TREE SPECIES DENSITY ENHANCES SOIL ORGANIC CARBON CONTENT ACROSS DHANMONDI LAKE AREA IN DHAKA CITY

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Chairman
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Dedicated to
My

Loving Parents
and

Respected
professors,

whose hopes,
dreams, and
prayers have
guided me
through life.

DEPARTMENT OF
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CERTIFICATE

This is to certify that the thesis entitled ***"TREE SPECIES DENSITY ENHANCES SOIL ORGANIC CARBON CONTENT ACROSS DHANMONDI LAKE AREA IN DHAKA CITY"*** *submitted to the Faculty of Agriculture, Sher-e-Bangla Agricultural University, Dhaka, in partial fulfillment of the requirements for the degree of* ***MASTER OF SCIENCE*** *in* ***AGROFORESTRY AND ENVIRONMENTAL SCIENCE****, embodies the result of a piece of bona fide research work carried out by* ***SUCHI TALUKDAR****, Registration number:* ***19-10286*** *under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.*

I further certify that such help or source of information, as has been availed during the course of this investigation has duly been acknowledged.

Dated: December, 2021
Dhaka, Bangladesh

Dr. Ferzana Islam
Professor
Supervisor

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ABSTRACT

The present study was conducted to determine the density of tree species and the amounts of soil organic carbon at the area of Dhanmondi Lake in Dhaka city. The research was carried out during June 2021 to January 2022. The MS Excel application was used to organize and analyze all of the data. In this study, total of 22 families were identified. The total number of plants was discovered to be 134. *Swietenia mahagoni* (Mahagoni), with a total of nine (9) tree individuals, had the highest percentage of tree individuals (6.72%), while an unidentified species and some others had the lowest percentage (0.75%). Height, DBH and canopy of trees were tabulated by different classes with number of trees. All the structural attributes like relative density (RD %), Relative frequency (RF %), Relative Dominance (RDo %) and Important value index (IVI %) were also calculated. For low, medium, and high-density plots around Dhanmondi lake, the average tree density was 2800, 4500, and 6000 trees/ha respectively. The relationship between soil organic carbon (SOC) and tree density were assessed. Soil organic carbon is higher in high density plots than medium and low-density plots. The relationship between SOC and tree density was positive and statistically significant correlated with carbon in the most cases because sometimes it showed negative and non-significant relationship.

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LIST OF ABBREVIATIONS

Full Name	Abbreviation	Full Name	Abbreviation
Above Ground Biomass	AGB	Leaf Dry Matter Content	LDMC
Above Ground Carbon	AGC	Leaf Toughness	LT
Above Ground Dry Biomass	AGDB	Nitrogen Dioxide	NO_2
Basal Area	BA	Oxygen	O_2
Bulk Density	BD	Oven Dry Weight	ODW
Below Ground Biomass	BGB	The Point of	
Below Ground Carbon	BGC	Measurement	POM
Bangladesh University of		Root Collar Diameter	RCD
Engineering and Technology	BUET	Sulfur Dioxide	SO_2
Carbon	C	Soil Organic Carbon	SOC
Clean Development		United Nations	
Mechanism	CDM	Framework Convention	
Carbon Monoxide	CO	on Climate Change	UNFCC
Carbon Dioxide	CO_2	Percent	%
Diameter at Breast Height of		Degree Fahrenheit	°F
tree	DBH	Degree Celsius	^0C
Dynamic Global Vegetation		Ton	t
Model	DGVM	Gram	g
For Example	e.g.	Square Miles	sq. mi
et cetra (and so on)	etc.	Square Meter	m^2
et alibi (and others)	*et al.*	Centimeter	cm
Food and Agriculture		Hectare	ha
Organization	FAO	Natural Logarithm	ln
Girth Breast Height	GBH	Wood Specific Gravity	ρ
Greenhouse Gas	GHG	(g/cm^3)	
Intergovernmental Panel on		Petagrams of Carbon	PgC
Climate Change	IPCC	Gigaton	Gt

CHAPTER 1
INTRODUCTION

Agroforestry is a land-use strategy that incorporates the retention, introduction, or combination of trees or other woody perennials with agricultural crops, pastures, or livestock in order to utilize the ecological and economic interactions between the various components (Nair, 1993; Young, 1997). The Kyoto Protocol recognizes agroforestry as a method for reducing greenhouse gas emissions because to the greater amount of organic material it adds to the soil (Nair *et al.*, 2009a; Jose 2009; Gama-Rodrigues *et al.,* 2010). Agroforestry systems are believed to store more carbon than grasslands or croplands (Sanchez 2000; Roshetko *et al.*, 2002; Kirby and Potvin 2007). This belief is based on the notion that incorporating trees into croplands and pastures would result in an increased net above- and below-ground carbon sequestration (Palm *et al.,* 2004). Agroforestry systems (AFS) with a high rate of litter fall are crucial due to their great potential for carbon (C) sequestration in soil (Montagnini and Nair, 2004; Oelbermann and Voroney, 2007). Urban forestry is a complicated land use system that is prevalent in Latin America, Southeast Asia, and Equatorial Africa, and is one of the most sustainable farming systems in the tropics (Beer *et al.,* 1990; Szott *et al.,* 1991). Fernandes and Nair, (1986) defined house gardens as close-knit, multi-level combinations of trees and crops surrounding residences. They are rich in plant diversity (Fernandes and Nair, 1986; Mc Connell, 1992; de Foresta and Michon, 1994). They are ranked first among all constructed agro-ecosystems, second only to natural forests, for their high biological diversity (Swift and Anderson, 1993). As a result of their forest-like structure and composition, these multispecies plant associations are regarded to have a significant potential for carbon sequestration (Nair *et al.*, 2009a), notably for soil carbon accumulation. Soil is an important part of the biosphere for storing carbon because it can hold more carbon than plants and the air (Batjes, 1996).

Dhaka is the capital of Bangladesh and one of the fastest-growing megacities in the world. The metropolitan city has a land area of 131 square kilometers and a population of more than 15 million people. A healthy and livable city should have 25% of its area covered by greenery. Dhanmondi Lake is positioned in the Dhanmondi suburban area of Dhaka, Bangladesh. The lake was formerly a dead channel of the Karwan Bazar River and was linked to the Turag River, which was wholly covered with natural vegetation. Due to its dense population, Dhaka city's high carbon emission rate from transportation, industry, and building is the rationale for picking the research area. However, the amount of organic carbon found in home garden soil depends on climatic and edaphic conditions, stand characteristics, and management strategies. Stand parameters, including tree density, species richness, species diversity, and soil properties, can directly or indirectly affect soil organic carbon concentration in agroforestry.

Soil Organic Carbon (SOC) is an essential component of the terrestrial carbon reservoir (Lal, 2008). The upper one-meter of soil contains approximately 1,500 Gt of SOC (FAO, 2001), twice the amount of carbon in the atmosphere, and three times the amount in terrestrial vegetation (Schlesinger, 1999). Soil can be a source or sink of atmospheric carbon depending on the land use types, climate, management practices, and CO_2 level in the atmosphere (Jobbagy and Jackson, 2000; Kirschbaum, 2000). SOC is crucial to the exchange of CO_2 between the atmosphere and the biosphere. Consequently, a slight change in SOC stock could result in a substantial shift in atmospheric CO_2 concentration. (Stockmann *et al.*, 2013). Soil organic carbon (SOC) storage is crucial because, in addition to serving as a sink for atmospheric CO_2 fixed by photosynthesis, SOC is positively connected with regulating and maintaining ecosystem services such as storm-water infiltration and nutrient holding capacity. According to Franzluebbers (2002), without a study of how planting trees affects soil organic carbon (SOC) and other soil properties that provide ecosystem services in an urban setting, it is impossible to understand what this common management practice means fully. In most cases, the resources and environmental conditions for stimulating forest growth are limited. Environmental factors such as the distribution of water, temperature, and soil, in combination, are important restrictive factors that determine the forest structure and tree density. This density, which is important for the stability of the ecosystem and biological productivity (Evans, 1992 and Zhang, 2004), is the main factor that can be controlled by human beings (Hans *et al.*, 1986; Xiao *et al.*, 1986) to determine whether the stand structure is sound both quantitatively and qualitatively (Li *et al.*, 1995).

Important potential carbon (C) sinks in the context of climate change, and rising atmospheric CO_2 concentrations are forest ecosystems and soils (Pan *et al.*, 2011; Schmidt, 2012). This potential varies by tree species, which can significantly affect soil organic C pools (Lang, 2017; Dawud *et al.*, 2016; Mueller *et al.*, 2015). The effects of diverse tree species on the stability of organic C in soil are poorly understood (Godbold, 2011; Augusto *et al.*, 2015). Because tree species composition in forests is dynamic (Ellison *et al.*, 2005; Silva, 2010), especially under a changing climate (Reich *et al.*, 2015; Zolkos *et al.*, 2015), a more detailed understanding of tree species effects on soil C stabilization is essential for predicting the persistence of soil C Furthermore, such knowledge can guide the selection of tree species for forest management or reforestation (Hemery, 2008; Stewart and Strathern, 2003).

This study was conducted to analyze soil organic carbon and tree species density in selected important sections of Dhanmondi lake in Dhaka. Therefore, the study focused on the relationship between tree species density and carbon sequestration in order to achieve the following objectives:

- To evaluate the tree species density status in the Dhanmondi lake area in Dhaka city.
- To find out the relationship between tree species density and soil organic carbon.

CHAPTER 2
REVIEW OF LITERATURE

Some of the published reports are reviewed under the following headings:

2.1 Soil organic carbon (SOC) and tree species density

According to Edmondson *et al.* (2014), urban trees convert carbon into biomass and provide numerous benefits to the ecosystem. Since 75% of the organic carbon in an ecosystem is in the soil, it is very important to know how urban trees affect soil organic carbon (SOC) and soil characteristics that support below-ground ecosystem services. We use an observational study to compare the effects of three key tree genera and mixed-species forests on soil characteristics (down to a depth of 1 m) with those of nearby urban grasslands. It has been discovered that urban trees provide aboveground biomass, and belowground ecosystem services are not directly linked. SOC increases most in Fraxinus excelsior and Acer spp. Grasslands are compared to urban grasslands as a whole but are comparable to grasslands under Quercus robur and mixed forest. The tree cover has little effect on the soil bulk density of the soil, or C: N ratio, qualities that reflect a soil's ability to deliver ecosystem services, including nitrogen cycling and flood control. The patterns found in this research show that choosing the right genus is important if you want to maximize the long-term storage of SOC under urban trees. However, rising concerns posed by genus-specific diseases must also be considered.

Davies *et al.* (2011) stated that there had been few attempts to quantify and map ecosystem service supply at a city-wide scale, even though urbanization is a key driver of land-use change worldwide. Biological carbon storage is a service that is becoming an increasingly vital component of climate change mitigation programs, with additional potential advantages. By monitoring urban vegetation, they explored the quantity and geographical patterns of carbon stored above ground in a typical British city, Leicester. They also evaluate the differences in carbon density between private gardens, managed from the bottom up by homeowners, and public property, managed from the top down by local authorities. Finally, they compared a national map of ecosystem services with the predicted quantity and distribution of carbon aboveground in the city under study. Carbon is projected to be stored in the above-ground vegetation of Leicester at a rate of 316 kg cm^2 of the urban area, with 97.3% of this carbon pool connected with trees rather than herbaceous and woody vegetation. Domestic gardens retain just 0.76 kg of carbon per square meter, which is comparable to herbaceous vegetation land cover (0.14 kg cm^2). The highest above-ground carbon density is 2886 kg cm^2, which is associated with tree-covered, publicly managed locations. Current national estimates of this ecosystem service significantly undervalue Leicester's contribution. The synthesis and application of materials. The British government has recently established a goal of reducing greenhouse gas emissions by 80% from 1990 levels by the year 2050.

Tilman *et al.* (1997) discovered that high species assemblages in home gardens are more likely to contain species with strong resource utilization characteristics than systems with fewer species and encourage better net primary production, which contributes to increased carbon sequestration.

Cairns *et al.* (1997) showed that the average carbon stocks in root biomass in home gardens, food crop fields, and woodlots were 3.6, 1.0, and 1.2 Mg C ha^{-1}, respectively.

According to Drescher (1998) and Karyono (1990), the Shannon Wiener diversity indices in tropical home gardens range from 0.93 in rural Zambia to over 3.0 in wet Java, Indonesia.

According to Kumar *et al.* (1998) and Nair *et al.* (2009), the size of home gardens is the most important factor influencing C stocks per unit area, and it decreases in the order of small > medium > large.

According to Gajaseni and Gajaseni (1999), Shannon diversity index values in Thai Homegardens ranged from 1.9 to 2.7, which is equivalent to the present study's range of 1.45 to 3.14.

According to Hulscher and Durst (2000) and Kumar and Nair (2004), the likeness of backyard gardens to forests entails that they can store carbon and provide numerous benefits to people by providing economic stability through the provision of fuel wood, fodder, timber, and food crops.

According to Sampson and Scholes (2000), converting natural forests and grasslands to permanent agriculture results in a 20 to 50 percent carbon loss.

According to Kumar (2006), Most agroforestry systems are essential in terms of carbon sequestration, carbon conservation, carbon substitution. However, home gardens may be unique for all three mechanisms, i.e., they sequester carbon in biomass and soil, reduce fossil-fuel burning by promoting wood fuel production, and aid in conserving carbon stocks in existing forests by reducing pressure on natural forests.

Saha *et al.* (2009) have reported that smaller homegardens with higher tree and plant species density include more soil organic carbon (SOC) per unit area, which is 119.3 Mg ha^{-1}, whereas large homegardens with lower tree species density contain 7-14% less soil organic carbon (SOC) per unit area in the homegardens of Kerala, India. They also discovered that the soil organic carbon (SOC) concentration within a one-meter soil profile in a home garden in Kerala, India ranged from 101.5-227.4 Mg ha^{-1}.

Nair *et al.* (2009) reported that homegardens with high species richness had the maximum soil organic carbon (SOC) storage at 127.4 Mg ha^{-1}, whereas homegardens with medium and low species richness had 16-17% lower soil organic carbon (SOC) storage, respectively.

Saha *et al.* (2009) showed that the soil organic carbon (SOC) stock in the homegardens of Thrissur, Kerala was higher per unit volume of soil in small homegardens (0.4 ha) with higher species density, richness, and diversity than in large homegardens (> 0.4 ha).

According to research conducted by Bodansky (2010), subsistence agriculture accounts for 48% of deforestation; commercial agriculture accounts for 32% of deforestation; logging accounts for 14% of deforestation; and fuel wood removal accounts for 5% of deforestation.

In Kerala, India, Kumar (2010) found that the Simpson's diversity index for woody species was highest in small home gardens (0.64), with values of 0.41 and 0.46 for medium and large home gardens.

According to Sampson and Scholes (2000), soil carbon is lost by 20–50% when natural grasslands and forests are converted to permanent agriculture.

According to Kumar (2006), while most agroforestry systems are significant for carbon sequestration, carbon conservation, and carbon substitution, home gardens may be unique for all three mechanisms, i.e., they sequester carbon in biomass and soil, reduce fossil-fuel burning by fostering the production of wood fuel, and aid in the conservation of carbon stocks in existing forests by easing pressure on natural forests.

Tittonell (2007), reported that the estimated soil C stocks ranged between 24 and 56 Mg C ha^{-1} for the upper 0.3 m of the soil in western Kenya small farming system. Thus, there is much more to gain in terms of C sequestration in the belowground C components.

Saha (2008) discovered that soil carbon sequestration potential of homegardens is higher than that of agricultural systems rice-paddy and comparable to that of single species tree-crop system of rubber and coconut.

Lee *et al.* (2009) reported that the soil carbon stock for a Pinus densiflora forest at Gwangneung, central Korea was estimated using the soil carbon model, Yasso. The soil carbon stock measured in the forest was 43.73 Mg ha^{-1}.

Brown *et al.* (2005) stated that the carbon stocks of trees are estimated most accurately and precisely by direct methods, e.g., through a field inventory, where all the trees in the sample plots above a minimum diameter are measured. The diameter was wrapped around a tree and is specially designed to convert the tree circumference to tree diameter. Diameter was measured with the forest diameter tape. It was needed to convert each measurement after recorded because the diameter tape are actually measuring tree circumference. This was a very simple equation, just divide circumference by (3.14) use the equation for circumference and solve for diameter. The minimum diameter often is 5 cm in DBH but it can vary depending on the expected size of trees. For arid environments in which trees grow slowly, the minimum DBH may be as small as 2.5 cm; for humid environments in which trees grow rapidly, the minimum DBH may be up to 10 cm. DBH biomass and carbon stock are estimated using appropriate allometric equations applied to the tree measurements.

It was estimated by Roy and Ravan (1996) that the biomass in tropical dry deciduous forest of Madhav National Park of Madhya Pradesh, India using two approaches viz., Homogenous vegetation stratification (HVS) and spectral response model. They reported that the total biomass of the different community types of dry tropical forests ranged from 7.42 to 52.41 t ha^{-1}.

Jaman *et al.* (2016) carried out a study to quantified total above and below ground carbon stock and tree species diversity in home garden around four villages of two Upazilas of Rangpur district situated in northern part of Bangladesh. A total 64 home gardens were sampled on size, diameter at breast height (DBH) of trees and tree height. Using allometric equations mean above and below ground biomass carbon stocks (AGB+BGB) was found 53.53Mg ha^{-1}. Mean carbon stock per unit area was higher in small home garden (69.15 Mg ha^{-1}) compared to medium (47.96 Mg ha^{-1}) and large (39.93 Mg ha^{-1}) home garden respectively.

Du *et al.* (2018) estimated that the AGC and BGC of Lesiolouna tropical rainforest of Congo were 168.60 Mg ha^{-1} and 39.55 Mg ha^{-1}, respectively.

Godgift *et al.* (2014) estimated that in Hanang forest, Tanzania where soil organic carbon was 64.2, 41.93 and 31.0 Mg ha^{-1} in the upper (0-15 cm), mid (> 15-30 cm) and lower (>30-45 cm) layer, respectively.

Ramachandran *et al.* (2007) stated that Carbon sequestration, which is part of the global C cycle, is one of the environmental services that natural ecosystem can provide. Absorbing CO_2 from the atmosphere and storing it in the physiological system of plants, diffusing it into the soil, and reusing it in the biological system is a natural cycle of removing atmospheric GHG (CO_2). As such, the atmospheric CO_2 sequestered in soils, ocean, fossil fuel, and vegetation is important.

Burras *et al.* (2001) define C sequestration as storing of C in a solid form through direct or indirect means like soil C sequestration and plant C sequestration. Direct SOC sequestration occurs by inorganic reaction that converts atmospheric CO_2 into inorganic compounds such as calcium and magnesium carbonates, whereas plant C sequestration occurs during photosynthesis.

Sakin (2012) reported that forest soils are an essential component of the global carbon cycle which stocks a large amounts of soil organic carbon (SOC) and are the largest reservoirs in the world. SOC plays an important role in alleviating the effects of greenhouse gases and storing them, enhancing soil quality, sustaining and improving food production, maintaining clean water, and reducing CO_2 in the atmosphere.

2.2 Factors affecting soil organic carbon (SOC) storage

According to Batjes (1996), the SOC storage in the soil is affected by various factors like land use management practices, climatic conditions, vegetation, organisms, and parental rocks present in the soil. Land use types and vegetation cover affects the C dynamics by influencing soil respiration, C flux, and C fixation within the soil and substrate. In agriculture land, types of land management practices like dryland, wetland, use of farmyard manure and nitrogen fertilizers had greater impact on SOC stock and eventually on C sequestration.

Sitaula *et al.* (2004) reported that intensive usage of mineral fertilizers in agricultural field would reduce soil C, though it will increase crop productivity in short run. Practice of non-tillage practices will enhance SOC in agricultural field. Overall, the SOC storage in the soil can be increased by practicing sustainable land management practices. As the predominant source of SOC, the vegetation cover was regarded as important factor on the variation of SOC stock in the soil.

According to Inouye (1988) and Morel *et al.* (2011), competition for nutrients and light is the main variables affecting biomass allocation. However, responses to additional conditions, like increasing CO_2 and water stress, may also be crucial.

Friedlingstein *et al.* (1999) stated that the distribution of carbon is also influenced by CO_2 concentration; where CO_2 concentrations are higher, more carbon is distributed to the above-ground compartment. In tropical areas, light restrictions encourage the allocation of stems and large leaves. Due to the fact that the predicted biomass depends on the allocation pattern, the final idea is particularly crucial.

Tilman (1998) and Friedlingstein (1999) stated that the distribution of fixed carbon is a primary determinant factor for plant growth. Environmental variables, such as climate and resource availability, considerably influence carbon allocation. Theoretically plants maximize their growth by adjusting their allocation pattern. A plant in an environment is saturated of resources and try to reaches its maximum growth rate by allocating all freshly obtained photosynthesized material to leaves, since the allocation to non-photosynthetic tissue yields no returns in future carbon sequestration.

Several studies of Friedlingstein (1999) and Morel *et al.* (2011) described that plants allocate more carbon relatively to roots when nutrients and water are limiting to shoots when light is limiting. Light, water and nutrients: are considered three limiting resources. According to the optimal partitioning theory demonstrates that plants should allocate biomass according to the most limiting resource.

According to Keeling and Philips (2007), Most dynamic global vegetation model (DGVM) simulations demonstrate that increasing CO_2 concentration and rising temperatures will stimulate the growth of tree across most of the Earth's surface, so expending globally averaged vegetation and productivity potential biomass stores through to at least the mid 21st century.

Malhi *et al*. (2011) stated that the fraction allocated to leaves determine leaf life time, photosynthetic capacity, production of fruit, canopy leaf area and flower and consumption, rates of litterfall, putrefaction and consumption by soil fauna. Whereas, the fraction allocated to fine roots and exudates influences uptake of water, addition of nutrient and soil faunal regions.

According to Sakin (2012), forest soils constitute a significant part of the global carbon cycle since they are the greatest carbon reservoirs in the world and store significant amounts of soil organic carbon (SOC). The effects of greenhouse gases can be lessened and stored by soil organic carbon (SOC), which also improves soil quality, sustains and improves food production, maintains clean water, and lowers atmospheric CO_2 levels.

According to Asner *et al.* (2005), removing land for development often results in significant immediate reductions in the amount of carbon stored in the forest. Forest degradation reduction in forest biomass through no sustainable harvest or land-use practices can also result in substantial reductions of forest carbon stocks from selective logging, fire and other anthropogenic disturbances, and fuel wood collection.

Gissen *et al.* (2011) reported that forests are also affected by climate change and their contribution to mitigation strategies may be influenced by stresses possibly resulting from it. Socio-economically, global forests are important because many citizens depend on the goods, services, and financial values provided by forests.
Nowak and Crane (2001) reported that tree density and diameter distribution also considered as main factor which affect carbon storage density (t C ha^{-1}) and diameter

distribution. Carbon densities will tend to increase with tree density (tree ha-1) and/or increased proportion of large diameter trees.

Research by Chave *et al.* (2004), Malhi *et al* (2006), Slik *et al.* (2010), and Quesada *et al.* (2009) demonstrates that climate factors contribute significantly to the explanatory variation in all three stand characteristics, especially basal area. Contrasting relationships were seen between the soil texture (percentage of sand), which had a strong positive bond with the explanatory variation in mean wood specific gravity (WSG), and the explanatory variation in stand mean diameter at breast height, which had a strong negative bond (DBH). In particular, basal area and DBH show a negative relationship between soil phosphorous and explanatory variation in all three stand characteristics.

According to Baraloto *et al*. (2011) Spatial variation of AGB, three groups of factors have been proposed in tropical forests at regional level, namely climate, soil and stand variables. The correlation of these environmental descriptors of AGB with the spatial variation can be better understood by the following figure modified by.

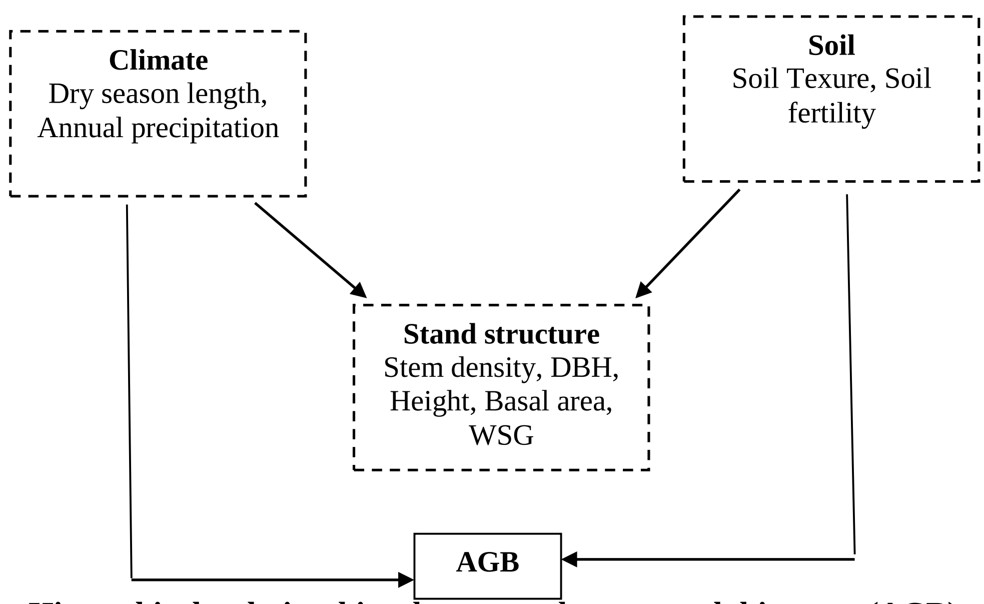

Figure 1: Hierarchical relationships between aboveground biomass (AGB) and environmental descriptors. Modified from Baraloto *et al.,* (2011).

Keenan *et al.* (2015) observed that selective logging, fire and other anthropogenic disturbances, and fuel wood collection have also carbon balance implications. Such disturbances affect roughly 100 million ha of forests annually.

CHAPTER 3
MATERIALS AND METHODS

The investigation focused on the density of tree species and organic carbon levels around Dhanmondi lake in Dhaka.

3.1 Description of the experimental site

3.1.1 Location

Dhanmondi lake of Dhaka city served as the site of the current study. It is situated in Dhaka's Dhanmondi neighborhood. The lake was once a dried-up section of the Turag River, which was connected to the Karwan Bazaar River. The Begunbari Channel has a partial connection to the lake. Dhanmondi was transformed into a residential area in 1956. In the development plan, about 16% of the total area of Dhanmondi was designated for the lake. The study area was 8.6 meters above sea level and was situated at 23.7455^0 N latitude and 90.3776^0 E longitude. There were around 18 thousand trees, with a scientific collection of approximately 5000 preserved specimens (Anonymous, 2015). It is managed by Department of Forest under the Ministry of Environment and Forests and Climate Change, Government of Bangladesh (DoF, 2019).

3.1.2 Soil

The soil of the Dhanmondi lake area of Dhaka city belongs to the Tejgaon series under the Agro-ecological Zone, Madhupur Tract (AEZ-28), and the general soil type is deep red-brownrrace soils with pH 5.8-6.5 and electrochemical equivalent (ECE) 25.28 (Chowdhury *et al.,* 2015).

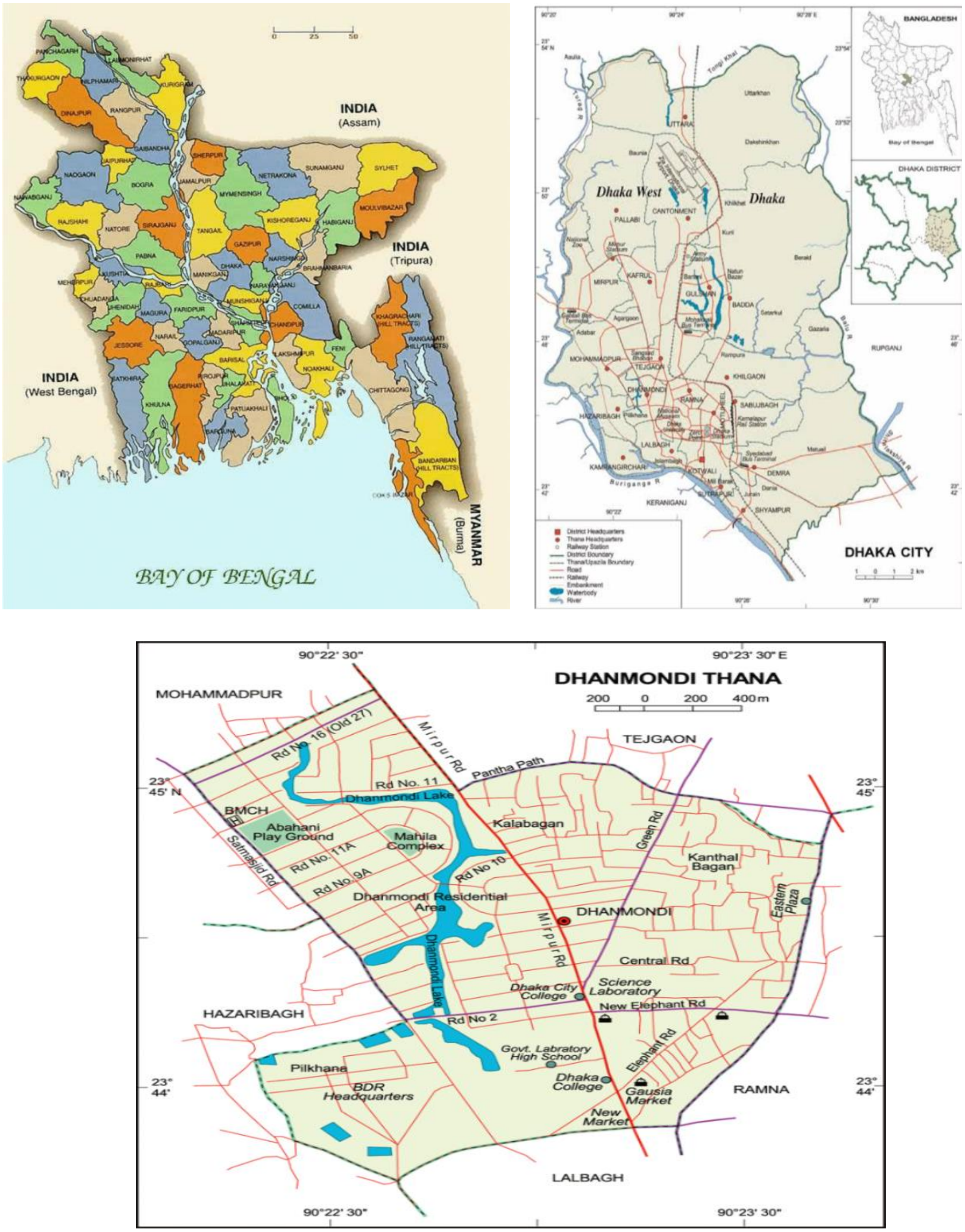

Plate 1. Stepwise location of the study area where (a) Bangladesh (b) Dhaka city area map (c) Dhanmondi Thana .

3.1.3 Climatic condition

A typical hot, humid, and tropical environment is present at Dhanmondi lake in Dhaka City. The city experiences a distinct monsoonal season, with Dhaka's yearly average temperature being 26.1^{o}C. The hottest month is June, with an average temperature of 29.10^{o}C, while the coldest month is January, with an average temperature of 19.1^{o}C. This year, Dhaka has received 2148.8 mm on average of precipitation (Weather base, 2019).

3.1.4 Experimental duration

The study was conducted during June 2021 to January 2022.

3.2 Data Collection

3.2.1 Selection of Sampling Area

A list of all tree species was made in order to collect more information. A reconnaissance survey was conducted in the research area to get general information on the vegetation and accessibility to the Dhanmondi lake area. Using a purposive sampling technique, the survey areas were chosen.

3.2.2 Equipments/Materials used in the field study

SL No.	Name of the equipments	Function of the equipments
1	Measuring tape	50 m metal tape for measuring plots
2	Dia tape	2 m tape for measuring diameter at breast height (1.37m)
3	Augar	To collect a soil sample
4	Record book	Used to write down information about plants
5	Data measurement sheet	To note the height and DBH of trees
6	Haga altimeter	To measure the height of the tree

3.3 Field Methods

3.3.1 Plot Sampling

Using a purposive quadrate sampling technique, the structure and composition of tree cover were quantitatively assessed in June 2021. A list of all the tree species in Dhanmondi lake was created. Plots were selected purposively at Dhanmondi lake area in Dhaka city.

3.3.2 Plant Species Sampling

A total of 12 sample plots were selected from the Dhanmondi lake areas for the tree classifications. Each quadrate's trees were counted, and the quantity of each species of tree was calculated. In the field, the all species were recognized. The scientific name and family of each species discovered in the sampling area were recorded in a list. According to tree density three categories of plots will be used to group the species. These were:

- High density plots: Total number of trees- 60.
- Medium density plots: Total number of trees- 45.
- Low density plots: Total number of trees- 29.

3.3.3 Diameter, Height and crown area measurement

All recognized trees had their diameters measured and recorded at breast height (1.3 meters above the ground). DBH of individual trees were recorded to determine basal area and relative basal area per hectare to determine the tree species that were present in the research region's canopy. Before measuring DBH (Diameter at breast height) at first need to measure GBH (Girth at breast height) by using measuring tape in centimeter (cm).

All trees included in the sampling area were measured in height using haga altimeter and the percent (%) scale calculation as follows:

Percentage scale = $\frac{(TR+BR) \text{ X } H.D}{100}$

Where, TR= Top reading

BR= Bottom reading and

HD= Horizontal distance

Crown area was measured as the proportion of a fixed area of the ground covered by tree crowns. It was measured from four sides (east, west, north and south) by using a measuring tape at noon.

Plate 2. Measurement of plant height, GBH and crown area

3.3.4 Data analysis

After completion the field data collection, MS Excel software were used to organize and analyze the data. Following the formulas of Moore and Chapman (1986), Shukla and Chandel (1980), the density (stem/ha), frequency (%), relative frequency (%), basal area (m^2/ha), relative dominance, and Importance Value Index (IVI) were determined for each tree species.

1. Percent (%) of occurrence = $\frac{\text{Total No. of individuals of one species in all the quadrates}}{\text{Total No. of quadrates studied}} \times 100$

2. Density of one species = $\frac{\text{Total No. of individuals of one species in all the quadrates}}{\text{Total No. of quadrates studied}} \times 100$

3. Relative density of one species = $\frac{\text{Total No. of individuals of one species in all the quadrates}}{\text{Total No. of individual of all species}} \times 100$

4. Frequency of one species = $\frac{\text{Total No. of quadrates in which the species occurs}}{\text{Total No. of quadrates studied}} \times 100$

5. Relative frequency of one species = $\frac{\text{Frequency of one species}}{\text{Sum of all frequencies}} \times 100$

6. Abundance of one species = $\frac{\text{Total No. of individuals of one species in all the quadrates}}{\text{Total No. of quadrates in which the species occurs}} \times 100$

7. Relative abundance of one species = $\frac{\text{Abundance of the species}}{\text{Total abundance of all the species}} \times 100$

8. Relative dominance of one species = $\frac{\text{Total basal area of one species in all quadrates}}{\text{Total basal area of all species in all quadrates}} \times 100$

9. Importance Value Index = Relative density + Relative frequency + Relative dominance

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

Basal area/ha = $\frac{\frac{\pi}{4}D^2}{\sum \text{area of all quadrates}}$ x 10000

Basal area =$\pi/4$ x D^2

Where, Ba = Basal area in m^2

D = Diameter at breast height in meter, Π = 3.14

3.4 Soil sampling and analysis

Soil samples were collected from each plot of the study area. Soils were collected from two different sampling depths (6-12 cm and 12-24 cm). The study area was divided into three categories viz. low, medium, and high density sampling plots. Soils were collected from three different categories of plots then samples were obtained from each study plot for each depth. Total 24 soil samples were collected from the research area. The soil collected was analyzed for bulk density. The analysis of soil was done at soil science laboratory of Sher-e-Bangla Agricultural University (SAU).

Bulk density (BD g/cc) = (Oven dry weight of soil)/ (volume of soil in the core)

Organic carbon content percentages were calculated by using following formula [Walkley-Black (1934)]:

$$\% \text{ OC} = \frac{(B-T) \times N \times 0.003 \times 1.3 \times 100}{ODW}$$

Where,

B = $FeSO_4.7H_2O$ Solution required for blank titration

T = Volume of $FeSO_4.7H_2O$ solution required for actual titration

N = Strength of $FeSO_4.7H_2O$ or Normality

1.3 = Convention recovery fraction

ODW= Oven Dry Weight

Plate 3. Soil sampling and analysis

CHAPTER 4

RESULTS

This study's objective is density of tree species and organic carbon levels around Dhanmondi lake in Dhaka.

4.1 Composition of plant species

In this study, the Dhanmondi lake region contained 22 different tree families. Table 2 displays the composition of plant species found in Dhanmondi lake across all species. The total number of plants, according to the results, was 134. At Dhanmondi lake, the highest number of tree was *Swietenia mahagoni*. We found (9) individuals of *Swietenia mahagoni* and the percentage of occurances was (6.72%). An unknown species and others like *Tabernaemontana divoricata*, *Tamarisk dioica*, *Leucaena lecocephala*, *Barringtonia asiatica*, *Mussaenda erythrophylla*, *Acacia mengium* were present at the lowest number (1) and the percentage of occurrences was (0.75%).

Table 2. Most dominant tree species found at Dhanmondi lake area and their common name, scientific name, family and Percentage (%) of occurrences

SL No.	Local name	English Name	Scientific name	Family	Total number	Percentage (%) of occurences
1	Chapalish	Chapalish	*Artocarpus chapalasha*	Moraceae	3	2.24
2	Kanthal	Jackfruit	*Artocarpus heterophyllus*	Moraceae	4	2.99
3	Shimul	Cotton tree	*Bombyx ceiba*	Malvaceae	3	2.24
4	Mehogony	Mahagoni	*Swietenia mahagoni*	Meliaceae	9	6.72
5	Aam	Mango	*Mangifera indica*	Anacardiaceae	7	5.22
6	Radhachura	Radhachura	*Caesalpinia pulcherrima*	Fabaceae	6	4.48
7	Unknown	Unknown	Unknown	Unknown	1	0.75
8	Rajkoroi	Lebber tree	*Albizia lebbeck*	Fabaceae	3	2.24
9	Jam	Malabar palm	*Syzigium cumini*	Myrtaceae	4	2.99
10	Ashok	Ashoka tree	*Saraca asoca*	Leguminaceae	3	2.24
11	Shefali	Night flowering jasmine	*Nyctanthes arbor-tristis*	Oleaceae	5	3.73
12	Chalta	Elephant apple	*Dillenia indica*	Dilliniaceae	2	1.49
13	Horitoki	Chebulie myrobalan	*Terminalia chebula*	Combretaceae	3	2.24
14	Kamini	Orange jasmine	*Murraya paniculata*	Rutaceae	3	2.24
15	Bokul	Indian melder	*Mimosops elengi*	Sapotaceae	8	5.97
16	Golapjam	Rose apple	*Syzygium jambos*	Myrtaceae	2	1.49
17	Tagor	Creepy jasmine	*Tabernaemontana divoricata*	Apocynaceae	1	0.75
18	Kamranga	Star fruit	*Averrhoa carambola*	Oxalidaceae	3	2.24
19	Kadom	Bur flower tree	*Neolamarckia cadamba*	Rubiaceae	4	2.99
20	Debdaru	Asopalav	*Pollyalthia longifolia*	Annonaceae	2	1.49
21	Jarul	Asian tree	*Lagerstoemia speciosa*	Lythraceae	6	4.48
22	Chatim	Blackboard tree	*Alstonia scholaris*	Apocynaceae	3	2.24
23	Arjun	Arjun	*Terminalia arjuna*	Combretaceae	3	2.24
24	Bilimbi	Pickle fruit	*Averrrhoa bilimbi*	Oxalidaceae	2	1.49
25	Kathbadam	Indian almond	*Terminalia catappa*	Combretaceae	2	1.49
26	Jhau	Tamarisk tree	*Tamarisk dioica*	Tamaricaceae	1	0.75
27	Eucalptus	Eucalptus	Eucalptus sp.	Myrtaceae	3	2.24
28	Neem	Neem	*Azadirachta indica*	Meliaceae	2	1.49
29	Bohera	Beach almond	*Terminalia bellerica*	Combretaceae	2	1.49
30	Ata	Sugar apple	*Annona squmosa*	Annonaceae	2	1.49
31	Sonalu	Golden shower	*Casia fistula*	Fabaceae	2	1.49
32	Chismas tree	Chrismas tree	*Picea abies*	Aurocariaceae	3	2.24
33	Ipil-ipil	Ipil-ipil	*Leucaena lecocephala*	Fabaceae	1	0.75
34	Segum	Teak	Tectona grandis	Lamiaceae	2	1.49
35	Jambura	Pomelo	*Citrus grandis*	Rutaceae	2	1.49
36	Naglingom	cannonball tree	*Barringtonia asiatica*	Lecythidaceae	1	0.75
37	Musanda	Red flag bush	*Mussaenda erythrophylla*	Rubiaceae	1	0.75
38	Amra	Hog plum	*Spondias mombin*	Anacardiaceae	3	2.24
39	Belibat	Belibat	*Clitora termatia*	Fabaceae	2	1.49
40	Minjiri	Yellow cassia	*Siamese cassia*	Caesalpiniaceae	3	2.24
41	Krisnochura	Krisnochura	*Delonix regia*	Fabaceae	3	2.24
42	Mengium	Mengium	*Acacia mengium*	Myrtaceae	1	0.75
43	Tetul	Tamarind	*Tamarindus indica*	Leguminosae	5	3.73
44	Amloki	Amla	*Polyanthus emblica*	Combretaceae	3	2.24
			Total		134	

4.2 Major tree species and their Percentage (%) of occurrences

The most frequent and dominating tree species identified in the sampled plot of the Dhanmondi lake area are five major tree species, including the Mahagoni (*Swietenia mahagoni*), Indian melder (*Mimosops elengi*) , Mango (*Mangifera indica*), Radhachura, (*Caesalpinia pulcherrima*) and Asian tree (*Lagerstoemia speciosa*). Those five species are found from 44 species of 23 distinct families. At several sample plots used in this study, Mahagoni was the most prevalent species (9), followed by Indian melder (8), Mango (7), Radhachura (6) and Jarul (6) (Figure 2). In this study, 5 species covered 26.87% of the occurences, while the other 39 species covered the remaining value.

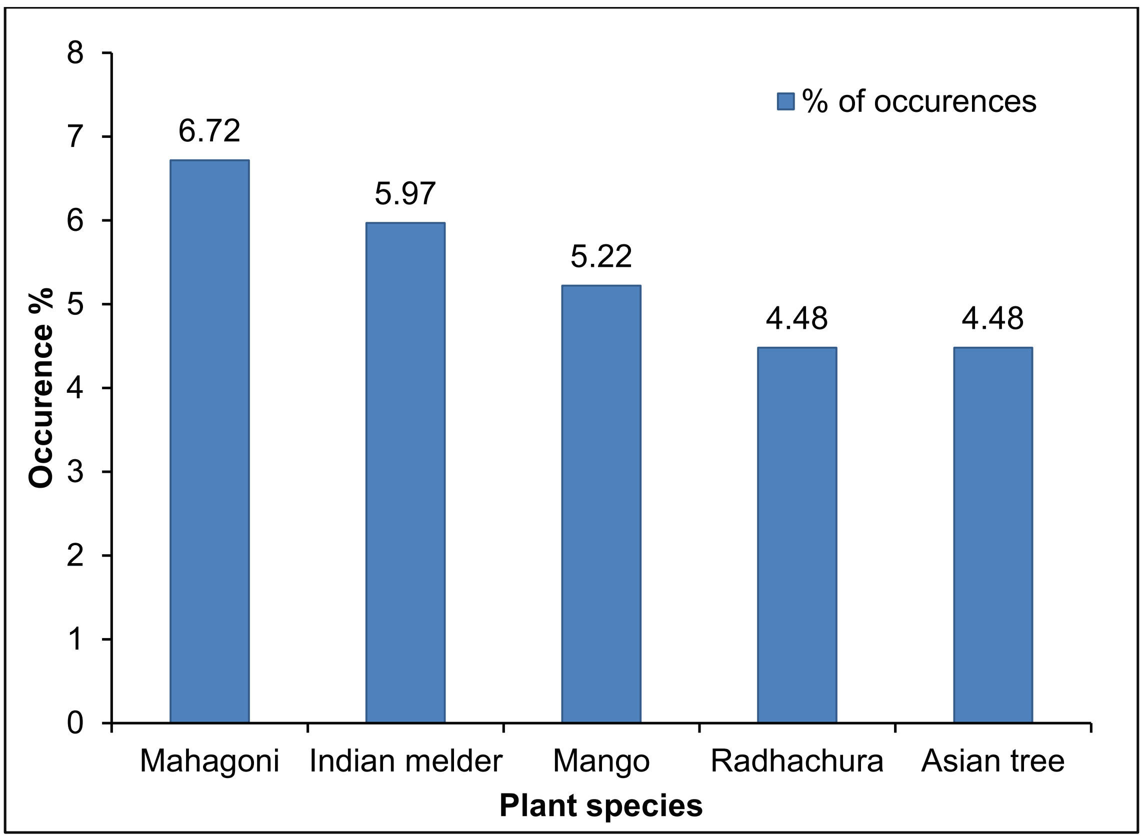

Figure 2. Percentage (%) of occurrence five major species present in study areas

4.3 Structural parameters of Tree

4.3.1 Height (m)

The average trees number at Dhanmondi lake is 26.8. Findings indicated that at Dhanmondi lake study area, the largest number of tree individuals (63) was found at heights of (8–16 m) and the lowest number (04) was discovered at heights of (24–32 m). (Table 3)

Table 3. Tree individuals' distribution in different rang of height (m) at the Dhanmondi lake study area

Height (m)	No. of trees in Dhanmondi lake
< 1.60 m	21
(1.6 - 8) m	34
(8 - 16) m	63
(16-24) m	12
(24-32) m	04
Total tree	134
Average number of trees	26.8

4.3.2 DBH (cm)

In Dhanmondi lake study area, the maximum number of tree individuals (53) was found at the rang of DBH (5.0-10.0 cm) and the lowest number of tree individuals (14) at the rang of DBH (15-20 cm). The average number of trees for DBH was 26.8 cm. (Table 4)

Table 4. Tree individuals' distribution in different rang of DBH (Diameter at breast height) in centimeter at Dhanmondi lake study area

DBH (cm)	No. of trees in Dhanmondi lake
<1.0	00
1.0-5.0	23
5.0-10	53
10-15	44
15-20	14
Total tree (no.)	134
Average (cm)	26.8

4.3.3 Crown area (m)

The crown area of the trees in Dhanmondi lake varies from 1.00 to 7.00 m, with an average number of trees 22.33. According to the results, Dhanmondi lake had the largest concentration of trees (36) at crown areas between 1 to 2 m and the lowest concentration of trees (8) at canopies above 5 m. (Table 5)

Table 5. Tree individuals' distribution in the different crown area in meter at Dhanmondi lake study area

Crown area (m)	No. of trees in Dhanmondi lake
<1	24
1-2	36
2-3	28
3-4	18
4-5	20
>5	8
Total trees	134
Average number of trees (m)	22.33

4.4 Structural attributes of tree species found in five study areas

Table 6. shows the relative density, relative frequency, relative abundance, relative dominance and importance value index of different tree species found in Dhanmondi lake study area.

Table 6. Structural attributes of dominant tree species at Dhanmondi lake are listed

SL No.	Local name	Botanical name	No. of trees	RD %	RF%	RA %	RDo %	IVI
1	Chapalish	*Artocarpus chapalasha*	3	2.24	2.03	2.01	0.72	4.99
2	Kanthal	*Artocarpus heterophyllus*	4	2.99	3.05	1.79	0.422	6.46
3	Shimul	*Bombyx ceiba*	3	2.24	3.05	1.34	0.26	5.55
4	Mehogony	*Swietenia mahagoni*	9	6.72	11.18	1.10	0.1	18.00
5	Aam	*Mangifera indica*	7	5.22	4.07	2.35	0.25	9.54
6	Radhachura	*Caesalpinia pulcherrima*	6	4.48	3.05	2.69	1.61	9.14
7	Unknown	Unknown	1	0.75	3.05	0.45	0.05	3.85
8	Rajkoroi	*Albizia lebbeck*	3	2.24	2.03	2.01	0.155	4.43
9	Jam	*Syzigium cumini*	4	2.99	3.05	2.15	0.24	6.27
10	Ashok	*Saraca asoca*	3	2.24	2.03	2.01	0.07	4.34
11	Shefali	*Nyctanthes arbor-tristis*	5	3.73	1.02	6.71	2.41	7.16
12	Chalta	*Dillenia indica*	2	1.49	5.08	2.69	0.47	7.04
13	Horitoki	*Terminalia chebula*	3	2.24	2.03	2.01	0.15	4.42
14	Kamini	*Murraya paniculata*	3	2.24	2.03	2.01	0.619	4.89
15	Bokul	*Mimosops elengi*	8	5.97	5.08	2.15	0.15	11.20
16	Golapjam	*Syzygium jambos*	2	1.49	2.03	1.34	0.132	3.66
17	Tagor	*Tabernaemontana divoricata*	1	0.75	1.02	1.34	0.03	1.79
18	Kamranga	*Averrhoa carambola*	3	2.24	1.02	4.03	0.55	3.81
19	Kadom	*Neolamarckia cadamba*	4	2.99	2.03	2.69	0.176	5.19
20	Debdaru	*Pollyalthia longifolia*	2	1.49	2.03	1.34	0.34	3.87
21	Jarul	*Lagerstoemia speciosa*	6	2.99	5.08	1.07	10.29	18.36
22	Chatim	*Alstonia scholaris*	3	2.24	1.02	4.03	0.67	3.93
23	Arjun	*Terminalia arjuna*	3	2.24	1.02	4.03	0.6	3.86
24	Bilimbi	*Averrrhoa bilimbi*	2	1.49	1.02	2.69	1.08	3.59
25	Kathbadam	*Terminalia catappa*	2	1.49	1.02	2.69	2.722	5.23
26	Jhau	*Tamarisk dioica*	1	0.75	1.02	1.34	8.478	10.24
27	Eucalptus	*Eucalptus* sp.	3	2.24	7.11	0.58	0.942	10.29
28	Neem	*Azadirachta indica*	2	1.49	1.02	2.69	1.511	4.02
29	Bohera	*Terminalia bellerica*	2	2.24	1.02	4.03	2.411	5.67
30	Ata	*Annona squmosa*	2	1.49	1.02	2.69	1.14	3.65
31	Sonalu	*Casia fistula*	2	1.49	1.02	2.69	0.46	2.97
32	Chismas tree	*Picea abies*	3	2.24	1.02	4.03	0.47	3.73
33	Ipil-ipil	*Leucaena lecocephala*	1	0.75	1.02	1.34	1.75	3.51
34	Segum	*Tectona grandis*	2	2.99	3.05	1.79	2.99	9.02
35	Jambura	*Citrus grandis*	2	1.49	1.02	2.69	6.69	9.20
36	Naglingom	*Barringtonia asiatica*	1	0.75	1.02	1.34	11.53	13.29
37	Musanda	*Mussaenda erythrophylla*	1	0.75	1.02	1.34	0.55	2.31
38	Amra	*Spondias mombin*	3	1.49	1.02	2.69	0.5	3.01
39	Belibat	*Clitora termatia*	2	1.49	1.02	2.69	1.75	4.26
40	Minjiri	*Siamese cassia*	3	2.24	1.02	4.03	1.43	4.69
41	Krisnochura	*Delonix regia*	3	2.24	3.05	1.34	1.78	7.07
42	Mengium	*Acacia mengium*	1	0.75	1.02	1.34	0.55	2.31
43	Tetul	*Tamarindus indica*	5	3.73	4.07	1.68	1.22	9.02
44	Amloki	*Polyanthus emblica*	3	2.24	3.05	1.34	0.15	5.44
		Total	134					

RD = Relative Density, RF=Relative Frequency, RA = Relative Abundance, RDo = Relative Dominance, IVI = Important Value Index

From the (Table 6) it was found that total 44 species was found at Dhanmondi lake study area. It becomes evident that only five tree species Mahagoni (*Swietenia mahagoni* - 9), Indian melder (*Mimosops elengi* – 8), Mango (*Mangifera indica* - 7), Radhachura (*Caesalpinia pulcherrima* - 6) and Asian tree (*Lagerstoemia speciosa* – 6*)* are occurring at Dhanmondi lake within the dominant tree species. All the structural attributes like relative density (RD %), Relative frequency (RF %), Relative abundance (RA %) Relative Dominance (RDo %) and Important value index (IVI %) of 5 dominant tree species were Mahagoni (6.72, 11.18, 1.10, 0.1 and 18.00), Bokul (5.97, 5.08, 2.15, 0.15, 11.20), Aam (5.22, 4.07, 2.35, 0.25, 9.54), Radhachura (4.48, 3.05, 2.69, 1.61, 9.14), Jarul (2.99, 5.08, 1.07, 10.29, 18.36).

4.5 Tree density

Tree density is an important factor to store carbon as it directly relates to the carbon sequestration (Roshetko *et al.*, 2007).Tree density of the study area varied from 1600 to 6400 per hectare and 4-16 trees per plot (plot size- 5m×5m). The mean density of the tree in Dhanmondi lake for low, medium and high density plots were 2800, 4500 and 6000 trees/ha. According to Shankar *et al.* (2014) these also stipulate by the top most values of tree density and carbon storage variables for trees, tree saplings, shrubs and herbs along the different parks demonstrating the impact of plant species diversity, soil and climatic conditions.

4.6 Soil organic carbon (%)

Table 7. Tree density of various sample plots at Dhanmondi lake study area

Plot categories	**Plot number**	**Number of trees**	**Tree density/ha**	**Mean density/ha**
Low density plot (29)	Plot 1	4	1600	2800
	Plot 7	8	3200	
	Plot 8	9	3600	
	Plot 9	8	2800	
Medium density plot (45)	Plot 3	10	4000	4500
	Plot 4	13	5200	
	Plot 5	11	4400	
	Plot 6	11	4400	
High density plot (60)	Plot 2	14	5600	6000
	Plot 10	16	6400	
	Plot 11	15	6000	
	Plot 12	15	6000	

In general, the SOC % decreased with soil depth across all plots of the present study area and increased with the increase in plant species density. Due to accumulation of higher quantity of litters and other organic materials on the surface and their rapid decomposition, trees act as a vital source of storing organic carbon in the soil. In the Dhanmondi lake study area, the mean values for soil organic carbon (SOC %) at 6-12 and 12-24 cm depth were in high density sample plot (1.65 % and 1.43 %), medium density sample plot (1.119 % and 0.88 %) and low density sample plot (0.936% and 0.70%) respectively. Soil organic carbon ranged from 0.897% to 1.774% at 6-12 cm depth, 0.64% to 1.72% at 12-24 cm depth. (Table 8).

Table 8. Soil organic carbon at various sample plots of Dhanmondi lake study area according to the density of trees

Sample plots (No. of trees)	Plot number	SOC (%)		Mean (%)	
		6-12 cm	12-24 cm	6-12 cm	12-24cm
Low Density plots (29)	Plot 1	0.897	0.64	0.94	0.70
	Plot 7	0.975	0.74		
	Plot 8	0.897	0.78		
	Plot 9	0.975	0.64		
Medium density plots (45)	Plot 3	1.072	0.72	1.12	0.88
	Plot 4	1.072	0.92		
	Plot 5	1.287	0.92		
	Plot 6	1.045	0.96		
High density plots (60)	Plot 2	1.56	1.22	1.65	1.43
	Plot 10	1.599	1.60		
	Plot 11	1.774	1.72		
	Plot 12	1.657	1.17		

SOC= Soil organic carbon

4.7 Soil organic carbon in relation to tree density

Figure (5, 6 and 7) depict the relationship between tree density and soil organic carbon in low, medium, and high density plots. These graphs show a linear equation with the following values: $y = 0.0002x + 0.756$ ($R^2 = 0.187$), where R^2 value was positive and very significant in low density plot; $y = -2E\text{-}05x + 1.230$ ($R^2 = 0.012$), where R^2 value was positive and slope is negative in medium density plots and $y = 0.0002x + 0.364$ ($R^2 = 0.963$), where R^2 value was positive and very significant in and high density plot at 6-12 cm depth. On the other hand, in 12-24 cm depth the values were: $y= 0.0001x + 0.655$ ($R^2 = 0.071$), $y = 0.0001x + 0.311$ ($R^2 = 0.344$) and $y = 0.0005x - 1.422$ ($R^2 = 0.321$), where R^2 were positive and significant. This figure also shows that at both 6-12 cm and 12-24 cm, low density plots had fewer trees per unit area and contained lower amounts of SOC (0.94% and 0.70%) than medium density plots (1.12% and 0.88%) and high density plots (1.65% and 1.43%). Low<medium<high density plots are followed by a progressive increase in values.

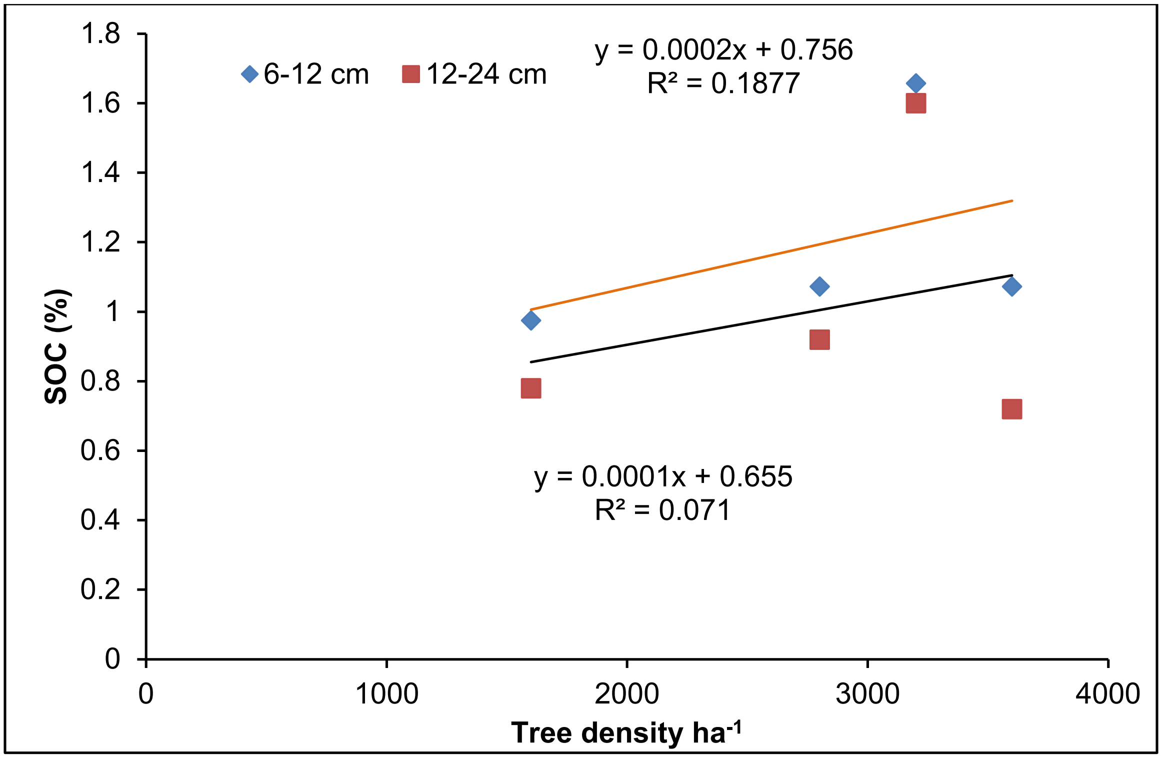

Figure 3. The relationship between tree density (ha^{-1}) and soil organic carbon (SOC %) at low density plots in Dhanmondi lake

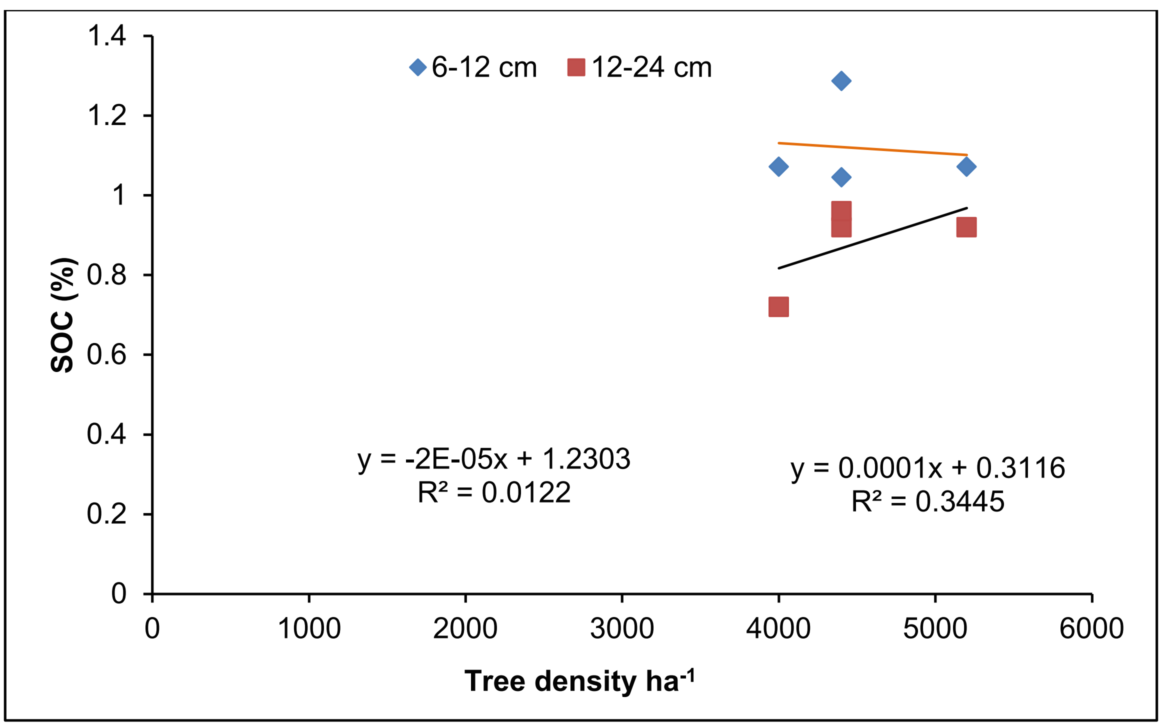

Figure 4. The relationship between tree density (ha^{-1}) and soil organic carbon (SOC %) at medium density plots in Dhanmondi lake

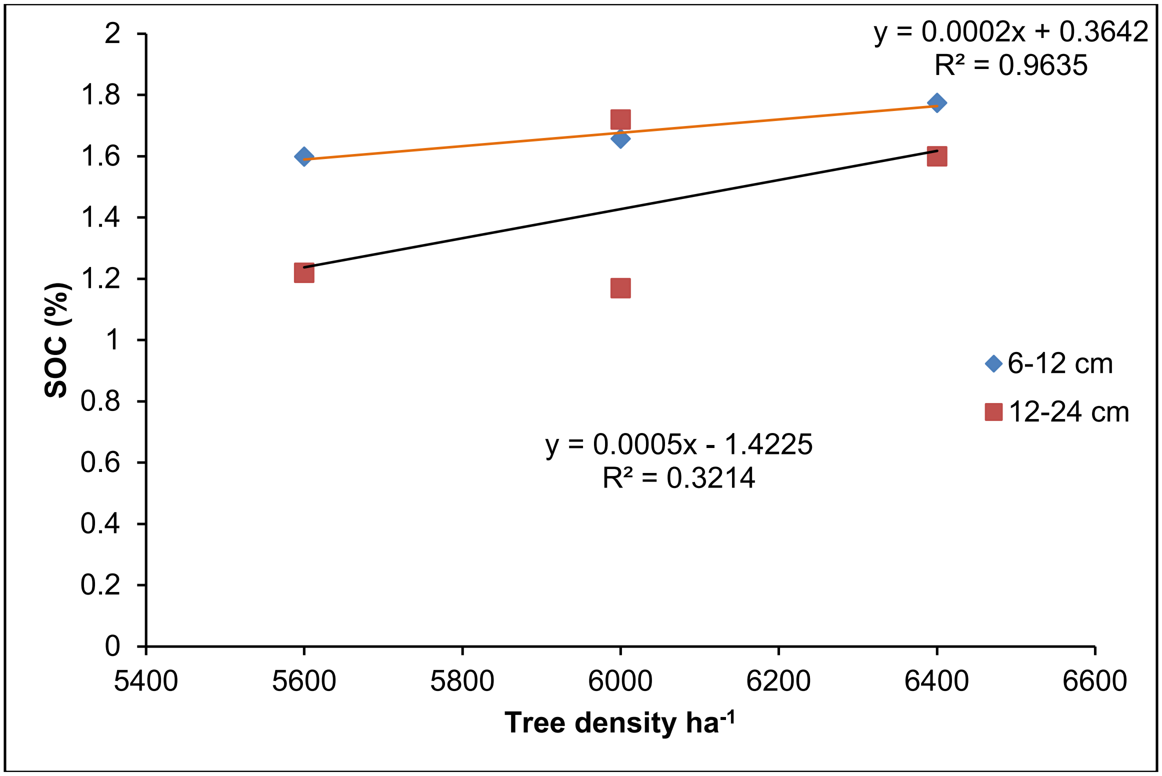

Figure 5. The relationship between tree density (ha^{-1}) and soil organic carbon (SOC %) at high density plots in Dhanmondi lake

In one study conducted in Borneo, Southern Asia shown very weak relationship between tree density and carbon stock where the value of R^2 was 0.049 (Silk, 2010). Considering the relationship between tree density and soil organic carbon it is indicated that tree density is strong determinant factor of soil organic carbon stock.

Chapter 5
Discussion

Controlling the present level of atmospheric carbon dioxide through reducing deforestation, increasing afforestation or reforestation, and preventing biodiversity loss is a significant concern among scientists and policy makers (Kanowski *et al*., 2011; Pandey *et al*., 2019). The importance of engaging in meaningful action to combat deforestation is recognized in the United Nations Framework Convention on Climate Change (UNFCCC) and parties are discussing policies and approaches to reduce CO_2 emissions from deforestation in a post-2012 international agreement on climate change. The UNFCCC recognizes various mitigation and adaptation options: firstly, the Clean Development Mechanism (CDM); secondly, Reduced Emissions from Deforestation and Forest Degradation (REDD); and most recently the newstrategy—reducing emissions from deforestation and forest degradation, and enhancing forest carbon stocks in developing countries (REDD+). These are intended to engage multi-scale stakeholders in conservation and sustainable management of forest resources for enhancing carbon sequestration in developing countries with incentives as a reward for mitigating global climate change (Gardner *et al*., 2012). There are two integral parts of REDD+ used as an effective mechanism for reducing global climate change one is afforestration and second is reforestration (Bonan, 2008; Wang *et al*., 2011; Pandey *et al*., 2019). So that the parties involved need accurate information on carbon stocks, biodiversity and the socioeconomic status of the communities in developing countries participating in the REDD+ financial mechanism (Pandey *et al*., 2014).

5.1 Tree density

Tree density is an important factor to store carbon as it directly relates to the carbon sequestration (Roshetko *et al*., 2007).Tree density of the study area varied from 385.3 to 1629.5 per hectare. Regression analysis showed a positive but moderately significant relationship between tree density and biomass carbon stock where R^2=0.508 but strongly significant relationship between tree density and soil organic carbon stock (SOC) where R^2=0.904. In one study conducted in Borneo, Southern Asia shown very weak relationship between tree density and aboveground carbon stock where the value of R^2 was 0.049 (Jaman *et al.,* 2016).Another study that was carried out in an old aged forest of Costarica andCentral America found tree density 462 to 504 per hectare where above ground carbon stock (AGB) was 139 to 138 Mg ha^{-1} respectively (Saatchi *et al.*, 2011). Considering the relationship between tree density and biomass carbon stock it is indicated that tree densityis not a strong determinant factor of aboveground carbon stock. Above ground carbon stock correlated with basal area.

5.2 Soil Organic Carbon (SOC)

Urban forests are comprised of trees, shrubs, and herbs and these plant classes have different belowground growth patterns. The majority of root growth and activity of shrubs and herbs are expected to be restricted within the upper soil (Waisel *et al*., 1997). In general, the SOC stock decreased with soil depth across all treatments of the present study area and increased with the increasein plant species density. Due to accumulation of higher quantity of litters and other organic materials on the surface and their rapid decomposition, urban forest act as a vital source of storing organic carbon in the soil. The SOCstocks in urban forest in relation to both tree species density and richness were also higher in the upper, than in the lower soil layer. In the selected study area average soil organic carbon in two different layer (5-10 and 20-25 cm) was found 49.24 Mg ha^{-1} with the range from 2.95 to 70.19 Mg ha^{-1} is lower thanthe urban forest of Kerala, India ranged 101.5 to 127.4 Mg ha^{-1} (Saha *et al*., 2009) in four different soil layer, coastal land area of Ireland (383 Mg ha^{-1}) in (0-10 cm) soil depth (X. Xu *et al*., 2011) but higher than the urban forest of Golestan province, Iran (0.49 to 16.64 Mg ha^{-1}) (M. Zeraatpishe and F. Khormali 2012) and Brazilian savanna soils (22.98 Mg ha^{-1}) (Juliana Hiromi Sato *et al*., 2014). On the other hand soil organic carbon content within 1 m soildepth under moist deciduous forests in the district of Kerala were 176.6 Mg ha^{-1} (Saha, 2008) that is much higher than the present urban forest SOC because forests characterized by high rates of litterfall, very low soil disturbance and high plant species diversity. A positive relationship was found between tree density and SOC as well as between urban forest size and SOC with significant R value. This results also similar to our current study.

5.3 Species composition

The most important attribute of urban forest is species composition. Species composition is closely related to tree density of individual urban forest. This study found 44 different tree species within 22 different families. The number of tree species in this study area was slightly smaller than those found in urban forest of Sandwip upazilla (76 spp.) of Chittagong (Maher *et al.*, 2005), coastal area urban forest of Potuakhali (57 spp.) (Rakib *et al*.,2022), Tangail (52 spp.) and Ishurdi (34 spp.) but higher than that of Bhola (31 spp.), Borguna (30 spp.) (Miah *et al*., 2020), Patuakhali (20 spp), Rajshahi (28 spp.), and the other part of Rangpur district (21spp) respectively (Abedin and Quddus, 1990). Millat-e-Mustafa identified 92 perennial plant species in one study conducted in different part of the country (Millat-e-Mustafa *et al.,* 2002). This study was conducted considering the whole homegarden area in one plot so uniform counting of tree species was possible but little variation also occurred from one homegarden to another because homestead need and choice of the family influenced the distribution of tree species. This study also explored that *Areca catechu* (27.10%), *Mangifera indica* (21.66%) and *Artocarpus heterophyllus* (10.65%) are the most important and common fruit species followed by the timber yielding species *Swietenia mahogany* (8.73%) and*Melia azedirach* (7.66%) that are also found in Sylhet Sadar (Rahman *et al*., 2005), Patuakhali (Rakib *et al*., 2022), Azmirigonj upazilla of Habigonj district (33.33% fruit and 28.57% timber) (M.A. Mannan *et al*., 2014) and CharGobadia of Mymenshing district (10 fruits and 6 timber) (A. Zico *et al*., 2011). The urban forest are specially concentrated on rapidly growing and ornamental trees and timber species because of their subsistence and beautification. These findings also similar with our current study area.

CHAPTER 6
SUMMARY AND CONCLUSION

6.1 SUMMARY

The goal of the current study was to determine the density of tree species and amounts of organic carbon in the area of Dhanmondi lake in Dhaka. Information was gathered from Dhanmondi Lake area.

In this study, A total of 22 families were identified. The total number of plants was discovered to be 134. *Swietenia mahagoni* (Mahagoni), with a total of nine tree individuals, had the highest percentage of tree individuals (6.72%), while an unidentified species, which included *Tabernaemontana divoricata, Tamarisk dioica, Leucaena lecocephala, Barringtonia asiatica, Mussaenda erythrophylla, Acacia mengium,* and others, had the lowest percentage (0.75%). Five primary tree species, including the Mahagoni (*Swietenia mahagoni*), Indian melder (*Mimosops elengi*), Mango (*Mangifera indica*), Radhachura, (*Caesalpinia pulcherrima*), and Asian tree (*Lagerstoemia speciosa*) have been shown to be the most prevalent and dominant tree species in the Dhanmondi lake area.

Results found that the highest amount of tree individuals (63) was found at heights (8-16 m) and the lowest amount of tree individuals (04) was found at heights (24-32 m). The Dhanmondi lake was discovered to have the maximum number of tree individuals (53) at (5- 10 cm) and the lowest number of tree individuals 14 at (15-20 cm) DBH class. In case of canopy class, the highest number of canopy (36) were obtained from 1.00-2.00 m. On the other hand, the lowest number of tree individuals (8) were found in >5.00 m canopy class.

It was also calculated that all the structural attributes like relative density (RD %), Relative frequency (RF %), Relative abundance (RA %) Relative Dominance (RDo %) and Important value index (IVI %) in *Swietenia mahagoni* (6.72, 11.18, 1.10, 0.1 and 18.00) was highest.

Results found that tree density of the study area varied from 1600 to 6400 ha^{-1} (4-16 trees plot^{-1} for 25 m^2 area). The mean density of the tree in Dhanmondi lake for low, medium and high-density plots were 2800, 4500 and 6000 trees ha^{-1}. The relationship between soil organic carbon (SOC) and tree density were assessed. Results demonstrates that low density plots had less SOC (0.94% and 0.70%) and fewer trees per unit area than medium density plots (1.12% and 0.88%) and high-density plots (1.65% and 1.43%) at both 6-12 cm and 12-24 cm depth. A gradual increase in values follows low< medium <high density plots. Carbon demonstrated a positive (not always positive), statistically significant association in the relationship between SOC and tree density. Due to the structure and species composition of trees, as well as the soil structure, the relationships between various parameters may be varied from place to place.

6.2 CONCLUSION

At the Dhanmondi Lake study area, a total of 134 trees from 44 species were discovered. *Swietenia mahagoni* (Mahagoni) with a total 9 tree individuals, had the highest percentage of occurance while *Tabernaemontana divoricata*, *Tamarisk dioica, Leucaena lecocephala*, *Barringtonia asiatica, Mussaenda erythrophylla, Acacia mengium*, etc. had the lowest number of plants. The relationship between SOC and tree density was positive with carbon in the most cases because sometimes it showed negative relationship and soil organic carbon was higher in upper layer at the depths of 6 -12 cm than at the depths of 12 - 24 cm.

RECOMMENDATIONS

Roadside, park, and garden tree planting is ideal from an aesthetic and environmental point of view, and there are numerous potential to improve the plantation at Dhanmondi lake. The variety and composition of the tree species in Dhanmondi lake were found to be quite low. However, the following suggestions are provided for better protecting and managing the plantation in Dhanmondi lake:

- Preservation and upkeep of the current roads, parks, and other green spaces
- In order to determine the composition and structure of plant species, similar research must be conducted in other parks and in garden areas. The soil organic carbon (%) of chosen locations needs more attention.

Findings from this kind of research will be useful in facilitating comparable studies in other regions of Bangladesh. If all of the green space is studied in a similar manner, Bangladesh's overall capacity for sequestering carbon as well as its pattern of tree species will be represented.

REFERENCES

Abedin, M.Z. and Quddus, M.A. (1990). Agroforestry systems in Bangladesh with particular reference to economics and tenurial issues. In Expert Consultation on Agroforestry in the Asia-Pacific Region. Bangkok (Thailand).

Anonymous. (2015). Index Herbarium, entry for Bangladesh National Herbarium, Herbarium code DACB.

Asner, G.P., Carlson, K.M. and Martin, R.E. (2005). Substrate age and precipitation effects on Hawaiian forest canopies from spaceborne imaging spectroscopy. *Remote Sens. Environ.* **98**(4): 457-467.

Augusto, L., De Schrijver, A., Vesterdal, L., Smolander, A., Prescott, C. and Ranger, J. (2015). Influences of evergreen gymnosperm and deciduous angiosperm tree species on the functioning of temperate and boreal forests. *Biol. Rev.* **90**(2): 444-466.

Baraloto, C., Rabaud, S., Molto, Q., Blanc, L., Fortunel, C., Herault, B. and Fine, P.V. (2011). Disentangling stand and environmental correlates of aboveground biomass in Amazonian forests. *Glob. Change Biol.* **17**(8): 2677-2688.

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. *Eur. J. Soil Sci.* **47**(2): 151-163.

Beer, J., Bonnemann, A., Chavez, W., Fassbender, H.W., Imbach, A.C., Martel, I. (1990). Modelling agroforestry systems of cacao (*Theobroma cacao*) with laurel (*Cordia alliadora*) or poro (*Erythrina poeppigiana*) in Costa Rica. V. Productivity indices, organic material models and sustainability over ten years. *Agrofor. Syst.* **12**(3): 229–249.

Bodansky, D. (2010). The Copenhagen climate change conference: a postmortem. *Am. J. Int. Law*. **104**(2): 230-240.

Bonan, G.B. (2008). Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *sci.* **320**(5882): 1444-1449.

Brown, S., Pearson, T., Slaymaker, D., Ambagis, S., Moore, N., Novelo, D. and Sabido, W. (2005). Creating a virtual tropical forest from three-dimensional aerial imagery to estimate carbon stocks. *Ecol. Appl.* **15**(3): 1083-1095.

Burras, C.L., McLaughlina, J.M., Brasterb, M.L., Sellersb Jr, J.E., Willsa, S.A. and Larabeea, B.E. (2001). Soil color: An inexpensive yet effective method for documenting soil carbon content. In *Fifth Biomass Conference of the Americas,* pp. 15-222.

Cairns, M.S., Brown, Helmi, E.H. and Baumgrdner, G.A. (1997). Root Biomass Allocation in the World Upland Forests. *Oeclogia.* **111**(1): 1-11.

Chapman, D.S. (1986). Thermal gradients in the continental crust. *Geol. Soc. Lond. Mem.* **24**(1): 63-70.

Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S. and Perez, R. (2004). Error propagation and scaling for tropical forest biomass estimates. *Philosophical Transactions of the Royal Society of London. Series B: Biol. Sci.* **359**(1443): 409-420.

Chowdhury, M.S.N., Mazed, H.K., Pulok, M.A.I., Hoque, F., Afsana, N. and Ahmed, S. (2015). Effect Of Organic Manures On Yield And Economic Analysis Of Tomato Varieties. *Int. j. res. anal. rev.* **2:** 211-16.

Davies, Z.G., Edmondson, J.L., Heinemeyer, A., Leake, J.R. and Gaston, K.J. (2011). Mapping an urban ecosystem service: quantifying above-ground carbon storage at a city-wide scale. *J. Appl. Ecol.* **48**(5): 1125-1134.

Dawud, S.M., Raulund-Rasmussen, K., Domisch, T., Finér, L., Jaroszewicz, B. and Vesterdal, L. (2016). Is tree species diversity or species identity the more important driver of soil carbon stocks, C/N ratio, and pH?. *Ecosyst.* **19:** 645-660.

de Foresta, H., Michon, G. (1994). Agroforests in Sumatra: where ecology meets economy. *Agrofor. Today.* **6**: 12–13.

DoF-Department of Forestry. (2019). National Botanical Garden. Department of Forestry, of Environment and Forests, Bangladesh.

Drescher, A.W. (1998). Hausgärten in afrikanischen Räumen. *Bewirtschaftung nachhaltiger Produktionssysteme and Strategien der Ernährungssicherung in Zambia and Zimbabwe. Pfaffenweiler.*

Du, H., Mao, F., Zhou, G., Li, X., Xu, X., Ge, H. and Li, Y. (2018). Estimating and analyzing the spatiotemporal pattern of aboveground carbon in bamboo forest by combining remote sensing data and improved biome-bgc model. *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.* **11**(7): 2282-2295.

Edmondson, J.L., O'sullivan, O.S., Inger, R., Potter, J., McHugh, N., Gaston, K.J. and Leake, J.R. (2014). Urban tree effects on soil organic carbon. *PloS one*. **9**(7): e101872.

Ellison, A.M., Bank, M.S., Clinton, B.D., Colburn, E.A., Elliott, K., Ford, C.R. and Webster, J.R. (2005). Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Front. Ecol. Environ.* **3**(9): 479-486.

Evans, J. (1992). Plantation Forestry in the Tropics: Tree Planting for Industrial, Social, Environmental, and Agroforestry Purposes; Clarendon Press, Oxford University Press: Oxford, UK.

Fernandes, E.C.M., Nair, P.K.R. (1986). An evaluation of the structure and function of tropical homegardens. *Agric. Syst.* **21**(4): 279–310.

Franzluebbers, A.J. (2002). Soil organic matter stratification ratio as an indicator of soil quality. *Soil. Till. Res.* **66**: 95–106.

Friedlingstein, P., Joel, G., Field, C. B. and Fung, I.Y. (1999). Toward an allocation scheme for global terrestrial carbon models. *Glob. Chang. Biol.* **5**(7): 755-770.

Gajaseni, J. and Gajaseni, N. (1999). Ecological rationalities of the traditional homegarden system in the Chao Phraya Basin Thailand. *Agrofor. Syst.* **46**: 3–23. doi:10.1023/A:1006188504677.

Gama-Rodrigues, E.F., Nair, P.K.R., Nair, V.D., Gama-Rodrigues, A.C., Baligar, V.C., Machado, R.C.R. (2010). Carbon storage in soil size fractions under two cacao agroforestry systems in Bahia, Brazil. *Environ. Manag.* **45**(2): 274–283.

Gardner, A.S., Maclean, I.M. and Gaston, K.J. (2020). A new system to classify global climate zones based on plant physiology and using high temporal resolution climate data. *J. Biogeogr.* **47**(10): 2091-2101.

Gissen, A., Vukasinovic, B., McMillan, M. and Glezer, A. (2011). Distortion management in a BLI inlet diffuser using synthetic-jet hybrid flow control. In *49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition*, p. 35.

Godbold, J.A., Bulling, M.T. and Solan, M. (2011). Habitat structure mediates biodiversity effects on ecosystem properties. Proceedings of the Royal Society B*: Biol. Sci.* **278**(1717): 2510-2518.

Godgift, S., Henry, J.N., Pantaleo, K.M. and Deo, D.S. (2014). Carbon stocks of Hanang forest, Tanzania: An implication for climate mitigation. *J. Ecol. Nat. Environ.* **6**(3): 90-98.

Hans, M., Xiao, C., He, M., (1986). Afforestation is Based on Community and Ecology. In Principles of Silvicultur; China Forestry Press: Beijing, China.

Hemery, G.E. (2008). Forest management and silvicultural responses to projected climate change impacts on European broadleaved trees and forests. *Int. For. Rev.* **10**(4): 591-607.

Hulscher, W. and Durst, P. (2000). Global availability of wood energy. *AMBIO: J. Hum. Rights. Environ*. **29**(3): 180-181.

Inouye, R.S. and Tilman, D. (1988). Convergence and divergence of old-field plant communities along experimental nitrogen gradients. *Ecol.* **69**(4): 995-1004.

Jaman, M.S., Hossain, M.F., Islam, M.S., Helal, M.G.J., Jamil, M. and Rahman, M.M. (2016). Quantification of carbon stock and tree diversity of homegardens in Rangpur District, Bangladesh. *Int. j. res. agric. For.* **6**(5): 169-180.

Jobbagy, E.G. and Jackson, R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecol. Appl.* **10**: 423–436.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agrofor. Syst.* **76**: 1-10.

Kanowski, P.J., McDermott, C.L. and Cashore, B.W. (2011). Implementing REDD+: lessons from analysis of forest governance. *Environ. Sci. Policy.* **14**(2): 111-117.

Karyono, (1990). Homegardens in Java; their structure and function. In: Tropical Homegardens. United Nations University Press, Tokyo. pp. 138–146.

Keenan, R.J., Reams, G.A., Achard, F., de Freitas, J.V., Grainger, A. and Lindquist, E. (2015). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *For. Ecol. Manag.* **352**: 9-20.

Kirby, K.R., Potvin, C. (2007). Variation in carbon storage among tree species: implications for the management of a small scale carbon sink project. *For. Ecol. Manag.* **246**(2): 208–221.

Kumar, B.M. (2006). Carbon sequestration potential of tropical homegardens. In: Kumar, B.M., Nair, P.K.R. (Eds.), Tropical Homegardens: A Time-Tested Exam- ple of Sustainable Agroforestry. Advance in Agroforestry 3. Springer, The Netherlands. pp. 185–204.

Kumar, B.M., George, S.J., Jamaludheen, V. and Suresh, T.K. (1998). Comparison of biomass production, tree allometry and nutrient use efficiency of multipurpose trees grown in wood lot and silvopastoral experiments inKerala, India. *For. Ecol. Manage*. **112**: 145–163.

Kumar, S., Jena, S.N. and Nair, N.K. (2010). ISSR polymorphism in Indian wild orange (Citrus indica Tanaka, Rutaceae) and related wild species in North-east India. *Sci. Hortic.* **123**(3): 350-359.

Lal, R. (2008). Carbon Sequestration. *Phil Trans R Soc B.* **363**: 815-830.

Lang, F., Krüger, J., Amelung, W., Willbold, S., Frossard, E., Bünemann, E. K. and Chmara, I. (2017). Soil phosphorus supply controls P nutrition strategies of beech forest ecosystems in Central Europe. *Biogeochemistry*. **136**: 5-29.

Lee, A.R., Noh, N.J., Cho, Y.S., Lee, W.K. and Son, Y.W. (2009). Estimating the soil carbon stocks for a Pinus densiflora forest using the soil carbon model, Yasso. *J. Ecol. Environ.* **32**(1): 47-53.

Li, M. Li, C. Xu, Z. Li, X. and Sun, Y. (1995). Natural Rarefaction Model of Larch Leaf Tree Artificial Forest and Preparation of a Growth Process Table; Forest Investigation Design: Harbin, China. pp. 30–33.

Maher, J.F., Hines, R.S., Futterweit, W., Crawford, S., Lu, D., Shen, P. and Cowan, B.D. (2005). FEM1A is a candidate gene for polycystic ovary syndrome. *J. Gynaecol. Endocrinol.* **21**(6): 330-335.

Malhi, Y., Doughty, C. and Galbraith, D. (2011). The allocation of ecosystem net primary productivity in tropical forests. *Philosophical Transactions of the Royal Society B: Biol. Sci.* **366**(1582): 3225-3245.

Malhi, Y., Wood, D., Baker, T.R., Wright, J., Phillips, O.L., Cochrane, T. and Vinceti, B. (2006). The regional variation of aboveground live biomass in old-growth Amazonian forests. *Glob. Change Biol.* **12**(7): 1107-1138.

Mannan, A., Liu, J., Zhongke, F., Khan, T.U., Saeed, S., Mukete, B. and Shah, S. (2019). Application of land-use/land cover changes in monitoring and projecting forest biomass carbon loss in Pakistan. *Glob. Ecol. Conserv.* **17**: e00535.

Mc Connell, D.J. (1992). The Forest Garden Farms of Kandy, Sri Lanka. FAO Farm Systems Management, Series 3, FAO, Rome.

Miah, J., Hossain, K.T., Hossain, M.A. and Najia, S.I. (2020). Assessing coastal vulnerability of Chittagong District, Bangladesh using geospatial techniques. *J. Coast. Conserv.* **24**(6): 66.

Millat-e-Mustafa, M., Teklehaimanot, Z. and Haruni, A.K.O. (2002). Traditional uses of perennial homestead garden plants in Bangladesh. *For. Trees Livelihoods.* **12**(4): 235-256.

Montagnini, F., Nair, P.K.R. (2004). Carbon sequestration: an under-exploited environmental benefit of agroforestry systems. *Agroforest. Syst.* **61**(1–3): 281–298.

Morel, A.C., Saatchi, S.S., Malhi, Y., Berry, N.J., Banin, L., Burslem, D. and Ong, R.C. (2011). Estimating aboveground biomass in forest and oil palm plantation in Sabah, Malaysian Borneo using ALOS PALSAR data. *For. Ecol. Manag.* **262**(9): 1786-1798.

Mueller, K.E., Hobbie, S.E., Chorover, J., Reich, P.B., Eisenhauer, N., Castellano, M.J. and Oleksyn, J. (2015). Effects of litter traits, soil biota, and soil chemistry on soil carbon stocks at a common garden with 14 tree species. *Biogeochemistry*. **123:** 313-327.

Mylavarapu, R., Sikora, F.J. and Moore, K.P. (2014). Walkley-Black Method. In *Soil test methods from the Southeastern United States*. **419**.

Nair, P. (1993). An introduction to agroforestry Kluwer Academic Publishers in cooperation with International Centre for Research in Agroforestry.

Nair, P.K.R., Kumar, B.M. and Nair, V.D. (2009). Agroforestry as a strategy for carbon sequestration. *J. Pl. Nutr. Soil Sci*. **172**: 10–23.

Nair, P.K.R., Kumar, B.M., Nair, V.D. (2009a). Agroforestry as a strategy for carbon sequestration. *J. Plant. Nutr. Soil. Sci.* **172**(1):10–23.

Nair, P.R., Nair, V.D., Kumar, B.M., and Haile, S.G. (2009). Soil carbon sequestration in tropical agroforestry systems: a feasibility appraisal. *Environ. Sci. Policy.* **12**(8): 1099-1111.

Nowak, D.J., Pasek, J.E., Sequeira, R.A., Crane, D.E. and Mastro, V.C. (2001). Potential effect of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on urban trees in the United States. *J. Econ. Entomol.* **94**(1): 116-122.

Oelbermann, M., Voroney, R.P. (2007). Carbon and nitrogen in a temperate agroforestry system: using stable isotopes as a tool to understand soil dynamics. *Ecol. Eng.* **29**(3): 342–349.

Palm, C.A., Tomich, T., van Noordwijk, M., Vosti, S., Alegre, J., Gockowski, J., Verchot, L. (2004). Mitigating GHG emissions in the humid tropics: case studies from the Alternatives to Slash-and-Burn Program (ASB). *Environ. Dev. Sust.* **6**(1–2): 145–162.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A. and Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *sci*. **333**(6045): 988-993.

Pandey, S., Shukla, R., Saket, R. and Verma, D. (2019). Enhancing carbon stocks accumulation through forest protection and regeneration. A review. *Int. J. Environ.* **8**(1): 16-21.

Pandey, S.S., Maraseni, T.N. and Cockfield, G. (2014). Carbon stock dynamics in different vegetation dominated community forests under REDD+: a case from Nepal. *For. Ecol. Manag.* **327**: 40-47.

Quesada, C.A., Lloyd, J., Schwarz, M., Baker, T.R., Phillips, O.L., Patiño, S. and Ramírez, H. (2009). Regional and large-scale patterns in Amazon forest structure and function are mediated by variations in soil physical and chemical properties. *Biogeosci. Discuss.* ***6***: 3993-4057.

Rakib, M.R.J., Rahman, M.A., Onyena, A.P., Kumar, R., Sarker, A., Hossain, M.B. and Sun, X. (2022). A comprehensive review of heavy metal pollution in the coastal areas of Bangladesh: abundance, bioaccumulation, health implications, and challenges. *Environ. Sci. Pollut. Res.* **29**(45): 67532-67558.

Ramachandran, A., Jayakumar, S., Haroon, R.M., Bhaskaran, A. and Arockiasamy, D.I. (2007). Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India. *Curr. Sci.* pp. 323-331.

Ramachandran, N.P.K., Mohan, K.B. and Nair, V.D. (2009). Agroforestry as a strategy for carbon sequestration. *J. Plant. Nutr. Soil Sci.* **172**(1): 10-23.

Reich, P.B., Sendall, K.M., Rice, K., Rich, R.L., Stefanski, A., Hobbie, S.E. and Montgomery, R.A. (2015). Geographic range predicts photosynthetic and growth response to warming in co-occurring tree species. *Nat. Clim. Change.* **5**(2): 148-152.

Roshetko, J.M., Lasco, R.D. and Angeles, M.S.D. (2007). Smallholder agroforestry systems for carbon storage. *Mitig. Adapt. Strateg. Glob. Chang.* **12**: 219-242.

Roshetko, M., Delaney, M., Hairiah, K., Purnomosidhi, P. (2002). Carbon stocks in Indonesian homegarden systems: can small-holder systems be targeted for increased carbon storage? *Am. J. Altern. Agric.* **17**(3): 125–137.

Roy, P.S. and Ravan, S.A. (1996). Biomass estimation using satellite remote sensing data—an investigation on possible approaches for natural forest. *J. Biosci.* **21**: 535-561.

Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T., Salas, W. and Morel, A. (2011). Benchmark map of forest carbon stocks in tropical regions across three continents. *Proc. Natl. Acad. Sci.* **108**(24): 9899-9904.

Saha, S., Nair, P.K.R., Nair, V.D. and Kumar, B.M. (2009). Soil carbon stock in relation to plant diversity of homegardens in Kerala, India. *Agrofort. Syst.* **76:** 53– 65.

Saha, S.K. (2008) Carbon sequestration potential of tropical homegardens andrelated land-use systems in Kerala, India. University of Florida Ph.D. dissertation, School of Forest Resources and Conservation, Gainesville.

Sakin, E. (2012). Organic carbon organic matter and bulk density relationships in arid-semi arid soils in Southeast Anatolia region. *Afr. J. Biotechnol.* **11**(6): 1373-1377.

Sampson, R.N. and Scholes, R.J. (2000). Additional Human induced activites. In Watson, B., Noble, I., Bolin, B., Ravindranath, N.R., Verardoand, D.J. and Dokken, D.J. (eds.) Land use and Land use Change Forestry. Aspecial report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge Unuversity press, Cambridge, UK.

Sanchez, P.A. (2000). Linking climate change research with food security and poverty reduction in the tropics. *Agric. Ecosyst. Environ.* **82**(1–3): 371–383.

Schlesinger, P. (1999). Carbon and Agriculture: Carbon Sequestration in Soil. *Sci. Mag.* **284**(5423): 2095.

Schmidt, H.P. and Wilson, K. (2012). 55 uses of biochar. *Ithaka. J.* **1:** 286-289.

Shankar, R., Chandra Sekhar, C., Joseph, B., Sunitha Devi, K.B. and Aarif Khan, M.A. (2014). Carbon Sequestration in multipurpose agroforesty plantations by using monoculture agroforestry models. *Int. J. Sci. Res.* **3**(9): 355-359.

Shukla, S.R. and Chandel, S.P. (1980). *Plant ecology*. 4thEdn. Chandel S. and Co. Ramnagar, New Delhi–110055, 197.

Silva, A., Uhlmann, A., Vicente-Silva, J. and Stürmer, S.L. (2010). How mycorrhizal associations and plant density influence intra-and inter-specific competition in two tropical tree species*: Cabralea canjerana* (Vell.) Mart. and *Lafoensia pacari* A. St.-Hil. *Plant. Soil.* **330:** 185-193.

Slik, J.W.F., Aiba, S.I., Brearley, F.Q., Cannon, C.H., Forshed, O., Kitayama, K. and van Valkenburg, J.L. (2010). Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. *Glob. Ecol. Biogeogr.* **19**(1): 50-60.

Slik, J.W.F., Aiba, S.I., Brearley, F.Q., Cannon, C.H., Forshed, O., Kitayama, K., Nagamasu, H., Nilus, R., Payne, J., Paoli, G., Poulsen, A.D., Raes, N., Sheil, D., Sidiyasa, K., Suzuki, E. and van Valkenburg, J.L.C.H. (2010). Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. *Global Ecol. Biogeography*. **19**: 50-60.

Stewart, P.J. and Strathern, A. (2003). *Landscape, memory and history: anthropological perspectives* (No. 23894). London: Pluto.

Stockmann, U. (2013). The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *Agric. Ecosyst. Environ.* **164:** 80-99.

Swift, M.J., Anderson, J.M. (1993). Biodiversity and ecosystem function in agricultural systems. In: Schulze ED, Mooney HA (eds) Biodiversity and ecosystem function. Springer, Berlin. pp. 15–42.

Szott, L.T., Fernandes, E.C.M., Sanchez, P.A. (1991). Soil–plant interactions in agroforestry systems. In: Jarvis PG (ed) Agroforestry: principles and practices. Elsevier, Amsterdam, pp 127–152.

Tilman, D., Lehman CL, and Thomson K.T. (1997). Plant diversity and ecosystem productivity: theoretical considerations. *Proc. Natl. Acad. Sci.* **94**: 1857– 1861. doi:10.1073/pnas.94.5.1857.

Tilman, D., Lehman, C.L. and Bristow, C.E. (1998). Diversity-stability relationships: statistical inevitability or ecological consequence? *Am. Nat.* **151**(3): 277-282.

Tittonell, P. (2007). Msimu wa Kupanda—Targeting Resources for Integrated soil Fertility Management within Diverse, Heterogenous and Dynamic Farming Systems of East Africa. Wageningen University.

Tiwari, K.R., Sitaula, B.K., Bajracharya, R.M. and Børresen, T. (2010). Effects of soil and crop management practices on yields, income and nutrients losses from upland farming systems in the Middle Mountains region of Nepal. *Nutr. Cycling Agroecosyst.* **86**: 241-253.

Waisel, Y., Ganor, E., Glikman, M., Epstein, V. and Brenner, S. (1997). Seasonal distribution of airborne pollen in the coastal plain of Israel. *Aerobiologia*, **13**: 127-134.

Wang, W., Wang, S., Ma, X. and Gong, J. (2011). Recent advances in catalytic hydrogenation of carbon dioxide. *Chem. Soc. Rev.* **40**(7): 3703-3727.

Weather base (2019). Historical Weather for Dhaka. Bangladesh. Weatherbase.com.

Xiao, G., Liou, S., Levy, A., Taylor, J.N. and Chien, C.L. (1986). Magnetic relaxation in Fe-(SiO 2) granular films. *Phys. Rev. B.* **34**(11): 7573.

Xu, X., Liu, W., Zhang, C. and Kiely, G. (2011). Estimation of soil organic carbon stock and its spatial distribution in the Republic of Ireland. *Soil Use Manag.* **27**(2): 156-162.

Young, A. (1997). Agroforestry for soil management, 2nd edn. CAB International, Wallingford.

Zeraatpishe, M. and Khormali, F. (2012). Carbon stock and mineral factors controlling soil organic carbon in a climatic gradient, Golestan province. *J. Soil Sci. Plant Nutr.* **12**(4): 637-654.

Zhang, J. (2004). Cultivation Technology of Fast-Growing and High-Yield Forest and Development Trend of Plantation in North China; China Forestry Industry: Beijing, China. p. 2.

Zico, A.S.A.D.U.Z.Z.A.M.A.N., Mondol, M.A., Wadud, M.A., Alam, Z. and Rahman, G.M.M. (2011). Study on Agroforestry and plant diversity in the char Gobadia of Mymensingh district. *J. Agrofor. Environ*. **5**(2): 101-104.

Zolkos, S.G., Jantz, P., Cormier, T., Iverson, L.R., McKenney, D.W. and Goetz, S.J. (2015). Projected tree species redistribution under climate change: Implications for ecosystem vulnerability across protected areas in the eastern United States. *Ecosystems*. **18**: 202-220.

Appendices

Appendix I. Center point co-ordinates of plots in Dhanmondi lake

Plot No.	Coordinates	
	N	E
Plot 1	23.747	90.379
Plot 2	23.747	90.379
Plot 3	23.747	90.379
Plot 4	23.747	90.379
Plot 5	23.747	90.377
Plot 6	23.748	90.378
Plot 7	23.749	90.378
Plot 8	23.750	90.376
Plot 9	23.750	90.377
Plot 10	23.750	90.375
Plot 11	23.750	90.375
Plot 12	23.747	90.375

Appendix II. Soil Organic Carbon (SOC) stock at two different depth classes in 12 sample plots in Dhanmondi lake

Plot no.	SOC (%) (6-12 cm)	SOC (%) (12-24 cm)	Total SOC	Mean	Standard Deviation	Standard error
Plot 1	0.975	0.78	1.755			
Plot 2	1.657	1.6	3.257			
Plot 3	1.072	0.72	1.792			
Plot 4	1.072	0.92	1.992			
Plot 5	1.287	0.92	2.207			
Plot 6	1.045	0.64	1.685	1.14	0.36	0.10
Plot 7	0.897	0.74	1.637			
Plot 8	0.897	1.51	2.407			
Plot 9	0.975	0.64	1.615			
Plot 10	1.599	1.22	2.819			
Plot 11	1.774	1.72	3.494			
Plot 12	1.56	1.17	2.73			

Appendix III Total tree density (ha^{-1}) in 12 sample plots in Dhanmondi lake

Plot categories	Plot number	Number of trees	Tree density/ha	Mean density/ha
Low density plot (29)	Plot 1	4	1600	2800
	Plot 2	8	3200	
	Plot 3	9	3600	
	Plot 4	8	2800	
Medium density plot (45)	Plot 3	10	4000	4500
	Plot 4	13	5200	
	Plot 5	11	4400	
	Plot 6	11	4400	
High density plot (60)	Plot 2	14	5600	6000
	Plot 3	16	6400	
	Plot 4	15	6000	
	Plot 5	15	6000	