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DECLARATION

I, Abdullah Al - Imran, declare that this undergraduate thesis is the result of my own works and that it has not yet been submitted or accepted for a degree in any other University/Institute.

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DEDICATED

TO

MY BELOVED PARENTS

ACKNOWLEDGEMENT

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ABSTRACT

Global warming and its effect on the earth are the recent most concerning global issue. Carbon emission by excessive burning of fossil fuel and forest degradation is considered as the key factor for global warming that's caused by increasing the atmospheric carbon dioxide. There is no alternative to reduce these effects except planting trees and stopping forest degradation. Roadside plantation under participatory management in southwestern Bangladesh plays a vital role in carbon sequestration and can contribute to REDD+. Moreover it is enhancing local livelihood and protects the adverse effect of global warming. In this research floristic composition and carbon stocks in three southwestern district (Satkhira, Jhenaidah and Narail) are studied. All woody plants with dbh $\geq$ 2 cm were identified and their diameters measured in 26 systematically selected zigzag plots of equal size (2×10 m). The previous study was performed in 2011 in same plot. This study assessed that high carbon is sequestering in strip plantation over last five years. Out of the recorded 16 species of 7 families, the most common species *Acacia nilotica* (Babla), *Leucaena leucocephala* (Ipil-Ipil) and *Dalbergia sissoo* (Sissoo) together constitute three-fourth of total population. Leguminosae accounted for 79% of species and 85% of total estimated carbon stocks. Out of total carbon stocks, *Acacia nilotica* (Babla) holds highest amount of carbon (49%). It was estimated a mean stem density of 3673 ha^{-1}, basal area of 106 m^2 ha^{-1} and diameter of 18.42 cm. The mean increased biomass carbon according to allometric equation is about 313 Mg ha^{-1} and according to Linear equation is about 206 Mg ha^{-1}. The study assessed that carbon stocking significantly increased over last 5 years (2011-2016). Roadside plantation under participatory management is very effective for mitigating atmospheric CO_2 and at the same time it also supports the livelihood of local people.

TABLE OF CONTENTS

List of Acronyms

BRTA	Bangladesh Road Transport Authority
CB	Carbon Biomass
CBD	Convention on Biological Diversity
CO_2	Carbon-di-Oxide
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
GPS	Global Positioning System
IPCC	International Panel on Climate Change
MGD	Millennium Development Goals
NGO	Nongovernmental Organization
REDD+	Reduced Emissions from Deforestation and Degradation
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Conference on Climate Change
USDA	United States Department of Agriculture

List of Tables

List of Figures

List of Figures

CHAPTER 1
INTRODUCTION

1.1 Background and justification of the study

Carbon dioxide (CO_2) is the most dominant greenhouse gas that is increased by fossil fuel combustion and rapid deforestation worldwide (Hamburg et al., 1997). Trees sequester carbon from the atmosphere through photosynthesis (Ferrini et al., 2011), extracting carbon dioxide from the air, separating the carbon atom from the oxygen atoms, and returning oxygen to the atmosphere. In doing so, trees sink a tremendous amount of carbon in their structures, and annual growth increases the carbon stored within the structure (Kiran and Kinnary, 2011). Carbon sequestration through forest activity has considerable potential to generate low-cost sequestration alternatives, especially in certain developing countries (Waran, 2001). Roadside plantation plays an important role in carbon sequestration. Roadside trees provide long and diverse benefits like aesthetic beauty, a range of psychological, social and economic benefits for residents including lowering of obesity, higher property values, reductions in asthma levels and overall betterment in human well-being and community vitality (Wetter et al., 2000; Maco and McPherson, 2003; Dumbaugh, 2005; Wolf, 2005). In decreasing urban temperature and reducing the intensity of urban heat, roadside tree plays vital role (Chow and Roth, 2006), thus reducing electricity uses (McPherson et al., 1997, Maco and McPherson, 2003). Roadside trees act as air purifier, noise filter and carbon sequester (Nagendra and Gopal, 2010). Besides the proximity of these trees to traffic and constant higher amount of atmospheric pollutants, roadside trees are able to sequester greater amount of particulate matter, CO_2 and ozone (McPherson et al., 1997, Beckett et al., 2000).

The world's scientists and policy makers emphasis on two important and currently most debated issues, one is global warming and another is biodiversity loss (Zhang et al., 2011) that is caused by increasing the emission of greenhouse gases (mainly CO_2) at the atmosphere mostly due to anthropogenic activities (Sharma et al., 2010). At a rate of 3.5 Pg (Pg = 1015 g or billion tons) per annum carbon is accumulating in the atmosphere, the major proportion of which resulting from the burning of fossil fuels and deforestation during the last few decades (Vander Werf et al., 2009; Paustian et al., 2000). The annual average increase of CO_2 concentration in the atmosphere is about 1.5 ppm (IPCC, 2001) and increasing amount of atmospheric CO_2 from 1906-2005 caused the increase of average global temperature by

0.74^{0}C (UNFCCC, 2007). There is an estimation that if global warming continue and accelerate, the earth could warm by (2-4)^{0}C by 2100 and the global sea level will rise by 28–98 cm due to melting of polar (IPCC, 2013). The sea level rise can alter the existence and livelihoods patterns of low-lying coastal countries like Bangladesh, Maldives, and Netherlands etc. (Rahman et al., 2015). Different afforestation and reforestation programs in tropical area can play a vital role to mitigate the global climate change through sequestering the atmospheric carbon (Dixon et al., 1994a, b; Jose, 2009; Kumar, 2011).

To mitigate the CO_2 buildup in the atmosphere increasing the amount of the global terrestrial carbon sink is one of the main strategies (Kumar, 2011). According to the Kyoto Protocol's Article 3.3, A and R (Afforestation and Reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases (Kundu, 2013). In a managed landscapes, forest vegetation potentially provides stable biodiversity, fodder, firewood and perhaps more importantly the potential for carbon sequestration (Dixon et al., 1994a; Henry et al., 2009; Jose, 2009). Roadside trees are unique in this case. In tropical forests, carbon storage depends largely on species composition (Bunker et al., 2005) and thus there may exist a close relationship carbon storage and biodiversity (Henry et al., 2008). However the removal capacity of greenhouse gases or carbon sequestration of forest varies considerably depending on a number of factors including species, vegetation type and site location, age etc. (Laffoley and Grimsditch, 2009). So it is essential to have data on tree distribution including species composition, size and age structure and spatial inventories for more effective and long term management of roadside trees (Nagendra and Gopal, 2010). But in many developing countries, forest managers in charge of maintaining roadside tree populations have lack of information on street trees including basic data such as city street surveys (Escobedo et al., 2006; Alvey, 2006; Jim and Chen, 2008).

1.2 Objectives

i. To investigate the floristic composition in the roadside plantation of three southwestern districts (Satkhira, Jhenaidah and Narail).
ii. To determine the amount of carbon stored in woody vegetation.
iii. To compare species composition, structure and carbon between this study and previous study (Rahman et al., 2015).

1.3 Scopes

i. The Kyoto Protocol of the UNFCCC has introduced Clean Development Mechanism concept among the low-income people who can store carbon through change in their land uses. It is normally known as carbon trade mechanism. This research will improve knowledge base necessary for country negotiations in the carbon trade mechanism. This serves to increase sinks for carbon while at the same time improving livelihoods of low-income people.

ii. Under REDD+, developing countries that are effectively protecting their forests through conservation and enhancement of forests carbon stocks will be eligible for carbon payments. Thus community based carbon finance project will insure three benefits- biodiversity conservation, climate change mitigation and livelihoods sequrity. Finally it will fullfil Government's three international treaties like the CBD, Kyoto Protocol and MDG.

iii. This research will provide some basic data such as roadside tree survey with their height and DBH. This will help the forest officers in charge of maintaining roadside plantation for proper management of roadside plantation.

iv. This research will help and make people more conscious to planting trees in the roadside as well as strip plantation.

CHAPTER 2
LITERATURE REVIEW

2.1 Concept of roadside plantation

Roadside plantation is a one kind of strip plantation that is established on relatively narrow areas on the sides of highway roads, railways, embankment of rivers etc. Physical conditions and characteristics of roadside plantation are varied from site to site. It depends on the factors like situation of the land, width of the strip and also the needs and aspirations of the people (Kundu, 2013). They are normally raised by the forest department with or without the participation of the non-government organization and poor people. According to Bhuiyan (1993), Bangladesh has about 4500 km of highway roads, 16000 km of district council road, 10500 km of thana and union porisad road, 2900 km of railroads, 560 km of river and coastal embankments and about 2 million big and small tanks with high banks. At present Bangladesh has total 2,855 kilometers railroad and total 20,947.73 km road of which 3544.06 km is national highway, 4278.07 km is regional highway and 13,247.79 km is zilla road (Wikipedia, 2013). These lands are not actually put to any major land uses but are necessary to support the land put to main trees (Huq and Alim, 1995). These lands have limitation for uses other than tree plantation and specialized agroforestry or silvopasture. Local needs and site condition normally governs the choice of species. However for sustained income of the beneficiary's production of food, forage, timber and fuel are as far as possible integrated (Huq and Alim, 1995). Thus multipurpose species under the prevailing technology, ecology, socioeconomic and cultural context should be of high priority.

2.2 History of roadside plantation in Bangladesh

In British colonial period, the British government take initiatives for avenue or roadside plantation in the present Bangladesh in eighteen century. This plantation was done only the purpose of beautification. The Pakistan government also continued this program in the urban area for scenic beauty. This plantation program bounded in the national highways and unban roadsides. With the passage of time, increasing population and reduced forest resources with throughout the country, this plantation program was the activity of the concerned government body for the production of wood (Kundu, 2013).

In Bangladesh, local people and government joint forest management has been practiced since 1976. Some pilot projects were taken in 1982-1989. In 1982, Bangladesh Forest Department launched the Community Forestry Project that ended in 1989 with the financial assistance from ADB and UNDP. FAO was the co-operative agency in this project. Roadside plantation was one of the major components of this project. A total 0f 4800 km zilla and union parishad roads, highways, railways and canal bank were taken under the project. Plantation targets were fully achieved (Bhuiyan, 1993). This projects provided the experience of countrywide participatory plantation program that can be a tool of reducing degradation and deforestation for the country (Kabir and Webb, 2005). Raising the supply of forest products like fuel wood, timber, non-timber forest products etc., improve the socioeconomic condition of the rural people, restore the environmental degradation, conserve the soil and watershed are the basic objectives of participatory forest management in Bangladesh. Form the beginning, about 48,420 ha of roadside plantations, 30,666 ha of woodlots and 8778 ha of agroforestry plantations have been developed in Bangladesh (Jashimuddin and Inoue, 2012). The surrounding landless people, poor villagers, tribal people, poor farmers, widows are the main targeted participants of roadside plantation. The participants willingly protect the plantation and get opportunities to take the intermediate products like fuel wood, branches, leaves, fruits etc. (Rahman et al., 2015). It also made provision for sharing tree crops harvested in the proportion of 10% to the land owing agency (BRTA), 10% to the forest department, 65% to the Participants and 5% to the union parishad (Day, 1996). The sharing percent is varied to roadside to woodlots. An evaluation done in June, 1994 showed that the project achieved 83% of its targets (GOB, 1995).

2.3 Species composition of roadside plantation

In roadside plantation there have wide variation in composition. Bangalore's street trees appear to have quite a healthy diversity, with the most dominant species constituting less than 10% of the total population, while the four most dominant species comprise about one-third of the population (Nagendra and Gopal, 2010). In Contrast to the USA, where the three most common species constitute almost two-thirds of the street trees in Syracuse (Sanders, 1981) or to Chicago where the four most common species comprise two-thirds of the entire population (McPherson et al., 1997). Species diversity also varies greatly from roadside plantation of one city to roadside plantation of another city. This is true not only for highly populated cities in the developing world but also cities like Mexico City where the four most common species constitute 49% of the trees (Chacalo et al., 1994) and to other highly populated Asian cities such as Bangkok, where one species *Pterocarpus indicus* constitutes over 40% of the trees (Thaiutsa et al., 2008) or Hong Kong, where the five most common species constitute over 50% of the total population (Jim, 1987).

Species composition and diversity in roadside plantation vary depending on the purpose of the tree (shade, fruit, seasonal color, windbreak), location of the planting site (overhead and/or belowground wires, existing utilities), size of tree (i.e. space to accommodate large, medium or small size trees), and existing soil conditions (depth, fertility and structure). In designing roadside planting for their aesthetic functions the trees must be selected for their form, size, texture and color (Zabala, 1991). According to Gilman (1997), for sites which have aboveground utility lines then selection of small species that will 'top out' at least 1.5 m below the wire are important or selection of a species with a narrow crown planted so that it will not grow into a utility line. Again different road categories can be expected to differ in the density, diversity, distribution and composition of street trees (Nagendra and Gopal, 2010).

Forest managers engaged in charge of maintaining roadside tree populations in many developing countries do not have the essential knowledge for appropriate species selection, care and maintenance (Chacalo et al., 1994). This is especially true, sadly, of many Asian cities despite the fact that these constitute some of the most densely populated parts of the world (Jim and Chen, 2008). The few Asian cities that have been studied in this regard mostly come from South East and East Asia, with very little published research from South Asia.

2.4 Carbon sequestration

Carbon sequestration refers to the capture and long term storage of carbon in forests and soils, so that the build-up of CO_2 (one of the principle greenhouse gases) in the atmosphere will reduce or slow (Carbon venture, 2011). 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. Carbon sequestration can be defined as the amount of carbon that can be additionally stored in an agro-ecosystem (Bernoux et al., 2006). 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 (UNFCCC, 2004). According to USDA Forest Service (2009), "Carbon sequestration is the process by which atmospheric CO_2 is taken up by trees, grass and other plants through photosynthesis and stored as carbon in biomass (trunks, branches, foliages and roots) and soils."

2.4.1 Types of carbon sequestration

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

i. Terrestrial sequestration or vegetative sequestration: Terrestrial sequestration is the natural intake of CO_2 by plants, which incorporate it in their wood, leaves, and 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 trees, mitigating deforestation or adjusting forest management practices. It is the easiest and most immediate option for carbon sequestration at the present time.

ii. Geologic sequestration: Geo-sequestration is burying the CO_2 deep within the earth. It can be done by the mechanical capture of CO_2 from an emissions source (e.g., a power plant) and the captured CO_2 is injected and sealed into deep rock units (Brown, 2010). The most suitable sites are deep geological formations, such as depleted oil and natural gas fields or deep natural reservoirs filled with saline water (saline aquifers).

iii. Oceanic sequestration: Oceanic sequestration is dumping the CO_2 into the oceans depths. Pumping CO_2 into the deep ocean basins (350-3000 meters), where it is anticipated it may form lakes of liquid, supercritical or solid hydrates.

2.5 Forest as a climate mitigation tool

Forest has an important role in the global carbon cycle (Pan et al., 2011) and forestry can contribute to climate change mitigation (TFD, 2008). There are two ways to reduce CO_2 concentrations in the air: (1) do not allowing CO_2 to enter the atmosphere (i.e., control emission or carbon conservation) and (2) removing some of the excess CO_2 already in the atmosphere and sequestering it where it does less harm (Brown, 2010).

2.5.1 Carbon conservation

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

2.5.2 Carbon substitution

The mechanism that produce high greenhouse gas can be substituted by forest products. Wood-based fuels such as fuel wood, charcoal, black liquor and ethanol can be used as substitutes for fossil fuels in heating, energy generation and transport. When wood is produced in forests under a sustainable forest management regime, it is effectively carbon-neutral. The production of goods made of steel, aluminum, concrete and plastic consumes large amount of energy and therefore causes significant greenhouse gas emission. The substitution of these products with sustainably produced wood products can therefore help reduce greenhouse gas emission (IPCC, 2015).

2.6 Carbon cycle in forest

Photosynthesis is a physiological process of plant that converts the nutrients into sugars and carbohydrates in present of sunlight. It is the only mechanism for making food for livelihood of the living organism. CO_2 is essential to building the organic chemicals that comprise leaves, roots and stems. The more photosynthesis is occurred, the more carbon dioxide is sequested as converting as biomass in plant tissue and belowground. Plants also respire, using oxygen to maintain life and emitting CO_2 in the process. In the whole life plants as well as forests sink carbon.

After tree vegetation dyeing, carbon release into atmosphere. This process of releasing carbon to the atmosphere is done very quickly as in firing or slowly fallen trees, leaves and other detritus decompose. The woody plants store carbon continuously until it dies or decomposes, but the herbaceous plants die annually and began to decompose and release carbon. This is the importance of carbon cycle for accumulation of net carbon by the forest and release carbon when vegetation dies. The amount of carbon accumulation or sequestration is frequently changing with the plant growth, death and decomposition. In addition to being sequestered in vegetation, carbon is also sequestered in forest soils. Carbon is the organic content of soil, generally in the partially decompose vegetation (humus) on the surface and in the upper soil layers, in the organisms that decompose vegetation and in the fine roots.

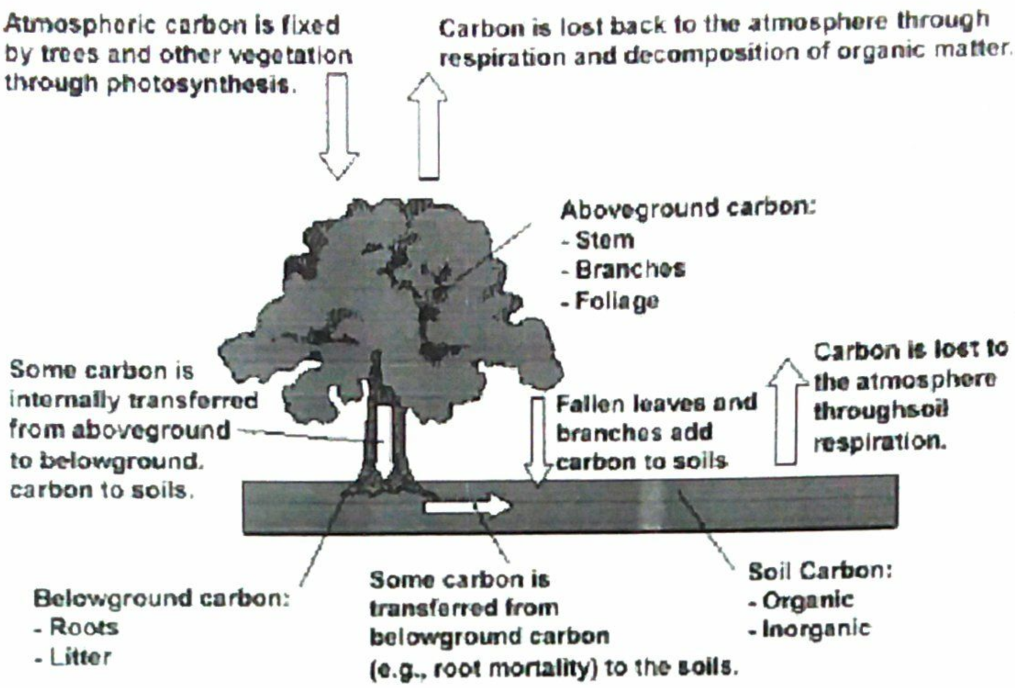

Figure 2.1: An illustrated guide to carbon cycle (Source: USEPA at www.epa.gov/ sequestration/local_scale.html)

2.7 Carbon sequestration in roadside plantation

Aboveground biodiversity can play an important role in carbon sequestration with consequent positive impacts on belowground carbon sequestration (e.g., through litter fall, root exudation and turnover or soil erosion control) (Henry et al., 2008).

Roadside trees are expected to capture higher amounts of particulate matter, CO_2 and other air pollutants, due to their closeness to traffic and consequently to higher loads of atmospheric pollutants (Beckett et al., 2000). This green cover in the form of urban forest has a significant potential in carbon sequestration (Nowak et al., 1994). Nowak and Crane (2002) has brought out that carbon sequestration is not only related to the increased tree cover but also very much related to the increased proportion of large and healthy trees in population. The net save in carbon emissions that can be achieved by urban planting can be up to 18 kg CO_2/year/tree and this benefit corresponds to that provided by 3 to 5 forest trees of similar size and health (Ferrini, 2011).

According to the study of Kiran and Kinnary (2011), this point is very clearly brought out as certain roads of Vadodara city in India with similar number of species exhibited variation in the values of the carbon sequestered and the amount of carbon sequestered by these road side trees has amounted to 73.59 tons of CO_2 per year. Their own findings suggest that 73.59 tons of CO_2 is removed by trees planted on road sides of Vadodara city in India which represents 22% of the city's estimated total CO_2 production. It is therefore evident that tree planting on roadside are an effective method of offsetting CO_2 from human sources.

CHAPTER 3
MATERIALS AND METHOD

3.1 Study area

3.1.1 Location

This study was conducted at the three southwestern districts (Namely Satkhira, Jhenaidah and Narail) of Bangladesh that is famously known as floodplain landmass lying between 21.50° and 23.91°N latitude and 88.55° and 89.50°E longitude (Fig: 3.1). The Satkhira and Jhenaidah district is situated the east of West Bengal of India. These three districts are lying the periphery of Jessore district and the Bay of Bengal is located in the southern part of these district. It is the part of the largest delta of the world. The largest mangrove forest 'Sundarban' is the part of this delta.

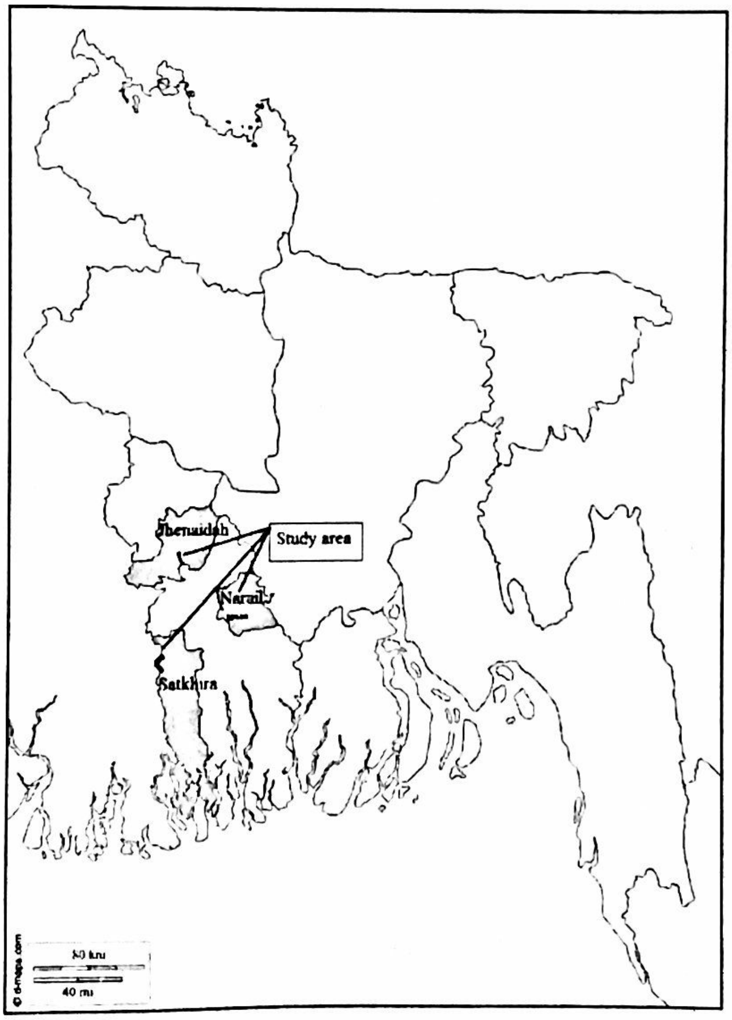

Figure 3.1: Study area. Satkhira, Narail and Jhenaidah in southwestern Bangladesh.

3.1.2 Climatic condition

These districts are embracing with a tropical to subtropical monsoon climate that can be differentiated by seasonal variation e.g. moderately warm temperatures, heavy rainfall, and excessive humidity (Kabir and Webb, 2008). The climate of these area is divided into six seasons which changes after every two months. But the total climate of here can distinct by three remarkable seasons namely summer (March to May), monsoon or rainy (June to October) and winter (November to February). In the winter season, Winds are mostly from the north and northwest, blowing gently at 1 to 3 km/h in northern and central areas and 3 to 6 km/h near the coast. From March to May, violent thunderstorms produce winds of up to 60 km/h. During the intense storms of the early summer and late monsoon season, southerly winds of more than 160 km/h cause waves to crest as high as 6 meters in the Bay of Bengal, which brings disastrous flooding to coastal areas of this region.

3.1.2.1 Temperature

The average annual temperature of Satkhira district is about 25°C, Narail 25.3°C and Jhenaidah 25.9°C. The warmest month, on average, is May with an average temperature of 30°C in Satkhira and Jhenaidah. In Narail, the warmest month is August, with an average temperature of 28.4°C. The coolest month on average is January, with an average temperature of 18.9°C for all of these District. The average temperature fluctuation does not exit 12^0C (Figure: 3.2).

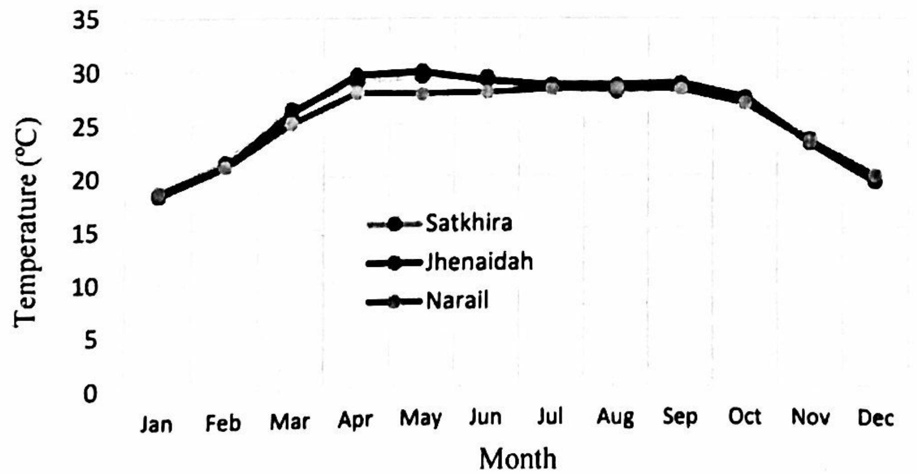

Figure 3.2: Mean monthly temperatures of Satkhira, Jhenaidah and Narail districts in southwestern Bangladesh. Data source: https://en.climate-data.org/region/2263/ (Data driven from 2001-2016 of raw data; Accessed on 03 February 2017)

3.1.2.2 Rainfall

Annual average rainfall of Khulna division is 1800 ± 268 mm ranging from 1400 to 2600 mm (Kabir and Webb, 2008). Approximately 85% of total rainfall occurs between May to October (Figure: 3.3). In Satkhira, the variation in the precipitation between the driest and wettest months is 341 mm and for Narail is about 520 mm and for Jhenaidah is about 304 mm. The monsoons result from the contrasts between low and high air pressure areas that result from differential heating of land and water. During the hot months of April and May hot air raises over the Indian subcontinent, creating low-pressure areas into which rush cooler, moisture-bearing winds from the Indian Ocean. This is the southwest monsoon, commencing in June and usually lasting through September.

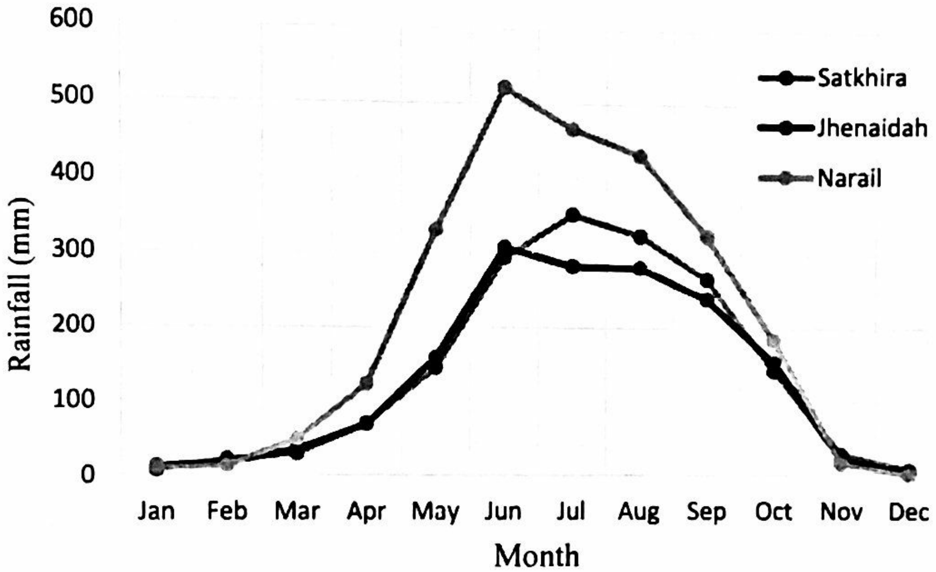

Figure 3.3: Mean monthly rainfall of Satkhira, Jhenaidah and Narail districts in southwestern Bangladesh. Data source: https://en.climate-data.org/region/2263/ (Data driven from 2001-2016 of raw data; Accessed on 03 February 2017)

3.1.2.3 Humidity

The average annual relative humidity of Satkhira is about 84%, Narail is about 79% and Jhenaidah is about 77%. The least humid month is March (67%). Due to heavy rainfall during the monsoon period the humidity increases up to 90% (range: 81% to 90%). But in the summer season humidity becomes low.

3.1.2.4 Hydrology

The main rivers of Satkhira is Kopotakhi river and other main rivers are Kholpetua river, Betna river, Raimangal river, Hariabhanga river etc. Naboganga, Kumar, Chitra, Bhyrab, Kapotakkhya, Ishamoti etc. are main rivers of Jhenaidah. Through Narail district flow the Madhumati, Nabaganga, Bhairab, and Chitra rivers. There are many beels and baors, the most noted of which is Chachuri Beel. Shallow deep of rivers in these area is the main cause flooding during the rainy season. The upstream river flow causes huge siltation of sediment.

3.1.3 Geology and soil

Geologically, the Bengal basin is one of the more active tectonic regions in the world. Khulna district has been formed by sediments deposited by the Ganges-Brahmaputra-Meghna river system. These sediments are thought to be as thick as 10000 feet. Soils in the delta have some localized variation, both aerially and stratigraphically but consist primarily of fine sands, silts, silty sands, sand silts and clayey silts. Remnants of swamp and forest appear in the form of peat layers in Khulna district. Excavation in this District show wood, trees or other vegetation at depths up to 100 feet below ground surface provides evidence of large scale subsidence, caused by compaction of recent sediments and possibly by structural down warping.

According to the report of Bureau of Bangladesh Statistics 2012, Bangladesh has three broad types of soil; flood plain soils (79%), brown hill soils (13%) and terrace soils (9%). Flood plain soils are of fourteen sub-types like non-calcareous alluvium soil, calcareous alluvium, acid sulphate soil, peat soil, non-calcareous grey floodplain soil, calcareous grey floodplain soil, grey piedmont soil, acid basin soil, non-calcareous dark grey floodplain soil, calcareous dark grey floodplain soil, calcareous brown floodplain soil, non-calcareous brown floodplain soil, brown piedmont soil and black terai soil extended over the floodplain area of the country. Calcareous floodplain is the basic soil types under this study area (Table 3.1).

Table 3.1 Major soil types of Satkhira, Jhenaidah and Narail districts in southwestern Bangladesh.

Major soil types	District		
	Satkhira	Narail	Jhenaidah
Calcareous Alluvium Floodplain Soils	√	√	-
Acid Sulphate soil	√	-	-
Peat soil	-	√	-
Calcareous Grey Floodplain Soils	√	√	-
Calcareous Dark Grey Floodplain Soils	√	√	√
Non-calcareous Dark Grey Floodplain Soils	√	√	√
Calcareous Brown Grey Floodplain Soils	√	√	√
Non-calcareous Brown Grey Floodplain Soils	√	-	√

Source: BBS 2012.

3.2 Methodology

3.2.1 Sampling design

A total of 26 plots of equal size (2 x 10m) were selected from the three study areas (Satkhira, Narail and Jhenaidah) by following systemic sampling in a zigzag manner (Fig: 3.4) on the both sides of the road. The distance from one successive plot to another plot were 500m. The selected plots were planted in same year plantations (2005-2006). Twenty-six plots were laid out along the roadside plantation in the three districts (10 from Satkhira, 8 from Narail and 8 from Jhenaidah).

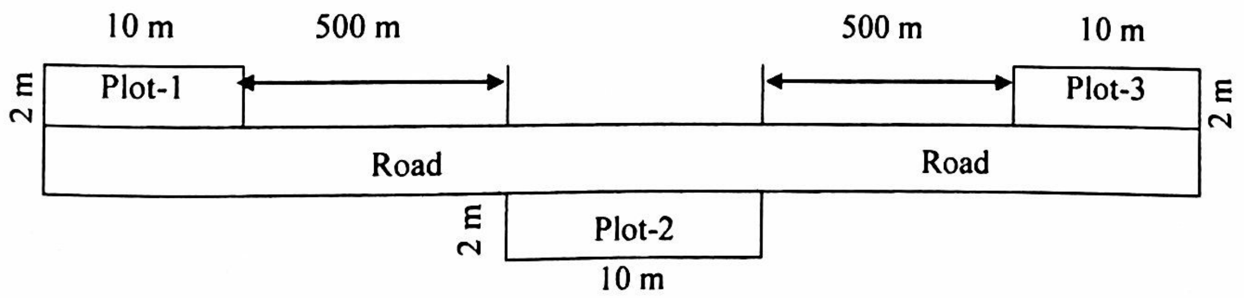

Figure 3.4: Schematic diagram of zigzag plot layout along the roadside plantations in southwestern Bangladesh.

3.2.2 Data collection

3.2.2.1 Tree survey

Trees dominate the aboveground carbon pool and are the best indicator of land use change. For this reason, it is essential to measure trees thoroughly and accurately. The basic concept is that measurements of stem diameter are used in allometric equations to compute biomass and carbon stocks. A botanical inventory was conducted in the sampling plots of the studied roadside plantation using a "Carbon Inventory Form" (developed by IPCC, 2007). All woody plant species present in the roadside plantation of each sampled plot was identified and recorded to species level or by local name and later was confirmed from authentic source(s). GPS reading at the center of each sample plots was also recorded. If there had any abnormalities or defects in diameter and height, those were also recorded in the data sheet.

According to source book for land use change and forestry by Pearson et al. (2005), trees were selected on the following basis:

All live woody stems having a diameter at breast height of 2 cm or greater. Diameter at breast height (DBH) is the stem diameter at 1.3 m above the ground.

3.2.2.2 Measurements

Every individual of woody species was counted. Diameter of every individual of woody species at breast height was measured using a diameter tape and huga-altimeter was used for height measurement. The wood density data were obtained from the World Agroforestry Database (Carsan et al., 2012) and the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009).

3.2.3 Data analysis

3.2.3.1 Tree biomass and carbon

3.2.3.1.1 Allometric computation for above-ground biomass

Tree biomass estimation from species- and site-specific allometric models is more suitable for tropical and subtropical regions, because of the presence of numerous species and individuals. Taking this point into account, the allometric equation for aboveground carbon estimation of Chave et al. (2005) was employed, as it covers a wide geographical and diameter range of vegetation of all types. Considering these factors Chave et al. (2005) developed allometric equation for tropical trees that was used for wide graphical and diameter range (Rahman et al., 2015).

$$AGB = \rho \times \exp(-1.499 + 2.148 \times \ln(DBH) + 0.207 \times (\ln(DBH))^2 - 0.0281(\ln(DBH))^3)$$

AGB = Aboveground biomass

ρ = Wood density (gcm^{-3})

DBH = Diameter at breast height

ln = Natural logarithm

1.499 = Constant

2.148 = Constant

0.207 = Constant

0.0281= Constant

3.2.3.1.2 Allometric computation for below-ground biomass

Below ground biomass was estimated by using regression model that was suggested by Cairns et al. (1997). It is considered as the most cost effective and practical model for calculating below ground carbon (Rahman et al., 2015).

$$BGB = EXP(-1.0587 + 0.8836 \times LN(AGB))$$

BGB = Below ground biomass

AGB = Aboveground biomass

LN = Natural logarithm

0.8836 = Constant

1.0587 = Constant

3.2.3.1.3 Basal area base linear computation for biomass carbon

Three basal area based model is developed by Rahman et al. (2015) for carbon estimation. It showed strong (R^2=0.96) and significant ($P < 0.05$) relationship with Allomectric Equations by Chave et al. (2005) and Cairns et al. (1997). Here, the linear basal area based equation is used for estimating carbon biomass.

Linear basal area based equation = 4.061 x BA – 22.516

BA = Basal area

4.061 = Constant

22.516 = Constant

3.2.3.2 Conversion of biomass to carbon

Because of comparatively poor physical condition and isolation from the natural forest system of the roadside plantation, it provides approximately 20% lower carbon than natural forest condition (Aguaron and McPherson, 2012). So the calculated carbon (Chave et al., 2005 and Cairns et al., 1997) is multiplied by 0.80 that was suggested by Aguaron and McPherson (2012). Finally, the total biomass was multiplied by 0.5 to compute actual tree carbon content as 50% of wood's total biomass is considered to be carbon.

Carbon (Mg) = Biomass estimated by allometric equation × 0.8 × Wood Carbon Content %

= Corrected biomass estimated by allometric equation × 0.5

3.2.3.3 Species diversity and structure

Aboveground carbon pools were computed using international standard common tree allometries combined with local tables of wood density by tree species. For describing floristic composition of study area the basal area, relative density, relative dominance, relative frequency and importance value index (IVI) were calculated (Moore and Chapman 1986, Shukla and Chandel 1980). Species diversity H' (Shannon and Wiener, 1949), evenness J' (Pielou, 1977) and richness R' (Margalef, 1958) indices were also estimated.

The basal area/ha is calculated according to the formula (Shukla and Chandel 1980):

$$Ba/ha = \frac{\sum \frac{\Pi}{4} D^2}{\sum area \quad of \quad all \quad quadrats} X \quad 10000$$

Basal area = $\Pi D^2/4$.

Where, Ba = Basal area in m^2ha^{-1}, D = Diameter at breast height in meter & $\Pi = 3.14$

Following the formulas derived by of Moore and Chapman (1986), Shukla and Chandel (1980) and Dallmeier et al. (1992) quantitative structure parameters of investigated trees were calculated:

1. Density (stem/ha) = $\frac{\text{Total no. of individuals of one species in all the plots}}{\text{Plot area} \times \text{Total no. of plots studied}}$

2. Relative density (%) = $\frac{\text{Total no. of individuals of one species in all the plots}}{\text{Total no. of plots studied}} \times 100$

3. Frequency (%) = $\frac{\text{Total no. of plots in which the species occurs}}{\text{Total no. of plots studied}} \times 100$

4. Relative frequency (%) = $\frac{\text{Frequency of one species}}{\text{Sum of frequency of all species}} \times 100$

5. Basal area (m^2/ha) = $\frac{\text{Total basal area of species } (m^2)}{\text{Sample plot area (ha)} \times \text{Total no. of plots studied}}$

6. Relative basal area (%) = $\frac{\text{Total basal area of one species in all plots}}{\text{Total basal area of all species in all plots}} \times 100$

7. Importance value index (%) = $\frac{\text{(Relative density + Relative frequency + Relative dominance)}}{3}$

Shannon- Wiener index (*H'*) for species diversity, Margalef index (*R'*) for species richness and Pielou index (*J'*) for species evenness were calculated using following formulae:

$H' = -\sum [(pi) * \ln (pi)]$

$R' = (S - 1) / \ln N$

$J' = H' / \log S$

Where, $\sum$ = Summation, pi= Number of individuals of species i/total number of samples, S = Number of species and N = Number of individuals in the sample

3.2.3.4 Statistical Analysis

The normality of distribution of the species diversity indices, aboveground carbon, belowground carbon and carbon stock for the entire data sets were tested by Shapiro-wilk test using SPSS-20. When and if distributions were approximately normally distributed, Pearson's correlation tests were performed to explore whether there is correlation between woody species diversity and species richness, species evenness and carbon stocks. Regression analysis was used to examine the relationship between tree basal area, tree density and carbon stocks. Analysis were performed using SPSS-20 and Microsoft Excel-2013. To assess differences plant communities of three districts, the results of species diversity (Shannon-Wiever index), species richness (Margalef index), species evenness (Jacoobs index) and carbon stocks were analyzed by using t test.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Species diversity and structure

4.1.1.1 Tree species composition

A total of 191 individuals of 16 species were enumerated from 26 sample plots of three districts (Satkhira, Narail and Jhenaidah). *Acacia nilotica, Leucaena leucocephala, Dalbergia sissoo, Melia azedarach and Samanea saman* are the five important species in the study areas considering stem density, basal area and DBH (Table 4.1). But three species (*Acacia nilotica, Leucaena leucocephala* and *Dalbergia sissoo*) comprise 64% of total population. Again these three species contribute 42% relative frequency of total population and 63% relative dominance of total population (Table 4.1). Considering relative density, relative frequency and relative dominance, *Acacia nilotica* occupies rank one and correspondingly *Leucaena leucocephala* occupies rank two and *Dalbergia sissoo* occupies rank three (Table 4.2).

Table 4.1 List of recorded species from roadside plantation in Satkhira, Jhenaidah and Narail districts of southwestern Bangladesh. List arranged according to the importance value index. RD: relative density, RF: relative frequency, RDo: relative dominance and IVI: importance value index.

Serial no.	Scientific Name	RD	RF	RDo	IVI
1	*Acacia nilotica* Karst.	36.13	16.90	33.62	28.88
2	*Leucaena leucocephala* (Lam.) de Wit	20.42	16.90	21.58	19.63
3	*Dalbergia sissoo* Roxb.	7.85	8.45	7.68	7.99
4	*Melia azedarach* L.	4.19	8.45	6.38	6.34
5	*Samanea saman* (Jacq.) Merr.	4.19	8.45	5.99	6.21
6	*Azadirachta indica* A.Juss.	5.76	5.63	2.75	4.71
7	*Senna siamea* (Lam.) Irw. & Barneby	4.19	2.82	6.15	4.39
8	*Gmelina arborea* Roxb.	3.14	7.04	2.77	4.32
9	*Trewia polycarpa* Benth. & Hook.f.	3.66	4.23	3.57	3.82
10	*Albizia procera* (Roxb.) Benth.	2.09	5.63	3.16	3.63
11	*Swietenia macrophylla* King	1.57	4.23	0.86	2.22
12	*Acacia auriculiformis* A. Cunn. ex Benth.	2.09	2.82	1.64	2.18

13	*Aegle marmelos* (L.) Correa	1.05	2.82	0.93	1.60
14	*Bombax ceiba* L.	1.05	2.82	0.80	1.55
15	*Pithecellobium dulce* (Roxb.) Benth.	1.57	1.41	1.09	1.36
16	*Artocarpus heterophyllus* Lam.	1.05	1.41	1.04	1.17

Table 4.2 Ranking of five most important species in roadside plantations in southwestern Bangladesh.

Species rank	Based on		
	relative density	relative frequency	relative dominance
1	*Acacia nilotica*	*Acacia nilotica*	*Acacia nilotica*
2	*Leucaena leucocephala*	*Leucaena leucocephala*	*Leucaena leucocephala*
3	*Dalbergia sissoo*	*Dalbergia sissoo*	*Dalbergia sissoo*
4	*Azadirachta indica*	*Melia azedarach*	*Melia azedarach*
5	*Melia azedarach*	*Samanea saman*	*Senna siamea*

4.1.1.2 Family composition

A total of seven families were encounted from the study area. Leguminosae and Meliaceae is the most important families in the study area and it's about 90% of total counted population. Leguminosae sub-families account for 150 individuals of total counted population and predominant with 79% of total population, followed by Meliaceae (11%), Euphorbiaceae (4%), Verbenaceae (3%) and Rutaceae, Bombacaceae, Moraceae (1%) (Table 4.3).

Table 4.3 List of recorded families from roadside plantation in Satkhira, Jhenaidah and Narail districts of southwestern Bangladesh. List arranged according to the importance value index. RD: relative density, RF: relative frequency, RDo: relative dominance and IVI: importance value index.

Serial no.	Family	RD	RF	RDo	IVI
1	Leguminosae	78.53	48.84	81.41	69.59
2	Meliaceae	11.52	20.93	9.36	13.93
3	Verbenaceae	3.14	11.63	2.80	5.86
4	Euphorbiaceae	3.66	6.98	3.62	4.75
5	Rutaceae	1.05	4.65	0.95	2.22
6	Bombacaceae	1.05	4.65	0.81	2.17
7	Moraceae	1.05	2.33	1.06	1.48

4.1.1.3 Vegetation structure

Vegetation characteristics like stem density, mean DBH, basal area; woody species diversity like Shannon-Wiener index, Margalef index and Pielou index at the study area (Satkhira, Narail and Jhenaidah) at 26 plots with minimum, maximum and mean values with their standard deviations and standard error are presented in Table 4.4. Mean stem density, DBH and Basal area were 3673 stem/ha (range: 1000-8000), 18.54 cm (range: 5.1-34.8) and 106 ha^{-1} (range: 16-265).

Table 4.4 Species diversity *(Shannon-Wiener, H')*, evenness *(Margalef, R')* and richness *(Pielou, J')* of roadside plantations across three study sites in southwestern Bangladesh.

Variables	Minimum	Maximum	Mean	SD	SE
H' (Shannon-Wiener)	0	2.7254	1.067	0.714	0.14
R' (Margalef)	0	2.7307	0.974	0.722	0.142
J' (Pielou)	0	1	0.687	0.362	0.071
Mean DBH (cm)	10.55	23.833	18.541	3.139	0.616
Stem Density/ha	1000	8000	3673.077	2144.492	420.57
BA/ha	15.51	265.195	105.475	66.875	13.115

4.1.1.4 Woody species diversity

Woody species diversity in the study area such as Diversity H', Richness R' and Evenness J' are calculated. Jhenaidah is most diversified (1.22 ± 0.28), riches (1.32 ± 0.29) and even (0.77 ± 0.12) site among the study area. There is no significant difference was observed in species diversity, richness and evenness across the three study sites ($P > 0.05$; Table 4.5, P value of $H' = 0.72$; $R' = 0.16$; $J' = 0.77$). Satkhira has highest density (5750 ± 442.53) and basal area (163.73 ± 16.24) among the study area. But Narail has the highest diameter (20.43 ± 1.02) among the study area (Table 4.6). Multiple comparisons with LSD found significant differences in mean diameter ($P < 0.05$) and highly significant differences in Stem density and Basal area ($P < 0.01$) in the three study areas (P value of DBH = 0.02; Stem density = 0.0002; Basal area = 0.002).

Table 4.5 Mean species diversity, evenness and richness indices of roadside plantations across three study sites in southwestern Bangladesh. Figures in parenthesis are standard errors.

Parameter	District			Average
	Jhenaidha	Narail	Satkhira	
Diversity *H' (Shannon-Wiener)*	1.22 (0.28)	0.98 (0.24)	1.02 (0.23)	1.07
Richness *R' (Margalef)*	1.32 (0.29)	0.95 (0.24)	0.72 (0.19)	0.97
Evenness *J' (Pielou)*	0.77 (0.12)	0.67 (0.14)	0.63 (0.11)	0.69

Table 4.6 Stem density, diameter and basal area of roadside plantations across three study sites in southwestern Bangladesh. Figures in parenthesis are standard errors.

Parameter	District			Average
	Jhenaidha	Narail	Satkhira	
Density (ha^{-1})	2375 (497.76)	2375 (488.71)	5750 (442.53)	3673.076923
Diameter (cm)	16.65 (1.38)	20.43 (1.02)	18.54 (0.51)	18.54056763
Basal Area (m^2ha^{-1})	58.11 (17.17)	80.01 (16.03)	163.73 (16.24)	105.4749422

4.1.2 Tree biomass and carbon content

Allometric equation is developed by estimating aboveground carbon according to Chave et al. (2005) and belowground Carbon is estimated using the regression model suggested by Cairns et al. (1997). Three basal area based equation is developed by Rahman et al. (2015). The basal area based linear equation (Rahman et al., 2015) and allometric equation (Chave et al., 2005 and Cairns et al., 1997) have strong relationship ($R^2 = 0.92$ and $r = 0.95$; range: $R^2 = 0.87$-0.92; for Linear 0.89, Polynomial 0.87 and Power 0.92 models) (Fig: 4.1) and has no significant difference ($P > 0.05$).

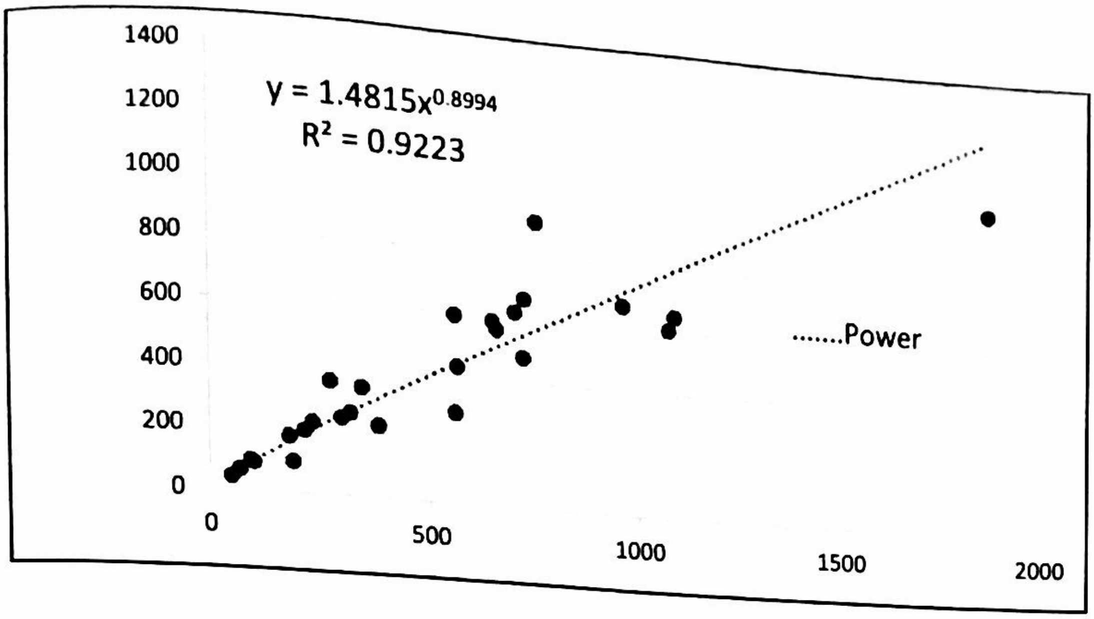

Figure 4.1: Relationship between carbon stocks calculated using basal-area based liner equation (Rahman et al., 2015) and carbon stocks calculated using allomectric equation (Chave et al., 2005 and Caims et al., 1997).

4.1.2.1 Species wise carbon content

The calculated carbon stocks are highly variable among different species. Different types of species store different amount of carbon when they grow at variable densities. *Acacia nilotica* occupies highest amount of carbon content of total carbon in the study area that is about 49% and other top four species are *Leucaena leucocephala* (16%), *Dalbergia sissoo* (7%), *Melia azedarach* (6%) and *Samanea saman* (4%) (Table 4.7). *Acacia nilotica* contains highest amount of carbon content because of its high wood density (1.2 gcm^{-1}) and also higher number of individuals. If we consider a tree carbon, *Albizia procera* occupies rank one because of its high diameter and other top four are *Melia azedarach, Acacia nilotica, Aegle marmelos* and *Samanea Saman* (Table 4.7).

Table 4.7 Ranking of top five carbon stocking species and top five carbon/ tree species in Satkhira, Jhenaidah and Narail districts in southwestern Bangladesh.

Species rank	Total biomass carbon	Carbon/ tree
1	*Acacia nilotica*	*Albizia procera*
2	*Leucaena leucocephala*	*Melia azedarach*
3	*Dalbergia sissoo*	*Acacia nilotica*
4	*Melia azedarach*	*Aegle marmelos*
5	*Samanea saman*	*Samanea Saman*

4.1.2.2 Family wise carbon content

The calculated carbon stocks are highly variable among different families. Leguminosae contains 85% of total calculated carbon in the three study area. Leguminosae and Meliaceae jointly occupies 94% of total carbon. Plants of leguminosae family are very fast growing. So it is suitable for participatory forest management because of its early benefits. As a result, most of roadside plantation is covered with leguminosae family.

4.1.2.3 Carbon stocks

Measurements were made on a total of 26 plots for carbon stocks estimation. An average carbon stocks is about 523 ± 81 Mg ha^{-1} using allometric equation (range: 49-1867 Mg ha^{-1}) and in basal area based linear equation 406 ± 53 Mg ha^{-1} (range: 41-1055 Mg ha^{-1}). Aboveground carbon biomass contains 87% and belowground carbon contains 13% of total estimated carbon. Aboveground and belowground carbon content was highly different ($P < 0.01$). Total carbon stocks in the three study area (Satkhira, Narail and Jhenaidah) are showed significant difference ($P < 0.01$) in both allometric and basal area based linear equation. Multiple comparison with LSD shows that among the study area Satkhira has highest carbon and there is no difference between Narail and Jhenaidah ($P > 0.05$). Because of high density and basal area, the carbon content of Satkhira district is higher. The basal area of Narail and Jhenaidah is almost same and the density is equal that's why there is no difference in carbon content between Narail and Jhenaidah.

4.1.2.4 Comparison between this study and previous study (Rahman et al., 2015)

The first inventory was done in these same plot in 2011(Rahman et al., 2015). This study in 2016 shows that the roadside plantation is enriched after five years. The mean basal area is increased through the three study area because of increasing the diameter of the trees. Last five years the increased basal area is about 53 m^2ha^{-1} across the study area (Table 4.8). Increasing rate of basal area is higher in Jhenaidah. The basal area of Jhenaidah is more than double over last five years. The density is decreased through the three study area because of reducing the number individuals by natural calamities, dead and theft. Decreasing rate of density over the study area is almost same. Species diversity of the study area is decreasing because of reducing the number of species. Richness is increased throughout the study area because of decreasing the number of individuals. The number of species is unchanged in compare to previous study (Rahman et al., 2015) but the number of individuals decreased, so the value of richness is increased. Evenness is almost same across the study area. As basal area is increased higher across the study area in compare to the reducing density, the amount of carbon stocks is also increased over five years. The mean increased carbon content is about 523 ± 81 Mg ha^{-1} using allometric equation (Chave et al., 2005 and Cairns et al., 1997). The participants are successfully protecting the same density and richness of trees for their livelihood and environmental betterment. This way carbon can be stored in tress which can help lowering the atmospheric CO_2 and address REDD+, carbon trading, CDM etc.

Table 4.8 Mean basal area, stem density, species diversity, evenness, richness and biomass carbon content of roadside plantation across the three study area of two inventory in southwestern Bangladesh.

Parameter	Sites	This study	Previous study (Rahman et al., 2015)
Basal Area (m^2ha^{-1})	Satkhira	163.73	93.3
	Narail	80.01	43.2
	Jhenaidah	58.11	20.7
Density (ha^{-1})	Satkhira	5750	7950
	Narail	2375	3143
	Jhenaidah	2375	3000
Diversity *H' (Shannon-Wiener)*	Satkhira	1.02	0.98
	Narail	0.98	1.01
	Jhenaidah	1.22	1.25
Richness *R' (Margalef)*	Satkhira	0.72	0.68
	Narail	0.95	0.88
	Jhenaidah	1.32	1.13
Evenness *J' (Pielou)*	Satkhira	0.63	0.62
	Narail	0.67	0.64
	Jhenaidah	0.77	0.79
Total biomass carbon (Mg ha^{-1}) (Chave et al., 2005 and Cairns et al., 1997)	Satkhira	8512.75	3801.12
	Narail	3299.39	1209.61
	Jhenaidah	1787.57	454.00

4.1.2.5 Carbon sequestration

After 5 years, in 2016 yearly amount of mean carbon sinked per plot is about 229.67 (One tons of carbon = 3.67 tons of carbon dioxide) according to allometric equation (Chave et al., 2005 & Cairns et al., 1997) (Table 4.9) and for basal area based linear equation 151.5 (Rahman et al., 2015) (Table 4.10). Highest amount of carbon sink per year in Satkhira district both in basal area based linear equation (2038.84) and allometric equation (3458.34)

(One tons of carbon = 3.67 tons of carbon dioxide). As the number of individuals, density and basal area is higher in Satkhira district, the amount of carbon sink is higher.

Table 4.9 Plot wise yearly amount of carbon sinked according to allomectric equation (Chave et al., 2005 & Cairns et al., 1997) in roadside plantation of study area in southwestern Bangladesh. (One tons of carbon = 3.67 tons of carbon dioxide)

Plot no.	Carbon (This study)	Carbon (Previous study: Rahman et al., 2015)	Gained carbon	Yearly carbon gained	Yearly amount of sinked CO_2
1	752.65	231.05	521.60	104.32	382.85
2	559.10	286.49	272.61	54.52	200.10
3	1866.53	734.18	1132.34	226.47	831.14
4	960.60	547.96	412.64	82.53	302.88
5	649.20	367.22	281.98	56.40	206.97
6	658.92	250.11	408.81	81.76	300.07
7	344.48	240.64	103.84	20.77	76.22
8	564.90	245.17	319.73	63.95	234.68
9	1084.99	459.50	625.49	125.10	459.11
10	1071.38	438.79	632.59	126.52	464.32
11	296.15	80.93	215.22	43.04	157.97
12	212.80	12.86	199.94	39.99	146.75
13	98.81	4.54	94.27	18.85	69.20
14	701.86	137.93	563.93	112.79	413.92
15	66.89	11.42	55.47	11.09	40.71
16	90.98	7.96	83.02	16.60	60.94
17	271.36	18.62	252.75	50.55	185.52
18	48.71	179.73	-131.02	-26.20	-96.17
19	316.64	171.26	145.38	29.08	106.71
20	721.37	242.05	479.32	95.86	351.82
21	381.46	157.34	224.12	44.82	164.51
22	230.67	127.25	103.42	20.68	75.91
23	724.06	262.86	461.21	92.24	338.52
24	560.24	160.61	399.64	79.93	293.33

25	186.23	46.85	139.37	27.87	102.30
26	178.72	41.41	137.31	27.46	100.79
Total	13599.71	5464.72	8134.98	1627.00	5971.08
				Average canbon sink/ plot	229.66

Table 4.10 Plot wise yearly amount of carbon sinked according to basal-area based liner equation (Rahman et al., 2015) in roadside plantation of study area in southwestern Bangladesh. (One tons of carbon = 3.67 tons of carbon dioxide)

Plot no.	Carbon (This study)	Carbon (Previous study: Rahman et al., 2015)	Gained carbon	Yearly carbon gained	Yearly amount of sinked CO_2
1	915.35	359.19	556.17	111.23	408.23
2	596.95	371.59	225.36	45.07	165.42
3	1054.44	506.70	547.74	109.55	402.04
4	673.52	442.97	230.55	46.11	169.23
5	588.71	442.51	146.19	29.24	107.31
6	563.13	324.34	238.79	47.76	175.27
7	342.22	296.05	46.17	9.23	33.89
8	433.17	261.74	171.43	34.29	125.83
9	649.70	347.24	302.46	60.49	222.01
10	606.88	294.22	312.66	62.53	229.49
11	243.19	66.47	176.72	35.34	129.71
12	195.34	2.00	193.34	38.67	141.91
13	88.64	-10.52	99.16	19.83	72.78
14	624.11	149.32	474.79	94.96	348.49
15	65.47	7.19	58.28	11.66	42.78
16	93.84	-4.26	98.09	19.62	72.00
17	356.84	12.73	344.11	68.82	252.58
18	40.45	268.37	-227.91	-45.58	-167.29
19	261.14	147.14	114.00	22.80	83.68
20	481.27	210.92	270.35	54.07	198.43
21	225.36	116.67	108.69	21.74	79.78
22	224.74	127.26	97.48	19.50	71.55

23	668.69	293.56	375.13	75.03	275.35
24	287.45	94.91	192.54	38.51	141.33
25	96.63	21.42	75.21	15.04	55.20
26	174.03	35.27	138.77	27.75	101.85
Total	10551.26	5184.99	5366.27	1073.25	3938.84
			Average carbon sink/ plot		151.49

4.1.3 Relationship of carbon stocks with stand structure (basal area and density)

4.1.3.1 Basal area and carbon stocks

It was found that basal area had a very strong and significant ($p < 0.01$) relationship with carbon stocks in both Allometric (Chave et al., 2005 and Cairns et al., 1997) and basal area based linear equation (Rahman et al., 2015). In relationship with basal area and carbon stocks (Chave et al., 2005 and Cairns et al., 1997), the value of r is 0.96 and R^2 is 0.92 (Figure 4.2). And in relationship with basal area and carbon stocks (Rahman et al., 2015), the value of r is 0.9977 and R^2 is 0.9988 (Figure 4.3). Biomass carbon highly depends of the basal area. If the basal area is higher, the biomass carbon content is also higher.

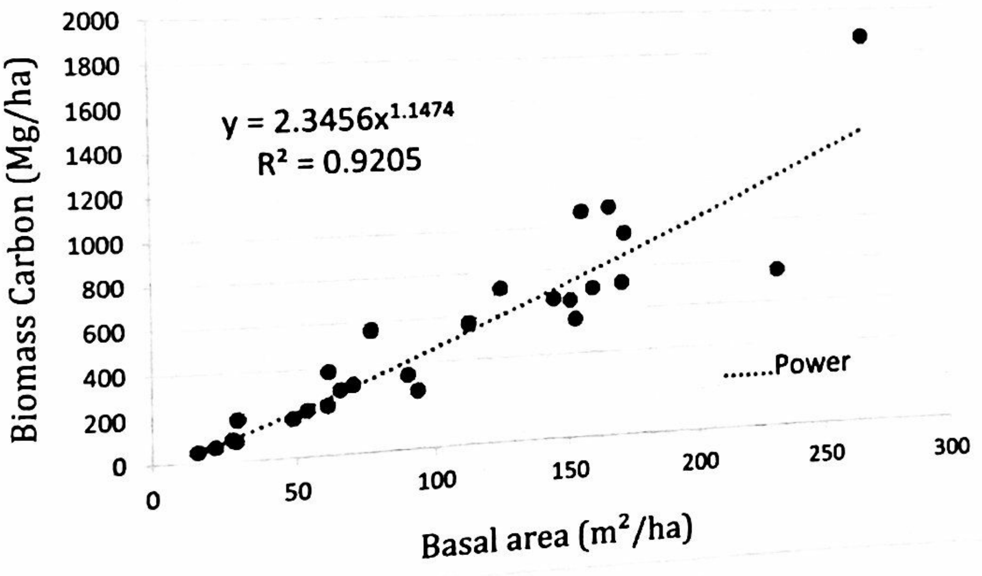

Figure 4.2: Relationship with basal area and carbon stocks calculated using (Chave et al., 2005 and Cairns et al., 1997) equation.

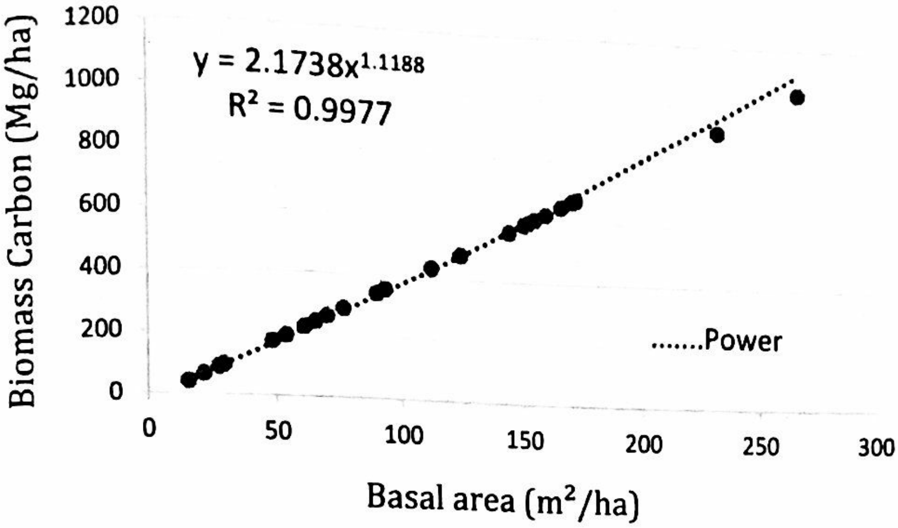

Figure 4.3: Relationship with basal area and carbon stocks calculated using (Rahman et al., 2015) equation.

4.1.3.2 Stem density and carbon stocks

It was found that stem density had a moderate and significant ($p < 0.01$) relationship with carbon stocks in both Allometric (Chave et al., 2005 and Cairns et al., 1997) and basal area based linear equation (Rahman et al., 2015). In relationship with stem density and carbon stocks (Chave et al., 2005 and Cairns et al., 1997), the value of r is 0.82 and R^2 is 0.68 (Figure 4.4). In relationship with stem density and carbon stocks (Rahman et al., 2015), the value of r is 0.87 and R^2 is 0.7544 (Figure 4.5). The relationship shows that biomass carbon mainly depends on basal area and moderately depends on density. The species with high density and basal area contains higher amount of biomass carbon.

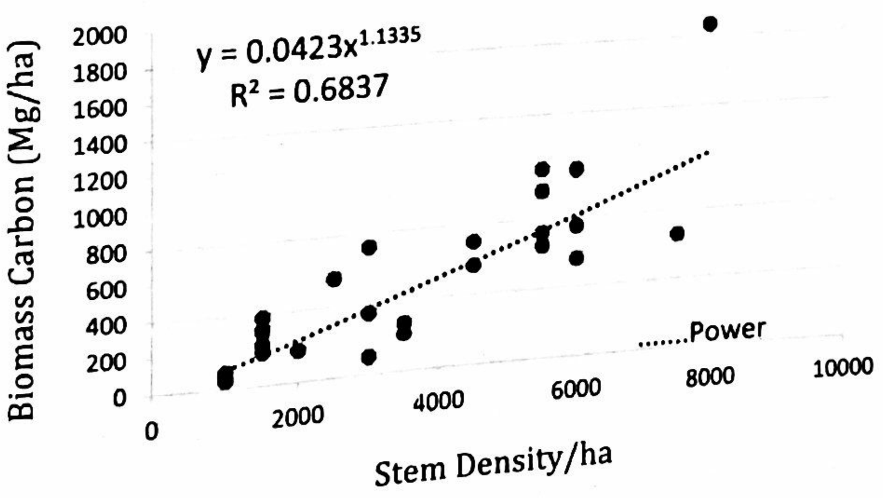

Figure 4.4: Relationship with stem density and carbon stocks calculated using allometric equation (Chave et al., 2005 and Cairns et al., 1997).

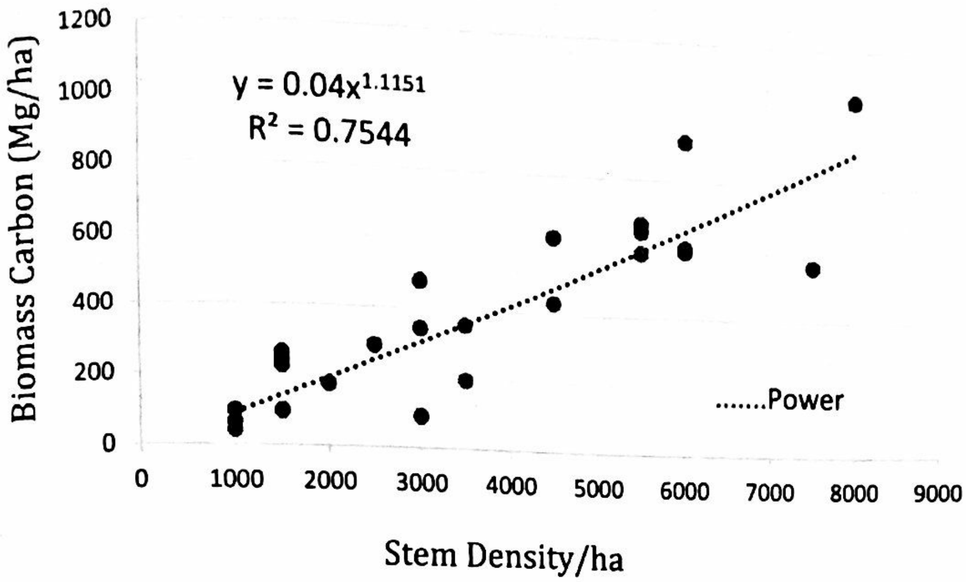

Figure 4.5: Relationship with stem density and carbon stocks calculated using basal area based linear equation (Rahman et al., 2015).

4.2 Discussion

4.2.1 Species composition

Roadside plantation around the world show significant variability in its species composition and stand structure. A total of 16 species of trees ≥2 cm DBH from 7 families were recorded in the study area (Satkhira, Narail and Jhenaidah). Our recorded number of species (16) were higher and families were lower from the roadside plantation in Khulna city bypass (13 species and 9 families) (Kundu, 2013). The species and families of our study area is lower than national highway plantation (62 species) in Taiwan (Wang, 2011), 19 species from roadside plantations in Kanchanpur District in Nepal (Baral et al., 2013) and 108 species of 33 families from roadside plantation in Bangalore, India (Nagendra and Gopal, 2010). Homestead plantation in south western of Bangladesh is richer in species richness than our study area (146 species; Kabir and Webb). The variation of species and families in different geographical area is occurred because of the number and type of roads and highways surveyed. The species composition varies from roads to roads according to the demand and reason of plantation.

Three most common species *Acacia nilotica, Leucaena leucocephala* and *Dalbergia sissoo* together comprised two third of total population that indicates species of Leguminosae are dominanting. Leguminosae family was occupied more than three fourth of total vegetation. In compare to the roadside plantation of Bangalore the four most dominant species comprise about the one third of total population (Nagendra and Gopal, 2010). In comparison to the road side plantation of Khulna city bypass, the composition of most common three species is approximately similar to our study area (Kundu, 2013). So the roadside plantation of southwestern Bangladesh is similarly enriched in compare the other roadside plantation of the world.

4.2.2 Stand structure

Our estimated stem density (3673 ha^{-1}) of three study area was much higher than other Asian countries roadside plantation and also higher than natural and restored forest systems. For example, 2010 tree ha^{-1} recorded from the Khulna city bypass a southwestern district of Bangladesh (Kundu, 2013), 705 tree ha^{-1} was recorded from Taiwanese highway plantations (Wang, 2011), 500 tree ha^{-1} Chennai metropolitan city (Muthulingam and Thangavel, 2012), 381 tree ha^{-1} in Chittagong Hill Tracts (South) Forest Divisin (Nath et al., 1998) and 464 tree ha^{-1} in Dudpukuria-Dhoapachori Wildlife Sanctuary of Chittagong South Forest Division (Hossain et al., 2013). Because of maintaining a certain lower spacing in plantation (1.5 m x 1.5 m) along with the higher survival rate from confirmed protection and planting hedgerow crops mainly *Cajanus cajan* one close to the road and *Acacia nilotica* on the outer side road are the main reason for high density in roadside plantation of the study areas (Rahman et al., 2015).

The mean basal area of three study area (106 m^2ha^{-1}) is much higher than the basal area in Chittagong Hill Tracts (South) Forest Divisin (53.5 m^2ha^{-1}; Nath et al., 1998), 16 m^2ha^{-1} in Chunati Wildlife Sanctuary, Cox's Bazar (Rahman and Hossain, 2003) and 16 m^2ha^{-1} in Dudpukuria-Dhoapachori Wildlife Sanctuary of Chittagong South Forest Division (Hossain et al., 2013). High diameter, age (15 years) and lower spacing is the main reason for this high mean basal area of the study area.

4.2.3 Carbon stocks

Carbon is stored in the leaves, stems, and other parts of plants when they absorb CO_2 from the atmosphere and use it to grow. Trees are very important for carbon sequestration because they live a long time and, therefore, store their carbon for many years. The present level of atmospheric carbon can be controlled by reducing deforestation, increasing afforestation or reforestation and preventing biodiversity loss. The UNFCCC developed different mechanisms to reduce the atmospheric carbon dioxide e.g. CDM, REDD and most recently

REDD+. Afforestation and reforestation are the integral parts of REDD+ as an effective mechanism for reducing global climate change. Protecting forest under REDD+ could be an effective measure to mitigate greenhouse gas emissions and will provide other ecosystem services, such as watershed management and biodiversity conservation (Wang et al., 2011 and Pandey et al., 2014).

In this study, the mean carbon biomass stocks is about 523 ± 80 Mg ha^{-1} in allometric equation stocks (Chave et al., 2005 and Cairns et al., 1997) (range: 49-1867 Mg ha^{-1}) and in Basal area based linear equation 406 ± 53 Mg ha^{-1} (Rahman et al., 2015) (range-(41-1055 Mg ha^{-1}). This difference of maximum and minimum carbon biomass is mainly for the variation in the number of trees present per plot. Again the certain plot with similar number of species exhibited variation in the values of carbon biomass stock. According to Nawak and Crane (2002), amount of carbon stocks varies from species to species and also the proportion of higher basal area, large and healthy trees. In our study, *Albizia procera*, *Melia azedarach* and *Acacia nilotica* contain higher carbon per tree (Range: 0.19-0.22 Mg/tree). And *Pithecellobium dulce, Azadirachta indica* and *Swietenia macrophylla* contain lower amount of carbon per tree (Range: 0.03- 0.06 Mg/tree). Our calculated mean carbon biomass stocks 523.07 ± 80.76 Mg ha^{-1} (Using the formulae Chave et al., 2005 and Cairns et al., 1997) and 405.82 ± 53.26 Mg ha^{-1} (Rahman et al., 2015) was higher than other reported Carbon stocks in Bangladesh and tropical and sub-tropical countries in the world. For example- (65–158 Mg ha^{-1}) of tree biomass carbon for Bangladesh (Gibbs et al., 2007); 83.72 Mg ha^{-1} (Shin et al., 2007) and 110.94 Mg ha^{-1} (Ullah and Al-Amin, 2012) in hill forest of Bangladesh, 176.9 ± 22.43 in Khulna city bypass (Kundu, 2013); 11.71±3.57 Mg ha^{-1} in Eastern Australia roadsides (Eldridge and Wilson, 2002), 45.49 Mg ha^{-1} in Buter Street and 22.29 Mg ha^{-1} in Penn Street, USA (Keating et al., 2005), 22.83 Mg ha^{-1} in USA national average urban forest carbon storage (Nowak and Crane, 2002), and 34.95 Mg ha^{-1} in roadsides of Shenyang, China (Liu and Li, 2012). The estimated carbon in the three study area is higher in compare to the tropical and sub-tropical countries of the world due to higher stem density and basal area (Rahman et al., 2015). Roadside plantation of Bangladesh plays a vital role for sequestering carbon.

4.2.4 Comparison between this study and previous study (Rahman et al., 2015)

This study shows that biomass carbon content is significantly increased in the roadside plantation of southwestern Bangladesh. The main reason for increasing this carbon content is the increasing basal area of the plants. Last five years the increased basal area is about 53 m^2ha^{-1} across the study area (Table 4.8). Increasing rate of basal area is higher in Jhenaidah. The basal area of Jhenaidah is more than double over last five years. The density is decreased through the three study area because of reducing the number individuals by natural calamities, dead and theft. Decreasing rate of density over the study area is almost same. Species diversity of the study area is decreasing because of reducing the number of species across the study area. Richness is increased throughout the study area because of decreasing the number of individuals. The number of species is unchanged in compare to previous study (Rahman et al., 2015) but the number of individuals decreased, so the value of richness is increased. Evenness is almost same across the study area. As basal area is increased higher across the study area in compare to the reducing density, the amount of carbon stocks is also increased over five years. The mean increased carbon content is about 523 ± 81 Mg ha^{-1} according to allometric equation (Chave et al., 2005 and Cairns et al., 1997). If the participants able to protect the same density as before Rahman et al. (2015), the increased carbon content can be 173% higher than present amount of carbon (Table 4.11). Basal area is increasing significantly throughout the study area. The increased basal area is the main reason for carbon stocking. The participants are successfully trying to protect the same density and richness of trees for their livelihood and environmental betterment. This way carbon can be stored in tress which can help lowering the atmospheric CO_2 and address REDD+, carbon trading, CDM etc.

Table 4.11 Sites wise predicted carbon content considering same density as Rahman et al., 2015. Figures in parenthesis represents the percent of predicted increased biomass carbon.

Sites	This Study		Density (ha^{-1}) in Rahman et al., 2015	Predicted biomass carbon (Mg ha^{-1}) based on density
	Density (ha^{-1})	Biomass carbon (Mg ha^{-1}) Rahman et al., (2015) equation		
Satkhira	5750	6424.07	7950	8881.98 (143%)
Narail	2375	2419.31	3143	3201.64 (205%)
Jhenaidah	2375	1707.88	3000	2157.32 (339%)
Total	10500	10551.26	14093	14161.80 (173%)

4.2.5 Carbon sequestration

Carbon sequestration is the general term used for the capture and long-term storage of carbon dioxide. Capture can occur at the point of emission (e.g. from power plants) or through natural processes (such as photosynthesis), which remove carbon dioxide from the earth's atmosphere and which can be enhanced by appropriate management practices. Sequestration methods include: enhancing the storage of carbon in soil (soil sequestration); enhancing the storage of carbon in forests and other vegetation (plant sequestration); storing carbon in underground geological formations (geosequestration); storing carbon in the ocean (ocean sequestration); and subjecting carbon to chemical reactions to form inorganic carbonates (mineral carbonation). Plants use the energy of sunlight to convert CO_2 from the atmosphere to carbohydrates for their growth and maintenance, via the process of photosynthesis. Biological storage could be enhanced through agricultural and forestry practices and revegetation. This study shows that roadside plantation of southwestern Bangladesh stored higher amount of carbon per year. The participants protect the plantation for their livelihood and environmental betterment. This participatory program enhance carbon sequestering in trees that provide a significant shorter-term contribution to climate change mitigation.

4.2.6 Relationship with woody species diversity and carbon stocks

Several measures of stand structure and diversity were assessed for finding the relationship with carbon biomass. Basal area and stem density had a strong and significant relationship with carbon stocks in both basal area base linear equation (Basal area: $r = 0.96$ and $R^2 = 0.92$, Figure 4.4; Stem density: $r = 0.82$ and $R^2 = 0.68$, Figure 4.5) and allometric equation (Basal area: $r = 0.9977$ and $R^2 = 0.9988$, Figure 4.6; Stem density: $r = 0.87$ and R^2 is 0.7544, Figure 4.7). Henry et al. (2008) has shown that tree volume is strongly related with total aboveground carbon biomass. So higher basal and stem density ha^{-1} indicate higher amount of biomass carbon.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Roadside plantation in southwestern Bangladesh plays an important role in the livelihood of participants of this area. They do not get only a good percentage (40%) of share after final harvest, but also get the supplementary support by attending this participatory program such as fodder, fuel-wood, fruits, leaves, branches etc. Southwestern districts of Bangladesh are vulnerable to climate change. Moreover, the world largest mangrove forest is situated in the southern part of these districts. So, maintaining a stable climate and suitable environment in this area is a great challenge. Roadside plantation as a land use system has potential to move the climate change mitigation one step forward. Overall this study showed that the amount of increased carbon is higher over five years. If we can improve management actions (enrichment planting and strict implementation of rules in use) to assist their sustainable retention, roadside plantation will be capable to mitigate climate change. The large area (4.65 million ha) of these plantations in Bangladesh suggests that their participation in the UNFCCC's financial based carbon mitigation strategies (e.g. CDM) could provide additional benefits to the local communities in a co-management system such as Payment for Environmental Services (PES).

5.2 Recommendation

To increase the forest cover and support the livelihood of participant's roadside plantation play a vital role. But still now, roadside plantation are facing problem with illegal felling or theft. The government should take strict laws and support the local people to protect the plantation. Moreover, due to natural calamities the tree covers is decreasing year to year. So, enrichment plantation should be done to maintain maximum density, improve soil conditions and create microenvironments favorable for wildlife. Further research after rotation would be done to understand the effectiveness of roadside plantation for supporting the livelihood of participants.

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APPENDIX

Roadside Plantation Botanical Inventory Form

Plot Code ______ Longitude ______ Latitude ______

Date ______ Place ______ Data Collectors ______

Sl. No.	Local Name	Scientific Name	DBH(cm)	Height(m)	Remarks
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					