in different components. The proportion of above and below-ground biomass of any species varies widely among the mangroves in the world due to the variation of environmental parameters (Clough 1992). The favourable environmental condition for mangrove growth in the tropical areas contributes to higher proportion of above-ground biomass. On the contrary, higher proportion of below-ground biomass was observed in the sub-tropical areas with increasing latitude (Clough and Attiwill, 1975; Suzuki and Tagawa, 1983; Gong and Ong, 1990; Steinke et al., 1995; Tam et al., 1995b).

Apart from the environmental factors, the biomass proportion in different components of mangroves species also depends on plant architecture (Turner et al., 1995). Tomlinson (1986) reported four different architectures of mangrove plants are found such as Attim's model (*Rhizophora* and *Lumnitzeraracemosa*), Rauh's model (*Xylocarpus* and *Heritiera*), Pettit's model (*Avicennia, Sonneratiaand Lumnitzeralittorea*) and Aubreville's model for large flowered *Bruguiera* spp. (*B. gymnorrhiza*). Each of the above plant architectural models varies considerably in their canopy structure and even the same species vary in their branching complex at different stages of development (saplings and trees) (Tomlinson, 1986).

Diameter at breast height (DBH) has shown considerable influence on biomass proportion in above-ground components of different mangrove species. Clough and Scott (1989) studied the above-ground biomass of different mangrove species with DBH range from 5 cm to 25 cm in north-eastern Queensland, Australia. They reported that different species showed different patterns of biomass distribution with their above-ground components and significantly varied with DBH classes. The ranges of biomass proportion in leaf, branch and stem of *B. gymnorrhiza* were 3.20-23.10%, 9.50-25.80% and 51.10-85.30%; for *B. parviflora* 1.60-3.50%, 3.50-15.90% and 82.20-96%; for *C. tagal* 3.70-4.9%, 13.20-24.70% and 71.40-83.20%; for *R. apiculata* 1.70-6.20%, 9-18.20% and 57.90-73%; and for *X. granatum* 4-7%, 12.80-41.70% and 53.90-83.20%, respectively.

2.3 Biodiversity and Biomass of Mangrove

The term "mangrove" refers to a group of taxonomically heterogeneous woody shrubs and trees growing in the intertidal zone of tropical and subtropical coasts. Worldwide there are 114 species of true mangroves belonging to 66 genera with species richness being greatest in the Indo-Pacific region (Tomlinson 1986). Recently their distribution has expanded to some temperate regions (Krauss et al.2008). The multi-species floristic pool in the Indo-Pacific (with around 60 species) has greater physical stability and ecological resilience than the Atlantic Coast mangroves (Blasco et al. 1996). The mangrove physical environment can be characterized by relatively high salinity and temperature, diurnal tidal inundation, occasional storms, and muddy anaerobic soil. High salinity in mangrove soils can be a limiting factor for many mainland species subsequently reducing the competition (Kathiresan & Bingham 2001; Kathiresan 2005; Lacerda et al.2002).

Mangrove communities are characterized by high productivity, high biomass and litter production (Alongi 2009; Boto & Bunt 1981; Mann 1982; Odum & Heald 1972). The structure and productivity of mangrove ecosystems are significantly affected by climatic conditions resulting in geographical variations in biomass and primary production. Productivity appears to decrease with latitude but is enhanced with increase in tidal amplitude (Woodroffe et al.1988) and the greatest structural and floristic diversity is observed in the tropics (Bray & Graham 1964). Snedaker (1978) suggested that the value of mangroves is largely based on the production of organic matter as leaf litter that enters the estuarine system where it forms the basis for a complex food web. Mangroves provide a plethora of goods and services, ranging from coastal protection from storm and erosion to income for human society (Krauss et al.2008). Mangrove ecosystem services play a crucial role in the maintenance of biodiversity, waste assimilation, cleansing, recycling, and renewal, as well as in protecting coastal areas from disturbance events (Alongi 2008; Dahdouh-Guebas et al.2005; Hussain & Badola 2010; Vo et al.2012). Globally, mangroves are generally undervalued, overexploited, and poorly managed (Ewel et al.1998) as evidenced by destruction of 35 % of world mangrove forests by human activities over last two decades (Alongi 2002; Valiela et al.2001).

2.4 Carbon Stock

The quantity of carbon in a "pool", meaning a reservoir or system which has the capacity to accumulate or release carbon is known as carbon stock. It includes above ground, below ground, dead wood, litter and soil carbon. Carbon in all living biomass above the soil, including stem, stump, branches, bark, seeds, and foliage include in above ground carbon. Carbon in all living biomass of live roots include in below ground carbon. Carbon in all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil include in dead wood biomass carbon. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country. Carbon in all non-living biomass with a diameter less than a minimum diameter chosen by the country in various states of decomposition above the mineral or organic soil known as litter carbon. This includes the litter, fumic, and humic layers. Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series is known as soil carbon (IPCC, 2003).

2.4.1 Carbon Stock of Mangrove

The coastal zone (<200 m depth), covering ~7% of the ocean surface (Gattuso et al., 1998) plays an important role in the oceanic carbon cycle. Various estimates indicate that the majority of mineralization and burial of organic carbon, as well as carbonate production and accumulation takes place in the coastal ocean (Gattuso et al., 1998; Mackenzie et al., 2004).

Mangrove trees are found along tropical and subtropical coasts and are the only known woody halophytes. A part of their productivity may flow into adjacent ecosystems, or conversely, they may receive organic materials from estuarine or oceanic ecosystems (Ong, 1993; Kristensen et al., 2008). The contemporary understanding of the global warming phenomenon, however, has generated interest in the carbon-stocking ability of mangroves in recent time. The carbon sequestration in this halophyte is a direct function of biomass production capacity (Mitra et al., 2011a; Banerjee et al., 2013; Sengupta et al., 2013).

2.4.2 Source of carbon in mangrove

The relevant carbon sinks to be considered are: The burial of mangrove carbon in sediments locally or in adjacent systems. Therefore, carbon accumulation is not necessarily all derived from the local production by mangroves (tree roots, stems, leaves, branches twigs etc); organic matter can be brought in during high tide and can originate from rivers, or from adjacent coastal environments. The quantity and origin of carbon in mangrove sediments appear to be determined to a large extent by the degree of openness of mangroves in relation to adjacent aquatic systems (Kristensen, et al, 2008).Seedlings and herbs are generally negligible for measurement of carbon pools in a mangroves ecosystem. Litter is a small component of the total ecosystem carbon stock and therefore not usually sampled. If it is measured, the total oven-dry mass must be scaled to a per-hectare estimate. Mean carbon concentrations of tropical forest leaf litter have been reported as 38–49% (Kauffman et al., 1993, 1995). The availability of nutrients to mangrove plant production is further controlled by a variety of biotic and abiotic factors such as tidal inundation, elevation in tidal frame, soil type, redox status, microbial activities of soil, and plant species (Reef et al., 2010).

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

I) **Terrestrial sequestration:** In this way CO_2 is absorbed by soil and vegetation near the earth's surface. Absorption of CO_2 can be increased through planting trees, mitigating deforestation, or adjusting forest management practices. It is the most popular and fast option for carbon sequestration at the present time.

II) **Oceanic sequestration:** Here CO_2 is buried into the deep ocean basins (350-3000 meters) at the form of liquid, supercritical, or solid hydrates.

III) **Geologic sequestration:** It is the injection and storage of greenhouse gases underground, out of contact with the atmosphere. E.g. oil and natural gas fields or deep natural reservoirs filled.

2.4.3 Carbon Stock Estimation Method

Over the years, forest ecologists have developed various methods to estimate the biomass of forests. Three main methods have been developed for estimating forest biomass: the harvest method, the mean-tree method, and the allometric method. In a mature mangrove forest, the total weight of an individual tree often reaches several tonnes (Komiyama et al., 2005). Therefore, the harvest method cannot be easily used in mature forests and in itself is not reproducible because all trees must be destructively harvested. The mean-tree method is utilized only in forests with a homogeneous tree size distribution, such as plantations. The allometric method estimates the whole or partial weight of a tree from measurable tree dimensions, including trunk diameter and height, using allometric equations based on field measurements. This is a nondestructive method and is thus useful for estimating temporal changes in forest biomass by meansof subsequent measurements. However, the site and species-specific dependencies of allometric equations pose a problem to researchers because tree weight measurement in mangrove forests is laborintensive (Komiyama et al., 2008).

3 Materials and Methods

3.1 Study area

The Sundarbans Reserve Forest is the largest single block of tidal halophyticmangrove forest in the world. About 60% of the Sundarbans is comprised within Peoples Republic of Bangladesh and the rest 40% constitute the Indian Sundarban in the State of West Bengal. The Sundarbans (21°30'- 22°30'N, 89°12'-90°18'E) belong to Bengalian Rainforest biogeographical province.

The total area of the Bangladesh section of Sundarbans is 595,000 hectares (ha) of which 139,699ha are protected as follows: Sundarbans West Wildlife Sanctuary with 71,502ha; Sundarbans East Wildlife Sanctuary with 31,226 hectares; and Sundarbans South Wildlife Sanctuary with 36,970ha. The Sundarbans, covering some 10,000 square kilometers of land and water, is part of the world's largest delta (80,000sq.km) formed from sediments deposited by three great rivers, the Ganges, Brahmaputra and Meghna, which converge on the Bengal Basin (Encyclopedia of earth, Sundarban, Bangladesh). Rainfall is heavy and humidity high (80%) due to the proximity of the Bay of Bengal. About 80% of the rain fall in the monsoon, which lasts from June to October. Mean annual rainfall varies from about 1,800 millimeters (mm) at Khulna, north of the Sundarbans, to 2,790mm on the coast (Christensen B. 1984).

Fig 3.1: Study Area in Sundarbans

The mangroves of the Sundarbans are unique when compared to non-deltaic coastal mangrove forest. The Rhizophoraceae are of only minor importance and the dominant species are sundry (*Heritiera fomes*), and gewa (*Excoecaria agallocha*).

This study was undertaken at Kolaghachia area of Sundarbans.

3.2 Sampling and data collection

Sample plots was taken by applying systematic sampling through transect line. All trees will be identified and tagged within the plots. Diameter at breast height (DBH) of trees will be measured and recorded inside the plots, while DBH<4 cm are considered as saplings. Height of the trees also will be measured and recorded.

3.3 Species diversity

In this study two methods for species diversity and similarity (Shannon-Weiner Index and Simpson's Index) was used for calculating species diversity.

Shannon-Weiner Index:

$$H' = -\sum P\square \ln P\square$$

Where pi = the proportion of individuals in the ith species.

Simpson's Index:

$$\text{Ds} = \frac{N(N-1)}{\sum n\square(n\square - 1)}$$

Where N the total number of individuals of all species, n_i the number of individuals of species i.

3.4 Vegetation Structure

Density, relative density, frequency and relative frequency, mean DBH, basal area, relative dominance and importance value index of saplings and trees were calculated from the relationship given by Cintron and Novelli (1984). The equations are as follows,

$$\text{Density (stem/ha)} = \frac{\text{Total number of individual stem}}{\text{Plot area (ha) x Number of sample plots}}$$

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Total number of individuals}} x100$$

$$\text{Frequency (\%)} = \frac{\text{Number of plots where individual species are present}}{\text{Total number of plots}} x100$$

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Sum - frequency of all species}} x100$$

$$\text{Basal area per hectare } (m^2) = \frac{\text{Total basal area of individual species } (m^2)}{\text{Sample plot area (ha) x Number of sample plots}}$$

$$\text{Mean DBH (cm)} = \sqrt{\frac{\text{Mean basal area per stem of individual species } (cm^2) \text{ x } 4}{\pi}}$$

Mean Height = Total height (m) of all stems in the sample plot/ Number of stems in the sample plots area

$$\text{Relative dominance (\%)} = \frac{\text{Total basal area of a species } (cm^2)}{\text{Basal area of all species} (cm^2)} x100$$

Importance value index (IVI) = Relative density + Relative frequency + Relative dominance

3.5 Biomass

3.5.1 Above-ground biomass

BDH of each tree was used to estimate the above-ground biomass of trees of the study site. The formula for the estimation of biomass is as follows:

$W = 0.251 \rho D^{2.46}$ (Komiyama et al. 2005)

Where, ρ is wood density ($t\ m^{-3}$) and D is DBH (cm) of the species.

3.5.2 Below-ground biomass

The pitch method was adopted for the below-ground biomass estimation. One pit of 50×50×50cm will be dug in the center of 10×10m plot within the study area. All soil of each pitch was collected with roots and roots was sorted and washed. Fresh weight of root was measured in the field and representative subsamples were taken to the laboratory where they were oven dried to constant weight. The total weight was calculated from the ratio of fresh to oven-dry weight.

3.5.3 Litter standing crop

Litter standing crops were collected from sub-sample plots (1 x 1 m) of main plots. All the litter on the forest floor in the sub-sample plots were collected separately and brought back to the laboratory for further analysis. The collected litter standing crops were washed and oven-dried at 80°C until constant weight.

3.6 Soil sampling

Soil sample were collected at 4 different depths (10 cm, 20 cm, 30 cm and 50 cm) by using 5cm stainless steel core sampler. Similarly, bulk density was also measure at the said depth using metal core method (Black, 1965). Bulk density was measured by using following formula:

Bulk density = Oven dry weight of the soil sample / Volume of the cylinder (g/m^3)

= Oven dry weight of the soil sample / $\pi r^2 l$ (g/m^3)

Here, r = radius of the cylinder (m), l = height of the cylinder (m) and π = constant

3.7 Processing of soil sample and plant parts

The collected root samples were oven dried at 80°C until constant weight. The collected soil samples were air-dried. The dried samples of plant parts and soil were crashed and sieved through 2 mm mesh size for carbon analysis (Allen, 1974).

3.8 Determination of Organic Carbon (C)

Loss on Ignition (LOI) method was used to determine the organic matter content (%OM) of a soil sample. It does not involve the use of any chemicals, only the use of a muffle furnace. LOI calculates %OM by comparing the weight of a sample before and after the soil has been ignited. The difference in weight before and after ignition represents the amount of the OM that was present in the sample. The subsample taken for carbon analysis was put on the porcelain crucibles samples can then be placed in trays to be oven dried at 105°C for 5 days. Then the oven dried weight of the samples was measured. For LOI we used 24 porcelain crucibles in a muffle furnace for 12 samples at a time. Then the sample was ignited with 500°C within the muffle furnace. The following equation developed by Bengtsson and Enell 1986, was used to compute the % OM.

$$\%OM = ((DW_{105}°C - DW_{550}\ °C)/DW_{105}°C) \times 100$$

Then, Soil carbon stock was calculated by using the equation given by Daniel et al. 2009 for each plot.

Soil C (Mg/ha) = bulk density (g/m^3) × soil depth interval (m) × % OC × 0.01 (Daniel et al. 2009)

4 Results and Discussion

4.1 Species richness, diversity and evenness

In this mangrove stand total 12 species was found which belonged to 11 genera and 8 plant families (Table 1). In seedling stage 7 species was found belonged to 7 genera and 6 plant families. In sapling stage 10 species was found belonged to 9 genera and 6 plant families and in tree stage 7 species was found belonged to 7 genera and 6 plant families. That means some species are not found in mature stage. They are not able to survive because of competition among species. This competition may be for nutrient, sunlight or space.

Table 4.1: Consolidated details of quantitative plant biodiversity

Parameter	Tree	Sapling	Seedling	Total
Species richness	7	10	7	12
Number of families	6	6	6	8
Number of genera	7	9	7	11
Diversity indices				
(1) Shannon-Weiner	1.1052	1.2437	1.2727	
(2) Simpson	2.1185	2.7099	2.5106	
Stand density (no ha^{-1})	1416	7563	33684	
Stand basal area (m^2 ha^{-1})	16.44			

The Shannon-Weiner index shows that diversity of seedling was higher than sapling and tree. And diversity of sapling was higher than tree. On the other hand Simpson index shows that diversity of sapling was higher than other two stages then seedling then tree. This is a clear indication that in seedling stage there is more diverse species composition is found when compared to other stage. When a stand goes in mature stage through seedling and sapling stage some species are eliminated because of competition.

4.2 Species-area curve

Species-area curves for tree, sapling and seedling show that when area increase then more species are found. For tree almost all species were found within 600 m^2 area. For sapling this area was about 1000 m^2 and for seedling this area was about 1500 m^2.

So that for tree, highest diversity of species is found within 600 m^2 area and no new species is found for further area increasing. And this is also true for sapling and seedling for 1000 m^2 and 1500 m^2 area.

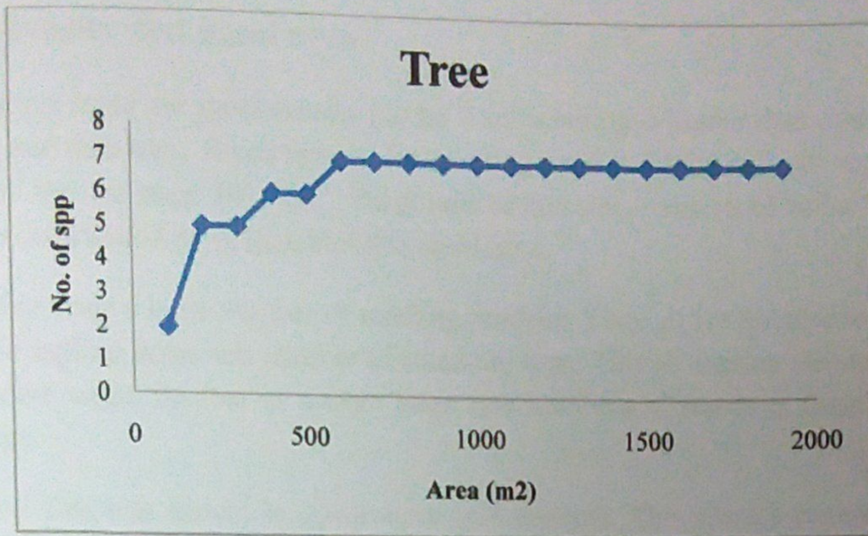

Fig 4.1: Species-area curves (Tree)

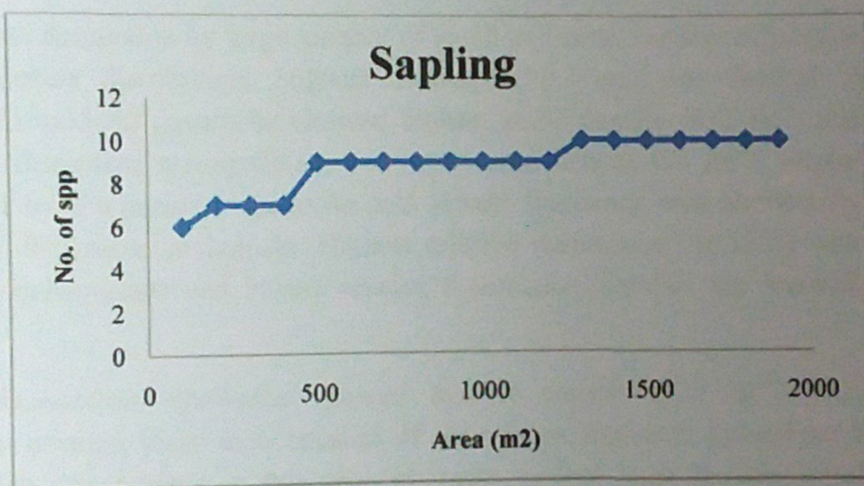

Fig 4.2: Species-area curves (Sapling)

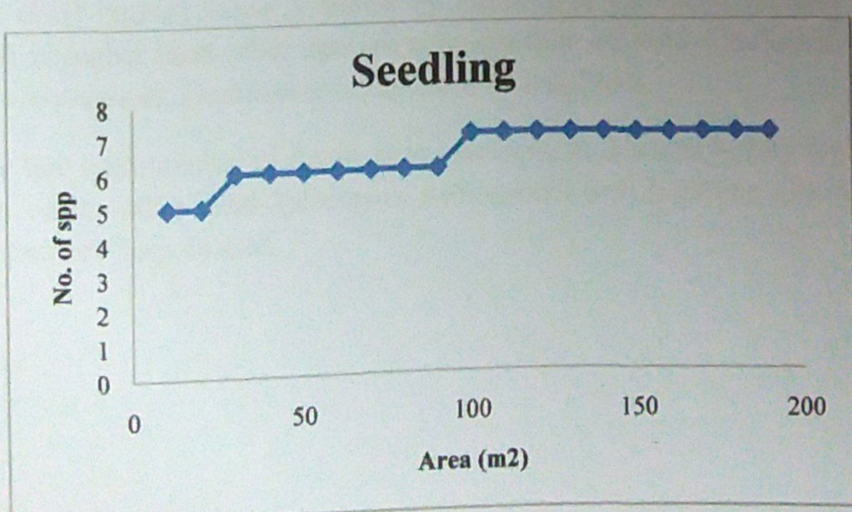

Fig 4.3: Species-area curves (Seedling)

4.3 Stand density and basal area

In this mangrove stand the stand density (no ha^{-1}) for seedling is higher than other two stages, then sapling and then tree. Stand density for seedling stage is 33684 ha^{-1}, for sapling stage is 7563 ha^{-1} and for tree stage 1416 ha^{-1}. Basal area of this stand was 16.44 m^2ha^{-1}. *Xylocarpus mekongensis* contributed more than half this basal area.

In regeneration stage a large number of seedling produce. They all are not able to survive. For this reason in sapling stage less number of stand are seen. This all sapling also are not able to reach in mature stage. So that in mature stage few numbers of stands is found compare to seedling stage.

Highest basal area was shown by *Xylocarpus mekongensis.* This species covered large area than other species. Diameter of this species is more or less high than other.

4.4 Vegetation structure

The forest was dominated by large number of small and small number of large trees showing various diameters distribution. Highest diameter (56.2 cm) was showed by *Avicennia officinalis. Excoecaria agallocha* showed highest stand density (932 ha^{-1}) and *Sonneratia apetala* and *Bruguiera sexangula* showed loyes stand density (21 ha^{-1}). Highest frequency was showed by *Excoecaria agallocha* and lowest frequency was showed by *Sonneratia apetala* and *Bruguiera sexangula.* Highest relative dominance (46.18%) was showed by *Xylocarpus mekongensis* and lowest relative dominance (0.48%) was showed by *Ceriops decandra.*

Although *Excoecaria agallocha* showed highest density (932 ha^{-1}) but *Xylocarpus mekongensis* covered more area because of their large diameter. *Xylocarpus mekongensis* species which was present in this area are more or less large in size. Total number of *Excoecaria agallocha* is higher than other but their diameter is less and they are small tree in size. So that they cover less area than *Xylocarpus mekongensis.* If we consider importance value index (IVI) highest value is shown by *Excoecaria agallocha* because their relative density (RF) is higher than other species although their relative dominance is lower than *Xylocarpus mekongensis.* Dominance is depended on basal area.

So it is clear that total number of *Excoecaria agallocha* in this area is very high but they are small in size on the other hand *Xylocarpus mekongensis* and *Avicennia officinalis* is few in number but they are large in size.

Table 4.2: Mean values of relative density (RD), relative frequency (RF), relative dominance (R Do), and importance value index (IVI) of mangroves.

	Species	RD	RF	Rdo	IVI
Tree	*Avicennia officinalis*	2.6	8.89	16.17	27.66
	Sonneratia apetala	1.49	4.44	11.47	17.4
	Xylocarpus mekongensis	18.59	26.67	46.18	91.44
	Aegiceras corniculatum	6.32	13.33	1.67	21.32
	Excoecaria agallocha	65.8	33.33	21.21	120.34
	Bruguiera sexangula	1.49	4.44	2.82	8.75
	Ceriops decandra	3.72	8.89	0.48	13.09
Sapling	*Bruguiera sexangula*	0.14	1.89		
	Aegiceras corniculatum	22.89	15.1		
	Excoecaria agallocha	12.94	26.42		
	Kandelia kandle	0.56	5.66		
	Ceriops decandra	54.21	22.64		
	Derris trifoliate	0.14	3.77		
	Heritiera fomes	0.84	13.2		
	Rhizophora apiculata	0.07	1.89		
	Rhizophora macronata	7.93	5.66		
	Avicennia officinalis	0.28	3.77		
Seedling	*Excoecaria agallocha*	6.25	9.09		
	Acanthus ilicifolius	7.81	13.64		
	Derris trifoliate	1.56	4.55		
	Kandelia kandle	6.25	4.55		
	Ceriops decandra	62.5	50		
	Heritiera fomes	3.13	4.55		
	Aegiceras corniculatum	12.5	13.64		

4.5 Biomass

Among trees above ground biomass was highest for *Xylocarpus mekongensis* and lowest for *Ceriops decandra* although the hihgt wood density was for *Bruguiera sexangula.* Total above ground biomass of this area was 143.38 t ha^{-1}.

Highest density was shown by *Excoecaria agallocha* but they didn't produce higher above ground biomass. So it is important to present various species for higher biomass production. If this stand consists only *Excoecaria agallocha* then total biomass production become low. So there is a strong relationship between biodiversity and biomass.

Fig 4.4: Above ground biomass of mangroves.

Among three pit highest below ground biomass was for pit-3. But among three pits the difference of below ground biomass was very low. Total below ground biomass of this area was 61.04 t ha^{-1}.

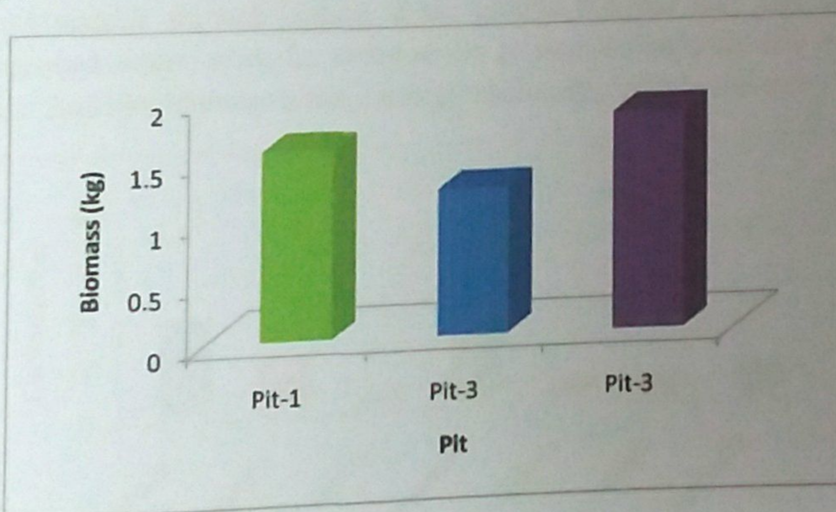

Fig 4.5: Below ground biomass of different pits.

Litter standing crops of this area was 0.805 t ha^{-1}. Finally total biomass of this stand was calculated 205.22 t ha^{-1}.

Although above ground biomass is very high but in total biomass production below ground biomass takes a large amount. Litter standing biomass is very low when compare to others.

Table 4.3: Overall biomass of this stand

	t/ha
Above ground biomass	143.38
Bellow ground biomass	61.04
Litter standing crops biomass	0.805
Total	205.22

4.6 Carbon Stock

The stored carbon in above ground biomass was 71.69 t ha^{-1}. Among trees the highest stored above ground carbon was for *Xylocarpus mekongensis* and lowest stored above ground carbon was for *Ceriops decandra.*

Xylocarpus mekongensis showed highest above ground biomass and they also stored the highest above ground carbon store. So stored above ground carbon is directly related to above ground biomass. And like biomass it has a strong relationship with biodiversity.

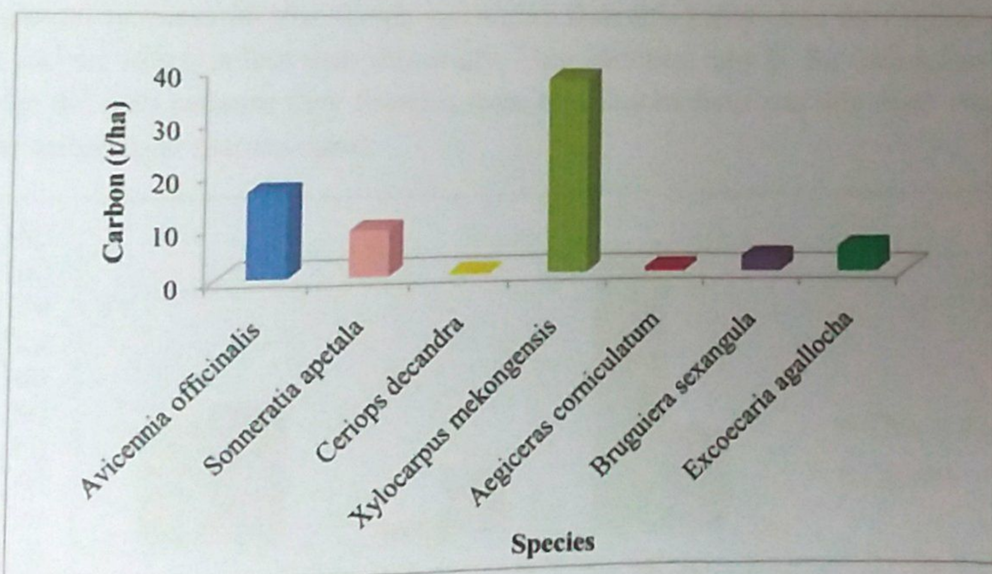

Fig 4.6: Above ground carbon of mangroves.

The below ground carbon stock of this area was 0.1008 t ha^{-1} and litter standing carbon stock of this area was 0.3328 t ha^{-1}. Soil stored a large quantity of carbon in this mangrove stand. Soil stored in this forest stand 203.16 t ha^{-1} carbon. The total amount of stored carbon in this mangrove stand was 275.29 t ha^{-1}.

Soil contain highest amount of carbon. Soil stores this carbon from dead material and environment. Carbons of living tree also one day go into soil. So large amount of above ground biomass can be make a soil with large carbons.

Table 4.4: Carbon Pool of this stand

Carbon Pole	t/ha
Litter standing crop	0.333
Bellow ground	0.101
Above ground	71.689
Soil	171.634
Total	**243.757**

4.7 Comparison with Other Study

4.7.1 Comparison with Collaborative REDD+IFM Sundarbans Project (CRISP)

Collaborative REDD+IFM Sundarbans Project (CRISP) which conducted by Nisorgo Network gave a report in 2011. Where they found total above ground biomass 82 t/ha and bellow ground biomass 36 t/ha which are higher than this study. And they found total 59.77 t/ha soil carbon which is less than this study. This variation may be for estimation method or may be for the area because they found it from total Sundarbans and this study was done in a particular saline zone mature stand.

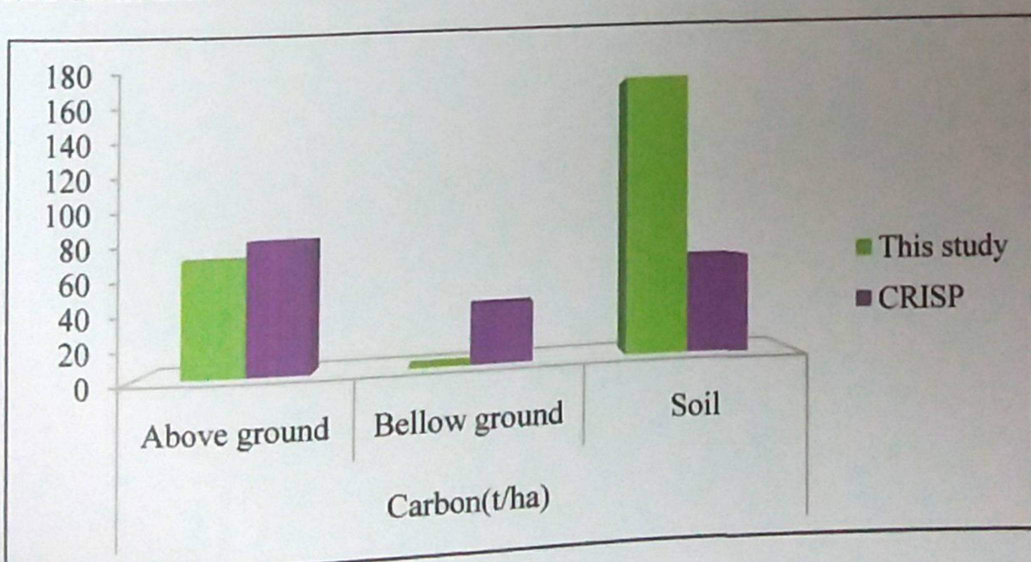

Fig 4.7: Comparison with Collaborative REDD+IFM Sundarbans Project (CRISP)

4.7.2 Comparison with a natural mangrove in Palawan, Philippines

A study was done on a natural mangrove in Palawan, Philippines to estimate biodiversity, biomass and carbon stock (Abino et al. 2014). Where they found above ground biomass 561.2 t/ha, bellow ground biomass 196.5 and above ground carbon 263.8 t/ha, below ground carbon 92.3 t/ha which are higher than this study. On the other hand they found 173.8 t/ha soil carbon which is about similar to this study. The variation may be for different estimation method or may be for environmental condition or may be for different vegetation structure.

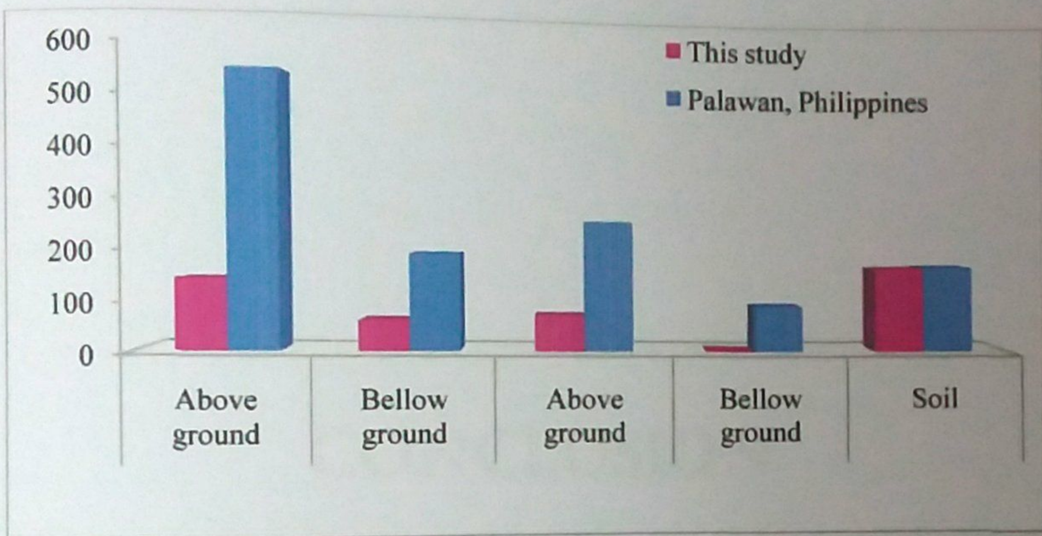

Fig 4.8: Comparison with a natural mangrove in Palawan, Philippines

5. Conclusion

This study shows species diversity in seedling, sapling and tree stage of a mature mangrove stand. In seedling stage species diversity is higher than sapling and tree stage. Tree shows lowest species diversity and sapling shows medium species diversity.

This study also gives a clear idea about vegetation structure and species composition of this mature stand. Stand density also higher in seedling stage and lower in tree stage. That's mean large number of seedling produce but they all are not able to survive and not reach in tree stage.

Biomass of a stand depends on biodiversity. Divers stand produce more biomass than homogenous stand. Only the large number of trees can not give highest biomass. It also depends on diameter of species that means the size of tree. Below ground biomass also takes a vital part of total biomass.

Soil contain highest amount of carbon in per hector area. Above ground carbon also take a greater part of total carbon stock which directly related to above ground biomass. Like above ground biomass above ground carbon has a strong relationship with biodiversity.

The information generated from this study will serve as a baseline for mangrove forest management and further research.

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