Khulna University
Life Science School
Forestry and Wood Technology Discipline

Author(s): Gauranga Kumar Kundu

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Supervisor(s): Dr. Md. Enamul Kabir, Professor, Forestry and Wood Technology Discipline, Khulna University

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FLORISTIC COMPOSITION AND ABOVEGROUND CARBON STOCKS IN THE ROADSIDE PLANTATION OF KHULNA CITY BYPASS ROAD, KHULNA

GAURANGA KUMAR KUNDU
ROLL NO. 080504

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Supervisor

22/12/13

Dr. Md. Enamul Kabir
Professor
Forestry and Wood Technology Discipline
Khulna University
Khulna-9208
Bangladessh.

Submitted By

22.12.13

Gauranga Kumar Kundu
Roll No. 080504
Forestry and Wood Technology Discipline
Khulna University
Khulna-9208
Bangladessh.

DECLARATION

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Gauranga Kumar Kundu
Student ID: 080504
Forestry and Wood Technology Discipline
Khulna University
Khulna- 9208.

DEDICATED

TO

MY BELOVED PARENTS

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ABSTRACT

Currently potential increment of greenhouse effect in the world is a major concern and CO_2 is the main contributor to this. Roadside plantations with different species composition have great potential for carbon sequestration particularly under changing environment. In this research floristic composition and aboveground carbon stocks of all woody species of Khulna city bypass road are studied. Out of the recorded 13 species of nine families, three most common species *Acacia nilotica* (babla), *Samanea saman* (rain tree) and *Pithecellobium dulce* (khoi babla) together constitute three-forth of total population that have similarity with some other Asian cities. Species of leguminosae family comprise about 77% of total population. The average standing aboveground carbon stocks is 176.9±22.43 Mg ha^{-1}, while the maximum standing aboveground carbon stocks is 419.43 Mg ha^{-1} and the minimum standing aboveground carbon stocks is 0 Mg ha^{-1}. Out of total aboveground carbon stocks, *Samanea saman* (rain tree) holds the highest amount of carbon (42%). Three attributes (e.g. stand basal area, canopy cover and stem density/ha) are strongly related to aboveground carbon stocks, but stand mean height is weakly related. Thus, by increasing roadside plantation with greater stem density/ha with good diameter trees, we can increase the amount of aboveground carbon stocks.

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LIST OF Acronyms

ADB	Asian Development Bank
CBD	Convention on Biological Diversity
CO_2	Carbon-Di-Oxide
FAO	Food and Agricultural Organization
DBH	Diameter at Breast Height
GHG	Greenhouse Gas
GOB	Government of Bangladesh
GPS	Global Positioning system
IPCC	International Panel on Climate Change
MGD	Millennium Development Goals
NGO	Nongovernmental Organization
NRCS	Natural Resources Conservation Service
REDD+	Reduced Emissions from Deforestation and Forest Degradation
TFD	The Forest Dialogue
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Conference on Climate Change
USA	United States of America
USDA	United States Department of Agriculture

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CHAPTER 1

INTRODUCTION

1.1 Background and justification of the study

There is increasing recognition of the fact that urban areas constitute a new type of environment with species compositions and habitats peculiar to urban-industrial areas (Nagendra and Gopal 2010). Urban residents interact with trees in varied ways and trees are generally found along roadside, in home gardens, in parks, commercial zones etc. Among these avenue trees constitute the most significant visual appearance and becoming a typical appearance in most European cities and those colonized by European settlers by the mid 19th century (Lawrence 1994). 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 lowering urban temperature and reducing the intensity of urban heat island effects roadside tree play important 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).

Global warming is a worldwide concern at the recent time (Asante 2011) because of increasing emission of greenhouse gases (mainly CO_2) at the atmosphere mostly due to human 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 the conversion of tropical forests to agricultural production (Paustian et al. 2000). The current average annual increase of CO_2 is about 1.5 ppm, with a predicted doubling of the preindustrial concentration by the end of the 21st century (IPCC 2001). Increasing amount of atmospheric CO_2 from 1906-2005 caused the increase of average global temperature by 0.74^0C (UNFCCC 2007). There is an estimation that if global warming continue and accelerate, the earth could warm by $(2\text{-}4)^0$C by 2100. The most substantial processes associated with an increased concentration of CO_2 in the atmosphere are harmful changes in the global climate (USDA 2000) and increasing global temperature at this rate could considerably alter the earth's climate, major vegetation zone, land use and raising sea level up to 5 m by melting polar icecap (Detwiler and Hall 1988).

For mitigating the CO_2 buildup in the atmosphere increasing the amount of the global terrestrial carbon sink is one of the strategies (Kumar 2011). Under the Kyoto Protocol's Article 3.3, A&R (afforestation and reforestation) with agroforestry as a part of it has been recognized as an option for mitigating greenhouse gases. In managed landscapes, woody vegetation potentially supports 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 green house 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). Thus in this study following objectives have been considered.

1.2 Objectives

i. To investigate the floristic composition in the roadside plantation of Khulna city bypass road.

ii. To determine the amount of aboveground carbon stored in woody vegetation in the roadside plantation of Khulna city bypass road.

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 though 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.

CHAPTER 2

LITERATURE REVIEW

2.1 Concept of roadside plantation

Establishment of tree plantation on relatively narrow areas on the sides of roads and railways are known as roadside plantation. Characteristics of roadside plantation vary from site to site and depend on the factors like situation of the land, width of the strip and also the needs and aspirations of the people. 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

The British government introduced roadside or avenue plantation in the present Bangladesh in eighteen century which was later continued by the then Pakistan government. This initiative was primarily concentrated on national highways and avenues and aesthetics was the primary concern. Thus this plantation program was the activity of the concerned government body. With the passage of time, increasing population and reduced forest resources with throughout the country compelled to utilize of roadside and other marginal lands for the production of wood.

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). The main problem of the roadside plantation was the low people's participation due to lack of defined benefit-sharing mechanism. Hired labors were used but real participation and support from the local communities were lacking (Bhuiyan 1991). Thana afforestation and nursery development project was considered as a sound social forestry project of Bangladesh government. This was a follow up of community forestry project (GOB 1988). Establishment of 17760 km strip plantation along highways, railways, embankment, feeder roads etc. was taken up under the project. For strip plantation on government lands, participating members of the public and societies were allowed to collect intermediate returns such as fruits, grasses, intercrops, fuel wood etc. It also made provision for sharing tree crops harvested in the proportion of 10% to the land owing agency, 10% to the forest department, 65% to the NGO and 5% to the union parishad (Day 1996). To this effect, a quadripartite agreement was executed between land owing agency, forest department, NGO and participants. 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). Contrast this 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, Canadell and Raupach 2008, TFD 2008).

2.5.2 Carbon sequestration

As they grow, trees absorb CO_2 and through photosynthesis, sequester carbon to produce wood. Newly established forests (on reforested or afforested sites) and forest re-growth can sequester carbon quickly and will store it for the life of the forest. When trees are harvested efficiently, a large part of the sequestered carbon can be used to produce wood products such as house frames and thus stored over the medium to long term (IPCC 2007, TFD 2008).

2.6 Carbon cycle in forest

Carbon is the major component of all cellular life forms. Trees utilize carbon as a building material with which to form trunks, roots, stems, branches, and leaves. Trees remove (sequester) carbon from the atmosphere through photosynthesis (Ferrini 2011), extracting CO_2 from the air, separating the carbon atom from the oxygen atoms and returning oxygen to the atmosphere. In doing so, trees store a tremendous amount of carbon in their structures and annual growth increases the carbon stored within the structure. Photosynthesis is the chemical process by which plants use sunlight to convert nutrients into sugars and carbohydrates. Although individual plants die and decompose, forests eventually reach steady states in which the amount of CO_2 released by dying plants is offset by new plants.

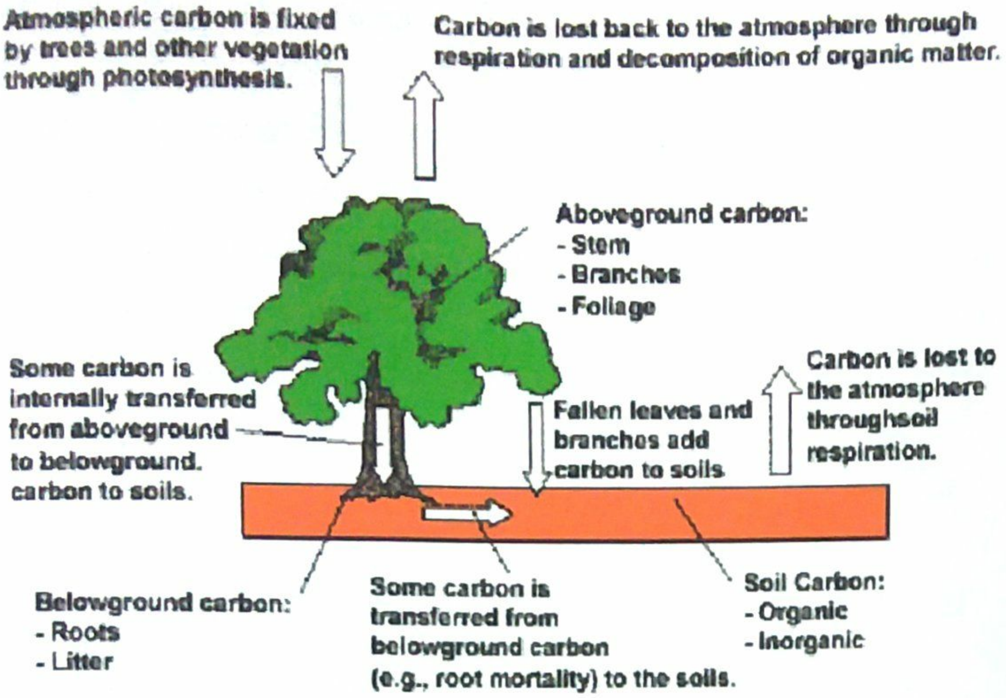

Figure 2.1 An illustrated guide to carbon cycle (Source: USEPA at www.epa.gov/ sequestration/local_scale.html)

2.7 Carbon sequestration in roadside plantation

In agroecosystems, organic carbon stocks in the soil represent often the largest carbon sink (Dixon 1995). On average, soil contains 59% of the carbon stored in a forest, trees contain 31%, forest litter holds 9% and understory vegetation accounts for 1% (Brown 2010). So 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

The study was conducted at Khulna city bypass road (rupsha bridge to arongghata) of Khulna district of Bangladesh. Khulna district is situated at the southwestern part of Bangladesh. The study area is in the northern part of the district that is primarily a flood plain landmass lying between 22.46° and 22.50° N latitude and 89.34° and 89.30° E longitude. Khulna district lies south of Jessore and Narail, east of Satkhira, west of Bagerhat and north of the Bay of Bengal. It is part of the largest delta in the world. In the southern part of the delta lies the Sundarban, the world's largest mangrove forest.

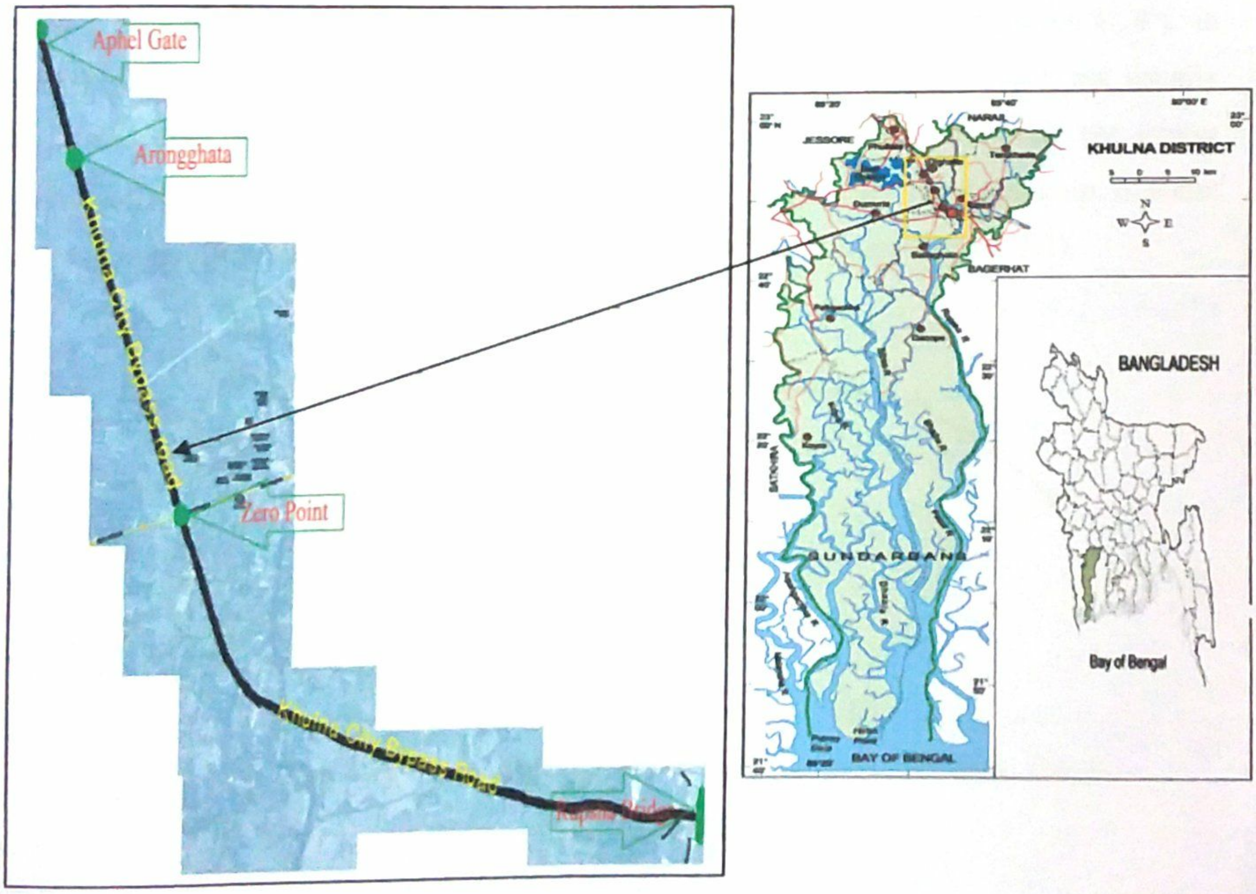

Figure 3.1 Study area, Khulna city bypass road (rupsha bridge to arongghata), Khulna, Bangladesh.

3.1.2 Climatic condition

Khulna district enjoys generally a tropical to subtropical monsoon climate. While there are six seasons (changes every two months) in a year, three namely summer (March to May), monsoon or rainy (June to October) and winter (November to February) are prominent. These three seasons are characteristic of Khulna region. Winds are mostly from the north and northwest in the winter, 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

Khulna has an annual average temperature of 26°C. January is the coolest month and April is the hottest month in this region where monthly means varying between 12.4°C in January and 34.6°C in April. The climate of Khulna is quite pleasant with not usually much fluctuation in temperature in winter and humid during summer. As the winter season progresses into pre-monsoon summer season, temperature starts rising up. In some places temperature reaches up to 40°C or more during the summer (Figure 3.2).

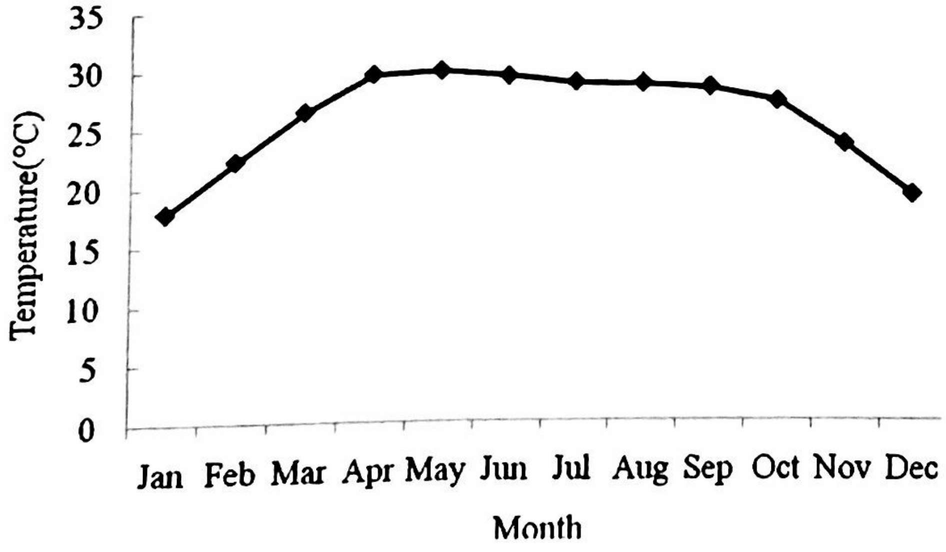

Figure 3.2 Mean monthly temperatures of Khulna district. Source: BBS 2012.

3.1.2.2 Rainfall

Annual average rainfall of Khulna is 1800±268 mm ranging from 1400 to 2600 mm. Approximately 87% of the annual average rainfall occurs between May and October (Figure 3.3). 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.

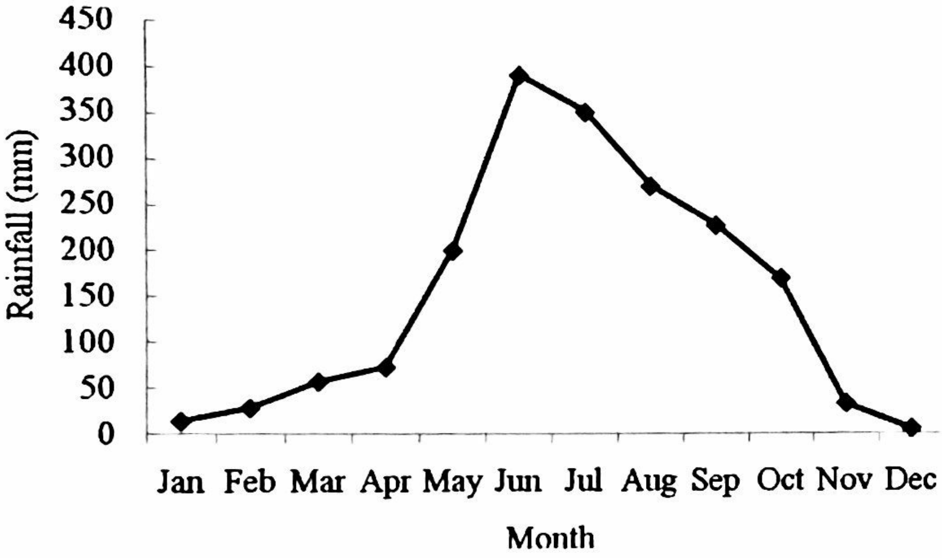

Figure 3.3 Mean monthly rainfall of Khulna district. Source: BBS 2012.

3.1.2.3 Humidity

The annual average relative humidity of the region is 78%. March is the least humid month (65%). The relative humidity is 84% during monsoon (June to September) because of heavy rainfall but in summer season humidity becomes low.

3.1.2.4 Hydrology

Few main rivers have crossed along this region like Rupsa, Bhairab, Bhadra, Kobadak etc. (BBS 2012). Because of this reason, seasonal flooding near the river is a prominent characteristic in this region. Most of the area belongs to above river flood level where small area like coastal part of this region usually subjected to flood deeply. Some level terrace areas are also subjected to shallow rainwater flooding.

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 (12.7%) and terrace soils (8.3%). 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 Soil Types Different Part of Khulna District

Region	Soil Type
Coastal Parts of Khulna	Acid Sulphate
Coastal Parts of Khulna	Peat
Other Parts of Khulna	Calcareous Alluvium
Other Parts of Khulna	Calcareous Grey Floodplain Soil
Other Parts of Khulna	Non-Calcareous Dark Grey Floodplain Soil
Other Parts of Khulna	Calcareous Dark Grey Floodplain Soil
Other Parts of Khulna	Calcareous Brown Floodplain Soil

Source: BBS 2012.

3.2 Methodology

3.2.1 Sampling Design

This study was conducted in Khulna city bypass road (rupsha bridge to arongghata) of Khulna district of Bangladesh. At first Khulna city bypass road was purposively selected. Sampling was started from rupsha bridge and the sampling plots were taken in zigzag pattern. First sampling plot was selected randomly and then systematic sampling was done. For primary data collection at every 500 m distance sampling plots were taken where the size of the sampling plots was 20 m × 2 m (40 m^2).

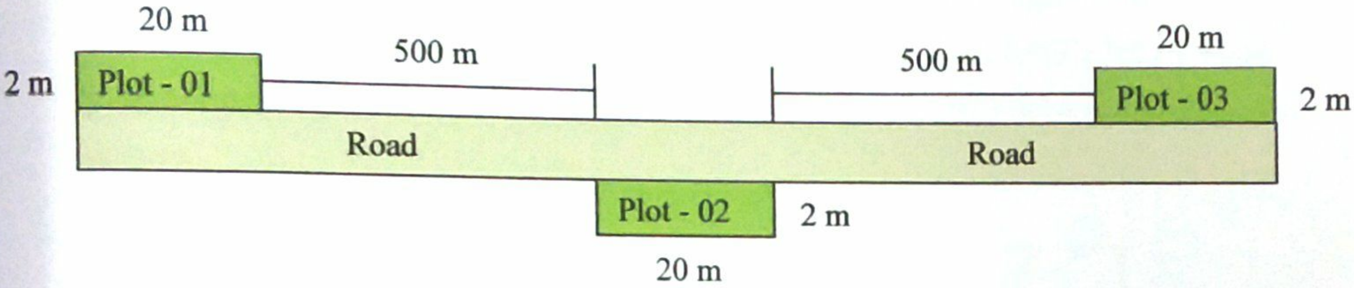

Figure 3.4 Schematic map of zigzag survey design

3.2.2 Field 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 (2005), trees were selected on the following basis:

- All live woody stems having a diameter at breast height of 3 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. For the sapling of palms those have not form any diameter only height was taken for them. So at the calculation of basal area of species level and every plot their calculation were not consider as it is not possible to calculate basal area without DBH. Canopy coverage of every plot was also measured using a densiometer. Wood density of every species was collected from secondary data such as FAO's list of wood densities for tree species from tropical Asia and Zanne et al. (2009), Global wood density database.

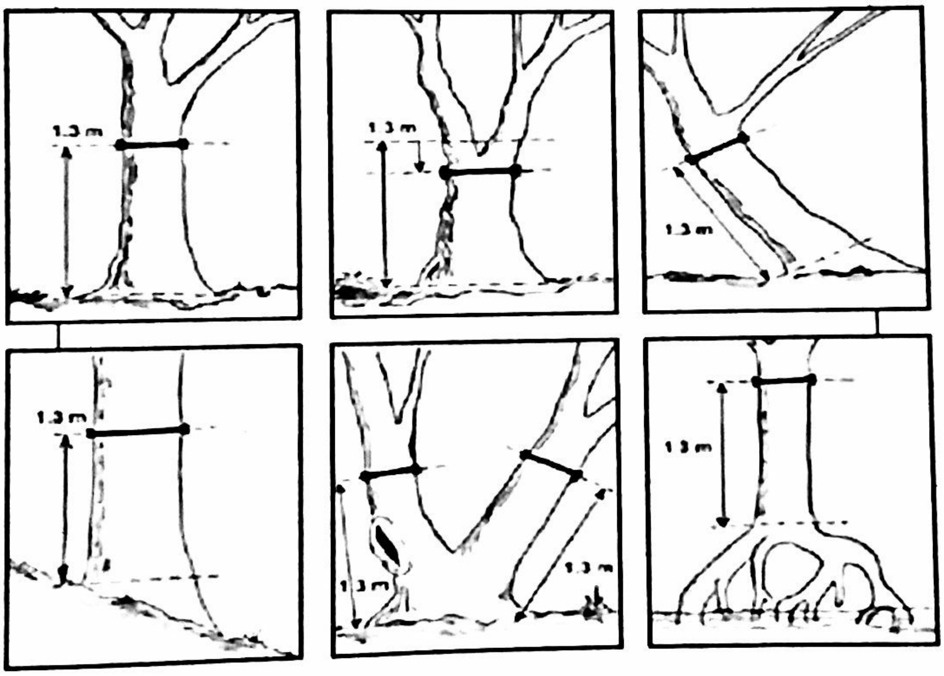

Figure 3.5 DBH measurement locations for irregular and abnormally shaped trees. Source: Pearson et al. (2005)

3.2.2.3 Canopy cover

A spherical densiometer was used to estimate canopy cover. The counted record was multiplied by 1.04 to obtain the percent of area not occupied by canopy. This is because there were only 96 dots to count instead of 100. Then the resulting value was subtracted from 100 to obtain canopy cover in percent. The 4 values from each plot (N, S, E and W) were averaged to provide a mean estimate of canopy cover at each plot.

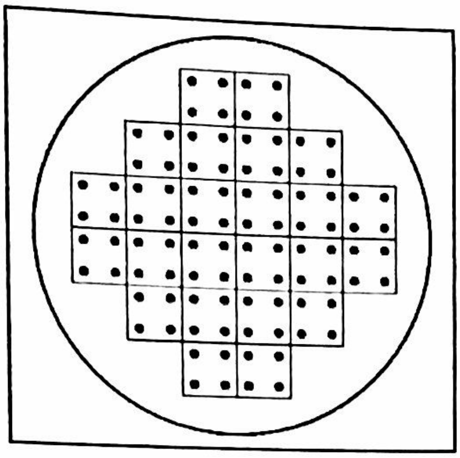

Figure 3.6 Schematic of densiometer mirror, with the 4 dots depicted in each square. Source: Donato et al. 2009.

3.2.3 Data analysis

3.2.3.1 Allometric computations for aboveground biomass

3.2.3.1.1 Live Tree

Biomass equations relate DBH to biomass and biomass may differ among species as trees in a similar functional group can differ greatly in their growth form between geographic areas (Pearson et al. 2007). Considering these factors Chave et al. (2005) developed allometric equation for tropical trees that was used for wide graphical and diameter range.

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

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 Live Sapling

Sapling biomass was calculated by using the same equation that was used to estimate tree biomass.

3.2.3.1.3 Palms

Palm, coconut and date are common in southwestern part of Bangladesh. Pearson et al. (2005) developed equation for palms that was used for aboveground biomass calculation:

$$\text{Aboveground Biomass} = 6.666 + 12.826 \times ht^{0.5} \times \ln(ht)$$

6.666 = Constant

12.826 = Constant

0.5 = Constant

ht = Height

ln = Natural logarithm

3.2.3.2 Conversion of aboveground biomass to carbon

Open-grown, maintained trees tend to have less above-ground biomass than predicted by forest derived biomass for trees of same diameter at breast height (Nowak et al. 1994). To adjust for this difference biomass results for roadside trees were multiplied by a factor 0.8 (Nowak and Crane 2002). After estimating the biomass from allometric relationship it was multiplied by the wood carbon content (50%). As almost all carbon measurement projects in the tropical forest assume all tissues (i.e. wood, leaves and roots) consist of 50% carbon on a dry mass basis (Chave et al. 2005, Prichard et al. 2000, Smith and Heath 2002).

$$\begin{aligned}\text{Carbon (Mg)} &= \text{Biomass estimated by allometric equation} \times \text{Wood Carbon Content \%} \\ &= \text{Biomass estimated by allometric equation} \times 0.5\end{aligned}$$

3.2.3.3 Density, frequency, basal area and importance value calculation

Aboveground carbon pools were computed using international standard common tree allometries combined with local tables of wood density by tree species. Statistical analysis was done in Microsoft Excel 2007 and SPSS-16 software. For describing floristic composition species 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).

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

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

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 of Moore and Chapman 1986, Shukla and Chandel 1980 and Dallmeier et al. 1992 quantitative structure parameters of investigated trees were calculated:

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

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

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

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

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

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

7. Importance value index (%) = (Relative density + Relative frequency + Relative dominance)/3

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Tree species composition

A total of 193 individuals of 13 species were enumerated from 24 sample plots of Khulna city bypass road. *Samanea saman*, *Acacia nilotica*, *Pithecellobium dulce*, *Phyllanthus emblica* and *Swietenia macrophylla* are the top five most-densest species in this study (Table 4.1). But three species (*Samanea saman*, *Acacia nilotica* and *Pithecellobium dulce*) comprise 76% of total population. Again these three species contribute 62% relative frequency of total population and 88% relative dominance of total population (Appendix 2). Considering relative density and relative frequency, *Acacia nilotica* occupies the rank one but considering relative dominance, *Samanea saman* occupies the rank one (Table 4.1). *Pithecellobium dulce* occupies the rank three at all the three cases.

Table 4.1 Five most important species list.

Species Rank	Relative Density (RD %)	Relative Frequency (RF %)	Relative Dominance (RDo %)
1	*Acacia nilotica*	*Acacia nilotica*	*Samanea saman*
2	*Samanea saman*	*Samanea saman*	*Acacia nilotica*
3	*Pithecellobium dulce*	*Pithecellobium dulce*	*Pithecellobium dulce*
4	*Phyllanthus emblica*	*Swietenia macrophylla*	*Swietenia macrophylla*
5	*Swietenia macrophylla*	*Phyllanthus emblica*	*Phyllanthus emblica*

4.1.2 Family Composition

A total of nine families were encountered from the study area. Leguminosae sub-families account for 148 numbers of individuals of the total counted population. The family Leguminosae is predominant with 77% of total population, followed by Meliaceae (8%), Euphorbiaceae (5%), Rhamnaceae (3%), Myrtaceae (3%), Moraceae (2%), Combretaceae (1%), Anacardiaceae (1%) and Palmae (1%).

4.1.3 Descriptive Statistics

Vegetation characteristics like stem density, mean DBH, mean height, basal area, canopy coverage and aboveground carbon stock at the study area (rupsha bridge to arongghata bypass road, Khulna) at 24 plots with minimum, maximum and mean values with their standard error are presented in table 4.2. Average standing aboveground carbon stock is 176.9±22.43 Mg ha^{-1} while the maximum standing aboveground carbon stock is 419.43 Mg ha^{-1} and the minimum standing aboveground carbon stock is 0 Mg ha^{-1}.

Table 4.2 Descriptive statistics (minimum, maximum, mean and standard error) of vegetation characteristics.

Stand Characteristics	No.	Minimum	Maximum	Mean	Std. Error
Stem Density (ha^{-1})	24	0.00	4500.00	2010.40	266.01
Mean DBH (cm)	24	0.00	21.88	14.45	1.03
Mean Height (m)	24	0.00	9.80	7.05	0.51
Basal Area (m²/ha)	24	0.00	74.71	35.15	4.18
Canopy Coverage (%)	24	0.00	70.00	37.67	4.79
Aboveground Carbon (Mg/ha)	24	0.00	419.43	176.9	22.43

4.1.4 Species wise aboveground carbon composition

The calculated aboveground carbon stocks are highly variable among different species as a consequence of high variability in floristic composition, density, tree size etc. Different types of species store different amount of carbon when they grow at variable densities. *Samanea saman* occupies highest amount of carbon in the study area followed by *Acacia nilotica, Pithecellobium dulce, Azadirachta indica, Swietenia macrophylla*. Among these species *Samanea saman, Acacia nilotica* and *Pithecellobium dulce* comprise about 90% of total carbon of the study area.

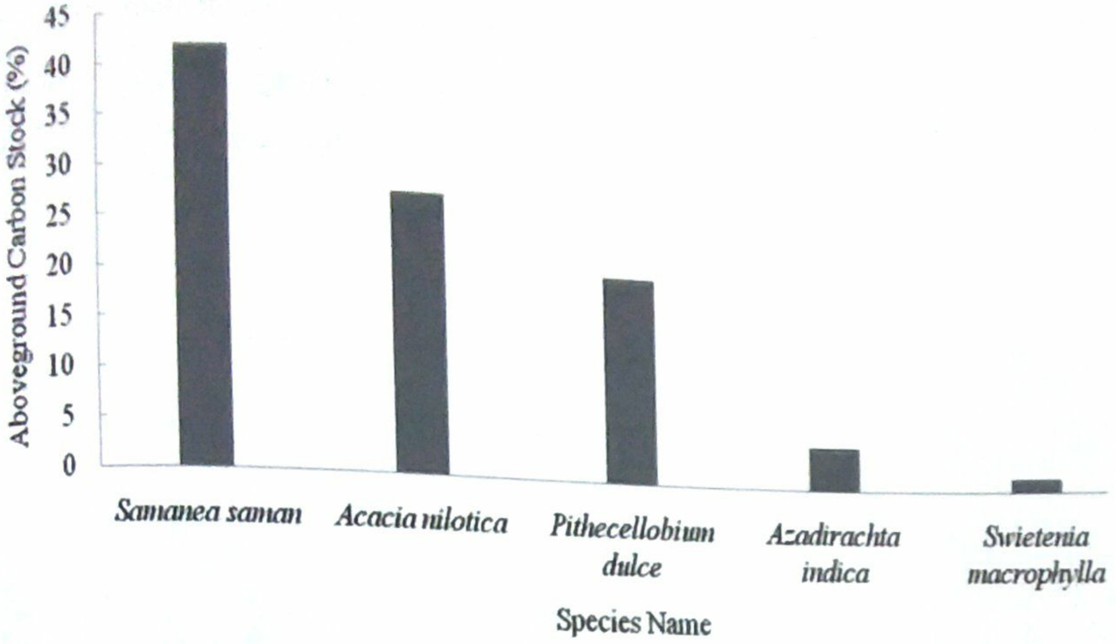

Figure 4.1 Aboveground carbon composition (%) of five most dominant species

4.1.5 Mean tree height

There was a moderate relation between mean tree height and total aboveground carbon stock but the relationship was significant ($p < 0.05$). The value of r is 0.51 and R^2 is 0.26 (Figure 4.2).

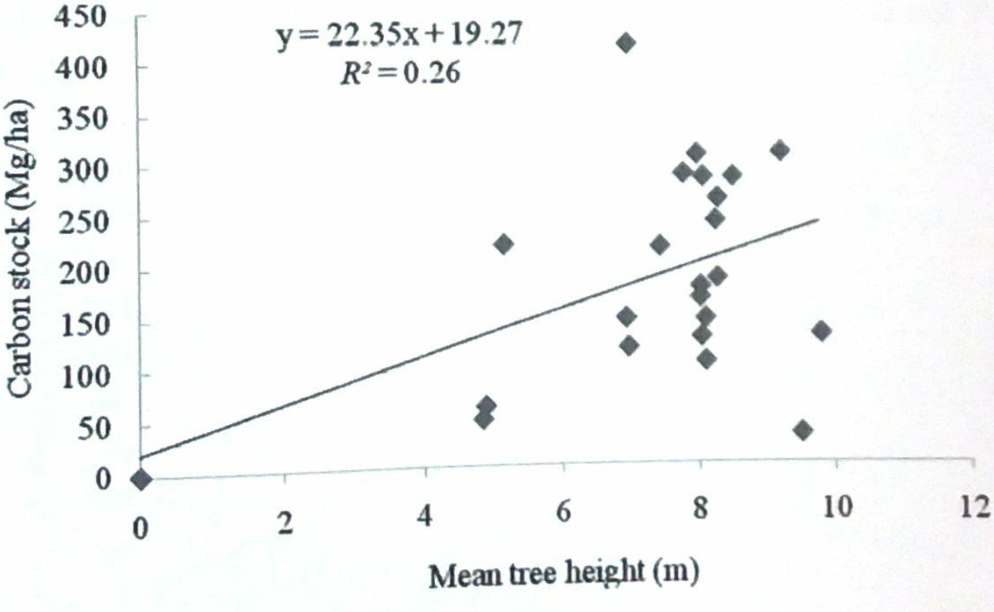

Figure 4.2 Relationship between mean tree height and total aboveground carbon stock

4.1.6 Basal area

It was found that basal area/ha had a very strong relationship with total aboveground carbon and the relationship was significant ($p < 0.05$). The value of r is 0.96 and R^2 is 0.92 (Figure 4.3).

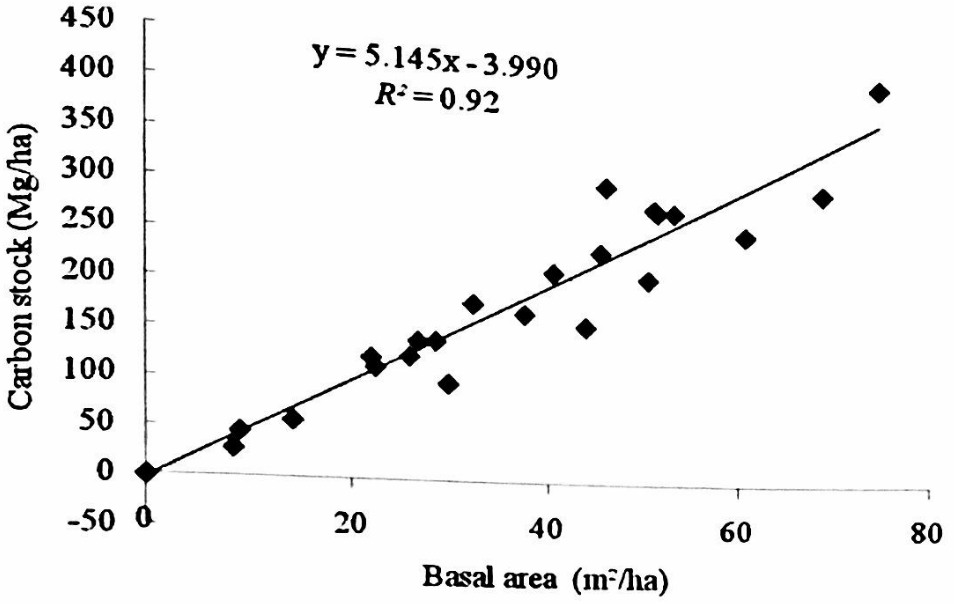

Figure 4.3 Relationship between basal area and total aboveground carbon stock

4.1.7 Canopy cover

There was a very strong relation between canopy cover and total aboveground carbon stock and the relationship was significant ($p < 0.05$). The value of r is 0.93 and R^2 is 0.86 (Figure 4.4).

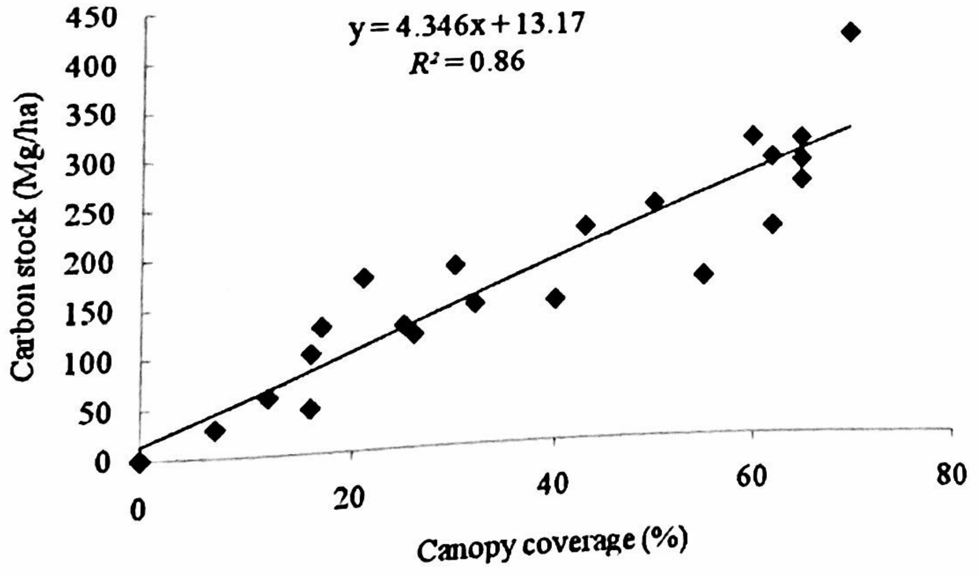

Figure 4.4 Relationship between canopy cover (%) and total aboveground carbon stock

4.1.8 Stem density

There was a very strong relation between stem density/ha and total aboveground carbon stock and the relationship was significant ($p < 0.05$). The value of r is 0.93 and R^2 is 0.87 (Figure 4.5).

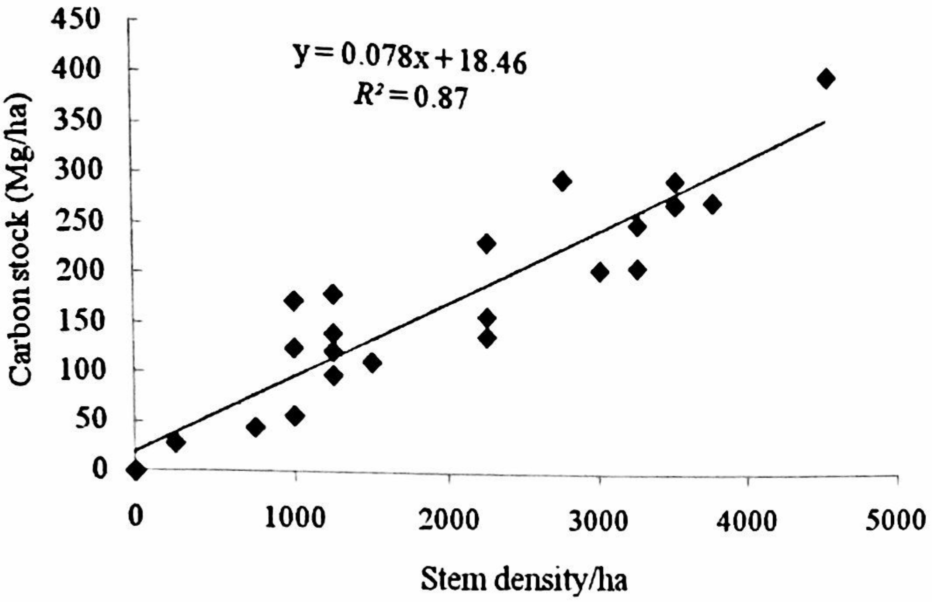

Figure 4.5 Relationship between stem density/ha and total aboveground carbon stock

4.2 Discussion

The population of roadside plantation of Khulna city bypass road, Khulna consists of 13 species from 9 families. The three most dominant tree species are *Acacia nilotica* (babla), *Samanea saman* (rain tree) and *Pithecellobium dulce* (khoi babla) (Table 4.1). But in Bangalore, one of the important cities of neighboring country India, the population of street trees composed of 108 species from 33 families where the most dominant species is *Samanea saman* (rain tree) (Nagendra and Gopal 2010). Here this difference is mainly for the number of roads. This research was conducted on a single road but Nagendra and Gopal (2010) conducted their research on different roads of different types like small, medium and large type of roads and species composition varies road to road.

In this study three most common species *Acacia nilotica* (babla), *Samanea saman* (rain tree) and *Pithecellobium dulce* (khoi babla) together constitute three-forth of total population (Appendix 2). Contrast to this in street trees in Bangalore the four most dominant species comprise about one-third of the population (Nagendra and Gopal 2010). But having similarity with the research in the USA, where three most common species constitute almost two-thirds of the street trees in Syracuse (Sanders 1981) or in Chicago where the four most common species comprise two-thirds of the entire population (McPherson et al. 1997). In Khulna city bypass road, Khulna, one species *Acacia nilotica* (babla) constitutes 35.23% of the population having similarity with highly populated Asian city Bangkok, where one species *Pterocarpus indicus* constitutes over 40% of the trees (Thaiutsa et al. 2008) but in Mexico City where the four most common species constitute 49% of the trees (Chacalo et al. 1994) and in Hong Kong, where the five most common species constitute over 50% of the total population (Jim 1987).

The average DBH of trees across the study area was 14.45 cm and the average height was 7.05 m. The biggest tree in diameter encountered was a *Samanea saman* (rain tree) with a DBH of 42.02 cm, with a height of 11.4 m while the tallest tree was a *Pithecellobium dulce* (khoi babla) with a height of 11.8 m with a DBH of 23.24 cm. But according to Nagendra and Gopal (2010) the average DBH of trees across all street trees in Bangalore was 39 cm and the average height was 9.7 m. The biggest tree in diameter encountered was a *Ficus benghalensis* (banyan) with a DBH of 232 cm, although with a height of just 15 m while the tallest tree was a Eucalyptus species with a height of 25 m, but a DBH of only 55 cm.

Considering relative density and relative frequency, *Acacia nilotica* (babla) occupies the rank one but considering relative dominance *Samanea saman* (rain tree) occupies the rank one. This is because of most of the large DBH trees belonging to *Samanea saman* (rain tree) and very few numbers of large DBH trees belonging to *Acacia nilotica* (babla).

The average standing aboveground carbon stock was 176.9±22.43 Mg ha^{-1} from this study while the maximum standing aboveground carbon stock was 419.43 Mg ha^{-1} and the minimum standing aboveground carbon stock was 0 Mg ha^{-1}. This difference is mainly for the variation in the number of trees presence per plot. Those plots where standing aboveground carbon stock were 0 Mg ha^{-1}, had no tree species but the plot where aboveground carbon stock was 524.29 Mg ha^{-1} had 18 tree species with good DBH size. Again certain plots with similar number of species exhibited variation in the values of the carbon stock. But according to Nowak and Crane (2002) 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. Thus it is undoubted that certain plots with similar number of species exhibited variation in the values of the carbon stock.

Several measures of stand structure and productivity were also assessed for any relationship with aboveground carbon stock. Three attributes which are strongly related to aboveground carbon stock, are stand basal area (*r*=0.96 and R^2=0.92) (Figure 4.3), canopy cover (*r*=0.93 and R^2=0.86) (Figure 4.4) and stem density/ha (*r*=0.93 and R^2=0.87) (Figure 4.5). But stand mean height was weakly related (*r*=0.51 and R^2=0.26) (Figure 4.2) with total aboveground carbon stock. According to Kayah et al. (2012) DBH is very strongly (R^2=0.98) related with aboveground biomass and also very strongly (R^2=0.83) related with crown area. Again Henry et al. (2009) has shown tree volume is very strongly related with total aboveground biomass. So more basal area, canopy cover and stem density/ha indicate more amount of biomass and more biomass means more carbon stock. But with similar height of different plots having wide variation in number of tree. For this reason mean tree height is weakly related with aboveground carbon stock.

CHAPTER 5

CONCLUSION

Khulna is an important city of Bangladesh and very much vulnerable to climate change. Roadside plantation as a land use system has the potential to move the climate change mitigation one step forward. So attention was given on study of floristic composition of woody vegetation of roadside plantation of Khulna city bypass road, Khulna and it's aboveground carbon estimation. Overall this study showed that the floristic composition of this roadside plantation is quite substantial with other studies of different countries. *Acacia nilotica* (babla), *Samanea saman* (rain tree) and *Pithecellobium dulce* (khoi babla) are the most dominant tree species that comprise three-forth of total population. Again aboveground carbon stock is quiet satisfactory and greater than any other agroecosystem. It is highly related with site productivity (e.g. basal area, canopy cover, DBH) and stem density/ha. If we can improve the value of these, roadside plantation will be capable to increase the amount of aboveground carbon stock. Then ultimately we will gain more ability for climate change mitigation.

REFERENCE

Alvey A A, 2006. Promoting and preserving biodiversity in the urban forest. *Urban Forestry and Urban Greening* 5: 195-201.

Asante P, 2011. Carbon Sequestration and the Optimal Economic Harvest Decision. Ph. D. Dissertation, University of Albert. 85pp.

BBS, 2012. Statistical Year Book of Bangladesh. Bangladesh Bureau of Statistics (BSS), Statistic Division, Ministry of Planning, Bangladesh Secretariat, The Government of the People's Republic of Bangladesh, Dhaka.

Beckett K P, Freer-Smith P and Taylor G, 2000. Effective tree species for local air quality management. *Journal of Arboriculture* 26: 12-19.

Bernoux M, Feller C, Cerri C C, Eschenbrenner V and Cerri C E P, 2006. Soil carbon sequestration. pp. 13-22. In Roose E, Lal R, Feller C, Barthes B and Stewart R (eds.), Soil erosion and carbon dynamics. CRC Press, Boston, USA.

Bhuiyan A A, 1991. Program and progress of social forestry in Bangladesh. Workshop on social forestry and community development, October 5, 1991at IFCU, Chittagong, Bangladesh.

Bhuiyan A A, 1993. Social Forestry A Development Strategy. The Daily Star, 1st July 1993. Dhaka, Bangladesh.

Brown D, 2010. Roadside Management Strategies to Reduce Greenhouse Gases. Caltrans Division of Research and Innovation, California, USA. 11-41pp.

Bunker D E, DeClerck F, Bradford J C, Colwell R K, Perfecto I, Phillips O L, Sankaran M and Naeem S, 2005. Species loss and aboveground carbon storage in a tropical forest. *Science* 310: 1029-1031.

Canadell J G and Raupach M R, 2008. Managing forest for climate change mitigation. *Science* 320: 1456-1461.

Chacalo A, Aldama A and Grabinsky J, 1994. Street tree inventory in Mexico City. *Journal of Arboriculture* 20: 222-226.

Chave J, Andalo C, Brown S, Cairns M A, Chambers J Q, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure J P, Nelson B W, Ogawa H, Puig H, Riera B and Yamakura T, 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87-99.

Chow W T and Roth M, 2006. Temporal dynamics of the urban heat island of Singapore. *International Journal of Climatology* 26: 2243-2260.

Dallmeier F, Kabel M and Rice R, 1992. Methods for long term biodiversity inventory plots in protected tropical forests. 14-46 pp. In Dallmeier F, (eds.) Long-term Monitoring of Biological Diversity in Tropical Forest Areas: Methods for Establishment and Inventory of Permanent Plots. UNESCO, Paris, France.

Day T K, 1996. The village and farm forestry program in Bangladesh. Workshop on prospect of village and farm forestry, January 25, 1996, Hotel Sonargoan, Dhaka, Bangladesh.

Detwiler R P and Hall C A S, 1988. Tropical forests and the global carbon cycle. *Science* 239: 42-47.

Dixon R K, 1995. Agroforestry systems: sources or sinks of greenhouse gases? *Agroforestry Systems* 31: 99-116.

Dixon R K, Winjum J K, Andrasko K J, Lee J J and Schroeder P E, 1994a. Integrated land-use systems: assessment of promising agroforest and alternative land use practices to enhance carbon conservation and sequestration. *Climate Change* 27: 71-92.

Donato D, Kauffman J B, Murdiyarso D, Kurnianto S, Stidham M and Kanninen M, 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience* 22: 108-115.

Dumbaugh E, 2005. Safe streets, livable streets. *Journal of the American Planning Association* 71: 283-298.

Escobedo F J, Nowak D J, Wagner J E, Maza C L, Rodriguez M, Crane D E and Hernandez J, 2006. The socioeconomics and management of Santiago de Chile's public urban forests. *Urban Forests and Urban Greening* 4: 105-114.

Ferrini F, 2011. Sustainable management techniques for trees in the urban areas. *Journal of Biodiversity and Ecological Sciences* 1(1): 1-20.

Gilman E F, 1997. Trees for urban and suburban landscapes. Delmar Publishers, Albany, New York, USA. 235pp.

GOB (Government of Bangladesh), 1988. Project Proforma of Thana Banayan and Nursery Development Project, Ministry of Environment and Forest. Ban Bhaban, Mohakhali, Dhaka, Bangladesh.

GOB (Government of Bangladesh), 1995. Environmental improvement through government of Bangladesh 1990. Report on survey of Farm Forestry, Bangladesh Bureau of Statistics, Statistic Division, Ministry of Planning, Bangladesh Secretariat, The Government of the People's Republic of Bangladesh, Dhaka. 312pp.

Henry M, Tittonell P, Manlay R J, Bernoux M, Albrecht A and Vanlauwe B, 2008. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. *Agriculture, Ecosystem and Environment* 129: 238-252.

http://en.wikipedia.org/wiki/ List of roads in Bangladesh

http://www.fao.org/nkks.htm

Huq F M and Alim A, 1995. Social Forestry in Bangladesh State of Art Study. *International Tree Crop Journal* 8: 56-62.

IPCC (Intergovernmental Panel on Climate Change), 2001. IPCC Third Assessment Report-Climate Change 2001. The Scientific Basis: Summary for Policymakers and Technical Summary, Geneva, Switzerland. 98pp.

IPCC (Intergovernmental Panel on Climate Change), 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Presented by Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA. 442pp.

IPCC, 2007. Fourth IPCC assessment report: climate change 2007. Cambridge University Press, Cambridge, UK. 268pp.

Jim C Y, 1987. The status and prospects of urban street in Hong Kong. *Landscape and Urban Planning* 14: 1-20.

Jim C Y and Chen W Y, 2008. Pattern and divergence of tree communities in Taipei's main urban green spaces. *Landscape and Urban Planning* 84: 312-323.

Jose S, 2009. Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems* 26: 87-96.

Kiran G S and Kinnary S, 2011. Carbon sequestration by urban trees on roadsides of Vadodara city. *International Journal of Engineering Science and Technology* 3(4): 3066-3070.

Kumar B M, 2011. Species richness and aboveground carbon stocks in the homegardens of central Kerala, India. *Agriculture, Ecosystems and Environment* 140: 430-440.

Kuyah S, Dietz J, Muthuri C, Jamnadass R, Mwangi P, Coe R and Neufeldt H, 2012. Allometric equations for estimating biomass in agricultural landscape: I. Aboveground biomass. *Agriculture, Ecosystem and Environment* 158: 216-224.

Laffoley D A and Grimsditch G, 2009. The management of natural coastal carbon sinks. *Chemosphere* 27: 1097-1107.

Lawrence H W, 1994. Origins of the tree lined boulevard. *Geographical Review* 78: 355-374.

Maco S E and McPherson E G, 2003. A practical approach to assessing structure, function and value of street tree populations in small communities. *Journal of Arboriculture* 29: 84-97.

McPherson E G, Nowak D, Heisler G, Grimmond S, Souch C, Grant R and Rowntree R, 1997. Quantifying urban forest structure, function and value: the Chicago Urban Forest Climate Project. *Urban Ecosystems* 1: 49-61.

Moore P D and Chapman S B, 1986. Methods in plant ecology. Blackwell scientific publications, Oxford, UK. 550pp.

Nagendra N and Gopal D, 2010. Street trees in Bangalore: Density, diversity, composition and distribution. *Urban Forestry & Urban Greening* 9: 129-137.

Nowak D and Crane N, 2002. Carbon storage and sequestration by urban trees in the USA. *Environmental Pollution* 116: 381-389.

Nowak D , McPherson E G and Rowntree R A, 1994. Executive Summary. pp 3-4. In McPherson E G, Nowak D and Rowntree R A (Eds), Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project, General Technical Report NE-186. USDA Forest Service, Northeastern Forest Experiment Station, Radnor, USA.

Pan Y, Richard A, Fang J, Houghton R and Pekka K, 2011. A Large and Persistent Carbon Sink in the World's Forests. *Science* 18: 1609-1619.

Paustian K, Six J, Elliott E T and Hunt H W, 2000. Management options for reducing CO_2 emissions from agricultural soils. *Biogeochemistry* 48: 147-163.

Pearson T, Walker S and Brown S, 2005. Sourcebook for land use, land-use change and forestry projects. Report from Biocf and Winrock International. Available at: http://www.winrock.org/ecosystem/tools.asp?BU=9086.

Pearson T, Brown S and Birdsey R A, 2007. Measurement guideline for the sequestration of forest carbon. General Technical Report-NRS-18, USDA Forest Service, Northern Research Station, USA.

Prichard S J, Peterson D L and Hammer R D, 2000. Carbon distribution in subalpine forests and meadows of the Olympic Mountains, Washington. *Soil Science Society of America Journal* 64: 1834-1845.

Sanders R A, 1981. Diversity in the street trees of Syracuse, New York. *Urban Ecology* 5: 33-43.

Sharma M C, Baduni N P, Gairola S, Ghildiyal S K and Suyal S, 2010. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *Forest Ecology and Management* 260(12): 2170-2179.

Shukla R S and Chandel P S, 1980. Plant Ecology, 4th Edition. Chand Company Ltd, Ram Nagar, New Delhi-120055. 71-102 pp.

Smith J E and Heath L S, 2002. A Model of Forest Floor Carbon Mass for United States Forest Types. *Forest Ecology and Management* 129(3): 371-360.

TFD, 2008. Beyond REDD: The Role of Forests in Climate. Yale University, 360 Prospect Street, New Haven, Connecticut 06511, USA. Available at www.theforestsdialogue.org

Thaiutsa B, Puangchit L, Kjelgren R and Arunpraparut W, 2008. Urban green space, street tree and heritage large tree assessment in Bangkok, Thailand. *Urban Forestry and Urban Greening* 7: 219-229.

UNFCCC, 2004. Modalities and procedures for afforestation and reforestation project activities under the clean development mechanism in the first commitment period of the Kyoto Protocol. pp. 13-31. In Report of the Conference of the Parties on its ninth session, held at Milan from 1 to 12 December 2003, Addendum, Decision 19/CP.9, Document FCCC/CP/2003/6/Add.2, United Nations Office at Geneva, Switzerland.

UNFCCC, 2007. Climate Change: Impacts, Vulnerabilities and Adaptation in Developing Countries. Climate Change Secretariat (UNFCCC) Martin Luther King Street 8, 53175 Bonn, Germany.

USDA NRCS (United States Department of Agriculture Natural Resources Conservation Service), 2000. Growing carbon: a new crop that helps agricultural producers and the climate too. The Soil and Water Conservation Society, USA. Available from http://www.unl.edu/nac.

USEPA at www.epa.gov/sequestration /local_scale.html

Wetter A, Goldberg J, King A, Sigman M, Bae R, Crayton E, Devine D, Drewnowski A, Dunn A, Johnson G, Pronk M, Snyder D, Walsh K and Warland R, 2001. How and why do individuals make food and physical activity choices? *Nutrition Reviews* 59: 11-20.

Wolf K, 2005. Business district streetscapes, trees and consumer response. *Journal of Forestry* 103: 396-400.

Zabala N Q, 1991. Urban tree cover: an ecological perspective. *Urban Ecosystem* 8: 229-247.

Zanne A E, Lopez-Gonzalez G, Coomes D A, Ilic J, Jansen S, Lewis S L, Miller R B, Swenson N G, Wiemann M C and Chave J, 2009. Global wood density database. Dryad. Identifier: http://hdl.handle.net/10255/dryad.235.

APPENDIX 1

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					

APPENDIX 2

Relative density (RD %), relative frequency (RF %), relative dominance (RDo %) and importance value index (IVI %) of all tree species found at the study area.

Sl No.	Botanical Name	Local Name	RD (%)	RF (%)	RDo (%)	IVI (%)
1	*Samanea saman*	Rain Tree	25.39	22.64	51.20	33.08
2	*Acacia nilotica*	Babla	35.23	24.53	20.35	26.70
3	*Pithecellobium dulce*	Khoi Babla	15.54	15.09	16.81	15.82
4	*Swietenia macrophylla*	Mehogone	5.18	7.55	2.65	5.13
5	*Phyllanthus emblica*	Amloki	5.18	3.77	1.37	3.44
6	*Azadirachta indica*	Nim	2.59	3.77	3.57	3.31
7	*Ziziphus mauritiana*	Boroi	3.11	3.77	0.80	2.56
8	*Psidium guajava*	Peyara	2.59	3.77	0.32	2.23
9	*Lannea coromandelica*	Kocha	1.04	3.77	0.73	1.85
10	*Terminalia catappa*	Kat Badam	1.04	3.77	0.34	1.72
11	*Ficus bengalensis*	Bot	1.55	1.89	1.02	1.49
12	*Albizia richardiana*	Raj Koroi	0.52	1.89	0.85	1.09
13	*Phoenix sylvestris*	Khejur	1.04	3.77	0.00	1.60